ASSESSING THE DROUGHT SITUATION OF INDIA AS PER THE NEW DROUGHT MANUAL 2016

Karan Choudhary[1], P. K. Bisen[2], Rajat Saxena[2],Preeti Tahlani[1]and S. S. Ray[1]
[1]Mahalanobis National Crop Forecast Centre (MNCFC), DAC&FW, Pusa Campus, New Delhi110 012, India
Email: karan.c@gov.in, preeti.tahlani@gov.in, shibendu.ncfc@nic.in
2 Randstad India Ltd. deputed at MNCFC, Pusa Campus, New Delhi 110 012, India
Email: prabisen@gmail.com, rajatgun@gmail.com

KEYWORDS: Rainfall, NDVI, NDWI, VCI, MAI

ABSTRACT: Government of India has brought out a New Manual for Drought Management in December 2016. In the manual different categories of indicators are recommended for assessing/declaring drought i.e Rainfall based, Remote sensing, Hydrology based, Agriculture based and Soil Moisture based. Out of the above mentioned indices, rainfall is kept as mandatory indicator and will be used to check the drought trigger 1. Other four types of indicators (viz. Agriculture, remote sensing, hydrology, Soil moisture) are impact indicators. In order to assess the drought situation as per the new guidelines, analysis was carried out, at district level for 17 agriculturally dominant states of the country. IMD Rainfall data was used for finding the Districts with Drought Trigger 1 'Yes' on the basis of Dry spell and Rainfall deviations. Remote Sensing and Soil moisture based indices were computed. The remote sensing derived Vegetation Condition Index (VCI) was generated from MODIS 250 m data. A spatial soil water balance model was used for daily soil moisture estimation and derivation of Moisture Adequacy Index (MAI). After checking the Drought Trigger, based on rainfall and dry spell, the impact indicators such as VCI and MAI were checked for three categories, Severe, Moderate and Normal/Mild. Based on the categories of Impact indicators, the districts were classified into various categories. District-wise analysis in 17 states, by the end of August 2017, showed that there are 225 Districts with the Trigger 1 (Rainfall) YES, out of which no District is having both the Impact Indicators in the severe Category, whereas 3 districts (Kanyakumari, Tirunelveli, Tuticorin of Tamil Nadu State) were having one Impact Indicator in severe & One Impact Indicator in Moderate Category, 1 District is having both the indicators in Moderate Category (Ganganagar of Rajasthan State), 54 Districts having One indicator in Severe/Moderate Category & One indicator in Normal/Mild Category. 167 districts out of the 225 districts had both the Impact Indicators in Normal/Mild Category.Hence, as per this assessment, at the end of August, the possibility of any District having severe drought was NIL and Moderate drought may, at the maximum, occur in 58 districts. However, this number (58) may reduce considerably, as the sowing percentage (one of the 4 indicators) is high in most of the districts. The results were shared with various state governments to use as inputs for drought declaration. This paper shows how remote sensing and various other parameters are being used operationally in the country for drought declaration.

1. INTRODUCTION

Drought is a condition of moisture deficit sufficient to have an adverse effect on vegetation, animals and man over a sizable area. In India, during 1900-2012, 15 major droughts have occurred, with 1362 million people affected and 2441 million dollar economic loss (Source: EMDAT). Drought can have economic, environmental and social impacts. Careful monitoring of the symptoms of drought and early warning are key to effective management of the calamity. It is essential that along with a drought monitoring system, medium and long term area specific plans be prepared for drought proofing of susceptible areas. In addition, contingency and crisis management plans need to be formulated with care to deal with drought in the short term. Such well-conceived plans, when executed promptly, can go a long way in mitigating distress and disruption to the rural economy and society. The objectives behind an effective monitoring and early warning system are to provide accurate and timely information on rainfall, crop sown area, data on soil moisture (wherever possible), stream flow, groundwater, lake and reservoir storage at the relevant spatial scale at the State / district / sub-district levels. Detect drought conditions as early as possible in order to implement District Agriculture Contingency Plans and the Crisis Management Plan.

There are three types of drought: Meteorological, Hydrological and Agricultural. Meteorological drought can be assessed by rainfall deficiency, Hydrological drought can be assessed by monitoring Reservoirs levels, Ground Water and stream flows, whereas agricultural drought can be assessed using real-time crop condition data which can be generated through remotely sensed satellite data (Ray et al., 2014). Assessment of drought condition is essential for taking various relief and rehabilitation measures (Choudhary et al., 2014).

On the basis of wide-ranging consultations with domain specialists, Government of India has brought out a New Manual in December 2016 for Drought Management (DAC&FW, 2016). Under this manual, the drought declaration procedure has been revised. In the manual different categories of indicators are recommended for assessing/declaring drought i.e Rainfall based, Remote sensing based, Hydrology based, Agriculture based and Soil Moisture based. Details about the methodology and various drought indicators used are given in section 2.

In this study, drought manual guidelines have been used for assessing the Drought Indicators for the country upto the month of August, 2017

2. MATERIALS AND METHOD

2.1 Study Area

Based on the approach defined in the New Drought Manual, analysis was carried out at district level for 17 major agricultural states of the country (Andhra Pradesh, Assam, Bihar, Chhattisgarh, Gujarat, Haryana, Jharkhand, Karnataka, Madhya Pradesh, Maharashtra, Odisha, Punjab, Rajasthan, Tamil Nadu, Telangana, Uttar Pradesh and West Bengal) (Figure1). The major crops grown during kharif season, in these states, are Paddy, Millets, Cotton, Pulses, Oilseeds, Sugarcane and Jute.

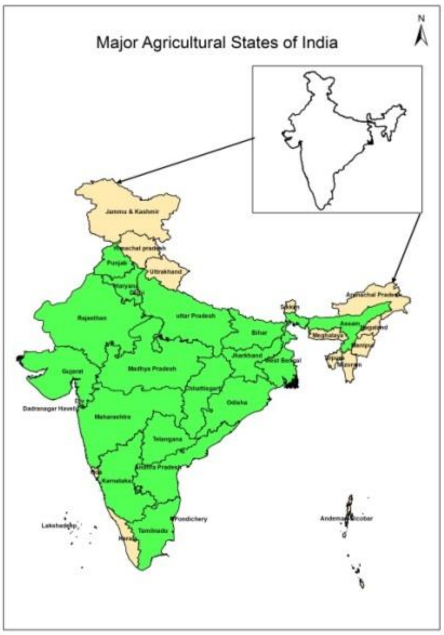


Figure 1: Selected states under study

2.2 Study Period

During the kharif season of 2017, the period of June to August month was considered for the analysis.

2.3 Methodology

In the New Drought Manual 2016, different categories of indicators are recommended for assessing/declaring drought. Those are:

- Rainfall based *(*Rainfall Deviation/ Standardized Precipitation Index and Dry spell*)*,
- Crop based (Area under sowing),
- Remote sensing based (Deviations Normalized Difference Vegetation Index / Normalized Difference Wetness Index, Vegetation Condition Index, VCI),
- Hydrology based (Reservoir Storage Index, RSI; Stream-Flow Drought Index, SFDI; Groundwater Drought Index, GWDI),
- Soil Moisture based (Moisture Adequacy Index, MAI, Per cent Available Soil Moisture, PASM).

Out of the above mentioned indicators, rainfall is kept as a mandatory indicator and has to be used to check the drought trigger 1. Other four types of indicators (viz. crop, remote sensing, hydrology and soil moisture) are categorized as impact indicators. If the Rainfall Trigger is ON/YES, the intensity of the drought will be contingent upon the values of at least three out of four Impact Indicators viz, crop, remote sensing, soil moisture and hydrology in the following manner, as per the New Drought Manual:

- **Severe drought:** if all the selected 3 impact indicators are in Severe category
- **Moderate drought:** if two of the selected 3 impact indicators are in ‘Moderate’ or ‘Severe’ class.
- **Normal:** for all other cases.
- Trigger 2 will be set off in the event of a finding of ‘severe’ or ‘moderate’ drought.
- The State has an option to reduce the drought category by one rank (i.e. Severe to Moderate) if the irrigation percentage of the administrative region (District/Taluk/Block/Mandal), for which drought is being declared is more than 75%.
- Finally the drought assessed using impact indicators needs to be validated through ground truth.

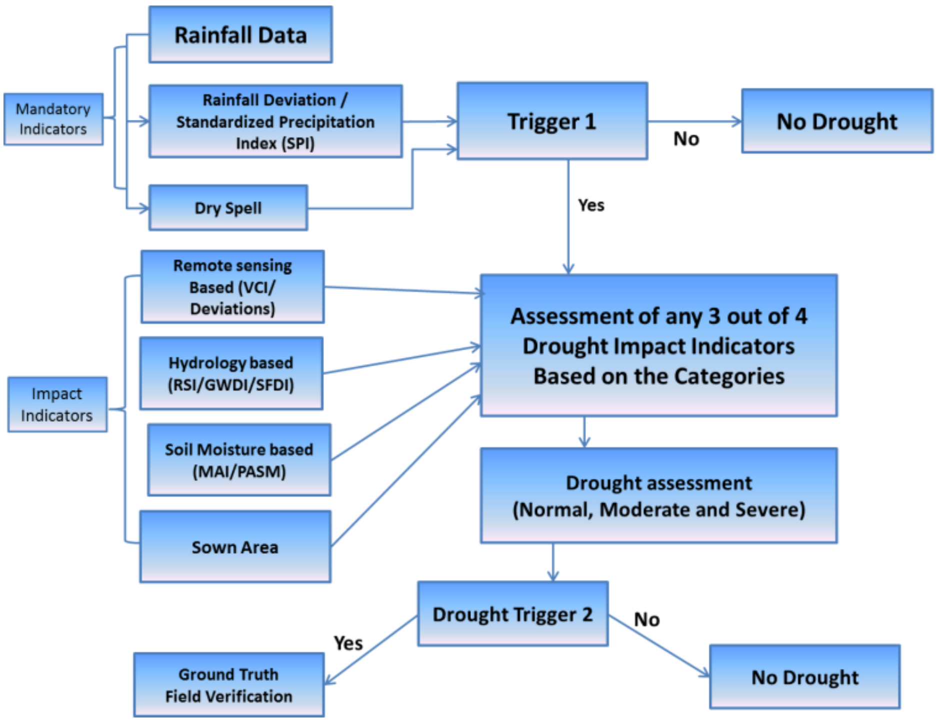


Figure 2: Methodology of Drought Assessment as per Drought Manual 2016

In this study, District level Rainfall data was used for identifying the Districts with Drought Trigger 1 ON, on the basis of Rainfall deviations and Dry spell. For the districts having Drought Trigger 1 ON, the Impact indicators were checked. Due to unavailability of data with us, only 2 (instead of 3) types of impact Indicators (Remote Sensing based Vegetation Condition Index (VCI) and Soil Moisture based Moisture adequacy Index (MAI)) were analysed. Finally, the districts were classified into 6 classes based on the severity of these 2 impact indicators:

1. Trigger 1 is NO

Trigger 1 is YES and

2. Both Impact Indicators are Severe
3. One Impact Indicator Severe & One Impact Indicator Moderate
4. Both Impact Indicators Moderate
5. One Impact Indicator Severe/Moderate & One Impact Indicator Normal/Mild
6. Both Impact Indicators Normal/Mild

2.4 Rainfall based Data

Rainfall is the most important indicator in the determination of drought and in Drought manual 2016 rainfall based indices are kept as mandatory indicators and used for checking the Drought Trigger 1. District level weekly rainfall data (June to August 2017) from Indian Meteorological Department (IMD) was used for identifying the districts with Drought Trigger 1 ON, on the basis of rainfall deviations and dry spell using the following table:

Table 1: Matrix for Checking Trigger 1 (Source: Drought Manual 2016)

Rainfall Deviation	Dry Spell	Drought Trigger 1
Deficient or Scanty	Yes	Yes
Deficient or Scanty	No	Yes, if Rainfall is Scanty
Normal	Yes	Yes
Normal	No	No

2.4.1 **Rainfall Deviation:** The rainfall deviation (RFdev) which is expressed in percentage terms is calculated as below:

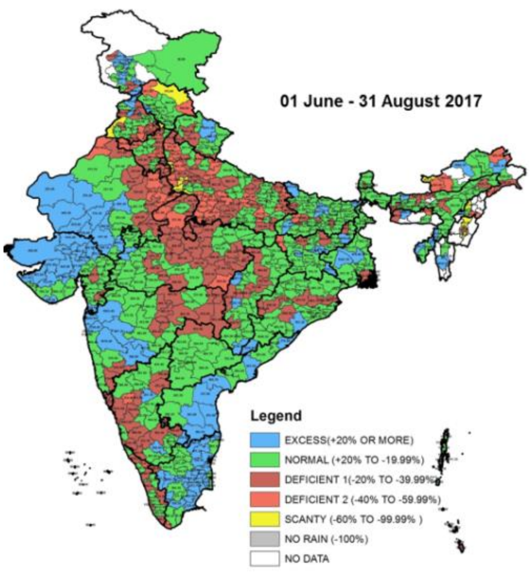
$$RFdev = \{(RFi - RFn)/RFn\}*100 \qquad (1)$$

Where RFi is current rainfall for a comparable period (June to August 2017) (in mm) and RFn is the normal rainfall (LPA Long Period average) for the same period (in mm). The classification of rainfall deviation is given in Table 2.The Rainfall Deviation for the period June to August month is shown in Fig.3 (a).

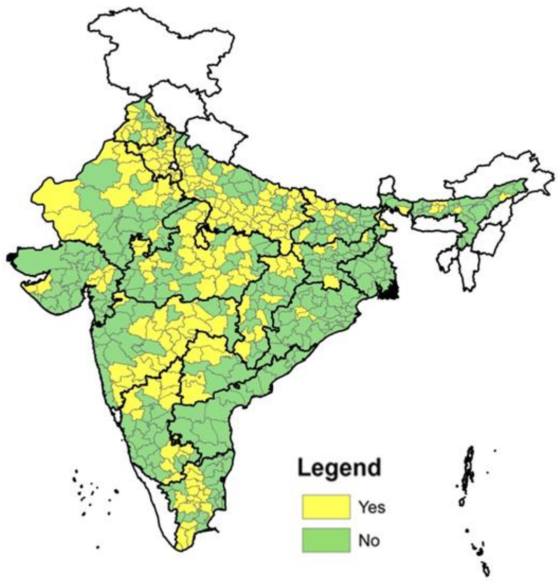
Table 2: Categories of Rainfall Deviations (Source: Drought Manual 2016)

Deviation from Normal Rainfall (%)	Category
+ 19 to -19	Normal
-20 to -59	Deficient
-60 to -99	Large Deficient (scanty)
-100	No Rain

2.4.2 **Dry Spell:** Dry spell is considered 'Yes' for the Districts which have received more than 50% deficiency in rainfall during three consecutive weeks during June to August month of 2017. Dry Spell map at District level is shown in Fig. 3 (b).



(a)



(b)

Figure 3: Maps of (a) Rainfall Deviation – 01st June to 31st August 2017 (b) Dry Spell – upto 31st August 2017

2.5 Vegetation Condition Index (VCI)

Observation of vegetation from space platform provides a unique vantage view and an insight into the dynamics of the vegetation, both temporally and spatially (Kogan 1997, 2000). There are two main optical domains influencing the optical properties of plant, viz, the visible region and Near Infrared Region (NIR). In the visible bands (0.4 to 0.7 um), light absorption by leaf pigments (chlorophyll a and b, carotenoids) dominate the reflectance spectrum of the leaf and lead to, generally, lower reflectance (15% maximum). The near infrared spectral region between 0.7 to 3.0 um has strong reflectance because of the spongy mesophyll cells, which mainly reflect light at cell/air space interface (Tucker and Sellers 1986). This is in contrast to almost all other surfaces of earth like water and bare soils where there is no pronounced difference between reflectance in the visible, near infrared, shortwave infrared and thermal infrared portions of the spectrum provide information for monitoring vegetation from space (Devenport and Nicholson 1993).

Taking the advantage of this differential reflectance nature from the vegetation, an index called Normalized Difference Vegetation Index (NDVI) has been derived. NDVI is defined as (Rouse et as., 1973):

$$NDVI = (NIR - Red) / (NIR + Red) \qquad (2)$$

Where NIR represent the percentage reflected radiation in the near-infrared region and red that of red region.

Since NDVI is a vegetation index, there has been limited success when this index was used to estimate 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 nm – 3000nm) and in particular the shortwave infrared (SWIR) reflectance (1300nm – 2500nm) (Chen et al., 2005). The shortwave infrared is sensitive to vegetation cover, leaf moisture and soil moisture (Tucker et al., 1985). The combination of NIR and SWIR bands has the potential of retrieving canopy water content (Ceccato et al. 2002a, b). The combination of NIR and SWIR has different nomenclatures with different authors. Gao (1996), Chen et al. (2005) called it as NDWI (Normalized Difference Wetness Index), which is given by:

$$NDWI = (NIR - SWIR) / (NIR + SWIR) \qquad (3)$$

Where the NIR and SWIR are the reflectance values. Jurgens (1997) termed equation 3 as modified NDVI (mNDVI), while Xiao et al. (2004) termed it as Land Surface Water Index (LSWI). 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 was used along with NDVI.

The MODIS Terra(250m) 16 days Vegetation Index (VI) product for the first and second fortnights of June to August for the years 2006 to 2017 was used in the analysis. The data were processed though appropriate image processing software to derive the NDVI using the reflectance of red and near infrared. Using equation 3 the NDWI was derived from the near and shortwave infrared reflectance. Using the Land Use and Land Cover layer generated at National Remote Sensing Centre (ISRO), the non-agricultural area was masked. Using the maximum value technique, monthly composites of the NDVI and NDWI was generated for June, July and August of every year (2006-2017).

Further using the long term NDVI and NDWI data (2006-2017) Vegetation Condition Index (VCI) was computed. VCI provides information of how the current status of the vegetation compared to 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 (2006-2017) of NDVI and NDWI was used to derive the VCI for 2017. The VCI of NDVI and NDWI is defined as

$$VCI (NDVI) = (NDVIi - NDVImin) / (NDVImax - NDVImin) \times 100 \qquad (4)$$

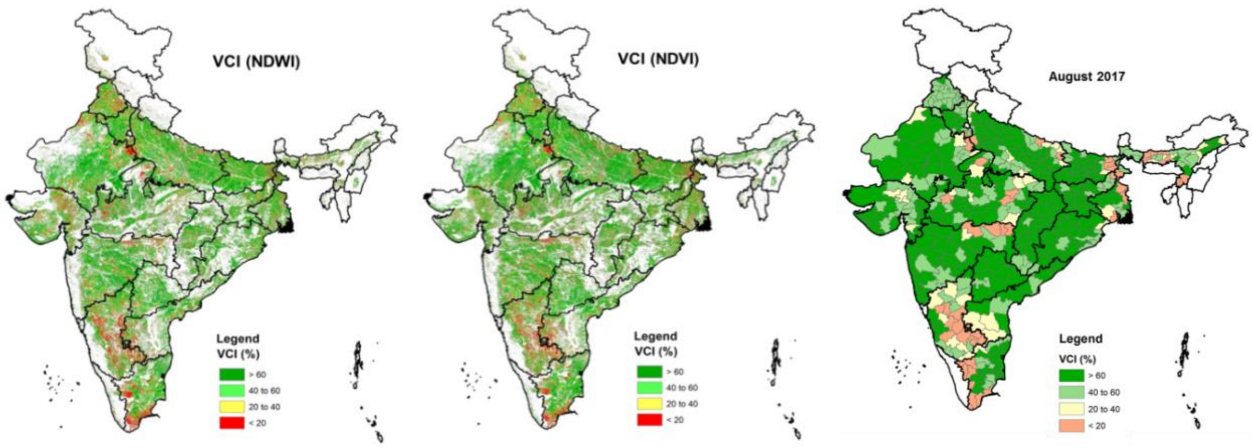
$$VCI (NDWI) = (NDWIi - NDWImin) / (NDWImax - NDWImin) \times 100 \qquad (5)$$

Where NDVIi/NDWIi is the NDVI/NDWI at time i, NDVImin/NDWImin is the historic minimum, NDVImax/NDWImax is the historic maximum NDVI.

Using the District level NDVI/NDWI statistics VCI (NDVI) and VCI (NDWI) were computed at district level.While combining VCI of NDVI and NDWI minimum of the VCI (NDVI) and VCI (NDWI) is taken as per the drought manual. And further each district is categorized on the basis of VCI Classification given in Table 3. Images of VCI (NDVI), VCI (NDWI) and District level combined VCI for the month of August 2017 is shown in Figure 4.

Table 3: Classification of Vegetation Condition based on VCI value (Source: Drought Manual 2016)

VCI Value (%)	Vegetation Condition
60-100	Good (Normal)
40-60	Fair (Mild)
20-40	Poor (Moderate)
0-20	Very Poor (Severe)



(a) (b) (c)

Figure 4: (a) Pixel level VCI (NDVI) (b) Pixel level VCI (NDWI) (c) District level Combined VCI -August Month

2.6 Soil Moisture based MoistureAdequacy Index(MAI)

The Soil Water Balance (SWB) model is a convenient way of estimating the soil moisture over a large area with considerable reliability. A simple book keeping – bucket type – water balance model has been used to derive the top 30 cm profile soil moisture (Chandrasekar et al., 2011). This model considers the initial root depth of 30 cm throughout the season to capture the soil water scenario for crops sown and germinated during any part of the cropping season. The climatic, soil and crop parameters are the main inputs for the SWB. The daily near real time spatial rainfall product from Climate Prediction Centre (CPC) of NOAA and the daily global Potential Evapo-Transpiration (PET) data are used as the rainfall and climatic input, respectively. The soil information has been derived from the 1:0.5 M scale soil map of NBSS&LUP (Chandrasekar et al., 2011). Since this model does not take into account the irrigation applied from various sources, the results of the model should be considered over rainfed areas alone. The Moisture Adequacy Index (MAI) is derived on daily water balance and is equal to the ratio of Actual Evapotranspiration (AET) to the Potential Evapotranspiration (PET)

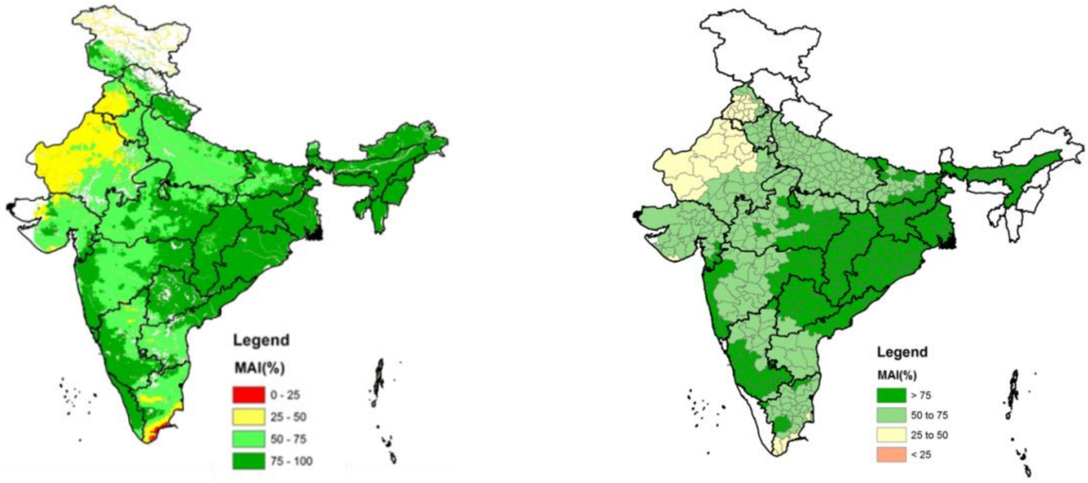
$$MAI = (AET/PET)*100 \qquad (6)$$

The index values range from 0 to 100 with 0 indicating extreme dry condition and 100 wet conditions.

For generating the cumulative Moisture Adequacy Index (MAI) for June to August month, the ratio of total Actual Evapotranspiration (AET) to the total Potential Evapotranspiration (PET) over the period was computed and statistics generated at district level. After that each district was categorized as per the MAI classification given in Table 4. Images of cumulative MAI upto August end at pixel level and district level is shown in Figure 5.

Table 4: Classification of Vegetation Condition based on MAI value (Source: Drought Manual 2016)

MAI Value (%)	Moisture Condition
75-100	Normal
50-75	Mild
25-50	Moderate
0-25	Severe



(a) **(b)**

Figure 5: Map of Moisture Adequacy Index (MAI) upto August end at (a) Pixel level (b) District level.

3. RESULTS AND DISCUSSION

This year, Monsoon onset, over Kerala, was on 30th May, 2017. The rainfall received till end of August was Normal or Excess in majority of meteorological sub-divisions (29 out of 36) and Deficient in 7 Meteorological Sub-divisions (East Uttar Pradesh, East Madhya Pradesh, Haryana, Chandigarh & Delhi, Kerala, S. I. Karnataka, Vidarbha, and West Uttar Pradesh). Total rainfall for the country as a whole upto 30th August 2017 was below normal by 3% (www.imd.gov.in).

As per the manual, using the Dry spell and rainfall deviation, number of districts with the Drought trigger 1 'ON' in the month of June month were found to be 54, which further increased to 104 upto July end and reached 225 upto August end. Out of these 225 Districts only 4 districts were having scanty rainfall. Majority of the districts catered to drought trigger 1 mainly due to the Dry Spell only (Figure 6). This showed, though the rainfall amount was not low, but this distribution may not be optimum.

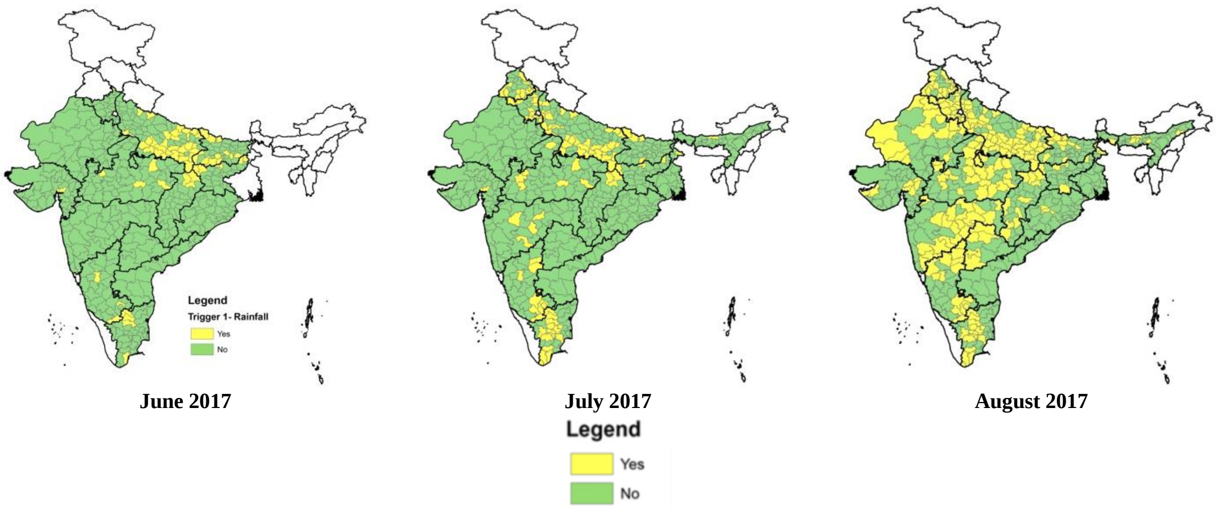


Figure 6: Districts having Drought Trigger 1 Yes during June, July and August 2017

For these 225 Districts in 17 states, two impact indicators VCI and MAI were checked and categorized in Drought severity classes separately and finally, the districts were classified into 5 classes (as per section 2.3) based on the severity of 2 impact indicators. It was observed that by the end of August 2017, out of 225 Districts (where rainfall trigger was On), no District was having both the Impact indicators in the severe category. 3 districts (Kanyakumari, Tirunelveli, Tuticorin of Tamil Nadu) were having one impact indicator in severe & one impact indicator in

Moderate Category. 1 District (Ganganagar of Rajasthan) had both the indicators in Moderate Category. 54 out of the 225 districts had one indicator in Severe/Moderate category and one indicator in Normal/Mild Category. 167 districts out of the 225 districts had both the Impact Indicators in Normal/Mild Category (Figure 7). Table 5 shows the state-wise number of districts under Drought Trigger 1 ON and also the number of districts having impact indicator VCI and MAI under Moderate/Severe Category.

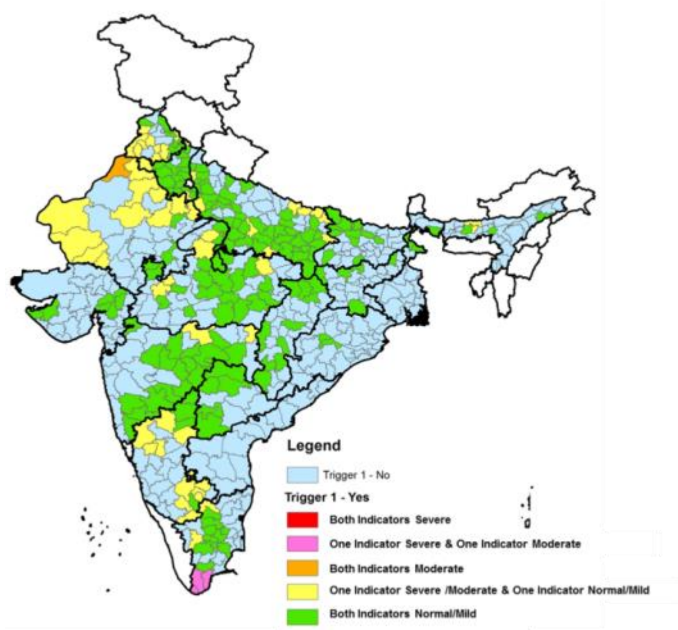


Figure 7: Classification of Districts based on severity of two Impact Indicators - August 2017

Table 5: State-wise number of districts with Drought Trigger 1 'ON' and Moderate/Severe Category of 2 Impact Indicators

State	**Number of districts with Drought Trigger 1 ON**	**Number of Districts having Impact indictor under Moderate/Severe Category with Drought Trigger 1 ON**	
		VCI	**MAI**
Assam	5	2	0
Bihar	12	0	0
Chhattisgarh	10	0	0
Gujarat	7	0	0
Haryana	19	2	1
Jharkhand	5	0	0
Karnataka	15	11	0
Madhya Pradesh	25	5	0
Maharashtra	20	2	0
Odisha	2	0	0
Punjab	15	0	9
Rajasthan	14	4	9
Tamil Nadu	14	5	3
Telangana	5	0	0
Uttar Pradesh	54	9	0
West Bengal	3	0	0

Hence, as per this assessment (According to the new Drought Manual), at the end of August 2017, the possibility of any district having severe drought was NIL and Moderate drought might, at the maximum, occur in 58 districts. However, this number (58) may reduce considerably, as the crop sowing percentage (one of the 4 indicators) is high in most of the districts.

4. CONCLUSION

Among the different types of the droughts, agricultural drought poses challenges in monitoring and assessment. As per the New Drought Manual of the Government of India, various types of indicators viz. Rainfall, Crop, Soil Moisture, Hydrology and Remote sensing can be effectively used for monitoring and assessing the Drought situation. The above analyst showed how operationally, district level drought assessment has been carried out for 17 states in the country, using the procedures defined e in the New Drought Manual. The analysis shows that overall situation of country (17 states) was found near to normal except in few districts of Tamil Nadu, Karnataka, U.P , M.P and Rajasthan state where remote sensing based VCI indicator showed moderate condition.

5. ACKNOWLEDGMENT

The authors are thankful to the Secretary, Department of Agriculture, Cooperation & Farmers' Welfare Dr. S. K. Pattanayak, the Additional Secretary and Central Drought Relief Commissioner Sh. U. K. Singh, the Joint Secretary (IT) Sh. Dinesh Kumar and the Joint Secretary (DM) Sh. K. Srinivas for their keen interest in the work. The contribution of the experts for developing approaches of Drought Assessment for the New Drought Manual is thankfully acknowledged. Thanks are due to the concerned scientists of National Remote Sensing Centre for their support of drought assessment work in MNCFC.

6. REFERENCES

Ceccato, P., Gobron, N., Lassee, S., Pinty, B. and Tarantola, S., 2002a. Designing a spectral index to estimate vegetation water content from remote sensing data: Part l, Theoretical approach. Remote Sens. of Environ., 82, pp. 188-197.

Ceccato.P., Flassee, S. and Gregoire, J. M., 2002b. Designing a spectral index to estimate water content from remote sensing data: Part2, Validation and applications. Remote Sens. of Environ., 82, pp. 198-207.

Chandrasekar, K., Seshasai, M., Behera, G., 2011. Assessment of Early Season Agricultural Drought through Land Surface Water Index (LSWI) and Soil Water Balance Model. In: International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Bhopal, Volume XXXVIII-8/W20.

Chen, D., Huang, J., and Jackson, T.T., 2005. Vegetation water content estimation for corn and soybean; using spectral indices derived from MODIS near and short-wave infrared bands. Remote Sens. of Environ., 98, pp. 225-236.

Choudhary, K., Goel, Inka, Bisen, P. K., Mamatha, S., Ray, S. S., Chandrasekar, K., Murthy, C. S. and Sesha Sai, M. V. R., 2014. Use of Remote Sensing Data for Drought Assessment: A Case Study for Bihar State of India During Kharif, 2013 In: High-Impact Weather Events over the SAARC Region (Ed. K. Ray, M. Mohapatra, B.K. Bandyopadhyay, L.S. Rathore). Springer. pp. 399-407.

DAC&FW, 2016. Manual for Drought Management. DAC&FW, MoA&FW, Government of India. 154 p

Devenport, M.L. and Nicholson, S.E., 1993. On the relation between rainfall and Normalized Difference Vegetation Index for diverse vegetation types of East Africa. Int. J. of Remote Sens., 12, pp. 2369-2389.

Gao, B.C., 1996. NDWI-A normalized difference water index tbr remote sensing of vegetation liquid water from space. Remote Sens. of Environ., 58, pp. 257-266

Hojin K., Huete, A.R., Pamela N, Ed Glenn, Emmerich, W. and Scott, R.L., 2004. Monitoring riparian and semi-arid upland vegetation using vegetation and water indices from the MODIS satellite sensor. Research insights in semiarid ecosystems (RISE) Symposium, 13th November, 2004, University of Arizona, Tucson, Marley Building.

Jurgens, C., 1997. The modified normalized difference vegetation index (mNDVI) a new index to determine frost damages in agriculture based on Landsat TM data. International Journal of Remote Sensing. 18 (17), pp. 3583-3594.

Kogan, F.N., 1997. Global drought watch from space, Bulletin of the American Meteorological Society, 78, pp. 621-636.

Kogan, F.N., 2000. Global drought detection and impact assessment from space. Drought: A Global Assessment, Vol. 1, Editor: D. A. Wilhite, Routledge, London, pp.196-210.

Ray, S. S., Sesha Sai, M. V. R. and Chattopadhyay N., 2014. Agricultural Drought Assessment: Operational Approaches in India with Special Emphasis on 2012. In: High-Impact Weather Events over the SAARC Region (Ed. K. Ray, M. Mohapatra, B.K. Bandyopadhyay, L.S. Rathore). Springer. pp. 349-364.

Rouse, J. W., Haas, R. H., Schell, J. A. and Deering, D. W., 1973. Monitoring vegetation systems in the Great Plains with ERTS', Third ERTS Symposium, NASA SP-351 I, 309-317.

Tucker, C.J., and Sellers. P.J., 1986. Satellite remote sensing of primary production. Int. J. of Remote Sens., 7:1395-1416.ote Sens. of Environ., 10, pp. 23-32.

Tucker, C.J., Vanpract, C., Sharman, M.J. and Van Ittersum, G., 1985. Satellite remote sensing of total herbaceous biomass production in the Senegalese Sahel: 1980-1984. Remote Sens. of Environ., 17, pp. 233-249.

Xiao, X., Zhang, Q., Braswel, B., Urbanski, S., Boles, S., Wofsy, S., Moore III, B. and Ojima, D., 2004. Modelling gross primary production of a deciduous broadleaf forest using satellite image and climate data. Remote Sens. of Environ. 91, pp. 256-270.33.