Science of the Total Environment 613–614 (2018) 88–97

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Latitudinal variation in summer monsoon rainfall over Western Ghat of India and its association with global sea surface temperatures

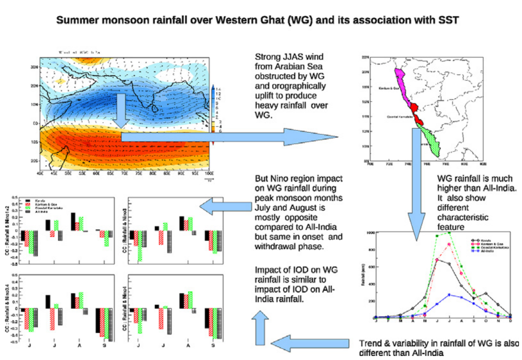
J.V. Revadekar [a,*], Hamza Varikoden [a], P.K. Murumkar [a,b], S.A. Ahmed [b,c]

[a] Center for Climate Change Research, Indian Institute of Tropical Meteorology, Pune 411008, India
[b] Department of Geology, Central University of Karnataka, Kalaburgi, India
[c] Department of Applied Geology, Kuvempu University, Shankaraghatta 577451, India

HIGHLIGHTS

- North-south oriented western ghat (WG) of India has narrow zonal width
- Latitudinal variation in summer-monsoon (JJAS) rainfall over WG
- Trends are not monotonous but has epochal behavior during 1871-2014
- Positive phase of IOD strengthen westerlies to enhance rainfall activity
- Asymmetric impact of El Nino on WG rainfall during summer monsoon

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 9 March 2017
Received in revised form 22 August 2017
Accepted 28 August 2017
Available online xxxx

Editor: D. Barcelo

Keywords:
Western Ghats
Sea surface temperature
IOD
El Nino
Summer monsoon

ABSTRACT

The Western Ghats (WG) of India are basically north-south oriented mountains having narrow zonal width with a steep rising western face. The summer monsoon winds during June to September passing over the Arabian Sea are obstructed by the WG and thus orographically uplift to produce moderate-to-heavy precipitation over the region. However, it is seen that characteristic features of rainfall distribution during the season vary from north to south. Also its correlation with all-India summer monsoon rainfall increases from south to north. In the present study, an attempt is also made to examine long-term as well as short-term trends and variability in summer monsoon rainfall over different subdivisions of WG using monthly rainfall data for the period 1871–2014. Konkan & Goa and Coastal Karnataka show increase in rainfall from 1871 to 2014 in all individual summer monsoon months. Short-term trend analysis based on 31-year sliding window indicates that the trends are not monotonous, but has epochal behavior. In recent epoch, magnitudes of negative trends are consistently decreasing and have changed its sign to positive during 1985–2014.

It has been observed that Indian Ocean Dipole (IOD) plays a dominant positive role in rainfall over entire WG in all summer monsoon months, whereas role of Nino regions are asymmetric over WG rainfall. Indian summer monsoon is known for its negative relationship with Nino SST. Negative correlations are also seen for WG rainfall with Nino regions but only during onset and withdrawal phase. During peak monsoon months July and August subdivisions of WG mostly show positive correlation with Nino SST.

1. Introduction

Indian climate is dominated by summer monsoon (June through September), which delivers most of rainfall over large part of the

* Corresponding author.
E-mail address: jvrch@tropmet.res.in (J.V. Revadekar).

http://dx.doi.org/10.1016/j.scitotenv.2017.08.285

country and it has a key impact on the economy. The rainfall over India is unevenly distributed on the spatial domain and the Western Ghats (WG) is one of the areas where monsoon rainfall is recorded maximum. The WG is basically north-south oriented mountain with slight east-west profile having narrow zonal width and a maximum height exceeding 2650 m. The moisture laden monsoon winds passing over the Arabian Sea are confronted and obstructed by the WG due to its uprising western face. Thus it lifted up over the WG orographically and became cool as a result of the adiabatic process. Moist air cools to saturation and then it condenses due to high amount of water vapor collected from the Indian Ocean and the Arabian Sea. Thus, from the west coast, rainfall increases along the slopes of the WG and rapidly decreases on the eastern leeward side due to the sinking air. The orography over the downwind side is irregular, rainfall features are also irregular and complex with respect to time and space (Venkatesh and Jose, 2007). Amount of rainfall is determined by many factors like availability of moisture, wind velocity, wind direction and orography of the region. The maximum rainfall appears to occur in the high altitudinal zones (Sarker, 1966; Patwardhan and Asnani, 2000). Grossman and Durran (1984), Ogura and Yoshizaki (1988) have shown that the orographic effect may affect horizontally up to 200 km in the windward direction and therefore WG's elevation is capable of deep convection well offshore in the Arabian Sea and western coast (Vishnu et al. 2013). Among the three subdivisions of WG, Coastal Karnataka receives the highest seasonal rainfall and Kerala receives the lowest. Kerala, southernmost region of WG has isolated, narrow mountain range whereas Karnataka has broad mountain barrier (Tawde, 2013) indicating the orographic dependence. One possible reason behind this could be the spatial extend of horizontal flow restricted by the isolated mountain is less compared to the chain of mountains. Kirshbaum and Smith (2008) have shown that advection time scale determines amount of precipitation. Rainfall intensity gradually steps down from north to south in Kerala (Soman et al., 1988; Simon and Mohankumar, 2004; Krishna Kumar et al., 2009).

Most of the past studies have indicated that all-India summer monsoon rainfall is trendless and is mainly random in nature (Mooley and Parthasarathy, 1984). However some studies have brought out other aspects of changes in precipitation over India. Rupa Kumar et al. (1992) studied the changes in total precipitation during 1871–1984 using linear trends at individual 306 stations well spread over India for their spatial patterns and found an increasing trend over west coast and northwest India and decreasing trend over eastern Madhya Pradesh. Significant increasing trend has been noticed by Singh and Sontakke (2002) over the central parts and significant decreasing trend over eastern parts of India from 1939 to 1999. Chhabra et al. (1997) have shown an increase in the precipitation in urban and industrial cities and decreasing trend over hilly stations. Out of 36 meteorological subdivisions of India, three subdivisions show significant decreasing trends in summer monsoon rainfall (Guhathakurta and Rajeevan, 2008), these subdivisions are Jharkhand, Chattisgarh and Kerala. Varikoden and Preethi (2013) found that the summer monsoon rainfall show significant positive trend over northeastern region. Summertime drying over different parts of India and its reasons have been documented by Bollasina et al. (2011), Krishnan et al. (2013), Roxy et al. (2014, 2015) and Preethi et al. (2017). Kripalani and Kulkarni (2001) examined the relationship of rainfall between South and East Asian regions and found secular variations with an out of phase relationship between the two sub-monsoon systems. In recent years, this contrast has been intensified (Kripalani et al., 2002; Yun et al., 2014) due to the increase in zonal sea surface temperature gradient (Yun et al., 2014). Preethi et al. (2017) have shown in-phase relationship between rainfall series over West Coast of India and rainfall variations over surrounding region. Over the WG of India, Krishnan et al. (2013) have shown a decreasing trend in summer monsoon rainfall for the period 1951–2007, whereas Preethi et al. (2017) documented an increasing trend over the northern parts of the west coast of India and a decreasing trend over the southern parts of the west coast of India based on data for the period 1970–2014. They attributed the increasing trend over west coast of India with negative correlation coefficient in the west equatorial Arabian Sea SST and positive correlation in the west equatorial Pacific Ocean SST. On a century long period the Indian summer monsoon is trendless, it does depict decreasing tendency during the period 1976–2004. Kulkarni (2012) has shown the deficit (excess) monsoons have become more (less) frequent during the recent period 1976–2004. Detection of long-term, linear trends is affected by a number of factors, including the size of trend to be detected, the time span of available data, etc. (Elizabeth et al., 1998). All past studies mentioned above are based on different grid-size/area and different data sources and hence have led to differences in results of trend analysis.

Indian summer monsoon rainfall exhibits large spatio-temporal variability that is always viewed in the greatest concern, and it is teleconnected with different oceanic and land surface phenomena (Walker, 1923, 1924; Sikka, 1980; Rasmussen and Carpenter, 1983; Mooley and Parthasarathy, 1984; Rajeevan and McPhaden, 2004). El Niño and La Niña are well known to be associated with significant monthly/seasonal climate anomalies at many places around the globe (Kiladis and Diaz, 1989; Ropelewski and Halpert, 1987). The El Nino Southern Oscillation (ENSO) is known to be a major forcing of the Earth's year-to-year climate variability. Association between ENSO and summer-monsoon rainfall over India has been rigorously studied (Sikka, 1980; Pant and Parthasarathy, 1981; Bhalme et al., 1983; Bhalme and Jadhav, 1984; Rasmussen and Carpenter, 1983; Parthasarathy and Pant, 1985; Shukla and Paolino, 1983; Parthasarathy and Pant, 1985; Gregory, 1989a, 1989b; Webster and Yang, 1992; Kripalani and Kulkarni, 1996; Mooley, 1997; Webster et al., 1998; Varikoden and Babu, 2015). The ENSO-monsoon teleconnections involve significant simultaneous relationships between monsoon rainfall and various ENSO indices (Krishna Kumar et al., 1995). Gadgil et al. (2003, 2004) have suggested that the deficit and excess rainfall monsoon seasons are linked not only to ENSO but also to Equatorial Indian Ocean Oscillation (EQUINOO): events over equatorial Indian Ocean involving an enhancement of deep convection over western part with suppression over eastern part of equatorial Indian Ocean and vice versa. It has been observed that the relationship ENSO with monsoon rainfall has been weakening in recent decades (Shukla, 1995; Kripalani and Kulkarni, 1997a, 1997b; Krishna Kumar et al., 1999; Kinter et al., 2002; Krishna Kumar et al., 2006). Such weakening is possibly a short-lived feature, considering the conflicting results reported by global warming simulations (Ashrit et al., 2001) and some subsequent instances of monsoon failures in association with moderate El Niño situations such as 2002, 2004 and 2009. Indian Ocean Dipole (IOD) mode has been shown to have significant association with the changes in circulation patterns (Saji et al., 1999). It is well documented that the SSTs of the Indian Ocean have had an impact on the Indian monsoon (Shukla, 1975; Shukla and Mooley, 1987; Ashok and Saji, 2007). In view of this, the present study attempted to bring out the trend and variabilities for long term period from 1871 to 2014 and also for short term period based on 31-year period sliding window for all the three subdivisions of Western Ghats. In addition, summer monsoon rainfall over WG is also to be studied in relation to global SSTs to bring out the features of teleconnections.

2. Data and methodology

West coast of India covers three subdivisions namely Kerala, Coastal Karnataka and Konkan & Goa (Fig. 1). Monthly rainfall data for these subdivisions for the period 1871–2014 (144 years) are taken from www.tropmet.res.in to examine changes in trends and variability. In addition to trend analysis for long-term period, epochal behaviors of rainfall are also assessed. For this purpose 31-year sliding (1871–1901, 1872–1902 … 1984–2014) analysis is done using the data for entire