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Temporal analysis of rainfall (1871–2012) and drought characteristics over a tropical monsoon-dominated State (Kerala) of India

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SUMMARY

The climate of Kerala is controlled by the monsoon, and the analysis of rainfall and drought scenario, for a period of 141 years (1871–72 to 2011–12), reveals a decreasing trend in southwest monsoon, and increasing trends for post-monsoon-, winter- and pre-monsoon-rainfall. The inconsistent periodicity (2–8 years) of annual- and seasonal-rainfall agrees with the periodicity of El-Nino Southern Oscillation (ENSO). The annual rainfall shows an irregular distribution, and is concentrated roughly in half of the year, which is due to the monsoon-driven climatic seasonality. The rainfall concentration at annual-, southwest monsoon-, and winter-scales exhibits significant decreasing trends, implying decline in the degree of irregularity in annual- and seasonal-rainfall. Temporal distribution as well as severity of the drought events have been analyzed using various drought indicators. The drought pattern is not only related to the rainfall trends, but also to the rainfall concentration (or monthly rainfall heterogeneity). The decreasing rainfall during southwest monsoon contributes to short-term meteorological droughts, which have serious implications on the agricultural sector and water resources of Kerala, while the increasing rainfall during other seasons helps to reduce the drought severity.

1. Introduction

The Western Ghats, a high-elevation passive margin trending NNW–SSE for a length of ~1500 km, has a significant role in determining the climate of the Peninsular India. Mean elevation of the Western Ghats is about 1000 m with the southern portion characterized by several peaks rising to over 2000 m above mean sea level. Kerala is an elongated strip of land (area = 38,863 km^2; between N. Lat. 8°15′ and 12°50′ and E. Long. 74°50′ and 77°30′) in the southwest tip of the Peninsular India, encapsulated between the Western Ghats in the east and the Arabian Sea in the west (Fig. 1). Physiographically, the State can be divided into three distinct zones, viz., the highland (in the east), the midland (between the highland and lowland), and the lowland (in the west). Lying mostly in the western (and windward) slopes of the Western Ghats, Kerala experiences heavy rainfall (roughly 3000 mm annually), of which, majority occur during the monsoon.

Monsoon, the most important phenomenon controlling the regional climate, is mostly contributed by two seasons of rain, viz., southwest monsoon (June–September) and northeast monsoon (October–December). The onset of the southwest monsoon normally starts over the Kerala coast by 1st June, advances along the western coast in early June and covers the whole country by middle of July, and withdraws by 15th October and is replaced by a northerly continental airflow called northeast monsoon (Attri and Tyagi, 2010). The monsoonal rainfall in Kerala oscillates between active spells associated with widespread and intense rains and breaks with little rainfall activity. So significant is the monsoon season to regional climate, the variability in the onset, withdrawal and quantum of rainfall during the monsoon season has profound impacts on the economy of Kerala. Therefore understanding the trends and changes in rainfall pattern as well as drought characteristics has a vital role in watershed development and management.

The trends in rainfall pattern as well as rainfall concentration and seasonality, in various parts of the world, have been subjected to detailed analysis (e.g., de Luis et al., 2000, 2011; Kanellopoulou, 2002; Kwarteng et al., 2009; Zhang et al., 2009; Batisani and Yarnal, 2010; Chowdhury and Beecham, 2010; Caloiero et al., 2011; Oguntunde et al., 2011; Feng et al., 2013; Burt and Weerasinghe, 2014; Awan et al., 2015). Similarly, in recent years, various attempts have also been made to study the trends in annual and seasonal rainfall over India, in different spatio-temporal domains, using various methodologies (e.g., Guhathakurta and Rajeevan, 2008; Rajeevan et al., 2008; Singh et al., 2008; Kumar et al., 2010; Joshi and Pandey, 2011; Jain and

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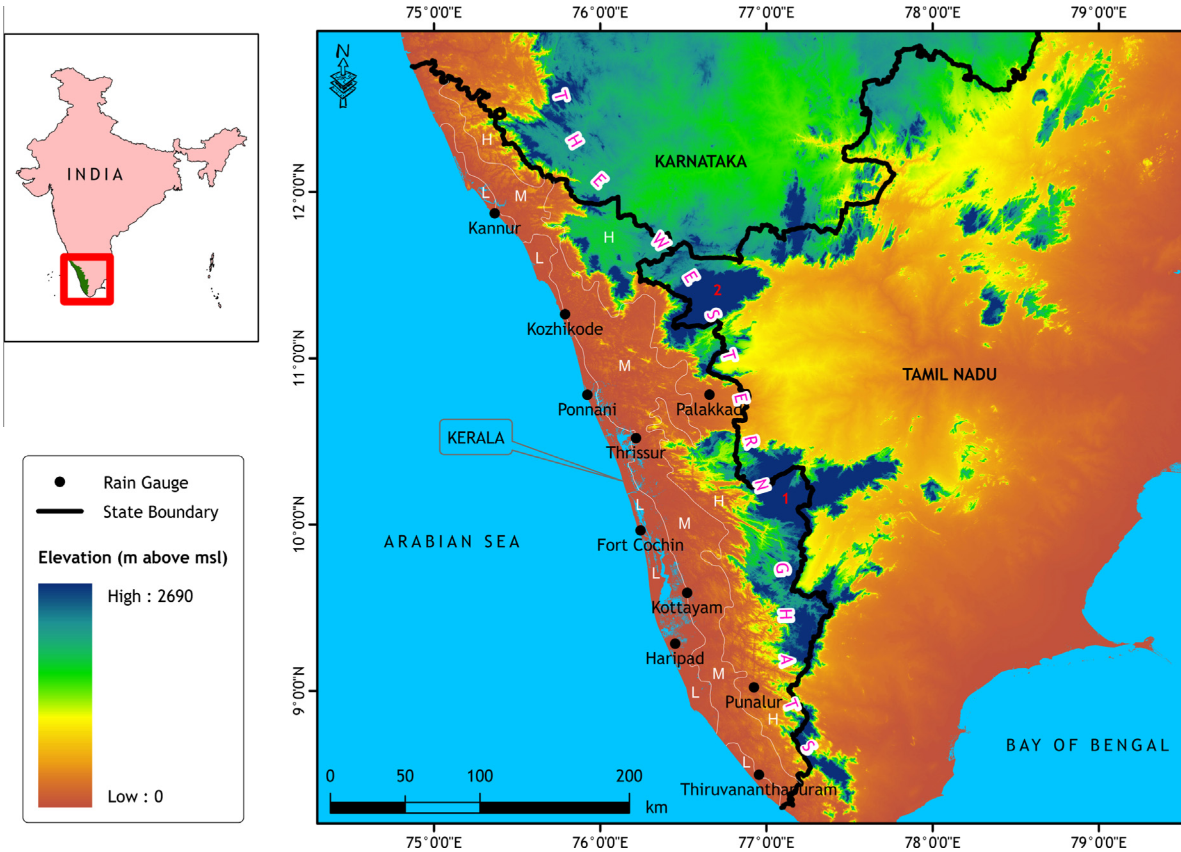

Fig. 1. Location of Kerala State (highlighted in the index map), India. The physiography is portrayed by SRTM DEM (3 Arc Second). Thin white lines represent the boundary of the various physiographic divisions, viz., highland (H), midland (M) and lowland (L). The numerals 1 and 2 denote the Anai Malai-Cardamom and Nilgiri Hills respectively.

Kumar, 2012; Kundu et al., 2014; Mondal et al., 2014). The State of Kerala exhibits spatio-temporal variations in rainfall budget, and the analysis of rainfall data of the last century indicates a significantly decreasing trend in the annual as well as southwest monsoon rainfall (Soman et al., 1988; Simon and Mohankumar, 2004; Guhathakurta and Rajeevan, 2008; Krishnakumar et al., 2009; Nikhil Raj and Azeez, 2012; Nair et al., 2014). The decreasing trends in pre-monsoon extreme rainfall and increasing frequency of the dry days suggest the vulnerability of Kerala to increasing probability of water scarcity in the pre-monsoon and delay in monsoon onset (Pal and Al-Tabbaa, 2009).

Droughts occur in virtually all climatic zones as a result of inadequate water availability due to a deficit in moisture supply resulting either from sub-normal or erratic rainfall distribution, higher water demands or a combination of both (Dracup et al., 1980; Wilhite and Glantz, 1985; Redmond, 2002). Although deficiency in rainfall is mostly responsible for the initiation of droughts, estimation of drought characteristics such as onset, termination, frequency, severity and intensity is often complicated (McKee et al., 1993). Besides, the amount of rainfall received in an area over an extended period of time, temperatures, high winds, low relative humidity, timing and characteristics of rains, including distribution of rainy days during crop growing seasons, intensity and duration of rain, and onset and termination, play significant roles in the occurrence of droughts (Mishra and Singh, 2010). Due to its complex nature (i.e., slow onset, varying durations, and large spatial coverage with modest structural damages), an understanding of spatio-temporal variability is essential to establish integrated drought early warning systems incorporating climate, soil, and all related water supply functions (Thomas et al., 2015a).

Wilhite and Glantz (1985) and American Meteorological Society (1997, 2004) classified droughts into four categories, viz., meteorological drought, hydrological drought, agricultural drought, and socio-economic drought. Although drought analysis can be carried out by employing a variety of methods, application of drought indices gained wide currency because drought index provides a comprehensive picture of drought, in terms of different drought parameters. Several drought indices were developed to quantify droughts, each with its own strengths and weaknesses (e.g., Palmer drought severity index, PDSI, Palmer, 1965; rainfall anomaly index, RAI, van Rooy, 1965; deciles, Gibbs and Maher, 1967; crop moisture index, CMI, Palmer, 1968; Bhalme and Mooley drought index, BMDI, Bhalme and Mooley, 1980; surface water supply index, SWSI, Shafer and Dezman, 1982; standardized precipitation index, SPI, McKee et al., 1993, 1995). Detailed reviews on drought concepts and various drought indices are available with American Meteorological Society (1997), Heim (2000, 2002), Keyantash and Dracup (2002), Niemeyer (2008), Mishra and Singh (2010), Zargar et al. (2011) and Thomas et al. (2015a).

India is one among the most vulnerable drought-prone countries in the world with an increased frequency, at least once in every three years, in the last five decades (FAO, 2002; World Bank, 2003 Mishra and Singh, 2010). Though drought proneness is predominantly restricted to arid and semi-arid areas (e.g., Mishra and Desai, 2005; Bhuiyan et al., 2006; Pandey et al., 2008; Thomas et al., 2015a,b), the occurrence of droughts in Cherrapunji in Meghalaya, one of the world's highest rainfall areas (>11,000 mm), indicates that it is an issue related to water resource management in India (Thomas et al., 2015a).

Hence, the formulation and effective implementation of comprehensive water resources- and disaster management-strategies call for an understanding of rainfall pattern and historical droughts. Although there exist several studies on rainfall characteristics at various spatial and temporal scales, none aims