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A Review On Forecasting Indian Monsoon Rainfall

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Abstract:- In recent years there have been many researches trying to understand climate changes in order to mitigate the natural disasters such as droughts, snowfall, floods and so on. In this paper we would like to present detailed literature review about variability of Indian monsoon rainfall based on statistical analysis, modeling and forecasting by various researchers in the past years. The result of this study shows that the variability of Indian rainfall time series explained varies with various tools and techniques used. The rainfall variability plays a major role to predict and develop new rainfall forecasting models in future. It has been observed that the rainfall time series data used in the past is mostly on the broad regions of India and its subdivisions. It will more useful to the farmers and the Indian economy if new statistical models can be developed in smaller spatial and temporal scales. In the process of review, it is seen that there is an average monsoon rainfall of India, which is treated as the normal level below which is considered as the poor monsoon and above which is considered as good monsoon. Also 70% of the annual rainfall occurs during monsoon season which is the sum of the rainfall during June to September. The average monsoon rainfall of India is 85 cm which is the average of 100 years rainfall from 1901 and 2000. The years 2002, 2004, 2009, 2014, 2015, and 2016 were noted to be below average rainfall years. This review helps the readers to understand the variability in monsoon rainfall of India and model it using an appropriate method.

Keywords:- *Review, Rainfall, Time Series, Modeling, Drought, Average.*

I. INTRODUCTION

Agriculture and farmers are called the back bone of the nation and are heavily dependent on monsoon season. The annual rainfall of India is about 110 cm, which is one of the largest in any part of the world. Out of this nearly 78% of the rainfall occurs in southwest monsoon (SWM) commonly during June to September and 11% of each in pre-monsoon (PRM) and post-monsoon or northeast monsoon (NEM), majorly occurs during January to May and October to December respectively. Due to the excessive variation there is considerable interest in analyzing past data with a view to simulate the conditions for the future to develop mathematical models with possible forecasting ability. There is continued interest among atmospheric scientists and engineers in data analysis and modeling. In this chapter major research available in the past literature are briefly reviewed to identify the areas where the further work is required. The review concentrates mostly on Indian rainfall data, however a few other relevant cases are also included.

Models available in the literature can be broadly classified into two categories, namely general circulation models and empirical models. General circulation models invoke the physics of atmospheric process in the form of partial differential equations involving large-scale computations. The various parameters needed in the model are selected based on available data about temperature, pressure, wind and so on. Empirical models are essentially built on the observed data of rainfall and other atmospheric variables. In this paper concentration has been towards the empirical models.

II. RANDOM VARIABLE MODELS

Empirical models can be categorized as time independent and time variable models. Both these models depend essentially on data analysis. The models which ignore time variation such as year to year variation and consider all the data as set of independent samples can be called random variable models. These models characterize rainfall at different time and spatial scales in terms of probability density functions. However if the aim is to capture the extreme values (droughts and floods) accurately, the Gaussian probability density function will not be an acceptable model. The models which include time variation in analysis and simulation may be called random process models. Such models use past rainfall time series data to understand internal correlations that may help in forecasting exercises.

The ability of a model to explain the events that have occurred in the past can be denoted as descriptive ability. This describes the efficiency of statistical modeling of random or extreme events (WMO, 1989). Parthasarathy and Mooley (1978) investigated the statistical properties of Indian SWM data for the period of 1866-1970. With the help of Chi-square statistic at 5% significance level, they showed that the data is normally distributed with the presence of dominant 2-3 year cycle. But as the rainfall data is a strictly positive quantity, it is clear that the normal distribution is not applicable except in some ranges near the mean value. Unless statistical tests are rigorously applied one may think that normal distribution is sufficient for rainfall models. In continuation of the above work Parthasarathy *et al* (1992) performed statistical analysis on Indian SWM rainfall for the period 1871-1990. It was shown that decadal averages of Indian SWM rainfall index were continuously less than the long term average for three decades. Reeves (1996) study on modeling Indian monsoon rainfall has been on the method of maximum likelihood, for

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estimation of monsoon rainfall using different distributions. He inferred that the general extreme value distribution and Weibull distributions produced a better description of the data in strict comparison with the normal distribution data. Singh (1998) used a general power transformation to transfer the data of 50 different stations across India to a near normal distribution, which was used in the estimation of quantiles. Parida (1999) attempted to model the random behavior of summer monsoon rainfall of India using a generalized four-parameter Kappa distribution. Parameters of this distribution were estimated using moment estimation. A comparison was made between the estimated quantiles at a recurrence interval of 20 years and the monsoon rainfall values observed at 50 stations across the country and this showed better results in comparison to the results previously obtained by Singh (1998). Dietz and Chatterjee (2014) suggested the use of a generalized linear mixed model, specifically the lognormal mixed model, to describe the underlying structure for Indian monsoon precipitation. It was applied to light, moderate and extreme rainfall events. Moment estimation method was used to estimate the parameters associated in the distribution function.

III. STATISTICAL MODELS WITH PRECURSORS

These statistical models are based on past rainfall data and statistical correlations among a few selected atmospheric variables. These models can be further classified on the basis of spatial scales such as global, regional, subdivision and temporal scales such as annual, seasonal, monthly and weekly. In this approach, rainfall is considered to be connected with the antecedent local and or global parameters that correlate with measured rainfall. The statistical correlation between rainfall and antecedent climate parameters are tested for its significance and used in long range forecasting. Blanford (1884) was the first person to suggest the use of a surface boundary condition such as snowfall over Himalayas in the preceding winter to predict the summer monsoon rainfall over India. Gilbert Walker (1923, 1924) developed the simple linear regression model based on statistical correlations between SWM rainfall, snow accumulation over Himalayas in the month of May and South American atmospheric pressure parameters during spring. The comprehensive review of this method made by Jagannathan (1960) indicated that the varying correlations over the decades resulted in factors having no consistent relationship between the various surface and upper air parameters and Indian monsoon rainfall. The models were found to be reasonable only for 65% of the samples, but slowly deteriorated over time. Banerjee *et al*. (1978) showed that the influence of the mean latitudinal position of the subtropical ridge at 500 hPa in April over India can be a predictor for monsoon rainfall over India. Using this along with the other parameters used by Walker, the above authors developed a regression equation was developed for forecasting purpose. However there were some limitations during that period in determining the location of the ridge. Many authors identified (Pant & Parthasarathy 1981, Joseph *et al*. 1981, Thapliyal 1982 and Shukla & Paolino 1983) parameters such as Southern Oscillation Index (SOI) of March–May, mean meridional wind at Bombay, New Delhi, Madras, Nagpur and Srinagar at 200 hPa in May, mean April sub-tropical ridge position at 500 hPa along 75º E over India, tendency of Darwin pressure from winter (December–January) to spring (March–May) to be strongly correlated with Indian summer monsoon rainfall. They opinioned that monitoring the El Niño and Southern Oscillation (ENSO) can provide useful guidance for the long-range forecasting of monsoon rainfall. Inspired by such feedbacks and models based on precursors, several linear and nonlinear regressions using as many as sixteen precursors have been proposed (Gowariker *et al* 1989 and 1991). Such models tend to have more undetermined parameters than the available data and hence show artificial skill and lead to poor forecasts (Delsole and Shukla 2002). Thapliyal and Kulshrestha (1992) and Thapliyal (1997) attempted to reduce the number of predictors by a transformation, but still the number of parameters required was 36 for a time series of 30 years, leading to spurious fit. The models of Rajeevan *et al* (2000 and 2001) and Thapliyal *et al* (2003) with reduced number of parameters selection and different predictor sets were found to be reasonably accurate for the period of 11 years since 1989 and therefore used extensively by IMD.But these years were found to be near normal years. However, Guhathakurta (2006) found these statistical models to be successful only in those years of normal monsoon rainfall and failed remarkably during the extreme monsoon years like 2002 and 2004. He observed that the correlations between monsoon rainfall and the predictors can never be perfect and therefore there is no ultimate end in finding the best predictors. Sahai *et al* (2003) made use of only global sea surface temperature data for long lead prediction of Indian monsoon rainfall, through multivariate correlation analysis. They showed that the performance efficiency of their model fit for 105 years of data was as high as 0.72. The corresponding value in the independent verification period for 22 years was also quite significant at 0.71. Nevertheless such a model failed to forecast the drought of 2002 and 2004 (Gadgil *et al*, 2005). Gadgil *et al* (2004) found existence of good relationship between the Indian monsoon rainfall and the indices of ENSO and Equatorial Indian Ocean oscillation (EQUINOO). They found a strong negative phase of EQUINOO connecting the drought of 2002. Hence they suggested including this parameter to improve the prediction of Indian monsoon rainfall.

New statistical models were developed in IMD using a two stage forecasting system, first stage requiring the precursor predictor data set up to March and the second stage up to May with six predictors to improve the official operational forecasting by Rajeevan *et al* (2005). Of all the models ANN model was shown to be marginally better performed with the efficiency of 0.68 in comparison with the other regression model of efficiency 0.65. These models were shown to replicate the drought years of 2002 and 2004. The new statistical models developed by Rajeevan *et al* (2007) based on the ensemble multiple linear regression and projection pursuit regression techniques are used for generation of the seasonal forecasts

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of SWM rainfall of India. They have shown that the correlation of SWM rainfall index with the predictions of these models is very high, ranging from 0.78 to 0.88. Guhathakurta (1998 and 1999) has observed that the weather prediction over high-resolution geographical regions is very complicated. However, since 1986, the Neural Network technique has been drawing considerable attention of research workers, as it can handle the complex non-linearity problems better than the conventional existing statistical techniques (Eisner and Tsonis, 1992). It is generally found that ANN methods work better in comparison with linear methods of forecasting. Ashok Kumar *et al* (2012) tried to improve the above methods with step wise linear regression and nonlinear ANN techniques with three stage forecasting (April, June and July) of SWM rainfall with suitable predictors selection for all the three stages. These three stages using the mentioned techniques are trained for the period 1958-2000. The validations of these models are done for the period 2001-2011 with the skill of 0.60, 0.65 and 0.62 respectively. Joseph *et al* (2013) explained that deficient monsoon rainfall in India is followed by warm sea surface temperature anomalies (SST) over tropical Indian Ocean and cold SST over western Pacific Ocean. He has shown that decadal oscillations of monsoon rainfall and the decadal oscillations in both the SST anomalies have the same period. Hence they suggested using these parameters in the precursors list in long range forecasting system. New predictors were introduced in the predictors list by Wang *et al* (2014) for seasonal prediction of Indian monsoon rainfall. The predictors were Central Pacific-ENSO, the rapid deepening of Asians low and strengthening of north and south Pacific highs during boreal spring. This helped them to produce 92 years retrospective forecast skill of 0.64 and an independent forecast skill of 0.51 for 1921-2012. This model could capture the nature of rainfall during 2013 and 2014. Gadgil et al (2015) found that the there is a strong dependency on skill of prediction of ENSO and EQUINOO of Indian SWM rainfall as the composite index variance explains about 54% of the all India SWM rainfall variance. They found that July-September rainfall prediction is possible on the basis of June indices and August-September rainfall is based on July indices. Kakade and Kulkarni (2016) identified coherent regions for various fields seal level pressure, temperature, geo-potential height and zonal wind anomalies at different surface levels by applying the shared nearest neighbor algorithm. They constructed the time series by averaging the parameters over the corresponding clusters. Also they examined the relation between the time series constructed and the SWM rainfall time series of India and its regions through positive and negative phases using multiple regressions. These independent multiple regressions for two phases have helped them to produce high skill of 0.75 to 0.8 in all the cases and to replicate drought years such as 2002 and 2009. A deep neural network-based predictor identification method is proposed by Moumita *et al* (2017) to improvise the accuracy of prediction of the regional monsoon. These authors have analyzed the climatic variables around the globe to identify the new monsoon predictors which predict Indian summer monsoons with high accuracy. Further they used ensembled regression tree model with the identified monsoon predictors in predicting all the categories of monsoon with mean deviation error of 4.1%, 5.1%, 5.5%, and 6.4% for the central, north-east, north-west, and south-peninsular Indian regions, respectively. Since the predictors used are atmospheric parameters such as pressures and sea surface temperatures, which are time varying and non-Gaussian, their correlation with SWM rainfall changes with time and hence selection of the right predictors remains unsolved.

IV. STATISTICAL MODELS WITH ONLY PAST RAINFALL DATA

Another approach to the problem is to handle rainfall data as a time series with no other climate parameters in either modeling or forecasting. Efforts have been made in the past to understand and model the weekly, monthly, seasonal and annual time series using different time series modeling. A detailed analysis on all India SWM data was made by Mooley and Parthasarathy (1984) for the period 1871-1978. They showed that there are 13 and 9 large scale deficient and excess rainfall years respectively in the above 108 yrs period. Also they noticed two cycles of 14yrs and 2.80 yrs in the given data period. In continuation of this work Parthasarathy (1984) analyzed SWM rainfall time series of 29 subdivisions of 108 yrs period for interannual and long term variability of rainfall. He performed standard statistical tests to show that the data of all the subdivisions are homogeneous and Gaussian distributed. The presence of 14 yrs cycle in few subdivisions was shown through correlelogram and spectrum analysis of the data. Monthly rainfall data analysis at 306 rainguage stations of India for the period of 114 years (1871-1984) was carried out by Rupa Kumar *et al* (1992) for long term trends. For each station the trends were quantified for both monthly and seasonal rainfall data. For a few stations such as north Andhra Pradesh, and northwest India along the west coast, an increasing trend was observed. Similarly a decreasing trend was seen in east Madhya Pradesh and adjoining areas, northeast India and parts of Gujrat and Kerala. Kriplani *et al* (2003) discussed Indian monsoon rainfall variability and its teleconnections on interannual and decadal time scales for a data length of 130 years. They found that interannual variability fluctuates randomly whereas decadal variability shows alternate epochs of above and below normal rainfall.

At any time scale generally it is found that the linear correlations are not significant. Even at weekly time scale, the correlations are small, but however there are signatures which indicate that there may be some connections from this step to the next step in any of these time scales (Iyengar 1986). Linear time series models such as autoregressive (AR), moving average (MA) models have been tried, but they do not work well. These models use the linear correlations between the present data and its past values. Auto-regressive integrated moving average (ARIMA) models were proposed for SWM data of all India and its broad regions. These were reported to have shown marginally better forecast skill over the multiple regression models (Thapliyal, 1990). However, the autocorrelations in

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all India SWM data during the period 1871-2000 are statistically insignificant. There have been efforts to transform the rainfall data into Gaussian process such as log normal transformations, power transformations and alternate year transformation and so on. The work of Iyengar (1982) suggested a square root transformation, which can transform a non-Gaussian monthly hydrological time series into a Gaussian one as verified with data of 10 Indian rainfall time series. Singh (1998) used power transformation for daily rainfall of Indian monsoon period covering 50 stations to convert the non-Gaussian distribution to Gaussian distribution and the results were verified with the observed rainfall data. Such transformations may be useful in modeling, but to work on forecasting, joint probability density functions have to be determined. Theoretically transformed non-Gaussian joint probability densities can be determined, but the expressions become too complex for further use. Therefore the non-linear models such as ANN, which handle unstructured data, are majorly used to model rainfall time series data. Guhathkurtha (1999) developed a hybrid principle component neural network model for long range forecasting of Indian SWM data. In this model he used 30 years data for modeling as training period and 10 years period as verification period. He compared this model with data ANN and ANN with atmospheric parameters for its performance and observed the skill to be 0.76. Sahai *et al* (2000) proposed ANN techniques to forecast monsoon rainfall using only past data. They considered the All India spatial average of each of the four monsoon months (June, July, August, September) and also their sum as time series data for the period 1871-1960. Five antecedent values of all the five time series were used to train the multilayer ANN to model and predict the five component vector for the subsequent year. This network requires 25 input nodes, 2 hidden layers and 1 output node, leading to a total of 276 model parameters. These are found from five time series each of ninety sample values, but the seasonal value is just the sum of the other four and hence is not an independent sample. Further since five antecedent years are used in training the model the sample size is effectively 335. The modeling efficiency, in terms of variance explained, was found to be 0.8 which is not surprising, since the number of independent parameters is more than half the sample size.

An attempt was made to develop a new non-linear time series model for Indian monsoon rainfall by Iyengar and Raghukanth (2003) in three stages. In the first stage climatic mean behavior was taken care and in the second and the third stages, important previous year connections and the periodic modulating terms were built in to the model. Together with all these stages the model was able to explain 50% of the inter-annual variability. The year to year forecast was verified for this model with the observed data for the impendent data set which was kept aside. A new approach of studying SWM rainfall by decomposing the data series into finite number of uncorrelated components called intrinsic mode functions (IMFs) was developed by Iyengar and Raghukanth (2004). They demonstrated that the SWM data (1901-2000) can be partitioned as the sum of a strongly non-Gaussian short period component and a nearly Gaussian long period component. The first part was modeled using ANN methods with one input layer having 5 nodes, a hidden layer with 5 nodes and a single output. The remaining part was modeled as a linear five step auto-regression. The total number of unknown parameters to be found in this model would be just 42, for a sample size of 100. The modeling efficiency of the non-Gaussian part through ANN was 0.84 and the overall variance explained by this model was as high as 0.83. This approach is very efficient in modeling and simulation, but for forecasting the empirical mode decomposition (EMD) suffers from end point approximations, because the numerical method is anticipative of at least one future value. The ANN model proposed by Guhathakurta (2008) for the 36 subdivisions of India includes 11 to 12 antecedent rainfall values in the input layer with 3 neurons in the hidden layer and an output. This amounts to 40 to 43 parameters in the model, more than half the length of the sample size of 51 used in the training period (1941-1991). The modeling efficiency in the training period of 51 years for all India time series was shown to be 0.7 and for the subdivisions it was found to be 0.8. Another example of this kind of ANN model was by Pritpal and Bhogeswar (2013) for All India rainfall data. They proposed five different three layered (input, hidden and output) ANN architectures with 43, 57, 73, 91 and 111 number of parameters. The efficiency of this ensemble model in the training period of 84 years was found to be 0.65. It is observed that some of the ANN approaches above are not skilful since by increasing the number of parameters to the sample size a polynomial function can be made to fit the data series exactly. Recently, based on the above points into consideration, a new ANN model was developed by Kokila Ramesh and R N Iyengar (2017) including all the seasons variability to forecast 2017 monsoon rainfall for all Indian and its broad regions with optimum number of parameters.

V. DISCUSSION

The above review brings out that there are two kinds of models used for rainfall data for different spatial and temporal scales. One of them is the random variable models which is univariate. These models are useful in modeling the distribution of the rainfall data. But if one is interested in forecasting, these models are not useful as the joint probabilities are complex to construct and use the same for prediction. The second one is the random process model, which includes both linear and non linear models. Linear time series models use linear correlations between the data and its past values. It may be noted at this stage that due to insignificant linear correlations between the rainfall data and its past values, the linear models shown to have no efficiency in forecasting exercises. Statistical models with precursors shown to have the usage of different precursors every time for long range forecasting of Indian rainfall time series. It is due to the fact that the linear correlations between the rainfall data and the precursors tend to change every year. This is one of the major limitations of these models and due to this limitation. Among the statistical approaches used in the literature,

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ANN technique appears to be the most promising one. This should not be surprising since, the data is strongly non-Gaussian and hence linear methods valid for Gaussian time series will prove to be unsuccessful for SWM rainfall data. However, the ANN architecture to be selected remains subjective and hence not unique. Modeling of time series data can be seen as an exercise in curve fitting, with minimum number of parameters in the model not exceeding half the sample size. At present the ANN models reviewed above do not satisfy this condition. Another limitation of the available models is the inherent assumption of stationarity and hence usage of the same model parameter values in the forecasting period. It is observed that even in the hybrid models, it has become essential to use the non-linear model to capture the non-linearity present in the data.

VI. CONCLUSION

With the comprehensive literature study made on the existing methods, a few limitations have been found in the area of modeling and forecasting:

- Random variable models for rainfall data provide only the basic statistics such as mean and standard deviation over long time, which will not remain same as the data may be non-stationary. This may involve assumption of stationarity and that the data are uncorrelated. Hence it is questionable as the time series analysis shows that the data is non-stationary. How can this be used to arrive at short term and long term forecasting at any scale is still to be done.
- Much of the work on empirical models is on finding the statistical relation between the rainfall and the other atmospheric and oceanic parameters. But these parameters may tend to lose their importance with time. Due to this limitation the selection of precursors are not fixed, but changes with time
- In the literature, there is limited work towards modeling of rainfall using only past data. Development of such a model would be simple for agricultural applications
- In most of the neural network models used in the literature, the number of parameters used is more than half of the data length. This results in over fitting. Therefore the results with high correlation and the performance parameter become spurious. Hence attention should be paid on minimizing the number of parameters.

Development of neural network models at shorter time scales such as seasons and months is neglected in the literature. More sophisticated models are to be developed to handle them with only past data relationship.

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