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Indian Summer Monsoon Rainfall Extremes Projections using Block Maxima Approach under Climate Change

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Abstract

The extreme rainfall projections under future climate are assessed by General Circulation Models (GCM) and these GCMs represent poorly at regional scale. The modified Statistical methodology (MSD) has been used to project extremes for the Indian summer monsoon rainfall at 0.25 degree spatial resolution. The extremes are assessed by two conventional extreme value theory approaches such as Block Maxima (BM) and Peak over Threshold (PoT). However, in the present study Block or Annual Maxima approach is used to assess 30 year return period. The extremes projections have been significantly improved with implementation of Kernel Regression. The rainfall projections are carried out three different time windows 2020, 2050 and 2080 using IPSL GCM from CMIP5 suite. Here we find spatial non uniform increase in rainfall for future time slices and results are in line with mean rainfall Indian summer monsoon Rainfall (ISMR) projections as observed from previous studies.

Keywords: Modified Statistical Downscaling, GCMs, Extreme Value Theory (EVT)

INTRODUCTION

Modeling of extremes is a major research challenge facing the hydrological community considering the complexities involved into it. As the factors affecting the extreme excesses are not clearly understood and methods for evaluation are still under developmental phase. Therefore, proper scientific study of extremes is necessary for proper planning and management of extremes events. Recent studies indicates occurrence of extremes have increased due to global warming/ anthropogenic activities [IPCC, (1)]. Although much progress in understanding the science of extremes modeling has been witnessed since the last two to three decades but still extremes are causing havoc to human life, infrastructure, industry, agriculture, ecosystem etc. at an unprecedented scales e.g. Mumbai floods in India 2005, Kedarnath (Uttarakhnad) floods in India 2013, Chennai floods (2015).

General Circulation Models (GCMs) have emerged credible models for understanding the variability and projections of rainfall under climate change scenario. [1, 2]. However, GCMs poor skills to model extremes pose serious challenge [3], as GCMs operate at coarse resolution. Many researchers have established that observations and climate models also reveal increases for extremes under warming climate. Therefore, accurate projections/predictions of future changes of extremes at local/regional scales are critical for policy formulations and policy decisions [3]. At present two downscaling approaches are popular for regional studies. Viz. Dynamic downscaling and statistical downscaling, however, they possess low skill for extremes projections. Here, we use statistical downscaling methodology proposed by Shashikanth et al [3] for the current study.

DATA AND METHODOLOGY

In the current study, the data required for statistical downscaling (SD) are obtained from IPSL GCM from CMIP5 suite from PCMDI. In SD model, predictors play a very crucial role [4]. Here, we use NCEP/NCAR reanalysis data [5] as predictors and gridded rainfall provided by APHRODITE as predictand for establishing the relationship between predictors and predictand. The predictors are air temperature, wind velocities (U and V) at surface and 500 hpa pressure level and specific humidity 500hpa at pressure field and Mean sea level Pressure (MSLP). GCM used for current work is IPSL_CM5A_LR Institut Pierre Simon Laplace and observed rainfall data is provided by APHRODITE [6]

METHODOLOGY

The projections of extremes in the present study are carried out by two steps. In the step one, we apply Kernel Regression based SD model for the simulation of rainfall projections [7, 8]. In the second step, 95 percentile values of rainfall series are segregated from the downscaled projections and on these; again Kernel Regression (KR) employed to model extremes. Later, on modeled rainfall extremes, the return periods are assessed by Block Maxima or Annual Maxima (BM/AM) [9, 10]

STATISTICAL DOWNSCALING

The philosophy of Statistical Downscaling is to obtain local to regional (10 to 50 km) projections from the large scale climate predictors. In this method, the statistical relationship is established between large scale climate predictors from reanalysis data (NCEP/NCAR) (Predictors) to regional-scale predictand variable (Predictands in this case rainfall). Later, the same relation is applied on GCM outputs to obtain predictands under the impacts of climate change for future. The present method utilizes the following methods to obtain the projections viz. Bias correction, K- mean clustering, classification and Regression trees [CART] and Kernel Regression [7, 8]. K-means clustering algorithm coupled with CART, is employed to for the generation of rainfall states using large scale synoptic scale circulation patterns. Conditional on the derived rainfall state, the kernel regression is employed for modeling the multisite rainfall [7, 8].

EXTREME VALUE THEORY

The Extreme Value theory (EVT) is a statistical tool used for assessing the hydrologic extremes [10]. The return periods are evaluated using Block Maxima (Annual Maxima) approach by applying the Generalized Extreme Value (GEV) distribution. The block maxima approach of EVT theory mainly consists of isolating the data into non-overlapping periods of equal size (monsoon days from June-September) and selecting the maximum data in each period. The new data series thus constitute extreme values. Parametric statistical GEV method is employed for the evaluation of return period. The Kolomogorov - Smirnov (K-S) [5% level significance] is used to obtain the goodness of fit on those fitted parameters and if the test fails an empirical distribution is fit in place of GEV. Further information can be obtained from the research papers of Ghosh et al 2011 [9] and Coles, 2001 [10]. The major disadvantage of the Block or Annual Maxima is that it does not consider the multiple occurrences of impactful extremes events [11].

The probability density function of GEV mentioned below:

Suppose 'x' represents the annual/block maxima of daily precipitation in a given series, then the GEV distribution is defined by [10]

$$F(x;\mu,\alpha,\xi) = \begin{cases} \exp\left\{-\left[1-\frac{\xi(x-\mu)}{\alpha}\right]^{-\frac{1}{\xi}}\right\} \\ 1+\xi(x-\mu)/\alpha > 0 \quad \xi \neq 0 \\ \exp\left\{-\exp\left[-\frac{(x-\mu)}{\sigma}\right]\right\} \quad \xi = 0 \end{cases} \qquad (1)$$

GEV distribution has three parameters namely location (μ), scale parameter (α) and shape parameter (ξ). In the present work the maximum likelihood estimation (MLE) technique is used to estimate the parameters.

The return period or intensity is defined as a particular value exceeding once in every N year (here, 30 year) with probability of 1/N in any given year

$$F^{-1}(1-p;\mu,\alpha,\xi) = \begin{cases} \mu-(\alpha/\xi)\{1-[-\ln(1-p)]^{-\xi}\} & \xi \neq 0 \\ \mu-\alpha\ln[-\ln(1-p)] & \xi = 0 \end{cases} \qquad (2)$$

A nonparametric Gaussian kernel distribution was fitted to those grids where KS test was failed for GEV.

RESULTS AND DISCUSSIONS

The statistical downscaling model developed by Kannan and Ghosh [7] and Salvi et al [8] is used for the multisite rainfall projections on daily scale. The mean rainfall projections are very well modeled by the present method. Since all statistical downscaling models fail to model day to day variability that well and hence extremes are not well simulated by them. Therefore slight modifications are suggested for modeling of extremes (Fig 1)

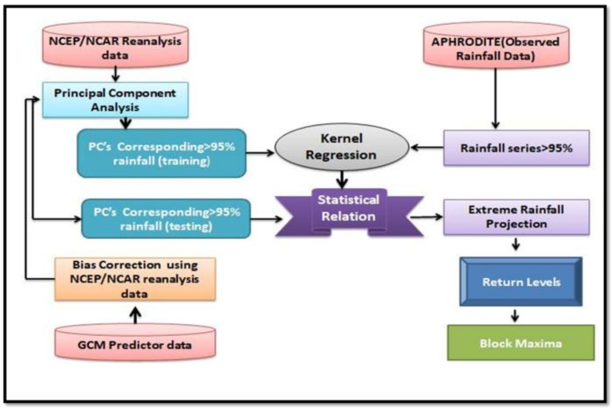

Figure 1: The Flowchart for Statistical Downscaling for extremes using Block Maxima approach.

The spatial distribution of observed mean rainfall, NCEP/NCAR simulated mean rainfall and IPSL simulated average rainfall (Figure 2) and standard deviation is very well modeled by the Kannan and Ghosh [7] method.

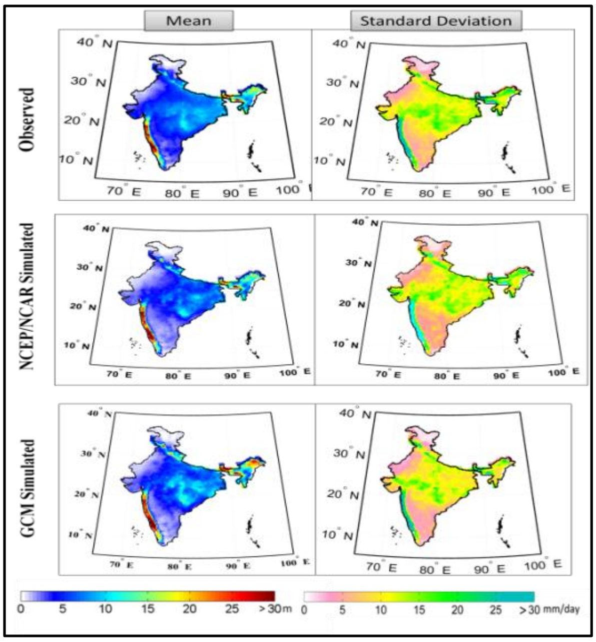

Figure 2: Spatial variation of mean and standard deviation of rainfall using conventional SD methodology (Kannan and Ghosh, [7]).

Since conventional SD method does not project the extremes that well hence methodology is modified (Fig 1).

The results are presented for visual interpretation (Fig 3).

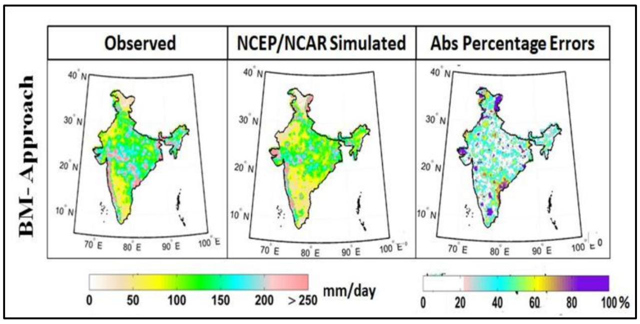

Figure 3: Extreme rainfall projections of ISMR with 30 year return period.

The rainfall intensity using Block maxima approach is assessed and for future RCP 8.5 scenario is used to know the impacts of climate change on extremes for ISMR. Based on the same approach the future extremes for ISMR is evaluated for different time windows viz. 2010-2040 (2020s), 2041-2070 (2050s) and 2071-2100 (2080s). The results are presented in Fig 4.

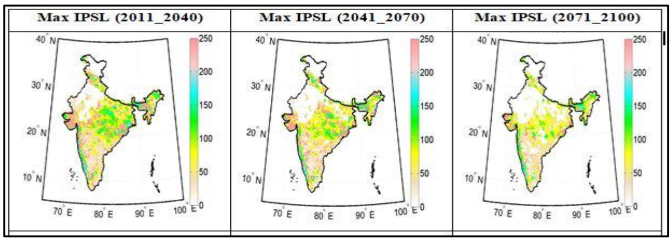

Figure 4: variation of extremes of IPSL for the three future windows 2020s, 2050s, 2080s.

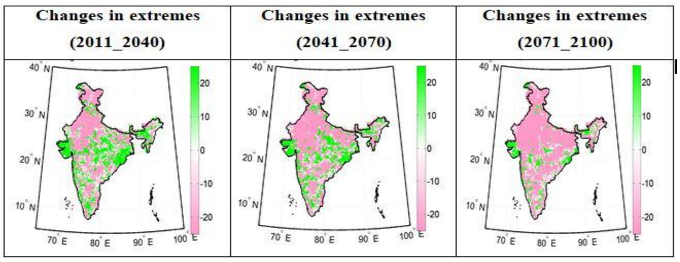

Figure 5: The changes in extremes at 30 year return period with respect to base line period (1981-2000).

The projected changes in return levels as obtained with block maxima exhibit spatially non uniform changes .The extreme projections for different time windows 2020s (2010-2040),2050s (2041-2070), 2080s (2071-2100) ,as they show decrease of changes in extremes . Although with increase in global warming, no doubt extremes are increase but are limited to few regions in India, but non uniform changes increases are found in the current study.

CONCLUSIONS

Projections of rainfall extremes are a major research challenge in climate science considering the challenges it poses and still it is even more complex for ISMR. The results from the present work can provide some basic strategies in countering the menace of extremes. In the downscaling of the extremes, the local factors such as urbanization and deforestation which play significant role have not been considered and would form the future scope of study from the present work.

The results show that in the future the extremes are heterogeneously poised across Indian region and this will form a valuable input to study the impact of climate change on local hydrology for the management of extremes.

LIMITATIONS OF PRESENT STUDY

Since the usage of single GCM in climate trajectory projections may sometimes produce misleading information [12]. Therefore for more reliability and acceptance more number GCMs should be used for better representation of ISMR extremes.

The main weakness of block maxima method is that it does not consider multiple occurrences of an extreme event over a particular threshold. Therefore Peak over Threshold (PoT) method should be applied for better improvements in the projections.

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