Chapter 38
Assessment of Agricultural Drought Vulnerability Using Remote Sensing and GIS: A Case Study of Lower Cauvery Basin, Tamil Nadu, India

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Abstract MODIS satellite provides many data products, including MOD11A2 and MOD13Q1, for the assessment of agricultural drought in a region. This study area of the lower Cauvery basin of Tamil Nadu was affected by agricultural drought as a result of scanty rainfall in the period 2010–2015. To assess the drought condition in the study area over nearly six years (2010–2015), certain drought indices are used. These include the Normalised Difference Vegetation Index (NDVI) from MOD13Q1 data product and seasonal Land Surface Temperature (LST) from MOD11A2 data product. After calculation of NDVI and LST, three other indices were derived: Vegetation Condition Index (VCI), Temperature Condition Index (TCI), and Vegetation Health Index (VHI). The spatial variation in VHI was also analysed. From the study, a significant relationship was observed between NDVI and LST-decreasing NDVI and increasing surface temperature. Results show that nearly one-third of the lower Cauvery basin was affected by mid to severe drought. During the dry season (February to May), the severity of drought has increased both in terms of intensity and extent towards the north.

38.1 Introduction

Drought is a natural hazard that affects a significant proportion of population in the world. Considering the aftermath of drought and its widespread nature, it is important to make an assessment of the severity of drought. Drought is defined as an extreme

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weather event characterised by an extended period of dry weather in a region where scarcity of water exists. Drought occurs in four temporal stages, viz., meteorological/climatological, agricultural, hydrological and socio-economic in the same order (Wilhite and Glantz 1985). Meteorological/climatological drought is characterised by precipitation deficiency which in turn causes soil moisture deficiency (agricultural drought). As a result of reduced stream flow and inflow into the reservoir, hydrological drought occurs. Due to excessive demand than supply of products that require water for production and thereby resulting in loss of income in food industry, socio-economic drought arises. Based on the type of drought, certain drought indices are employed for the assessment of drought in a region. Patel et al. (2009) and Chen et al. (2011) suggested the use of Temperature Vegetation Dryness Index (TVDI) derived from MODIS data to give information on soil moisture status in the study areas of Western UP, India and Huang-huai-hai plain, China, respectively. Tran et al. studied the monitoring of drought using various multispectral indices, including the Vegetation Health Index, in a study area of south coastal Vietnam by using the MODIS and Landsat data. Dalezios et al. (2012) used NOAA-AVHRR data to find the Reconnaissance Drought Index (RDI) to quantify drought in the Thessaly region of Greece. Palchaudhuri et al. (2016) showed how an analytic hierarchy process (AHP) can be combined with GIS to provide an assessment of risk for drought condition in Puruliya district, India. Parinaz et al. (2012) applied the concept of improved TVDI (iTVDI), Temperature Vegetation Dryness Index (TVDI) and Vegetation Dryness Index (VDI) to monitor vegetation and soil water stress by using AVHRR data in semi-arid regions of Iran. Ghulam et al. (2007) proposed how Modified Perpendicular Drought Index (MPDI) can be used as a method of drought monitoring in real-time for the study area of Shunyi district in China using MODIS data and data of Landsat ETM+. Tadesse et al. (2017) developed Veg-DRI (Drought Response Index) models for the Canada Prairie region using MODIS data and AVHRR data. Moon et al. 2004 used Leaf Area Index (LAI) in place of NDVI to calculate the TVDI in the study of evaluation of soil moisture status of the Western basin of South Korea, using MODIS data. Soil moisture status for entire China was also evaluated using the TVDI by Wang et al. Finally, Zargar et al. (2011) performed the review of different drought indices to be evaluated at different stages of drought, viz., meteorological drought, agricultural drought and hydrological drought. Thus, this study focuses on the usage of MODIS data for this study area of the lower Cauvery basin to assess the drought condition with the concept of VCI, TCI and VHI.

38.2   Study Area

Lower Cauvery river basin is located in the central portion of Tamil Nadu state in Southern India with spatial extent between longitudes $76°18'48"$ and $79°51'16"$ E and latitudes $10°8'10"$ and $12°42'35"$ N, covering approximately 47,483 sq km (Fig. 38.1). This region is characterised by a typical tropical hot and humid climate with a distinctive monsoon summer wet season (May–September) and a dry season
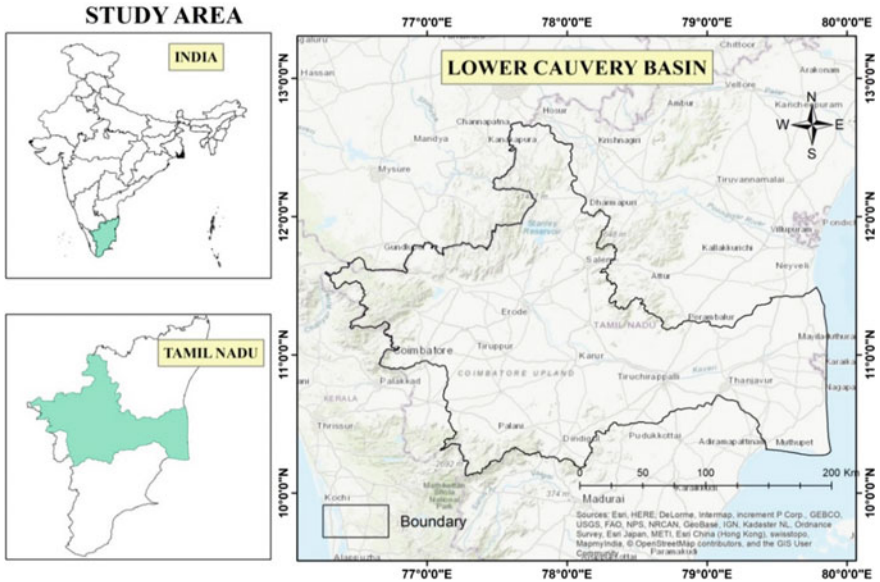
Fig. 38.1   Map showing lower Cauvery basin in Tamil Nadu

(February–April). During summer months, the Southwest Monsoon brings moisture to India from the southwest, traversing the Deccan plateau through the Utkal coast, and then moves north-west. The lithology of the basin is made up of metamorphic and igneous rocks although sedimentary rocks are exposed on the eastern side. The delta is the most fertile area in the basin and comprises alluvial soil. The major soil types existing in the basin are red soils, black soils, laterite soil, alluvium, forest soils and mixed soils. Red soils cover most of the areas in the basin. Also, in the basin exists a particular special kind of forest with well-defined species of flora and fauna and comprises many national parks and sanctuaries. Average population density in the basin is nearly 350 people per sq. km higher than the global average. Important urban centres of the past were Thanjavur and Madurai and the important urban centre of today is Tiruchirappalli. Rice is the principal crop cultivated in this basin. Major commercial crops are groundnut, sugarcane and cotton. Some other important food grain crops are bajra, jowar and pulses. The cultivable area in the basin is nearly 3.2 million hectares, which is 2% of the total cultivable area of the country.

38.3   Methodology

Vulnerability is the diminished ability of an entity to cope up with the hazard. Drought assessment is needed in order to take necessary steps to mitigate the hazard before it actually becomes a disaster. In this study, an effort is made to assess the drought

condition affecting crops in the lower Cauvery river basin of Tamil Nadu, India. An attempt is made to address the agricultural drought with the help of agricultural drought indices. The four parameters to determine vulnerability index signifying crop health and cover are the vegetation indices like NDVI (Rouse et al. 1974), Vegetation Condition Index (VCI), Temperature Condition Index (TCI) and Vegetation Health Index (VHI). MODIS data product MOD11A2 is used for deriving land surface temperature (LST) maps. NDVI maps are derived from MODIS data product MOD13Q1. Time-series analysis of NDVI and LST would reveal VCI and TCI, respectively. The VHI was estimated with the help of the two indices Vegetation condition Index(VCI) and Temperature condition Index (TCI). Vegetation Health Index (VHI) is given by the Equation 38.1:

$$VHI = a(VCI) + (1 - a)TCI \tag{38.1}$$

where 'a' is a value between 0–1. In this study, the value of 'a' is taken to be 0.5, indicating that thermal condition and moisture condition have equal weightage in the assessment of agricultural drought in this region. The index related to moisture condition is Vegetation condition Index (VCI) is given by Equation 38.2 and the index related to thermal condition is Temperature condition Index (TCI) and is given by the Equation 38.3, depicts the methodology in assessment of agricultural in the study area.

The equations of VCI and TCI are shown as follows (Table 38.1).

$$VCI = 100X\frac{\text{NDVI}_{\text{max}} - \text{NDVI}}{\text{NDVI}_{\text{max}} - \text{NDVI}_{\text{min}}} \tag{38.2}$$

$$TCI = 100X\frac{\text{LST}_{\text{max}} - \text{LST}}{\text{LST}_{\text{max}} - \text{LST}_{\text{min}}} \tag{38.3}$$

38.4   Results and Discussion

Spatial distribution of drought severity was constructed. The spatial relationships between LST and NDVI are depicted in Figs. 38.3 and 38.4. The spatial distribution of the Vegetation Condition Index, Temperature Condition Index and Vegetation Health Index is depicted in Figs. 38.5, 38.6 and 38.7 respectively. Overall, it was observed that LST and NDVI possessed a significant negative relationship with each other (see Figs. 38.8 and 38.9). This result is likely because the lower Cauvery basin is located at lower latitude (10° N) where the climate is hot and humid. Also, the monthly variation of mean NDVI, mean LST, mean VCI, mean TCI and mean VHI are plotted with time factor for the years 2010–2015. At the time of the dry season, the density of vegetation reduced, and the value of temperatures was very high, and at the time of the mid-dry season, the high proportion of the area had surface temperatures
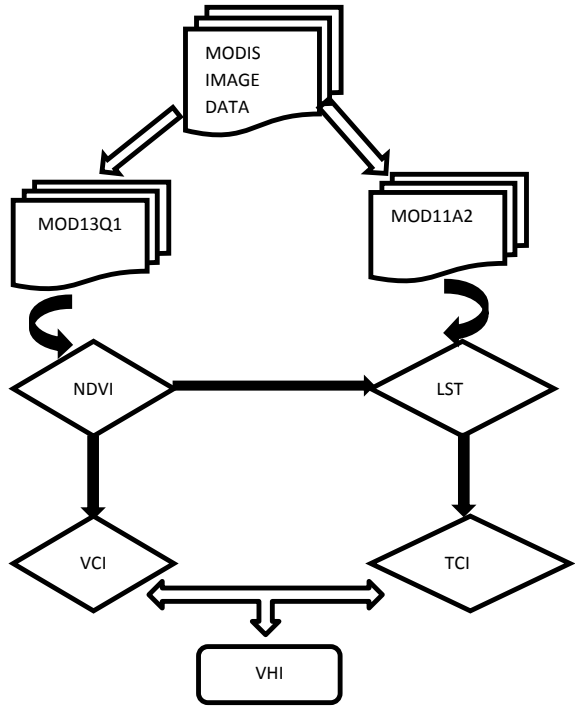
Fig. 38.2 Flowchart illustrating the methodology

Table 38.1 Categorisation of drought severity based upon values of VHI (Kogan 1995; Le Hung and Hoai 2015)

S. No	Value of VHI	Drought severity
1	0–10	Extreme
2	10–20	Severe
3	20–30	Moderate
4	30–40	Mid
5	>40	Nil

greater than 32 °C (red color). During the wet season, the density of vegetation was high, the surface temperature was low, but varied. Figure 38.9 describes the plot between monthly mean NDVI, LST, VCI, TCI and VHI and time factor, respectively. Figure 38.8 shows the spatial distribution of VHI for the dry year 2013.

38.5 Conclusion

From the spatial distribution maps, it can be inferred that the western and central regions of the study area in the rainfall deficient year 2011 are under stress, whereas the deltaic region in the east is not under the influence of drought conditions. The
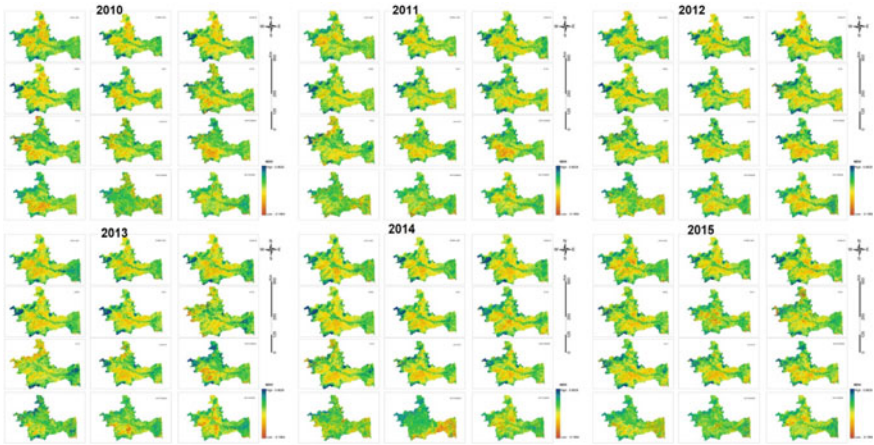
Fig. 38.3 NDVI images of study area of each month from 2010 to 2015
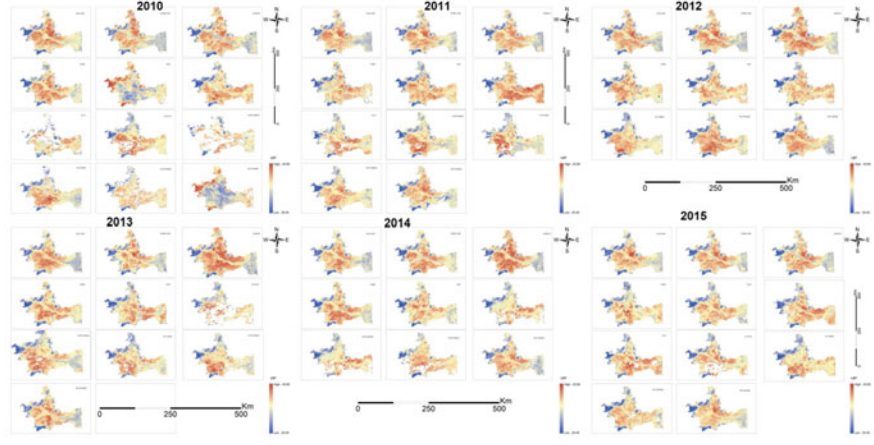

Fig. 38.4 LST images of study area of each month from 2010 to 2015

graphs show an inverse relationship between LST and NDVI for the different years. Relatively less NDVI is characterised by relatively high LST and vice versa. The year 2010 was a relatively wet year when compared to subsequent years of 2011, 2012 and 2013 with less rainfall, and which show stress in vegetation as seen in spatially distributed maps. The study also concludes that MODIS data offers freely available data at suitable resolution of 250 m which enable to conduct effective drought survey over large areas using drought indicators such as the VHI, TCI and VCI.
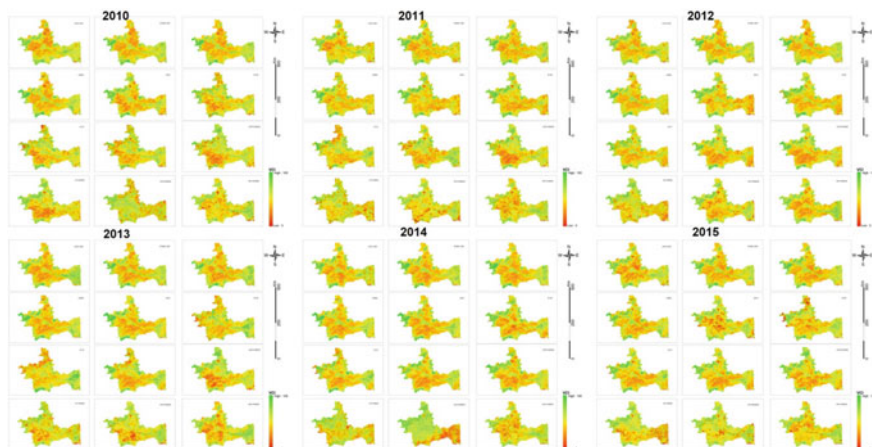
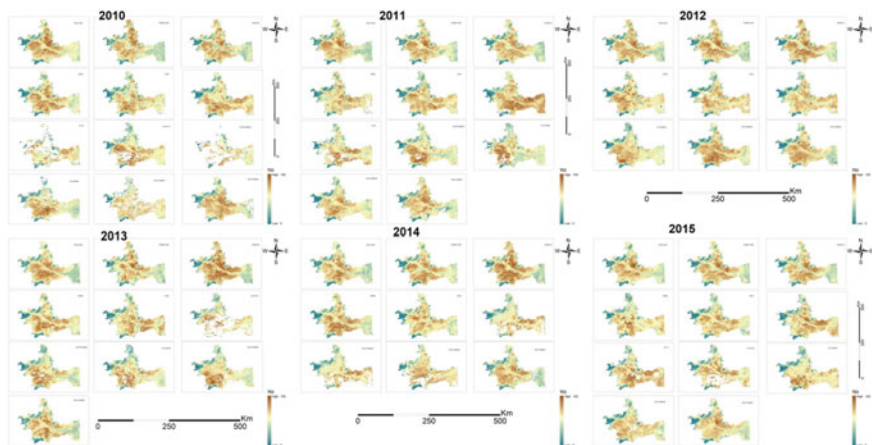**Fig. 38.5**   VCI images of study area of each month from 2010 to 2015

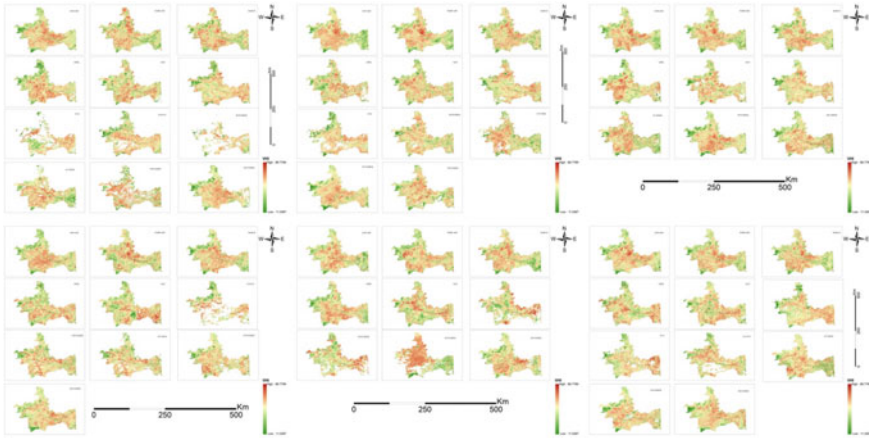**Fig. 38.6**   TCI images of study area of each month from 2010 to 2015

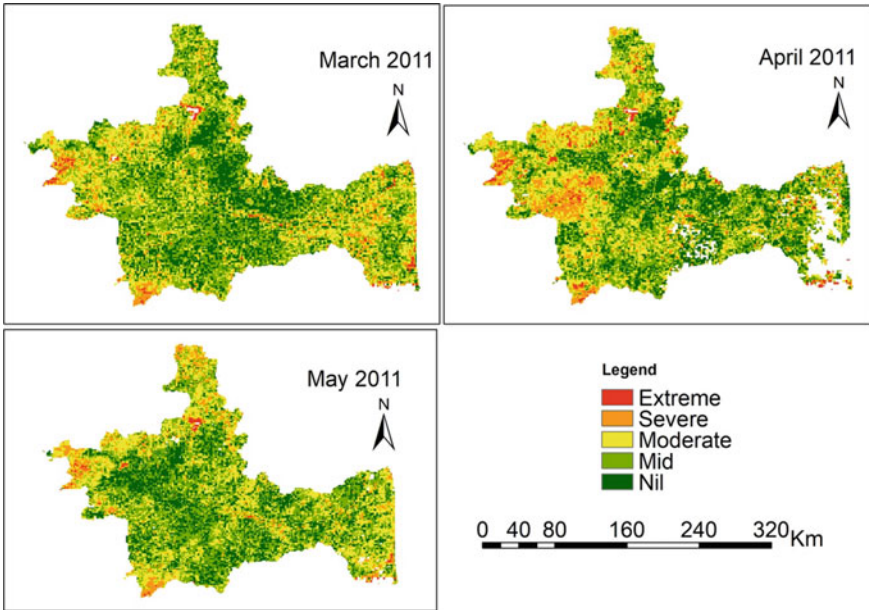**Fig. 38.7** VHI images of study area of each month from 2010 to 2015

Fig. 38.8 Maps showing VHI for March, April and May for the year 2011

(a) plot of Monthly Mean NDVI for Years 2010-2015

(b) plot of Monthly Mean LST for years 2010-2015

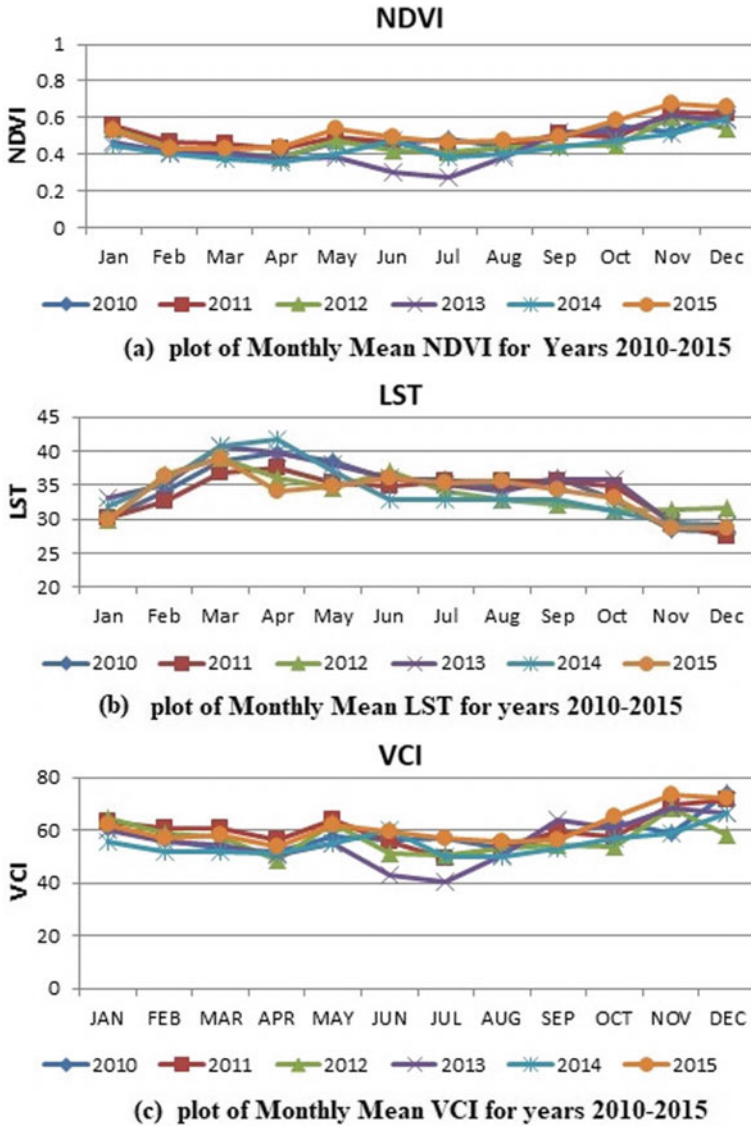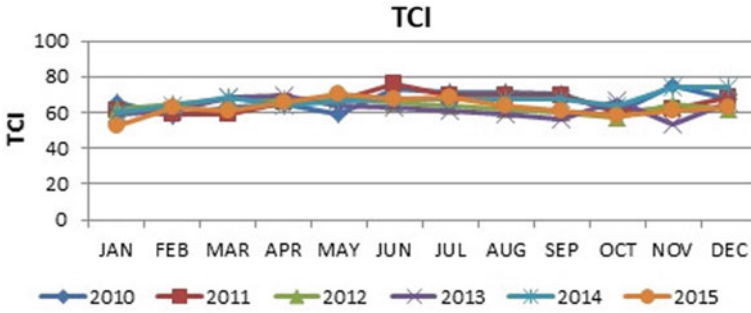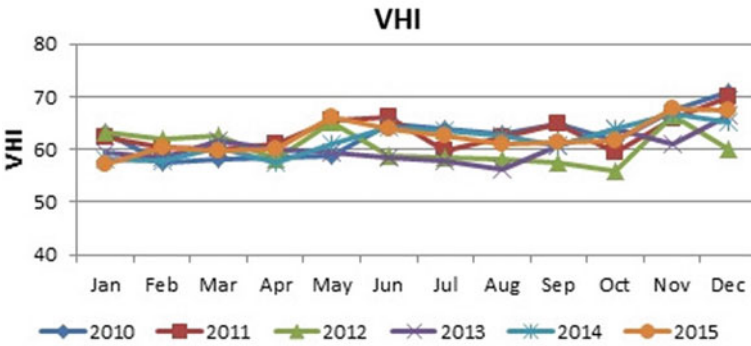(c) plot of Monthly Mean VCI for years 2010-2015

Fig. 38.9 Plot showing the monthly mean drought indices and time factor

(d) plot of Monthly Mean TCI for years

(e) plot of Monthly Mean VHI for years 2010-2015

Fig. 38.9 (continued)

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