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Block-level drought assessment using rainfall and remote sensing data

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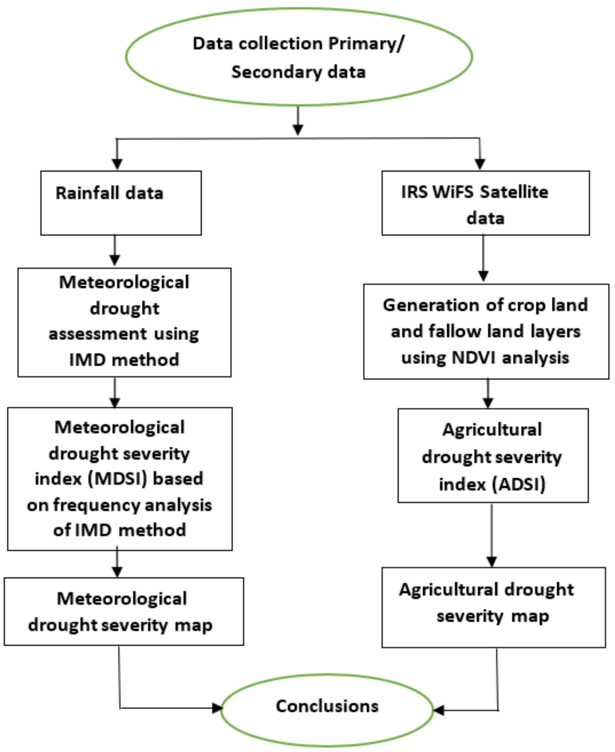
Graphical abstract



Abstract

Drought is a disastrous natural phenomenon. It is generally viewed as a sustained and regionally extensive occurrence of below average natural water availability either in the form of rainfall, river runoff or groundwater. Drought is defined based on different factors and generally assessed in meteorological, hydrological and agricultural contexts. Efficient management of drought over an area or catchment depends mainly on its correct assessment. In this study, Meteorological drought severity assessment was carried out based on the frequency analysis of IMD method producing Meteorological Drought Severity Index (MDSI). Agricultural drought severity assessment was carried out by developing an Agricultural Drought Severity Index (ADSI), which involves crop land and fallow land estimation, delineated from remote sensing data using NDVI analysis. The methodology was applied for Samba season (major crop season) of Palar Sub-basin encompassing Vellore (a chronic drought prone district), located in the North-East part of Tamil Nadu State, India. Block-wise drought severity maps were generated using geospatial environment to understand the drought severity status of the area. It is observed that 70% of the blocks in the study area were affected by moderate and severe droughts, which needs drought proofing measures.

Key words: Drought, meteorological drought, IMD method, agricultural drought, NDVI, drought severity index.

1. Introduction

Drought, a vague phenomenon, has been defined and analyzed in various ways. A drought may mean different things to different people. For example, for a meteorologist, it is a deviation from normal precipitation; for a hydrologist, a fall in stream flow, lake level or groundwater level; for an agricultural scientist, lack of soil moisture to sustain crop growth; for an economist, a famine condition and for an urbanite, shortage of tap water supply (Dracup *et al.,* 1980). National Commission on Agriculture (1976), India, broadly classified droughts into Meteorological, Hydrological and Agricultural droughts. The first two are supply based and the latter relates (water) supply with the demand (Crop water requirement).

Drought assessment involves analysis of spatial and temporal water related data. Droughts are assessed with reference to nature of water deficit, averaging period, and truncation level with regionalization approach. The onset and withdrawal of a drought is difficult to determine precisely and hence drought is often referred to as a creeping phenomenon (Mishra *et al.,* 2007).

The traditional methods of drought assessment do not provide the actual impact of drought situation and the distress felt by public as many of these methods are based on statistics of rainfall data that are averaged over an area. Remote Sensing technique offers unique potential to supply spatial data that helps very much the process of determining vegetation status and the water deficit aspects of any area along with spatial analysis tools such as Geographic Information System (GIS).

It has been universally accepted that satellite derived NDVI (Normalised Difference Vegetation Index) can be used to assess crop stage/condition (Tucker, 1976, Ayyangar *et al.,* 1980, Singh *et al.,* 2003 and Lei Ji and Peters 2003). Research works on agricultural drought monitoring & management and risk prediction using remote sensing techniques were carried out by Zaiwu Gong and Ruiling Sun (2010), Rulinda *et al.* (2010) and Rhee *et al.* (2010).

NDVI images derived from moderate resolution WiFS/AWiFS images from Indian Remote Sensing satellites are in use for detailed assessment of the agricultural drought situation at different administrative units (blocks) within a district (Murthy C *et al.,* 2007, Murali Krishna T *et al.,* 2009, Shibendu S. Ray ,2021, Sesha Sai M. V. R. 2016).

Drought can be assessed in meteorological, hydrological and agricultural aspects. Of these, rainfed agriculture is controlled by meteorological drought and the other cropped areas by agricultural drought. The present study aims to develop a methodology to assess meteorological drought using rainfall data and agricultural drought using remote sensing data. India Meteorological Department (IMD) method was used to carryout meteorological drought assessment. IMD method is a simple and widely used one which will give a preliminary idea about the drought condition of an area. In this method, drought is assessed on the basis of percentage deviation of rainfall from the long term annual mean rainfall. NDVI analysis was used to carryout agricultural drought assessment.

2. Study area

Palar Sub basin encompassing Vellore (a chronic drought prone district), located in the North-East part of Tamil Nadu State, India was selected as the study area. The total geographical area of the study is 5920 km^2. The area is conspicuous by the absence of perennial rivers and frequent susceptibility to recurring droughts. Vellore district is one among the 16 districts covered under Drought Prone Area Programme (DPAP) in Tamil Nadu State as on November 2008. The district lies between 12015’23” N and 13012’32” N Latitudes and 78024’16” E and 79054’56” E Longitudes. Geologically the entire district is underlain by hard rock formations, excepting few isolated patches of sedimentary formation. Physiographically, the district can be broadly classified as hilly terrains and plain regions. The index map of the study area is shown in Figure 1. Generally, sub-tropical climate prevails over the district. The temperature rises slowly to maximum in summer month’s upto May after which it drops slowly. The mean maximum temperature ranges from 28.2 °C to 36.5 °C and the mean minimum temperature from 17.3 °C to 27.4 °C. The average rainfall of the district is 953.4 mm. The principal rainy season commences from the month of June and extends upto the end of December. Rainfall during Southwest and Northeast monsoon seasons accounts for more than 75% of the total annual rainfall. Soil classification of Vellore district, based on the survey conducted by the Soil Survey and Land use Organization of Tamil Nadu Agricultural Department, indicates six different types of soils as Sandy soil, Sandy loam, Red loam, Clay, Clayey loam and Black cotton soil.

Vellore district, for all administrative purposes, has been divided into 7 taluks which are further subdivided into 20 blocks. Monthly rainfall data for 15 raingauge stations were collected from the Department of Economic and Statistics, Chennai for the period from 1971-2005 and also from the Institute for Water Studies (IWS), WRO, PWD, Chennai and India Meteorological Department, Chennai.

Paddy is the main crop, being cultivated in three seasons namely, Sornawari (April-August), Samba (August-January) and Navarai (December-April). Samba season is the major crop season in the study area influenced by both Southwest and Northeast monsoons. Land use map of Vellore district was collected from the Institute of Remote Sensing, Anna University. The collected land use map was digitized using Arc Map GIS software for different thematic layers. Land use classification in terms of area works out to (Out of the total geographical area of 5, 92, 071 ha) 55.5% of agriculture land, 8.4% of waste land, 27.3% of forest and 3.6% in built-up while 5.2% of the area is covered by water bodies.

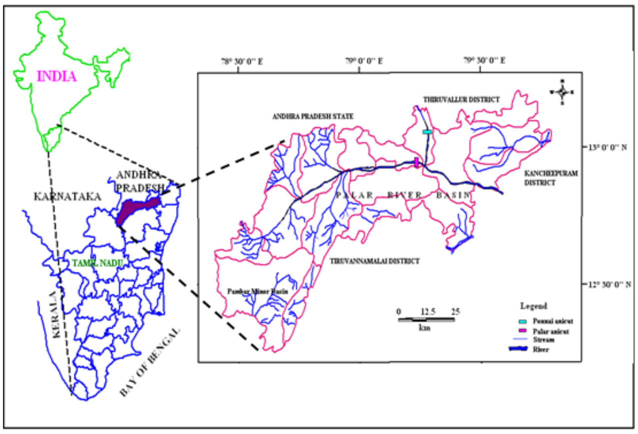


Figure 1. Index map of the study area.

3. Methodology and data used

In this study, meteorological drought assessment was carried out using India Meteorological Department (IMD) method. Meteorological Drought Severity Index (MDSI) was developed based on the frequency analysis of IMD method’s drought estimation and Agricultural Drought Severity Index (ADSI) was developed using NDVI analysis of remote sensing data.

3.1. Meteorological drought assessment

The assessment of drought severity in the meteorological context was carried out by employing IMD method

(Report of the Irrigation Commission, 1972, Arvind Singh Tomar, 2015, Ravikumar, 1996, Ram Kumar, 2022, R. Meenakshi, 2017, Susama Sudhishri, 2004). In this method, drought is assessed on the basis of percentage deviation of annual rainfall from the long term annual mean rainfall.

The percentage deviation (D_i) is given by:

$$D_i = \frac{P_i - \overline{P}}{\overline{P}} \times 100$$

where P_i is the annual rainfall in the year i; and P is the long term annual mean rainfall.

The percentage deviation of rainfall and the category of drought assessment are as given in Table 1.

Table 1. IMD classification of drought

S.No.	Range of D_i	Classification of drought	Category
1	>0	M0	No drought
2	0 to –25	M1	Mild drought
3	-25 to –50	M2	Moderate drought
4	< -50	M3	Severe drought

Thirty-five years of monthly rainfall data for fifteen rain gauge stations were analyzed for variation in space and time. An attempt was made to carry out the drought assessment for Samba season (major crop season) of the study area for all the rain gauge stations based on IMD method.

The drought severity classes were found out for each station on a seasonal basis using IMD method. The frequency of various classes of drought severity for each station was found out. Frequencies of drought classes, which are important in accurate calculation of return periods (Ghamghami M *et al.,*2017). Frequency analysis is based on the number of times the precipitation is deviated in a given period of time from historically established normal or mean rainfall value. The weightages 1, 2, 3 and 4 are assigned to drought severity classes of no, mild, moderate and severe droughts respectively. The MDSI of each station was found out by multiplying the frequency of each class of drought severity with the corresponding weightage. The spatial distribution of drought severity was found out using the natural neighborhood analysis. The block boundary and drought severity distribution maps were overlaid to represent the spatial drought proneness within the block area (Premkumar Sundararaj *et al.,* 2022).

3.2. Agricultural drought assessment

The agricultural drought severity could be monitored through an understanding of vegetation status because the vegetation condition reflects the overall effect of rainfall, soil moisture, weather and agricultural practices (Eleonora Runtunuwu 2005). Many previous works in agricultural drought severity assessment focus their attention only on agronomy of crops (Krishnan (1979), Choudhury (1987), Schmugge *et al.* (1986), Wang and Choudhury (1981). Jayaseelan A.T. (2002) has described the recent trends in remote sensing applications to drought assessment and monitoring with a case study on National Agricultural Drought Assessment and Monitoring System (NADAMAS). For regional drought monitoring (State level), NADAMS uses Wide image Field Sensor (WiFS) data of IRS-1C/1D and IRS-P3. Here, an attempt is made to develop an Agricultural Drought Severity Index (ADSI) using WiFS data. Crop land and fallow land layers delineated from remote sensing data using NDVI analysis were used to develop ADSI.

By using the digitized landuse map of the study area, the total area under agricultural vegetation has been deciphered for the satellite images by eliminating the area under forest, barren lands and land put to nonagricultural usage. NDVI values were generated for these satellite images using EARDAS IMAGINE 8.5 software package and were grouped to obtain the spatial extent of crop land and fallow land. The extent of area under crop land and fallow land of each block was used to obtain ADSI.

$$Agricultural\,Drought\,Severity\,Index\,(ADSI)_i = \frac{(Crop\,land)_i}{(Crop\,land + Fallow\,land)_i}$$

Where, 'i' denote the designated block.

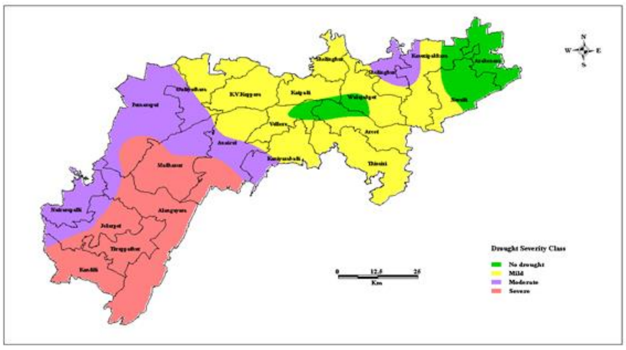


Figure 2. Meteorological Drought Severity map of the study area.

4. Results and discussion

4.1. Meteorological drought assessment

The assessment of drought severity for crop seasonal (Samba season) rainfall in meteorological context was carried out by employing IMD method. Meteorological drought assessment has been carried out for all the fifteen raingauge stations in the study area. Meteorological Drought Severity Index (MDSI) was developed by the frequency analysis of rainfall data (for 35 years) by calculating probability of each drought severity class (Vivek S *et al.,* 2019). The frequencies of different severities of meteorological drought were calculated for each rain gauge station and are presented in Table 2. The meteorological drought severity status of each station was determined, and the results are shown in Table 3. The drought severity index ranges from 1.34 at Arakonam block to 2.54 at Alangayam block. Four drought severity classes were delineated based on the range of drought severity index as shown in Table 4.

The spatial interpolation of meteorological drought severity index was carried out using Arc GIS software package. It is observed that almost 50% of the district is prone to severe and moderate droughts. The meteorological drought severity map for the study area is shown in Figure 2. In general, entire western portion of the district is more prone to drought. Arakonam, Nemili, Kaveripakkam, Thimiri, Arcot, Walajahpet, Sholinghur, Katpadi, Vellore and K.V. Kuppam blocks are less prone to drought. Natrampalli, Pernumput, parts of Gudiyatham, Anaicut, Kaniyambadi and Sholinghur blocks are under moderate drought severity status. Southwestern blocks such as Kandili, Tiruppathur, Jolarpet, Alangayam and Madhanur are all liable to severe drought.

4.2. Agricultural drought assessment

Rainfall analysis in the study area indicates that, the years 2001 and 2002 falls under normal and deficit years respectively and hence these two years have been considered to carry out the agricultural drought assessment. Remote sensing dataset used in this study consists of Indian Remote Sensing Satellite (IRS) 1C and 1D, Wide Image Field Sensor (WiFS) data during November 2001 and November 2002 of Samba season. Agricultural Drought Severity Index (ADSI) developed in this study, involves area under crop land and fallow land, delineated from remote sensing data based on the NDVI response during the crop season. The crop land and fallow land derived from the images were dissolved block wise in Arc GIS. The ADSI ranges from 0 to 1, which is divided into 4 drought severity classes with an equal interval of 0.25 as given in Table 5.

Table 2. Occurrence and frequency of meteorological drought using IMD method

Sl. No.	Name of Station	Occurrence and Frequency of Drought Severity Class							
		No		Mild		Moderate		Severe	
		No. of occurrences	Frequency	No. of occurrences	Frequency	No. of occurrences	Frequency	No. of occurrences	Frequency
1	Vellore	21	0.60	6	0.17	8	0.23	0	0.00
2	Ambur	10	0.29	9	0.26	11	0.31	5	0.14
3	Gudiyatham	12	0.35	13	0.38	7	0.21	2	0.06
4	Tirupathur	10	0.29	10	0.29	9	0.26	6	0.17
5	Vaniyampadi	13	0.39	9	0.27	9	0.27	2	0.06
6	Valajapet	18	0.51	11	0.31	6	0.17	0	0.00
7	Sholingur	15	0.43	7	0.20	7	0.20	6	0.17
8	Ranipet	21	0.60	7	0.20	7	0.20	0	0.00
9	Palar Anicut	17	0.49	12	0.34	6	0.17	0	0.00
10	Poiney	15	0.43	12	0.34	8	0.23	0	0.00
11	Arakonam	24	0.69	10	0.29	1	0.03	0	0.00
12	Kaveripakkam	16	0.46	11	0.31	8	0.23	0	0.00
13	Panappakkam	22	0.63	9	0.26	4	0.11	0	0.00
14	Alangayam	8	0.23	6	0.17	15	0.43	6	0.17
15	Jollarpattai	11	0.31	9	0.26	10	0.29	5	0.14

Table 3. Meteorological drought severity assessment

S.No.	Name of Station	Seasonal average rainfall (mm)	Probability of drought severity class				Drought Severity Index	Drought Severity Class
			No	Mild	Moderate	Severe		
1	Vellore	712.4	0.60	0.17	0.23	0.00	1.63	Mild
2	Ambur	591.2	0.29	0.26	0.31	0.14	2.31	Severe
3	Gudiyatham	632.7	0.35	0.38	0.21	0.06	1.97	Moderate
4	Tiruppathur	596.4	0.29	0.29	0.26	0.17	2.31	Severe
5	Vaniyambadi	571.0	0.39	0.27	0.27	0.06	2.00	Moderate
6	Walajahpet	736.5	0.51	0.31	0.17	0.00	1.66	Mild
7	Sholinghur	693.0	0.43	0.20	0.20	0.17	2.11	Moderate
8	Ranipet	747.9	0.60	0.20	0.20	0.00	1.60	No drought
9	Palar Anicut	836.4	0.49	0.34	0.17	0.00	1.69	Mild
10	Ponnai Anicut	714.3	0.43	0.34	0.23	0.00	1.80	Mild
11	Arakonam	863.6	0.69	0.29	0.03	0.00	1.34	No drought
12	Kaveripakkam	702.9	0.46	0.31	0.23	0.00	1.77	Mild
13	Panapakkam	841.0	0.63	0.26	0.11	0.00	1.69	Mild
14	Alangayam	523.8	0.23	0.17	0.43	0.17	2.54	Severe
15	Jolarpet	588.4	0.31	0.26	0.29	0.14	2.26	Severe

Table 6 shows the block wise agricultural drought severity assessment in the study area. Figure 3 shows the agricultural drought severity map for Samba season in the year 2001. Out of 20 blocks, 17 were under no drought, 2 under mild drought and 1 under moderate drought condition. 85% of the blocks in the district were falling under no drought condition in the year 2001. Figure 4 shows the agricultural drought severity map for Samba season in the year 2002. Out of 20 blocks, 6 blocks were under mild drought, 5 under moderate drought and 9 under severe drought condition. 70% of the blocks in the district were affected by moderate and severe droughts.

Table 4. Drought severity classification based on MDSI

S. No.	Range	Drought Severity
1	1.34 – 1.64	No drought
2	1.64 – 1.94	Mild
3	1.94 – 2.24	Moderate
4	2.24 – 2.54	Severe

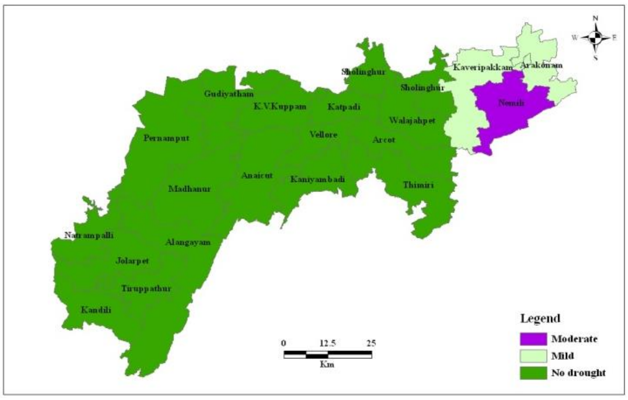


Figure 3. Agricultural Drought Severity map of 2001 (Samba season).

Table 5. Drought severity classification based on ADSI

S. No.	Classification	Drought severity
1	1 to 0.75	No drought
2	0.75 to 0.5	Mild
3	0.5 to 0.25	Moderate
4	0.25 to 0	Severe

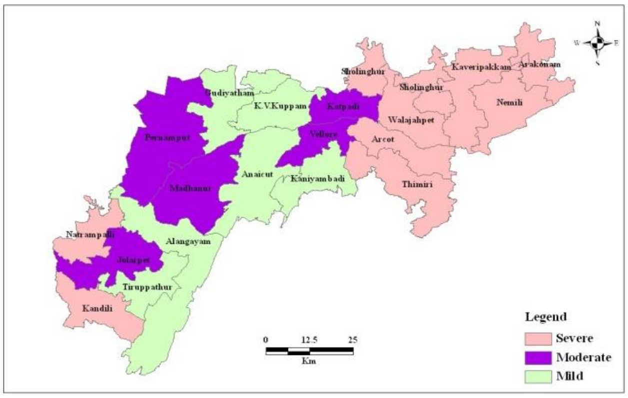


Figure 4. Agricultural Drought Severity map of 2002 (Samba Season).

5. Conclusions

In this study, an attempt was made to develop Meteorological Drought Severity Index (MDSI) using thirty-five years of rainfall data. The results were illustrated in the form of a drought severity map in GIS environment. It is observed that all the western blocks of the study area are prone to moderate and severe droughts, which needs drought proofing measures. Agricultural Drought Severity Index (ADSI) using NDVI response for the major crop season (Samba season) in the study area gave a better assessment of the situation considering the vegetation condition. The analysis of meteorological drought and agricultural drought indicates that a good correlation exists between rainfall and crop area in the study area.

Table 6. Block wise Agricultural drought severity assessment

S.No.	Block	2001(Samba season)				2002 (Samba season)			
		Crop land (ha)	Fallow land (ha)	Drought Severity Index	Drought Severity Class	Crop land (ha)	Fallow land (ha)	Drought Severity Index	Drought Severity Class
1	Alangayam	21567.81	840.69	0.96	No drought	13023.26	9199.23	0.59	Mild
2	Anaicut	19983.25	746.61	0.96	No drought	11954.98	9072.09	0.57	Mild
3	Arakonam	9532.71	6876.71	0.58	Mild	915.45	14639.47	0.06	Severe
4	Arcot	16723.96	1868.89	0.90	No drought	3257.74	15369.42	0.17	Severe
5	Gudiyatham	18912.94	974.95	0.95	No drought	10996.77	8937.69	0.55	Mild
6	Jolarpet	18781.00	677.34	0.97	No drought	7853.66	11784.08	0.40	Moderate
7	K.V.Kuppam	17339.04	399.36	0.98	No drought	10404.88	7269.69	0.59	Mild
8	Kandili	20809.99	2287.91	0.90	No drought	5093.68	17973.64	0.22	Severe
9	Kaniyambadi	10542.61	178.61	0.98	No drought	7968.98	2807.63	0.74	Mild
10	Katpadi	12343.55	775.03	0.94	No drought	4545.68	8755.29	0.34	Moderate
11	Kaveripakkam	21090.09	11219.77	0.65	Mild	1056.89	30925.59	0.03	Severe
12	Madhanur	13993.60	771.17	0.95	No drought	7321.63	7585.61	0.49	Moderate
13	Natrampalli	13739.78	1576.56	0.90	No drought	3209.77	12112.29	0.21	Severe
14	Nemili	9762.65	17081.85	0.36	Moderate	305.22	25637.15	0.01	Severe
15	Pernamput	20091.90	1868.65	0.91	No drought	9746.27	12485.22	0.44	Moderate
16	Sholinghur	22326.73	2835.15	0.89	No drought	5005.59	20222.78	0.20	Severe
17	Thimiri	27008.32	3837.85	0.88	No drought	6593.07	24390.74	0.21	Severe
18	Tiruppathur	17265.80	139.11	0.99	No drought	12881.23	4633.85	0.74	Mild
19	Vellore	7599.31	733.63	0.91	No drought	4043.56	4332.69	0.48	Moderate
20	Walajahpet	14743.11	3232.27	0.82	No drought	2619.16	15866.09	0.14	Severe

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