Dynamical Downscaling of Regional Climate: Simulation of Extreme Rainfall Events and Their Impacts over the State of Kerala in the Near-Future

Report 2017-2018

submitted to

Kerala Disaster Management Authority

Govt. of Kerala

by

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1. <u>Introduction:</u>

Rainfall is the primary source of water in Kerala, a state in the southwestern coast of peninsular India. Kerala receives 75% of annual rainfall in southwest summer monsoon season (June, July, August and September) and post monsoon season (Northeast monsoon) receives most of the rest (Rainfall statistic of India, 2016). The onset of monsoon starts over Kerala coast, normally by 1st of June, every year and receives ~300cm annual rainfall, which is almost three times of annual rainfall of India. The presence of Western Ghats, which lies almost perpendicular to monsoonal air flow, is crucial in triggering heavy rainfall over Kerala. An increasing or decreasing trend in heavy or extreme rainfall events can cause events like flood or draught which will have a direct adverse effect on lives and properties on large scale, especially a densely populated state like Kerala. Water availability in monsoon season also affect the energy sector, which is mainly hydro-power generated. Fig.1 shows an extremely heavy rainfall event happened in Kerala on 18 November 2006.

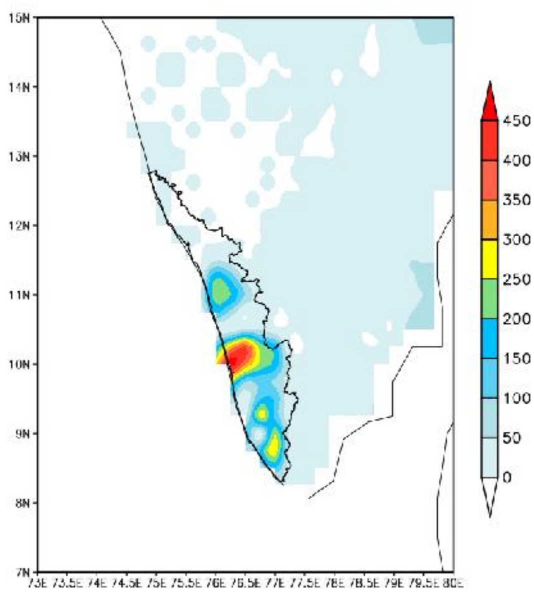

Fig.1 showing an extremely heavy rainfall event in Kerala on 18 November 2006

Extreme rainfall events (ERE) and related floods are one of the major natural hazards many part of the world including India (Ahern *et al.*, 2005). Goswami and Ramesh (2006) showed that the ERE's are quite common over India, by analysis of recent high-resolution daily rainfall data. These events contribute a significant part of the total monsoon rainfall and its variability (Ramesh and Goswami, 2007). Francis and Gadgil, (2006) reported that there is an increase in the intensity and frequency of heavy rainfall events over the Indian Monsoon region, recently. The long term trend and variability in rainfall over Kerala and their plausible causes are studied extensively in the past (Soman *et al.*, 1988; Krishnakumar*et al.*, 2009; Guhathakurta and Rajeevan, 2008; Thomas and Prasannakumar, 2016) and all these studies reported a significant decreasing trend in the south west monsoon season rainfall. But there is lack of studies focusing on extreme events in the state, especially those addressing all the 14 districts in the state in detail.

2. Objectives

1. Investigate observed extreme precipitation events in the last three decades.
2. Dynamically downscale near-future climate and study the plausible occurrence of extreme precipitation events in RCP4.5 and RCP 8.5 scenarios.

3. Work Done

The work done so far is an investigation on observed heavy and extreme precipitation events. A trend analysis is done using linear regression (ordinary least squares) for central India(CI, 74.5°E to 86.5°E and 16.5°N to 26.5°N), Kerala and in all 14 districts in Kerala. A statistical significance test also conducted with 95% confidence level. The analysis is done for three different rainfall categories; heavy, very heavy and extremely heavy, which are defined by India Meteorological Department (IMD, http://imd.gov.in/section/nhac/termglossary.pdf) and is given in table.1. Daily gridded IMD (India Meteorological Department) rainfall data from 1901 to 2015 with a spatial resolution of 0.25°×0.25° are used for the analysis. The rainfall trends are studied for southwest monsoon season (JJAS). All the calculations are done by using R statistical computing software (https://www.R-project.org/).

	Rain event	**Rain amount (mm/day)**
1	Heavy Rain	64.5 – 124.4
2	Very Heavy Rain	124.5 – 244.4
3	Extremely Heavy Rain	>244.5

Table.1 Definition of rainfall events

3.1. Analysis of Rainfall Trends

Goswami *et al.*, (2006) have observed an increasing trend in extreme rainfall over central India. Here we conducted an extended analysis and Fig.2 shows the trend in the above mentioned three different rainfall categories from the year 1901 to 2015 over central India, which is the same latitude – longitude box selected by Goswami *et al.* (2006). The number of rainfall events in southwest monsoon season is selected for respective category in each year and is plotted against 115 years. The result is in agreement with Goswami *et al.* (2006) that heavy to very heavy intensity ranges show significant increasing trends, with slopes 3.969 and 1.789respectevely, in the Central India. In the extremely heavy rainfall category also, the trend is observed to be increasing with 0.322 positive slope. A statistical significance test also conducted at 95% confidence level and it is found that the trend calculated were significant for all the three categories. Thus all the three categories- heavy, vary heavy and extremely heavy- were found to be increasing with 95% significance level. The impact of climate change in the extreme weather events has recently become one of the main focuses of the meteorological and climate community. Increase in the extreme rainfall events in central India has significant implications on disaster managements like flood, food security, fresh water availability, ground water and also the agricultural planning of India.

A similar trend analysis is done for Kerala (Fig 3a to 3c) region and is found that in south west monsoon, the heavy, very heavy and extremely heavy rainfall over Kerala is decreasing, in which the heavy category (64.5–124.4 mm/day) showing highest rate of decreasing trend with slope -0.75.The heavy and very heavy trend were significant at 95% confidence level but in the case of extremely heavy, decreasing trend was not significant. The trend slope and p value of the regression analysis for central India and Kerala is shown in table.2. It can be seen from the table.2 that, even though all the categories show a decreasing trend in Kerala, it is not as strong as the increasing trend in Central India. For example, in the case of heavy, the strength of increasing trend in Central India is 5 times that of the decreasing trend in Kerala. In a recent study by Varikoden *et al.* (2018) found that rainfall in southern region of Western Ghats, where Kerala lies, is decreasing by about 3% per decade and they are statistically significant at 99% confidence interval. This decreasing trend is reported in many earlier studies. Guhathakurta and Rajeevan (2008) found negative trends in three meteorological subdivisions including Kerala.

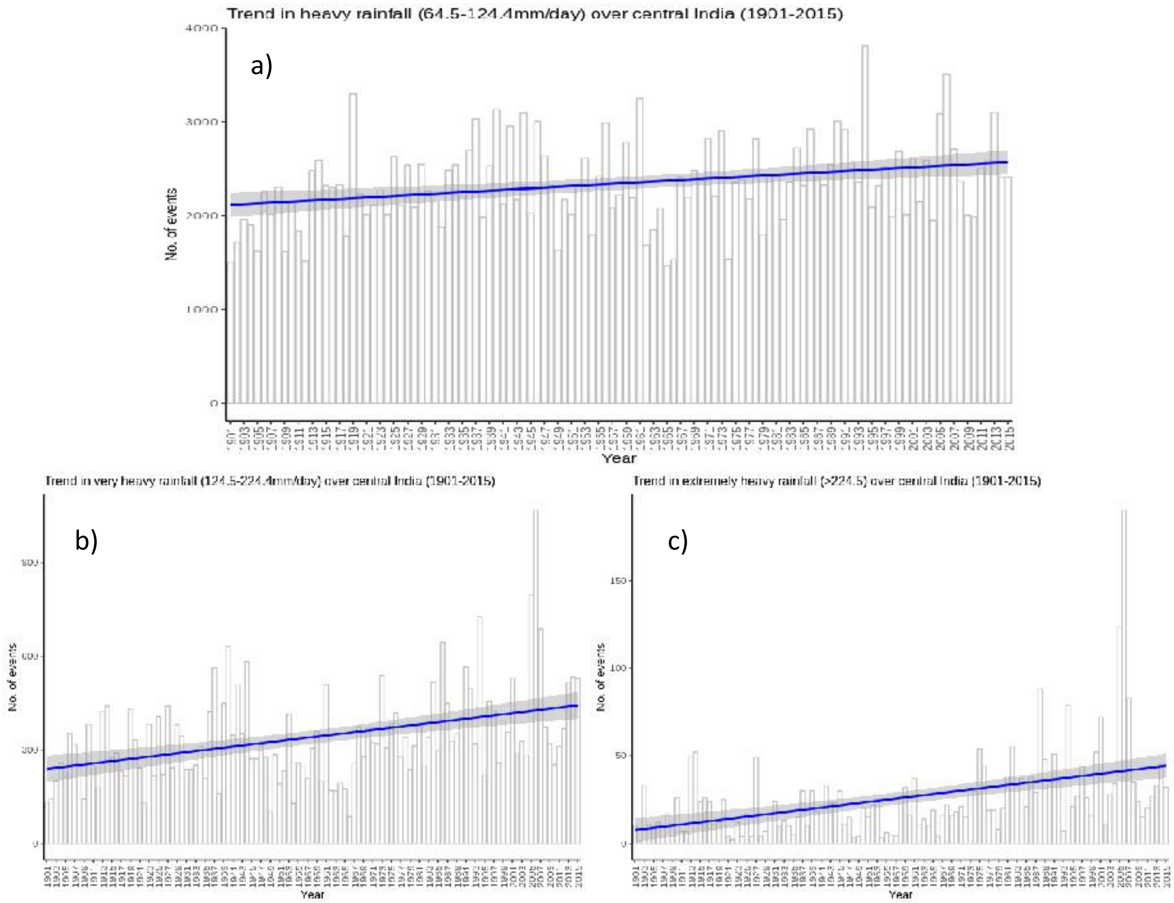

Fig.2 Trend in different categories of heavy rainfall over central India (CI, 74.5°E to 86.5°E and 16.5°N to 26.5°N) from 1901 to 2015.

Region	Heavy			Very heavy			Extremely Heavy		
	Slope	**p Value**	**Trend**	**Slope**	**p Value**	**Trend**	**Slope**	**p Value**	**Trend**
Central India	**3.969**	**p<0.05**	**Increasing**	**1.789**	**p<0.05**	**Increasing**	**0.322**	**p<0.05**	**Increasing**
Kerala	**-0.75**	**p<0.05**	**Decreasing**	**-0.171**	**p<0.05**	**Decreasing**	**-0.012**	**p>0.10**	**Decreasing**

Table.2 Slope of the trend and significance for Central India and Kerala

A study by Thomas and Prasannakumar (2016) using 140 years (1871–72 to 2011–12) of monthly rainfall data shows a decreasing trend in southwest monsoon, while the post monsoon-, winter- and pre-monsoon-rainfall have increasing trends. The same results were also reported by Soman *et al.* (1988) and Krishnakumar *et al.* (2009). The decrease in strength of Tropical Easterly Jet (TEJ), number of monsoon depression during south west monsoon, reduction in the low level monsoonal flow are considered the plausible reason for the reduction in rainfall over the years in Kerala (Sathiyamoorthy, 2005; Rao *et al.*, 2004; Krishnan *et al.*, 2012; Rajendran *et al.*, 2012).

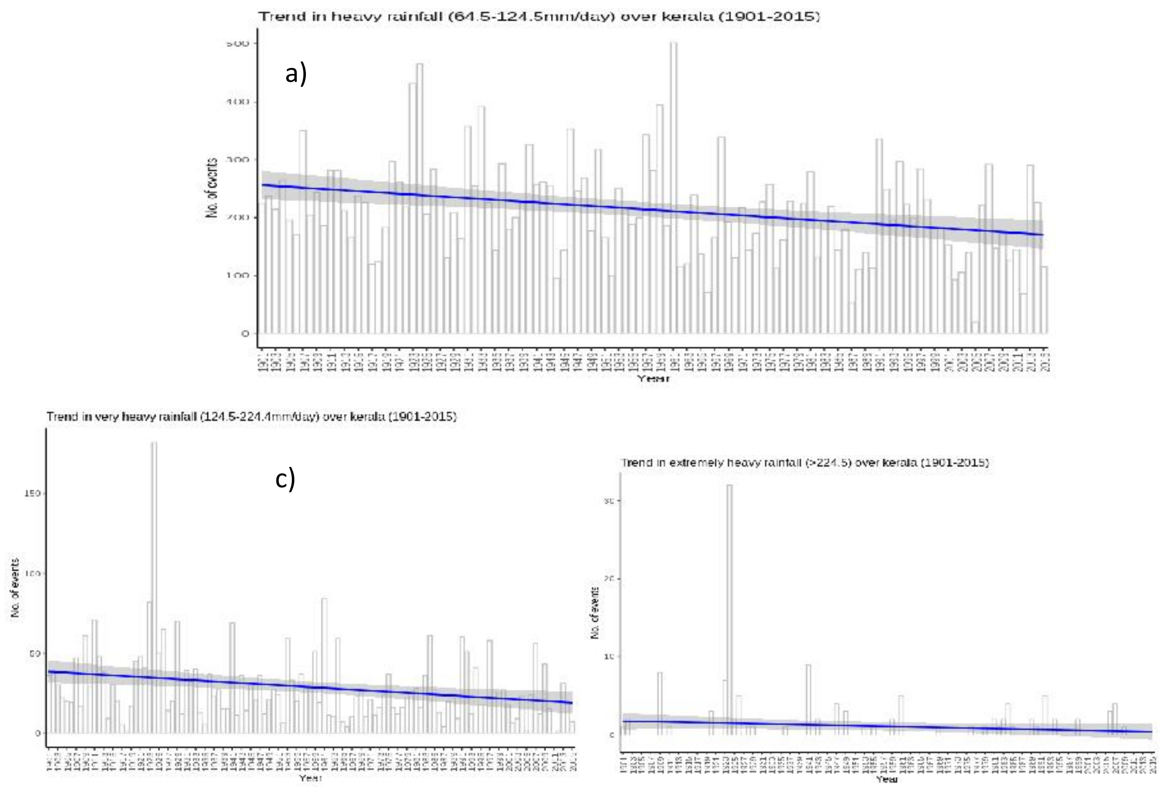

Fig.3 Trend in different categories of heavy rainfall over Kerala from 1901 to 2015.

The trend analysis in each district in Kerala is also done for the same 115 year period and rainfall categories. For heavy raifall, all of the districts were showing clear decreasing trend except Idukki and Thiruvanathapuram which were having a slight positive trend. The increasing trends seen in two southern districts were not significant but decreasing trends were statistically significant except for Eranakulam. Of all the districts, Kozhikode showed the most negative trend (slope -0.252) followed by Malappuram (-0.194), Kasragod (-0.138) and Wayand (-.103), all of which are northern districts. In the very heavy category, 5 districts (Ernakulam, Idukki, Kollam, Pathanamthitta and Thiruvananthapuram)shows slight positive trend, all others were having slight negative trend. The positive trends were not significant where as statistically significant negative trends were again from the northern districts which, in the decreasing order of trend magnitude are, Kozhikod, Kasaragod, Malappuram and Wayanad. It is also important to note that the number of very heavy rainfall events for each district are low that the trend analysis is not conclussively significant.

Fig.4 Trend in different categories of heavy rainfall in each district in Kerala from 1901 to 2015.

1924 is the year that has significant number of very heavy rainfall in all the districts. The 2018 august floods also must have a similar effect as 1924. However, the general trend that shows the slight increase in very heavy rainfall events in Iddukki, Kollam and Ernakulam is very important as many major dams and hydroelectric projects situated in this region. Since the number of events in extremely heavy events are very less or no events at all in each district, most of them does not show any trend. However, Kasaragod, Kozhikode, Malappuram and Wayanad continues to show the slight decreasing trend as in heavy and very heavy category, in which only Kozhikod and Malappuram were significant. This analysis shows that heavy rainfall events are on a decreasing trend and very heavy rainfall events are overall decreasing. Idukki district is observed to have slightly increasing trend in both heavy and very heavy rainfall events which is particulary important in the view of recent flood and presence of a number of dams including the state's biggest.

District	Heavy			Very heavy			Extremely Heavy		
	Slope	p Value	Trend	Slope	p Value	Trend	Slope	p Value	Trend
Alappuzha	-0.035	p<0.05	Decreasing	-0.002	p>0.10	Decreasing	0	p>0.10	No trend
Ernakulam	-0.015	p>0.10	Decreasing	0.013	p>0.10	Increasing	0	p>0.10	No trend
Idukki	0.011	p>0.10	Increasing	0.003	p>0.10	Increasing	0	p>0.10	No trend
Kannur	-0.081	p<0.05	Decreasing	-0.01	p>0.10	Decreasing	0.002	p>0.10	Increasing
Kasaragod	-0.138	p<0.05	Decreasing	-0.034	p<0.05	Decreasing	-0.006	p>0.10	Decreasing
Kollam	-0.028	p<0.05	Decreasing	0.003	p>0.10	Increasing	0	p>0.10	No trend
Kottayam	-0.091	p<0.05	Decreasing	-0.008	p>0.10	Decreasing	-0.001	p>0.10	Decreasing
Kozhikode	-0.252	p<0.05	Decreasing	-0.076	p<0.05	Decreasing	-0.006	p<0.05	Decreasing
Malappuram	-0.194	p<0.05	Decreasing	-0.034	p<0.05	Decreasing	-0.004	p<0.05	Decreasing
Palakkad	-0.07	p<0.05	Decreasing	-0.011	p<0.05	Decreasing	0	p>0.10	No trend
Pathanamthitta	-0.015	p<0.05	Decreasing	0.001	p>0.10	Increasing	0	NA	No trend
Thiruvananthapuram	0.001	p>0.10	Increasing	0.001	p>0.10	Increasing	0	NA	No trend
Thrissur	-0.032	p<0.05	Decreasing	-0.002	p>0.10	Decreasing	0	NA	No trend
Wayanad	-0.103	p<0.05	Decreasing	-0.019	p<0.05	Decreasing	-0.002	p>0.10	Decreasing

Table.3 Slope, pValue and trend direction in each district for all categories of rainfall.

Another important point noted in this study is that the northern districts show consistant decreasing trend than the southern distiricts. For example, Kozhikode and Malappuram shows significant decreasing trend in all the three categories. The decreasing trend were high in all the northern districts and none of them show increasing trend in any categoty except Kannur which shows a slight insignificant positive trend in extremely heavy rainfall category. This analysis also noted that there is a difference in the distribution of heavy to extreme rainfall categories in the north and south of the state. From table.4, which shows the average number of events in an year in each categories, it can be seen that there is a descending pattern in the number of events from north to south with Kasaragod having highest number of events (35.83) followed by Kannur (28.16), Malappuram (26.63) and Kozhikode (23.10). A similar pattern is also seen in very heavy and extremely heavy categories also.

Fig.5 Decadal trend in very heavy and extremely heavy categories for Kasaragod, Kannur Kozhikode, Malappuram, Ernakulam, Idukki, Pathanamthitta and Kollam.

District	Heavy	Very Heavy	ExtremelyHeavy
Kasaragod	**35.83**	**6.42**	**0.36**
Kannur	**28.16**	**4.50**	**0.35**
Kozhikode	**23.10**	**4.06**	**0.23**
Wayanad	**4.54**	**0.60**	**0.04**
Malappuram	**26.63**	**2.76**	**0.16**
Palakkad	**11.85**	**0.97**	**0.08**
Thrissur	**7.73**	**0.63**	**0.00**
Ernakulam	**22.37**	**2.04**	**0.12**
Alappuzha	**5.15**	**0.21**	**0.01**
Kottayam	**14.44**	**1.48**	**0.04**
Idukki	**5.02**	**0.48**	**0.04**
Pathanamthitta	**2.64**	**0.17**	**0.00**
Kollam	**4.03**	**0.39**	**0.03**
Thiruvananthapuram	**1.95**	**0.15**	**0.00**

Table.4 Average number of events in each category per year

A decadal trend analysis (Fig. 5) is also performed to confirm the trend in very heavy and extremely heavy categories since there is no significant number of rainfall events yearly in these categories. It is found that the trend pattern discussed in the fig.4 were clearly visible in the decadel trend analysis. Also, it is found that all the northern districts (Kasaragod, Kannur, Kozhikode, Wayanad, Malappuram and Palakkad) shows clear decreasing trend in very heavy rainfall except Kannur, which has a slight increasing trend. Extremely heavy category also shows similar pattern with a clear positive trend in Kannur. Even though the trend is decreasing over all in northern districts, the number ofevents is high as discussed earlier, especially in Kasaragod, Kannur and Kozhikode,where, both categories are high in number as compared to the southern districts.

4. Future work

The Weather Research and Forecasting (WRF) Model version 3.6 is installed and trial run has been done in AmritaWNA campus. In the next phase:

- The researchers of KSDMA will be familiarized with the model installation, pre-processing and analysis and interpretation of the simulated climate data. Model simulations to be completed.
- Data analysis, final report submission/publication of results.

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Number of Pages:	13
Number of Words:	2,560 (approx.)
Number of Characters:	14,596 (approx.)