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Forecasting the Rainfall Pattern on Upstream of Hirakud Reservoir Using L-Moment for Accessing the Inflow

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Abstract

Changes in the rainfall pattern are a challenge for filling schedule of reservoir, when it is fulfilling various demands. In monsoon fed reservoirs, the target remains for attaining full reservoir capacity in order to meet various demands during non-monsoon period and the flood control. The planners always eye towards the inflow trend and perspective frequency of rainfall in order to counter the extreme events. In this study, the case of Hirakud reservoir of Mahanadi basin of India is considered as this reservoir meets various demands as well as controls devastating floods. The inflow trend has been detected by using Mann Kendall test. The frequency analysis of monthly rainfall is calculated using L-moment program for finalizing a regional distribution. The falling trend in inflow to reservoir is visualized in the month of July and August. The Wakeby distribution is found suitable for the monthly rainfall of July, September and October, where as in June and August, General Extreme Value (GEV), General Normal (GN) and Pearson Type-III (PT-III) distributions are found suitable. The regional growth factors for the 20, 40, 50 and 100-year return period rainfalls along with inflow to reservoir observed between 1958-2010 are calculated in this study as a referral for reservoir operation policy.

Keywords

Hirakud Reservoir, Trend Analysis, L-Moment, General Normal (GN), General Logistic (GL) Wakeby Distribution, GEV

1. Introduction

Hirakud reservoir as a multipurpose dam resolving many demands of state of

Odisha. The operation of the reservoir is governed by a specified rule curve and it is supposed to attain its full reservoir level at the end of October 31st (end of monsoon season) in order to meet the demands till start of the monsoon season (end of May). In this regard the rainfall and its distribution of upstream districts play pivotal role in filling schedule of the reservoir. There are numbers of studies in these regards and a few of them are discussed. Reference [1] shows the characteristics of Miyun reservoir of China. It was found that annual inflow, flood peaks decreases in both quantity and proportion and this decreasing extent is higher than that of common runoff. Human activities like high population growth and corresponding land use changes remain the major concern. Forecasting of future water availability to meet conflicting demands is the major task. Under this study [2] seasonality, stochasticity and non-linearity of the inflow were identified. Reference [3] has analysed the effect of climate change for northern reservoirs of Indiana using Self Organisation Map (SOM) to perform trend and cluster analysis. The Mann Kendall and Revised Mann Kendall were used for regionalization. Another study [4] made on a saline reservoir of state Odisha, India which focused on trend analysis of rainfall using Mann Kendall, inflow quantification using ARNO model and performance evaluation of reservoir using WEAP model under changing climatic situations. Reference [5] has studied about trends in water quality and quantity for 11 major reservoirs of the Brazos and Colorado river basins in the southern Great Plains. The components like water quality, major contributing-stream inflow, storage, local precipitation, and basin-wide total water withdrawals were analyzed. The study of [6] has applied the Mann-Kendall (MK) statistical trend test on a wide range to analyze increasing, decreasing or trendless characteristics of precipitation, temperature, inflow to dam reservoirs, release from dam reservoirs, and storage volume in dam reservoir in Thailand from historical operation recorded data. As per [7], reservoir inflow corresponding to varying rainfall pattern under climate change conditions causing the variation of the reservoir inflow. They have proposed a hybrid SD model named Wavelet Support Vector Machine (WSVM) in combination of the multiscale Principal Components Analysis (MSPCA) and nonlinear Support Vector Machine regression model for Sutami Reservoir, Indonesia and found that WSVM shown better result in inflow forecasting.

L-moment approach has been applied to many events in number of cases for finding parent distribution. In case of flood frequency analysis L-moment has been applied in many occasions. However, in different rainfall events application of L-moment is seen in cases like [8], found that the frequency analysis of the largest or the smallest of a sequence of hydrologic events has long been an essential part of the design of hydraulic structure. Reference [9] has used L-moment for regionalization of annual precipitation in northern Central Italy. Reference [10] has applied L-moment for selection of parent distribution to fit maximum monthly rainfall data of 18 sites of the Zayanderhood basin, Iran. The obtained extreme rainfall values can be used for meteorological drought management in the arid zone. Reference [11] has applied L-moment for probability distribution of extreme value 1-day rainfall events.

2. Study Area

The Hirakud reservoir of Mahanadi basin cover almost 83,400 sq km of catchment area out of total catchment of 141,589 sq km and covering most part of two states like Chhatisgarh and Odisha (Figure 1).

The reservoir Hirakud was commissioned since 1958 as a multipurpose project. A catchment of 83,400 sq km drains into reservoir Hirakud covering 24 districts of four states fully or partly (Figure 2). The reservoir is monsoon fed and its storage of 4825 Mcum is being utilized for number of demands like irrigation, hydropower, industrial, domestic, environment and more. The reservoir has immense importance towards the economic development of the state. The monsoon generally breaks during the mid and latter June in the states of Chhatisgarh and Odisha, inflow starts entering into reservoir and the flow continues till end of October. As the both the states are developing fast, definitely there will be certain changes in the landuse pattern which may put direct impact on the inflow to reservoir. The climatic changes also showed lot of spatio-temporal variation in the rainfall patterns. Considering above facts, this study is done for

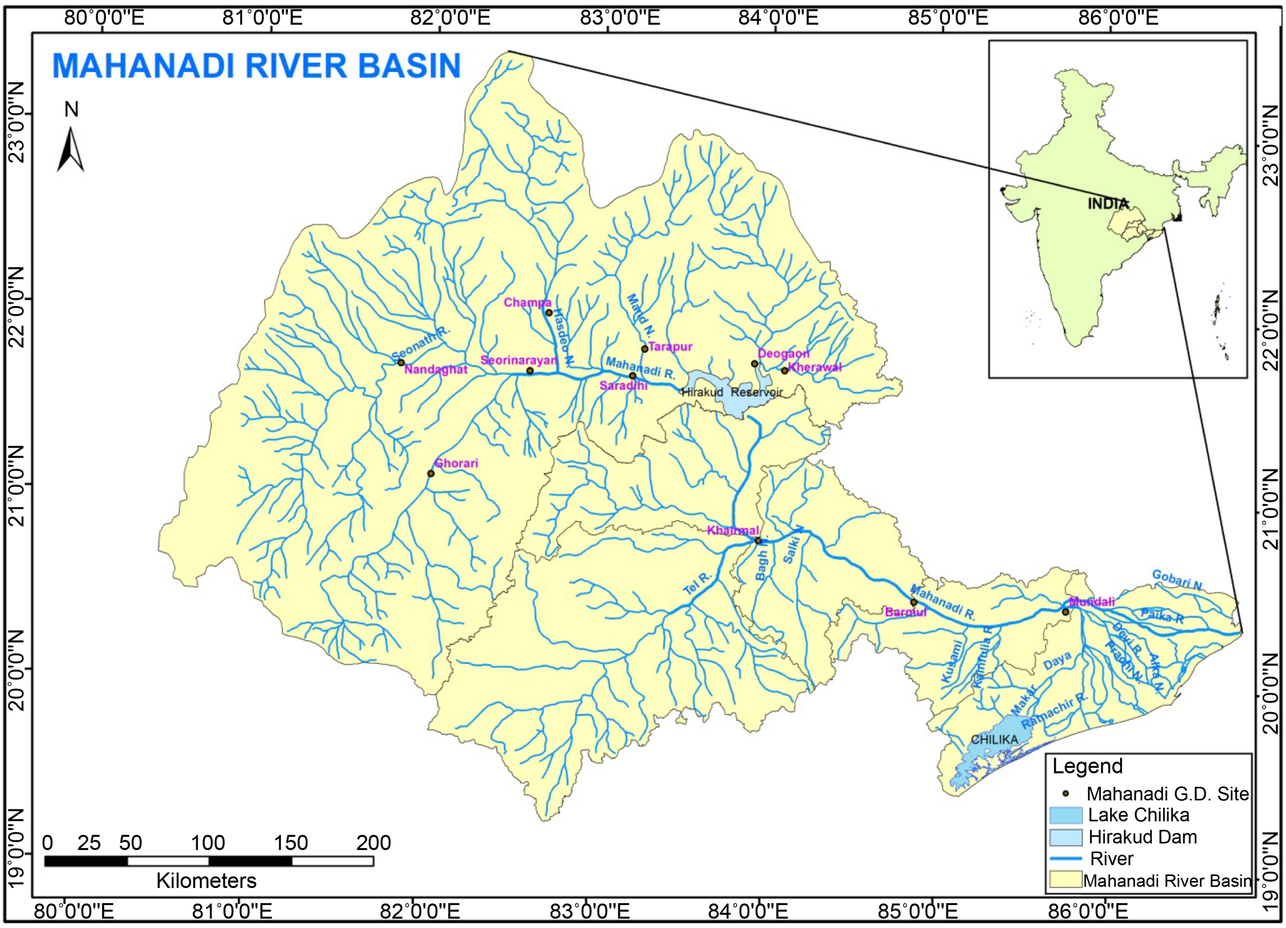

Figure 1. Mahanadi basin with Hirakud reservoir.

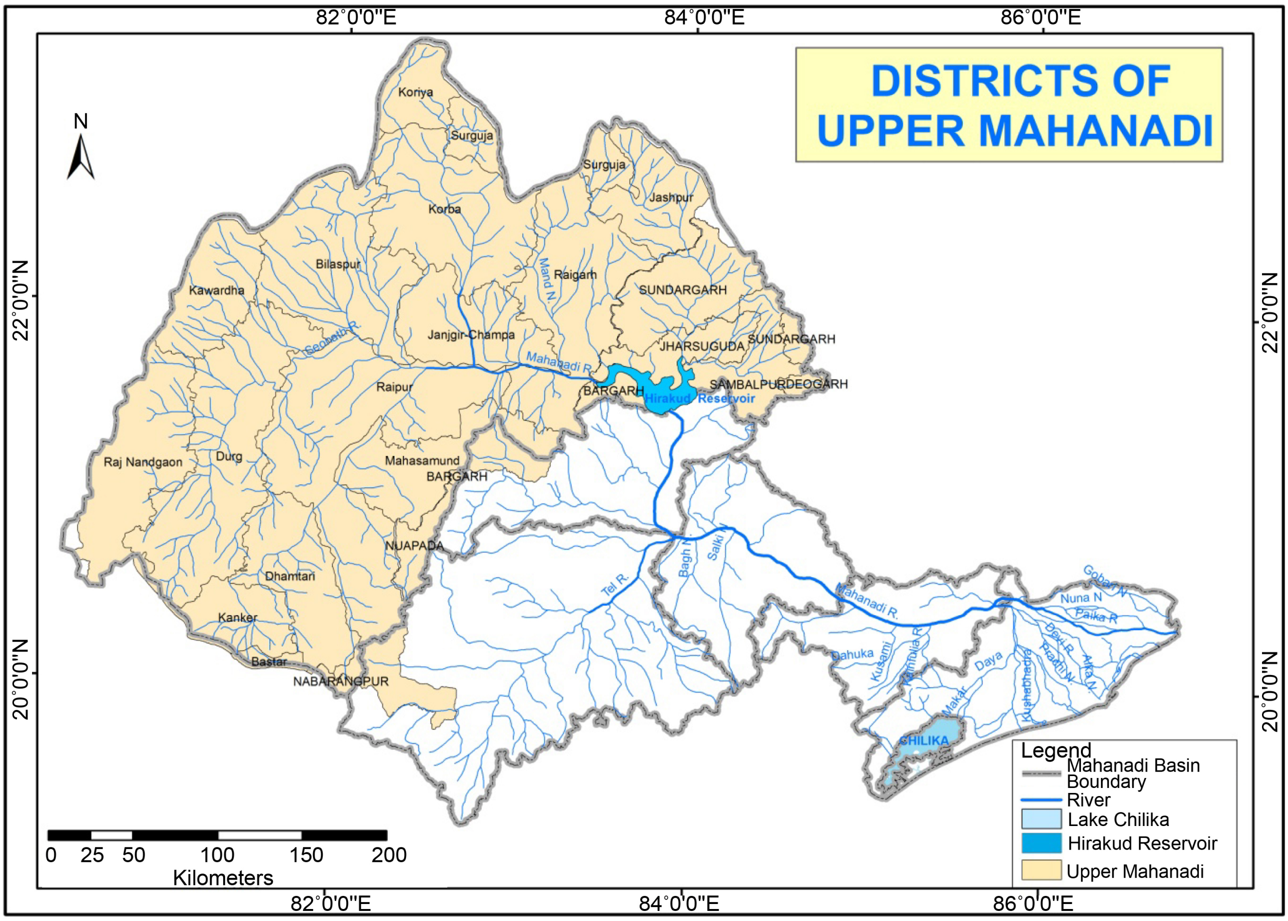

Figure 2. Mahanadi catchment showing districts of upper catchment.

searching a trend in rainfall and inflow as it may has been put direct impact on the operation and management of reservoir for fulfilling the necessary demands. As the study is related to inflow of reservoir, districts of its upstream part are only considered.

3. Methodology

1) *Trend Detection*: To identify trend in climatic variables with reference to climate change, the Mann-Kendall test has been employed by a number of researches with temperature, precipitation and stream flow data series ([12] [13] [14] [15] [16]). It is a common practice to use a non-parametric test to detect a trend in a time series. This test, being a function of the ranks of the observations rather than their actual values, is not affected by the actual distribution of the data and is less sensitive to outliers. On the other hand, parametric trend tests, although more powerful, require the data to be normally distributed and are more sensitive to outliers. The Mann-Kendall test is therefore more suitable for detecting trends in hydrological time series, which are usually skewed and may be contaminated with outliers. This test has been extensively used with environmental time series [17].

The Mann-Kendall trend test is based on the correlation between the ranks of a time series and their time order. For the statistics S is calculated as Equation (1). This statistic represents the number of positive differences minus the number of negative differences for all the differences considered as

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\operatorname{sgn}\left(x_j - x_i\right) \tag{1}$$

where, n is the number of total data points, x_i and x_j are the data values in time series i and $(j > i)$, respectively, and $\operatorname{sgn}\left(x_j - x_i\right)$ is the sign function as:

$$\operatorname{sgn}\left(x_j - x_i\right) = \begin{cases} +1, & \text{if } \left(x_j - x_i\right) > 0 \\ 0, & \text{if } \left(x_j - x_i\right) = 0 \\ -1, & \text{if } \left(x_j - x_i\right) < 0 \end{cases} \tag{2}$$

The variance of Mann- Kendall test is calculated by Equation (3) as

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i\left(t_i - 1\right)\left(2t_i + 5\right)}{18} \tag{3}$$

where, n is the number of total data points, m is the number of tied groups. The tied group means a simple data having a same value. The t_i indicates the number of ties of extent, i. In case of the sample size, $n > 10$, the standard normal test statistic Z_s is estimated by Equation (4) as

$$Z_s = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}}, & \text{if } S > 0 \\ 0, & \text{if } S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}}, & \text{if } S < 0 \end{cases} \tag{4}$$

The positive values of Z_s show increasing trends while negative values represent falling trends. As 5% significance level is taken standard for this study, the null hypothesis of no trend is rejected if $\left|Z_s\right| > 1.96$.

2) *L-moment analysis*: Three statistical measures discordancy measure, heterogeneity measure and goodness of fit measure as per L-moment approach are used in regional studies. These measures are explained by [18]. It is used to estimate the degree of heterogeneity and to assess whether they might reasonably be treated as homogeneous. Specifically, the heterogeneity measure compares between site variations in sample L-moments for the group of sites with that expected for a group of region. Hosking's Heterogeneity test fits 4 parameter Kappa distributions. A series of 500 simulations (N_{sim}) done and L-statistics of actual region is compared with a simulated series. The *H*-statistics defined as,

$$H_i = \left(V_i - \mu_v\right)/\sigma_v \tag{5}$$

For each simulated region, the measures of variability V_i (where V_i is any of three measures V_1, V_2 and V_3) is calculated. From the simulated data, the mean μ_v and standard deviation σ_v of the N_{sim} values of V_i are determined.

The critical H statistics for a region to be homogeneous is as mentioned below

$$H < 1 \quad \text{Homogeneous} \tag{6}$$

$$1 \le H \le 2 \quad \text{Possibly heterogeneous} \tag{7}$$

$$H > 2 \quad \text{Definitely heterogeneous} \tag{8}$$

Reference [12] has observed that statistics H_2 and H_3 based on measure of V_2 and V_3 lack the power to discriminate between homogeneous and heterogeneous regions but H_1 based on V_1 has much better discriminating power. So H_1 is treated as a much better indicator of heterogeneity measure. Also, H_1 was found to be a better indicator of heterogeneity in large regions, but has a tendency to give false indication of homogeneity for small regions [19].

The measure H_2 indicates whether at-site and regional estimates will be close to each other. A large value of H_2 indicates whether or not the at-site and regional estimates will be in agreement, whereas a large value of H_3 indicates a large deviation between at-site estimates and observed data.

3) *Selection of Regional Distribution*: The regional distribution has been adjudged on the basis of Z-statistics as follows:

It indicates suitability of a candidate distribution to a data series and is appropriate for evaluating and comparing a distribution. The *Z*-statistics for the goodness of fit measure as defined by Hosking is

$$Z^{DIST} = \left(Z_4^{DIST} - Z_4 + B_4\right) / \sigma_4 \tag{9}$$

$DIST$ = a particular distribution, Z_4^{DIST} = L-kurtosis for fitted distribution, Z_4 = pooled L-kurtosis, B_4 = bias correction, σ_4 = estimate of sample variability of L-kurtosis. The Z^{DIST} value should be close to zero. However, a value between −1.64 and 1.64 is considered to be suitable for a fitting distribution at 10% significance level. While a number of distributions may qualify the goodness-of-fit criteria, the most potential will be one that has minimum $\left|Z^{DIST}\right|$ value. The rainfall values based on different frequencies are calculated from the relationship between R_t and R_m, where R_t is the rainfall value at particular return period t and R_m is the mean rainfall.

Data Used: The district wise rainfall data from 1958-2010 is used from the India Meteorological Department (IMD) sources and the Inflow to reservoir has been obtained from Government of Odisha [20].

4. Results and Discussion

From the catchment map (**Figure 2**) it is found that, there are 23 districts in the upstream catchment of Hirakud reservoir out of them 7 districts comprising 13.10% of upstream catchment belongs to Odisha state. Chhatisgarh has 15 districts occupying 86.54% of the same.

As the upstream catchment analysis is needed for finding the inflow characteristics first of all the influence area of each districts which is influencing the inflow are obtained and mentioned in **Table 1**.

Table 1. Influence area of Upstream districts.

Districts	Area (sq km)	Influence area (%)
	Odisha	
Bargarh	800.06	0.96
Deogarh	296.83	0.36
Jharsuguda	2121.48	2.54
Nabarangapur	189.44	0.23
Nuapada	968.92	1.16
Sambalpur	2406.83	2.89
S.Garh	4140.66	4.97
Total		13.10
	Chhatisgarh	
Bastar	370.89	0.44
Bilaspur	6742.00	8.09
Dhmatari	4087.37	4.90
Durg	8660.60	10.39
Janjgir-Champa	3890.36	4.67
Jashpur	2982.82	3.58
Kanker	2337.85	2.80
Kwardha	3241.60	3.89
Korba	6520.13	7.82
Koriya	1763.77	2.12
Mahasamund	4774.70	5.73
Raigarh	6963.08	8.35
Raipur	12,517.36	15.01
Rajnandagaon	5502.94	6.60
Surguja	1799.44	2.16
Total		86.54
	Maharastra	
Gadachiroli	230	0.36

It was found that the district Raipur contains 15.01%, Durg 10.39, Raigarh 8.35, Bilaspur 8.09 and Korba 7.82% of upstream catchment. As these 5 districts, occupy 50% of geographical catchment, rainfall over these districts also to be carefully viewed as these may substantially influence the reservoir inflow.

The time series for month wise inflow to the reservoir is drawn for the period from 1958 to 2010 (**Figures 3-7**). The average inflows during these periods are in June 0.98, July 5.93, August 9.64, September 6.65 and in October 1.89 MAc ft. From the time series of June it is seen that, only 4 times an inflow of more than 4 MAc ft have occurred. From 1995 onwards inflow reduces to around 1 MAc ft in June. In July month during the year 1994, a maximum inflow of 22.98 and in 2001 inflow of 17.09 MAc ft was received, which resulted in flood. After 2001,

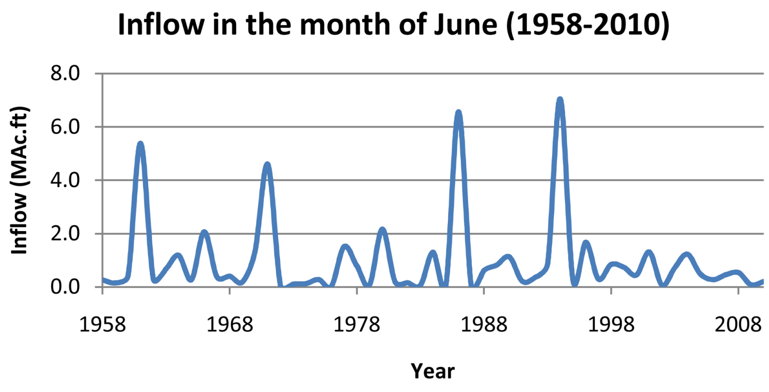

Figure 3. Timeseries of inflow to Hirakud Reservoir in the month of June.

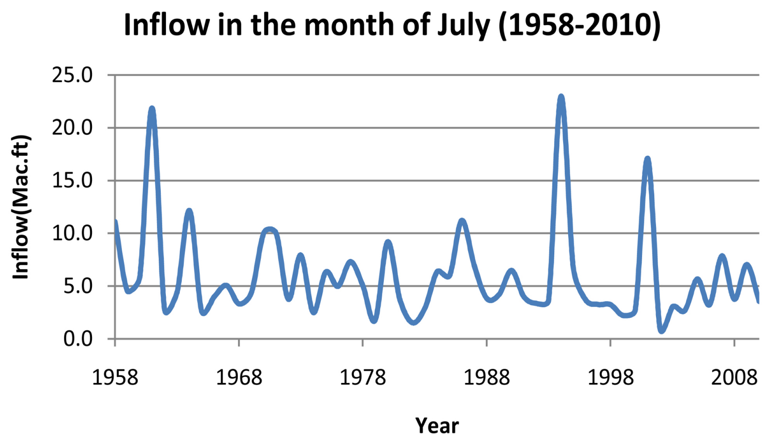

Figure 4. Timeseries of inflow to Hirakud Reservoir in the month of July.

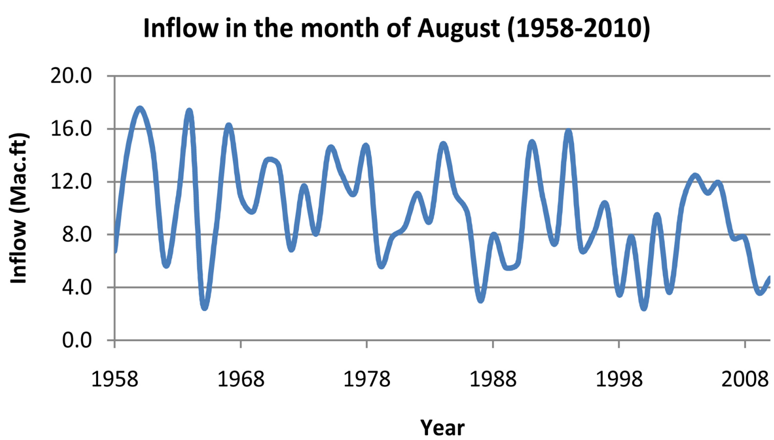

Figure 5. Timeseries of inflow to Hirakud Reservoir in the month of August.

inflow near to average was being received. In August, the inflow varies continuously. An inflow of 16.384 MAc ft was received during September 2003, which again resulted in flood. The month of October remain sensitive for flood as well as filling up of reservoir. In most of the successful monsoon years, reservoir almost attains its full capacity at the end of September. So, a higher inflow may result in flood. In 2003, an inflow of 6.207 MAc ft was received in October.

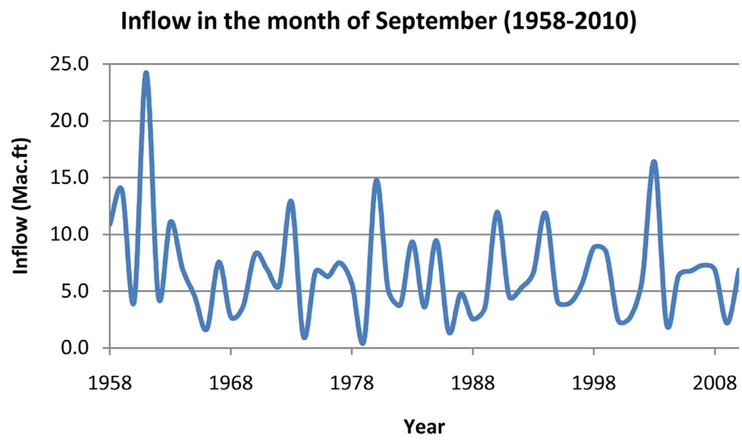

Figure 6. Timeseries of inflow to Hirakud Reservoir in the month of September.

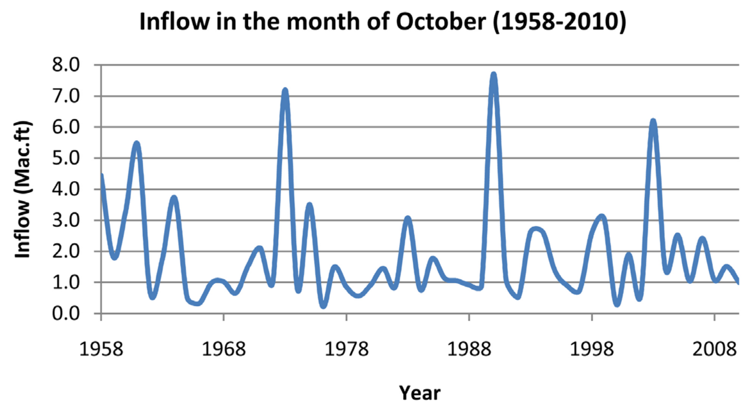

Figure 7. Timeseries of inflow to Hirakud reservoir in the month of October.

The reservoir has a live storage capacity of 3.91 MAc ft and major demands like Irrigation, Power, Flood control. The average inflow and demands/releases are shown in Table 2. So, the reservoir has to meet these demands as well as to control the flood or to create space for expected flood.

Applying trend analysis using Mann Kendall test, it was found that, no trends have been observed in June, September and October. In July no trend was seen at 1% and 5% significance level but a falling trend at 10%. In August, no trend was seen at 1% Significance level but falling trend at 5% and 10% (Table 3).

For finding the frequency of rainfall first of one homogeneous region was established by applying L-moment approach. The unsuitable districts are removed from the homogeneous regional group as per the discordancy test. The districts having discordancy values more than 3 are discarded. The rainfall values of Bilaspur district has been discarded in all the 5 months. The suitable distributions are selected from the goodness of fit criteria. The distributions and corresponding growth factors $\left(\frac{R_T}{R_m}\right)$ are shown in Table 4. Further the inflow to dam is calculated considering all the five monsoon months for the period 1958-2010 (Table 4).

Table 2. Average inflow and demands/releases of Hirakud.

Month	Average Inflow (MAc.ft)	Average Demands/Releases (MAc.ft)		
		Irrigation	Power	Spillway
June	0.98	0.057	0.53	0.384
July	5.93	0.165	0.943	4.012
August	9.64	0.172	1.086	4.928
September	6.65	0.197	0.999	8.67
October	1.89	0.801	0.801	3.683

Table 3. Month wise trends for inflow to reservoir at different significance level.

Month	Test statistics (t)	Significance Level		
		1%	5%	10%
June	0.03068	No	No	No
July	−1.79494	No	No	Falling
August	−2.31655	No	Falling	Falling
September	−0.75173	No	No	No
October	0.07671	No	No	No

Table 4. Suitable regional distributions for monthly rainfall with corresponding growth factors.

Month	Suitable Regional Distribution	Growth factors for return periods				Remark
		20	40	50	100	
June	GEV	1.767	1.945	1.998	2.155	Region contains 19 districts excluding Bilaspur, Jashpur, Surguja, Koriya
	GN	1.762	1.946	2.003	2.175	
	PT-III	1.762	1.942	1.998	2.163	
	Wakeby	1.78	1.954	2.004	2.145	
July	Wakeby	1.501	1.654	1.702	1.851	Region contains 22 districts except Bilaspur
August	GEV	1.489	1.592	1.623	1.711	Region contains 22 districts except Bilaspur
	GN	1.486	1.596	1.63	1.73	
	PT-III	1.486	1.595	1.628	1.726	
	Wakeby	1.489	1.612	1.65	1.762	
September	Wakeby	1.671	1.803	1.84	1.939	Region contains 20 districts except Bilaspur, Nawarangpur, Gadachiroli
October	Wakeby	2.446	2.721	2.796	2.994	Region contains 22 districts except Bilaspur
		Inflow to Hirakud dam				
Inflow	GL	2.465	3.184	3.449	4.406	Taking the inflows of all monsoon months for 53 years observed between 1958-2010
	GEV	2.526	3.211	3.454	4.295	
	GN	2.571	3.215	3.436	4.163	
	Wakeby	2.586	3.255	3.483	4.24	

5. Conclusion

The rainfall over five districts like Raipur, Durg, Raigarh, Bilaspur, Korba is very sensitive as this occupies almost 50% of the upstream catchment area. The rainfall during month of August is showing a falling trend. As most of the agricultural activities continue during this time a falling trend may hamper. The regional distributions like GEV, GN, PT-III and Wakeby are found suitable for month of June and August whereas Wake by found suitable for the month of July, September and October. The distributions GL, GEV, GN and Wakeby hold good for inflow forecasting taking the observed inflow series. The time series, trend analysis, regional fitting distributions and corresponding growth factors derived are useful for further planning and management of the reservoir operation.

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