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Long term trends of seasonal and monthly rainfall in different intensity ranges over Indian subcontinent

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सार – भारतीय ग्रीष्मकालीन मॉनसून वर्षा में अखिल भारतीय ग्रीष्मकालीन मॉनसून वर्षा श्रृंखला में किसी विशेष प्रकार की प्रवृत्ति का सामान्यतः पता नहीं चला है तथापि ISMR की स्थानिक प्रवृत्तियों के प्रभावित होने की रिपोर्ट मिली है। इस शोध पत्र में भारतीय उपमहाद्वीप के विभिन्न क्षेत्रों में ग्रीष्मकालीन मॉनसून वर्षा की तीव्रता की विभिन्न श्रेणियों की दीर्घकालीन प्रवृत्तियों का पता लगाने का प्रयास किया गया है। भारत मौसम विज्ञान विभाग के 1 जनवरी, 1901 से 31 दिसम्बर, 2003 तक की अवधि के 1° × 1° अक्षांश–देशांतर ग्रिड के स्थानिक विभेदन वाले ग्रिडयुक्त दैनिक वर्षा के आँकड़ों का उपयोग करके मौसमी और मासिक वर्षा की दीर्घ अवधि प्रवृत्ति भी तैयार की गई। दक्षिण पूर्व, उत्तर पश्चिम और उत्तर पूर्व क्षेत्रों में ग्रीष्मकालीन मॉनसून वर्षा की प्रवृत्ति में बढ़ोतरी दिखती है। जबकि मध्य और पश्चिम तटीय क्षेत्रों में कमी की प्रवृत्ति दर्शाती है। मासिक पैमाने पर, जुलाई की वर्षा भारत के पश्चिमी तटीय और मध्य क्षेत्रों में कमी की प्रवृत्ति तथा 0.1 प्रतिशत महत्वपूर्ण स्तर पर उत्तरपूर्व क्षेत्र में विशेष रूप से बढ़ोतरी की प्रवृत्ति दर्शाती है। अगस्त माह के दौरान, पश्चिमी तटीय स्थानों में विशेष रूप से 10 प्रतिशत कमी की प्रवृत्ति पाई गई है। अधिकांश स्टेशनों में, माध्य दैनिक वर्षा से कम और बहुत ही भारी वर्षा में बढ़ोतरी की प्रवृत्ति का पता चलता है। सामान्य वर्षा में विभिन्न क्षेत्रों के लिए प्रवृत्ति भिन्न–भिन्न है। मध्य और दक्षिणी क्षेत्रों में सामान्य और सामान्यतः उच्च श्रेणियों से वृद्धि की प्रवृत्ति का पता चला है। उच्च और अति उच्च तीव्रता श्रेणियों में विशेष रूप से कमी की प्रवृत्ति का पता चलता है। उत्तर पूर्वी क्षेत्रों में, 10 मि.मी./दिन से अधिक की वर्षा 0.1 प्रतिशत के महत्वपूर्ण स्तर के साथ महत्वपूर्ण वृद्धि की प्रवृत्ति दर्शाती है।

ABSTRACT. In general Indian summer monsoon rainfall did not show any significant trend in all Indian summer monsoon rainfall series, however, it was reported that the ISMR is subjected to spatial trends. This paper made an attempt to bring out long term trends of different intensity classes of summer monsoon rainfall in different regions of Indian subcontinent. The long term trend of seasonal and monthly rainfall were also made using the India Meteorological Department gridded daily rainfall data with a spatial resolution of 1° × 1° latitude-longitude grid for the period from 1st January, 1901 to 31st December, 2003. The summer monsoon rainfall shows an increasing trend in southeast, northwest and northeast regions, whereas decreasing trend in the central and west coastal regions. In monthly scale, July rainfall shows decreasing trend over west coastal and central Indian regions and significant increasing trend over northeast region at 0.1% significant level. During the month August, decreasing trend is observed in the west coastal stations at 10% significant level. In most of the stations, mean daily rainfall shows an increasing trend for low and very high intense rainfall. For the moderate rainfall, the trend is different for different regions. In the central and southern regions the trend of moderate and moderately high classes show increasing trend. And for the high and very high intensity classes, the trend is decreasing significantly. In the northeastern regions, above 10 mm/day rainfall shows significantly increasing trend with 0.1% significant level.

Key word – Summer monsoon rainfall, Trend analysis, Intensity classes, Monthly rainfall.

1. Introduction

Indian summer monsoon rainfall has been associated with the large fluctuations in different time scales. These fluctuations are different at various locations with different magnitudes. An understanding of the variability of the summer monsoon rainfall from year to year (*i.e.*, inter annual variations) is of great relevance since these variations have a direct impact on the agricultural production and the Indian economy. Rakhecha and Pisharoty (1996) found that rainfall received from the weather systems at many locations can range from 400 mm to 900 mm in one day, which can have sizable contribution to their total annual rainfall and it may lead to good monsoon. Realizing the importance of the subject, researchers (Iwashima and Yamamoto, 1993; Karl *et al.*, 1995; Mason *et al.*, 1999) have used long term daily extreme rainfall records to investigate changes in the frequency of extreme rainfall. They found a trend towards the higher frequency of extreme rainfalls over Japan, US, UK, China and much of South Africa. However, there have not been systematic attempts to study the possible significance of variability in the extreme rainfall events although several papers treat the problem of the long term fluctuations in monthly, seasonal and annual rainfall over India (Dhar *et al*., 1982; Mooley and Parthasarathy, 1984; Alvi and Koteswaram 1985; Rupakumar *et al*., 1992). Many investigators have looked for regular patterns of droughts and floods in the Indian summer monsoon rainfall data. Some have speculated that the variations in sunspot cycle may be associated with regular patterns of droughts and floods (Jagannathan and Bhalme, 1973; Kailas and Narasimha, 2000).

Long term trends of ISMR for the country as a single unit as well as for smaller regions have been studied extensively (Parthasarathy, 1984; Rupakumar *et al*., 1992; Goswami *et al*., 2006; Guhathakurta and Rajeevan, 2008). Most of the studies are based on the rainfall series constructed by Parthasarathy *et al*. (1994). The variability of ISMR was extensively studied by many researchers in different temporal and spatial domains (Mooley and Parthasarathy, 1984; Parthasarathy, 1984; Parthasarathy *et al*., 1994; Pant *et al*., 1988; Parthasarathy *et al*., 1990; Hamza and Babu, 2007). Goswami *et al*. (2006) made a comprehensive study of trends in three different intensity classes such as moderate (5<R<100 mm/day), heavy (R>100 mm/day) and very heavy (R>150 mm/day) of ISMR and found that moderate intensity ranges show a decreasing trend while heavy and very heavy intensity ranges show significant increasing trend over Central India. Guhathakurta and Rajeevan (2008) studied the long term trends of rainfall using 103 year data set over the Indian meteorological sub-divisions and they found that three subdivisions (Kerala, Jharkhand and Chattisgarh) are showing decreasing trends and eight increasing trend in other eight meteorological sub-divisions. In a country like India, with large spatial and temporal variability of monsoon rainfall, it is obvious that the characteristics of the different monsoon rainfall over spatial domains are different for different intensity classes. Therefore, it is imperative to study the trends of the seasonal and monthly rainfall in different intensity classes over different regions. The present study is focused to understand the trends in different intensity ranges over different parts of Indian subcontinent. We analyzed the trends in southwest monsoon rainfall as a whole and monthly scales for all the different intensity classes.

2. Data and methodology

The present study utilizes the gridded rainfall data for 103 year period (1901-2003) available from India Meteorological Department (IMD) (Rajeevan *et al*., 2008). The gridded data is available with a spatial

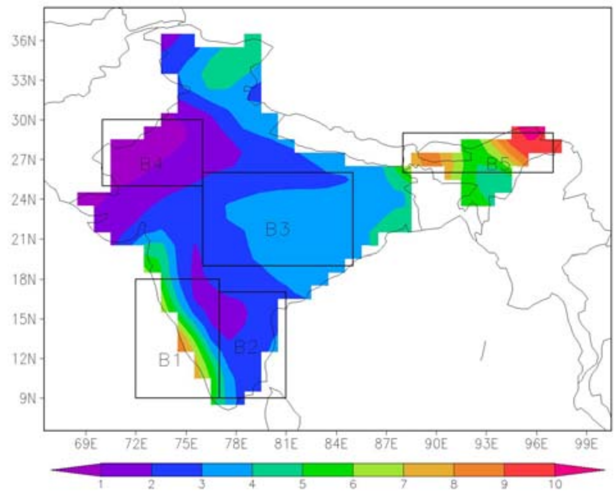


Fig. 1. Daily mean rainfall (mm/day) for the years 1901-2003. The boxes are marked as B1 to B5 representing southwest, southeast, central India, northwest and northeast regions respectively

Resolution of 1° × 1° latitude-longitude grid and a temporal resolution of a day. The IMD has daily archive of rainfall data of more than 100 years for many stations and a daily gridded rainfall data set for a long period (1901-2003) was prepared. In order to remove the temporal in homogeneities, it was developed by considering 1476 stations which had a minimum 90% data availability. Before interpolation (Shepard, 1968), the observed station rainfall data set was subjected to multistage quality control analysis (Rajeevan *et al*., 2006; Rajeevan *et al*., 2008; Guhathakurta and Rajeevan, 2008). The geographical area, 6.5° N to 37.5° N, 66.5° E to 101.5° E was considered for interpolating the station rainfall data to gridded rainfall data. Based on the mean rainfall, we classified the Indian region into five different rainfall zones. Each zone has almost uniform rainfall in the spatial domain. Fig. 1 shows the daily mean rainfall for the entire period of study (1st January, 1901 to 31st December, 2003) and the five grid boxes from B1 to B5 are marked as the study regions. Moreover, we analyzed the trends of rainfall in different intensity classes. These intensity classes were classified as very small (VS = 0.01 < R ≤ 2.5), small (SM = 2.50 < R ≤ 5), moderate (MO = 5.00 < R ≤ 10), moderately high (MH = 10.00 < R ≤ 15), high (HI = 15.00 < R ≤ 20), and very high (VH = R 20), where R is the intensity of rainfall.

3. Results and discussion

3.1. *Linear trends in summer monsoon rainfall over different rainfall zones*

Indian monsoon rainfall has been characterized with the intra-seasonal, inter-annual and inter-decadal

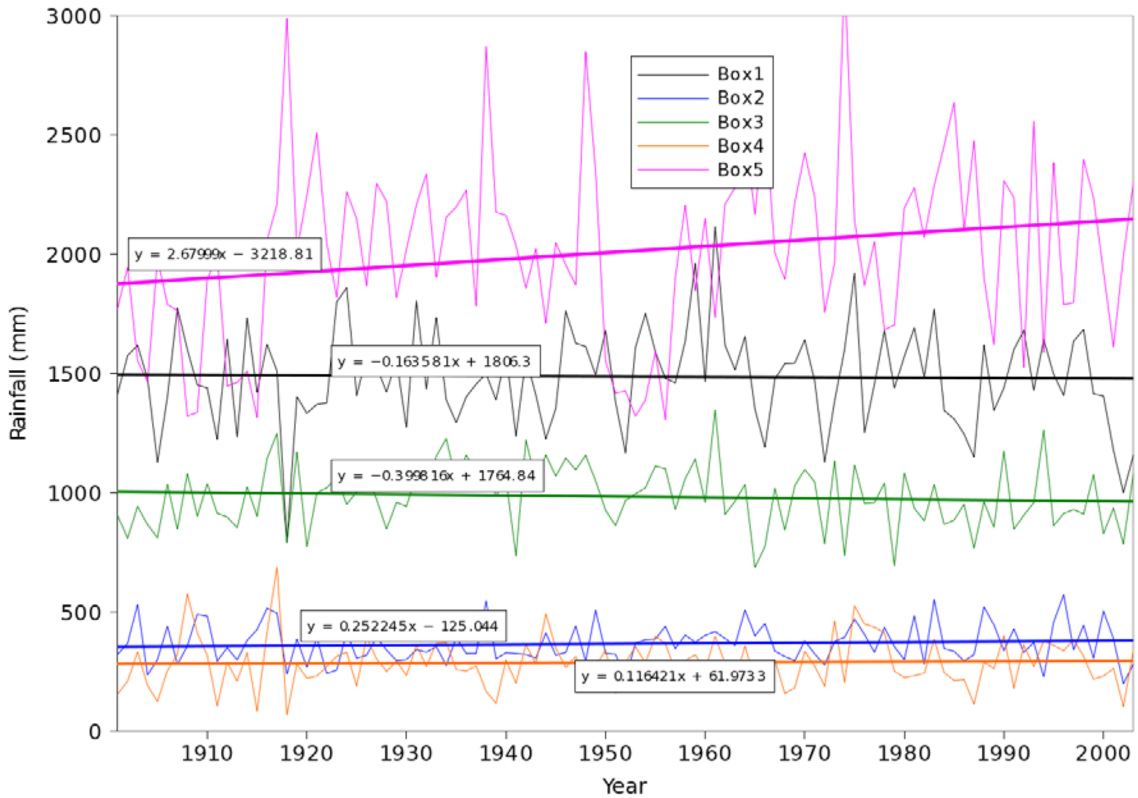


Fig. 2. Year to year variability of ISMR for the period 1901-2003 for different regions from B1 to B5. The trend line is given for individual locations. The regression equation is also given near to the trend line

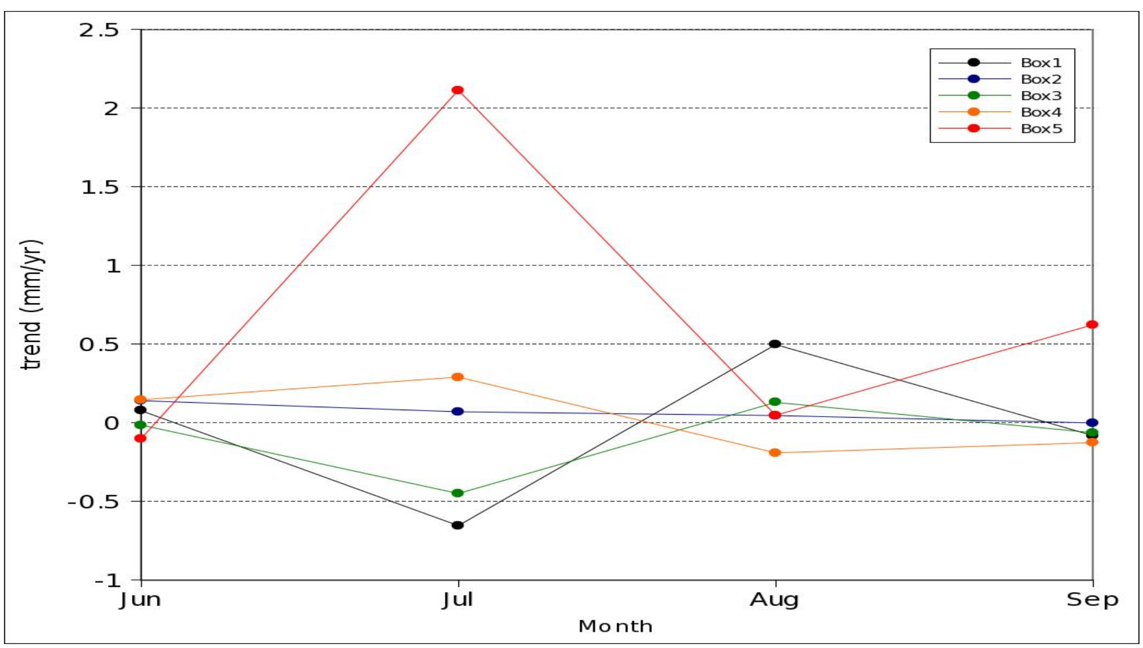
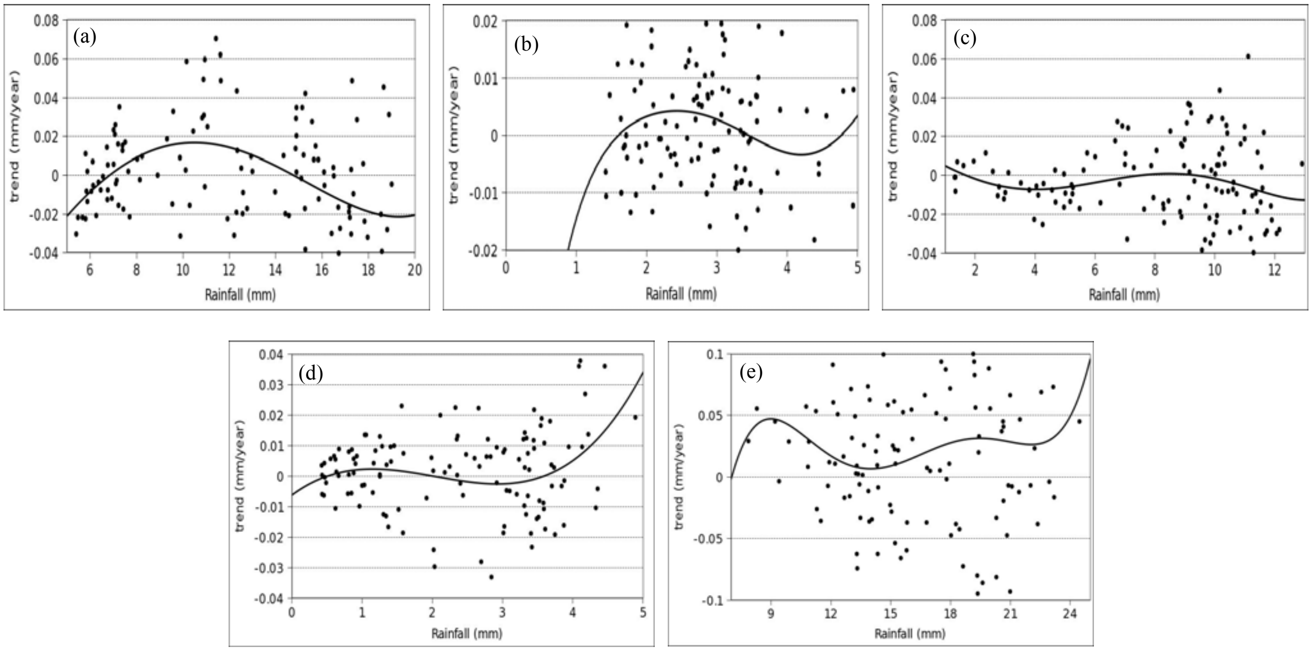


Fig. 3. Linear trend of different months in the summer monsoon period for different regions



Figs. 4(a-e). Scatter plot between the mean daily rainfall and its trend during the southwest monsoon period, (a) west coastal (b) southeast, (c) central India, (d) northwest and (e) northeast regions

variability (Ajayamohan and Goswami, 2000). In all the five zones selected here, we noticed variability of different time scales. Fig. 2 gives the time series of summer monsoon rainfall from 1901 to 2003 for the five different regions marked in the Fig. 1. We noticed negative trends in the west coastal and central Indian boxes and positive trends in other three regions. The significance was tested based on the F-distribution test and found that the positive trend in the Box5 is significant at 5% level. However all other trends are not statistically significant. While examining carefully, ISMR is subjected to long term change by increasing/decreasing the total amount of rainfall in certain places.

3.2. *Trend analysis of different months of ISMR over different zones*

Monthly trends of rainfall were calculated from the IMD gridded rainfall data set for the period 1901-2003. Values of trends are different for different months during summer monsoon for all the zones considered here (Fig. 3) and we found that the trends vary widely from July to September (during summer monsoon season). For the west coastal stations, the trend during June is not much significant. However, during the month of July and August, the rainfall trends are significant at 10% level, however, during July the trend is negative and that during August is positive. Therefore, the decrease in rainfall during July may be compensated by the increase in rainfall during August. The June and September months do not have significant trends. In the case of southeast regions (Box2), the rainfall pattern does not show any significant trend in any of the monsoon months. Even though the trend is not significant, the long term trend shows a slight positive value indicating an over all increase in total rainfall, *i.e.*, strengthening of the southwest monsoon over southeast regions. Central India (Box3) where the monsoon rainfall is dominant and mostly the rainfall pattern is homogeneous (Dahale and Puranik 2000; Goswami *et al*., 2006). In central India we noticed a significant (5% level) decrease in tendency of rainfall pattern during July and a slight positive trend during August. The decreasing trends in other three months led the ISMR to a long term decrease of about 0.4 mm/year. Northeastern region is behaving differently from the other three regions. Significant positive trends are found during June and July and these are significant at 5% and 10% significant levels respectively. In the month of August a slight decreasing trend is observed. In the northwestern regions, the summer monsoon rainfall shows an increasing trend of 2.7 mm/year (significant at 5% level). The monthly trend in this area is positive in summer months except June (not significant). The positive trend in the month of July is significant at 0.1% and that during September is at 10% significant level. These two months together contribute almost 50% of summer monsoon rainfall over the region.

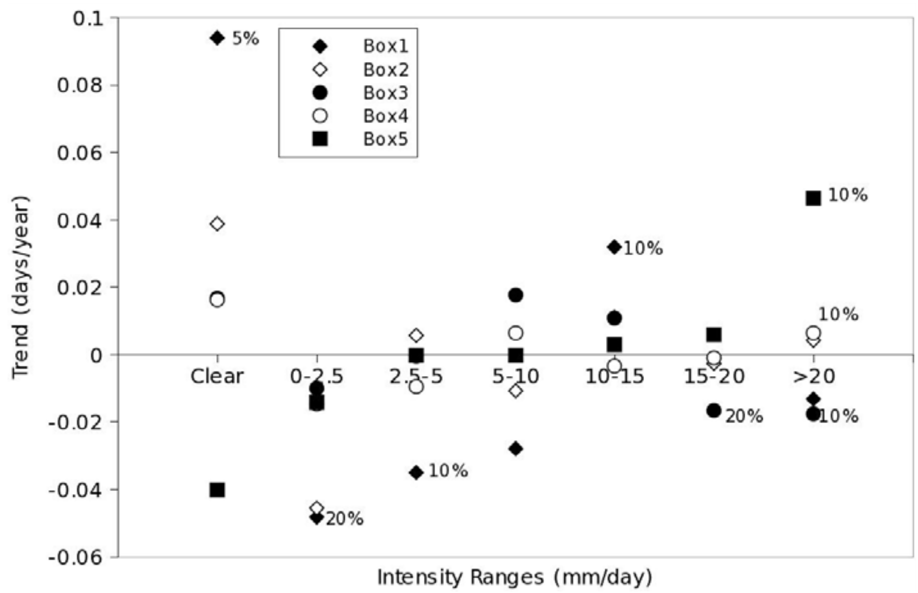


Fig. 5. Long term trends of number of rainy days in different intensity classes for all the five grid boxes. The significant levels corresponding to the values are given in the figure

3.3. *Relation between daily long term trend and mean daily rainfall*

Fig. 4 shows the relation between mean daily rainfall and daily trend for different regions of Indian subcontinent and found that the relation between them is different for different stations. In the west coastal region, the polynomial fit shows a distinct increasing trend in the low intensity classes up to about 10 mm/day and thereafter the fit shows a decreasing trend. In the Box2, there is no distinct relationship between the trend and the mean daily rainfall. In this region, the mean daily rainfall is very less while comparing to Box1, 3 and 5. In Box3 (Central India), the mean daily rainfall below 5 mm/day shows decreasing trend in the polynomial fit and shows a slight increase from 4 mm/day to 10 mm/day and the fit shows again a decreasing slope above 10 mm/day. In central India, the rainfall shows an over all decreasing trend for the long term scale. In the case of northwestern regions, the intensity classes above 3.5 mm/day and below 1.5 mm/day show distinct increasing trends. In the northeast region, the mean daily rainfall shows an increase in all the intensity classes except between 9-12 mm/day. In this region, about 87% of the rainfall registered is above 12 mm/day and therefore, the rainfall contribution is very high from these intensity ranges. In general, the northeast region shows a very high and significant positive trend in the long term scale.

3.4. *Linear trend of ISMR in different intensity classes*

Here, we made a detailed analysis of different intensity classes of rainfall in all the five zones. The intensity classes and their ranges are given in methodology section. In the paper Goswami *et al*. (2006) the authors described the trends of rainfall in moderate, high and very high intensity ranges over central Indian region during the southwest monsoon period. However, they have not reported the trends in other regions. Here, we made a detailed analysis of different intensity classes of rainfall in all the five zones. We counted the number of non rainy days and rainy days in different intensity classes and inferred the trends of each category (Fig. 5). In the west coastal areas (Box1) shows that an increase in the number of non rainy days (10 days/decade) and this value is significant at 5% level. This indicates that the total number of rainy days are decreasing almost 10 days in a decade. Similarly the number of rainy days in the SM intensity class shows a decreasing trend while MH rainy days show an increasing trend (both are significant at 10% level). In general, the intensity classes below MO show decreasing and above that show increasing trends. In the southeastern regions (Box2) there were no considerable decrease/increase in number of rainy days in any of the intensity classes. In the case of central India (Box3), the number of rainy days in HI and VH intensity classes show

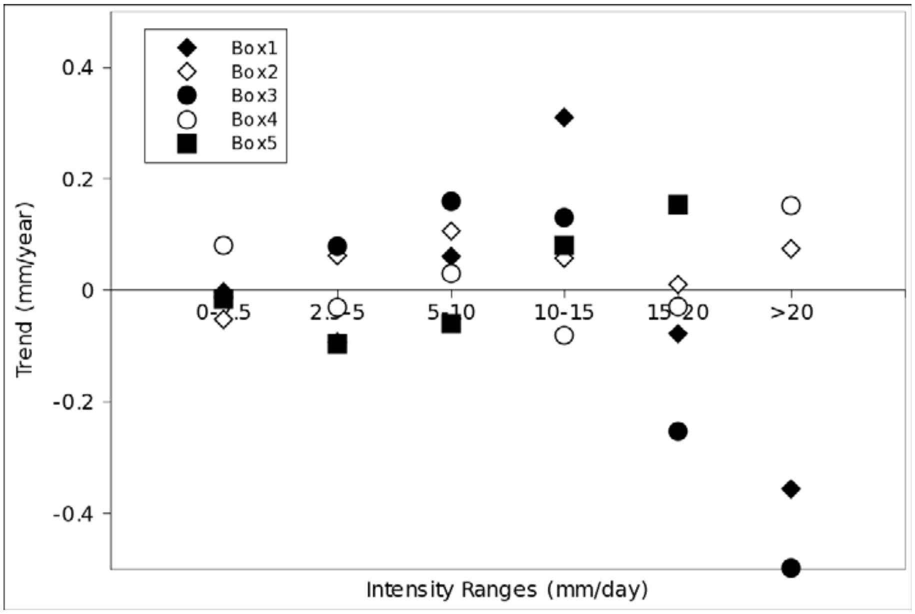


Fig. 6. Long term trend of ISMR in different intensity classes for different regions of Indian subcontinent. The intensity classes are categorized as very small, small, moderate, moderately high, high and very high

considerable decreasing trend while the MO and MH intensity classes show increasing trends, even though it is not significant statistically. However, the decreasing trend in the VH intensity class is significant at 10% level. In the northeastern regions (Box4), the number of days with VH intensity rainfall shows an increasing trend significant at 10% level even though the number is relatively small. The average number of VH intensity rainfall days in a year is about 11 day/decade. No considerable increase/decrease in the rainy days for other intensity classes were observed. The northwest Indian region (Box5) shows an increasing trend in the VH intensity class with a significant level of 10%. For all other classes the number of rainy days does not show any remarkable changes in linear trend. However, the number of rainy days in the VH intensity class affects considerably the annual rainfall over the region.

Fig. 6 shows the trends in the amount of daily rainfall in all the different intensities over different parts of Indian subcontinent. This pattern is different from the Fig. 4 because here we considered all the individual days and in the previous section, we considered the mean of every day for the 103 year period. In this section, we are describing the daily rainfall whereas in the previous section we described the mean daily rainfall. VH intensity class shows a decreasing trend in the west coastal regions. In the southeastern region, no significant trend was observed. However, MO, MH and VH intensity classes show positive trend in the trend line. Central India shows significant decreasing rainfall amount in the HI and VH intensity classes and both are significant at 10% and 5% levels respectively during the southwest monsoon season. This decreasing trend may be contributing mainly from the month July, as explained earlier about the decreasing trend in the monthly total rainfall. The intensity classes SM, MO and MH show a positive trend even though they are not so significant. In the northwest India the significant trends are not observed in any of the intensity classes. Similarly in the northeast region, the VH and HI intensity classes show increasing trend with 0.1% and 5% significant levels.

4. Summary of the work

This paper tried to bring out the different trends of seasonal, monthly rainfall during the summer monsoon season over different topographical regions of Indian subcontinent. The country is subjected to monsoonal rainfall and the main rainy season is southwest monsoon in most parts of India except over southeastern region. The summer monsoon rainfall shows increasing trend in southeast, northwest and northeast regions, whereas decreasing trend in the central and west coastal regions (Guhathakurtha and Rajeevan, 2008). We observed significant trend only in the northeast regions and the trend is significant at 5% level. In the monthly scale, July rainfall shows decreasing trend over west coastal and central India with statistically significant, whereas in the northeastern region it shows increasing trend, which is significant at 0.1% level. During August, the central and west coastal regions show decreasing trend and the trend in the west coastal stations is statistically significant at 10% level.

The analysis of the mean daily rainfall shows that the trend and the intensity has some non linear relationship in certain stations, where more intense daily rainfall has been registered. In most of the zones, for low and very high intense rainfall the trends are increasing whereas for the moderate rainfall the trend is different for different regions. The number of rainy days in most of the boxes considered here are decreasing but they are increasing only in the box5 for the high and very high intensity classes. The decreasing trend is significant 5% level only in the west coastal areas. Similarly the trends in rainfall amount in different intensity classes show opposite behaviour especially for small and high intensity classes. In the central and southern regions, the trend of moderate and moderately high classes shows increasing trend. And for the high and very high intensity classes, the trend is decreasing significantly. In the northeastern region, below 10 mm/day shows a slight decreasing trend. However, above 10 mm/day rainfall shows significantly increasing trend.

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