Analytical Study of Monsoon Rainfall South Mahanadi Delta and Chilika Lagoon, Odisha

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Abstract:

The rainfall has become anomalous today along Odisha coast, India. The southern distributaries, Daya and Bhargovi in Mahanadi delta join the sea via Chilika lagoon. The lagoon stands variations in geomorphology, ecology and biodiversity for changes in precipitation and threshold flushing flow. The abnormal rainfall has caused high floods during 2001, 2003, 2006, 2008, 2011 and 2014. Year 2000 was the minimum discharge year of the millennium. Chilika Lagoon, largest in Asia receives 61% of inland flow from Mahanadi system. The tourist, flora and aqua catch decreased remarkably 1995-2000 for lagoon's reduced salinity, siltation and biodiversity. As engineering intervention, a new inlet dredged, few barrages and cuts constructed upstream in the river system. The anomaly in monsoon precipitation has trimmed down the threshold flushing flow to maintain salinity. Hence frequency analysis and prediction of rainfall at a desired recurrence interval became univocal. As post studies of hydrology to the engineering interferences, the frequency analysis of rainfall has been done after verifying the outliers, goodness of fit with handful recorded data. A suitable probability distribution pattern has been selected and PDF function used to predict monsoon rainfall against various recurrence periods. Out of L-moment, PWM methods available, Log Pearson type III method is found the best and realistic for rainfall analysis. Attempt has been made in this paper to predict annual monsoon rainfall of the delta and lagoon for 10000 years at different return periods.

Key words: *Bhargovi, Chilika Lake, Daya, Mahanadi delta, Statistical analysis*

Introduction

South Mahanadi delta and the lagoon form a triangle apex at Naraj and the base is the Bay of Bengal coast line of 66.5km extending from Rushikulya river mouth to old Sunamukni river mouth (Fig 1, source google).The area is a part of East coast of central peninsular India. It covers four populated districts of Odisha Cuttack, Puri, Khordha and Ganjam. The area geographically lies in the northern fringe of Eastern Ghats belt and touching the 85 degree ridge in the Bay of Bengal. The place is also the rim of the SW monsoon and the NE monsoon prevalence zone. The average rainfall of the area is about 1400mm and numbers of rainy days are 90 days. The climate of the area is tropical with hard hit summer, high humidity, and medium to high rainfall, short & mild winter. The area receives rainfall mostly through SW monsoon, spatially distributed during months of June, July, August, September and October. Some parts Chilika receive rainfall by NE monsoon *i.e.* October and November. The rainfall intensity is highest in the month of August. The place receives 85-90% of total rainfall during monsoon. The entire runoff of the area drains to the Rivers Kuakhai, Daya and Bhargovi. The major part of flood runoff drains to Chilika which maintain the status and number of tidal inlets during rainy season and finally the salinity. The southernmost branches of Mahanadi delta finally falls in the northern swamps of the lagoon **Figure 1**.The area and length of drainage system contributing to Chilika lagoon and available rain gauge stations are given in T**able 1**

Table 1: River / Drainage System Contributing Flow to Chilika Lagoon through Mahanadi Delta

River/drains	Length in km	Catch. area in sqkm	RG station
Daya and Rajua	30.6	540	Bhubaneswar, Kanas
Nuna drainage system	26	445	Delanga, Kanas, Pipili
Bhargovi drainage system	85.5	646	Pipili, sakhigopal, Puri
Ratnachira Drainage system	22	145	Sakhigopal, Kanas
Total Daya Bhargovi doab to Chilika		**1777**	
Other system contributing Flow to Daya Bhargovi Doab (Doab VII)			
Malaguni (West catchment system)	22.5	289	Kanas
Gangua (Kuakhai system)	37	650	Bhubaneswar
Other system contributing flow to Lagoon via Doab VII		**939**	

Fig 1: Catchment of drainage system in Daya Bhargovi Doab

1.1 Review of Literature:

As per Department Water Resources record, Mohalanabis, 1928[1] was the first who made the flood frequency study of south Mahanadi delta and made a correlation between the discharge and average rainfall . The prediction formulae is D = 243.7334 X + 731.04 where D is the discharge at Naraj in Kilocusec and X is the rainfall in inches per day in Mahanadi catchment. On regression analysis the regression equation is given by N = 1.54 R + 0.67 G + 23.81 where N is the predicted height in Naraj, R is the rainfall of 50 gauge stations in the catchment and G is the gauge at Naraj. Rainfalls frequency analysis in India have been carried out by many researchers (Asokan S.M., et al, 2008[2], Goswami et al., 2006[3], Rajeevan et al., 2006[4]; Ghosh et al., 2009, 2010[5,6]; Patra et al., 2012[7]. Researchers worked on the rainfall frequency analysis of Mahanadi basin are Raje D. and Mujumdar P. P., 2009[8], A significant increasing trend of rainfall frequency and magnitude was reported over central part of India during the monsoon period by Mohapatra M. and Mohanty U. C., 2005[9], Goswami et al., 2006[10]. Later Ghosh et al., (2009)[11] contradicted the results of Goswami et al[10]. Shukla et al[14] studied the extreme rainfall data of Jharkhand area and of opinion that GEV model is the suitable model for statistical analysis. The recent frequent high floods in the Delta during 21st century is due to increase in rainfall in the middle reaches between Hirakud and Naraj (Jena P. P., Chaterjee C. et al 2014)[12]. The predicted rainfall amount obtained by Gumbel method and Log Pearson Type III give almost same results whereas Gumbel method results are slightly higher in Hafr Albatin regions in the kingdom of Saudi Arabia, Ibrahim H. E., 2012[13] .The runoff and floods due to rainfall maintain the tidal inlet of the lagoon in rainy season and the tides during rest of the period of the year, Mishra S. P. et al, 2014.[16]

1.2 Methods and methodology

Rainfall data for eight blocks (1991-2014) is available in the catchment of rivers Daya and Bhargovi. The only rainfall station available within the lagoon is Krushnaprasad block. The data is processed and the authenticity of the time series is verified. Delanga block observations found off beam for 2007 and 2008. The reported data as abnormally low, the rainfall of nearest station Pipili is taken for Delanga. For river Daya the stations considered are Bhubaneswar, Pipil, Delanga and Kanas. The stations Pipili, Sakhigopal, Puri and Brhmagiri stations are taken for analysis of river Bhargovi. For the lagoon, the rainfall of Krushna Prasad block is taken. The works carried are drawing annual series curve, fixation of Hypothesis, studying homogeneity, finding the basic statistics, testing the outliers, ranking PDF from goodness of fit (GoF) tests (Kolmogorov-Smirnov test, Anderson-Darling test and the chi-square test), finding the parameters of fit equation. Then two parametric equations Gumbel and Log Pearson type III is used to predict future monsoon rainfall for different recurrence interval. Finally the comparison of results is made and the reality of the forecasted data is decided. (**Stedinger J. R 2006)**[15]

2.1 Time series and moving average curve

The time series curve is drawn to study the positive or negative correlation of the data. The time series is linear and have three small peaks which is smoothened by drawing the moving average curve fig 2. The trend analysis of data is shown in graphs fig 3.The variation in annual total monsoon rainfall of the area is not much of wide range and data is seasonally dependant. The actual monsoon total is floating at close proximity of the line of average except some abnormalities are observed which accentuate the correctness of the data.

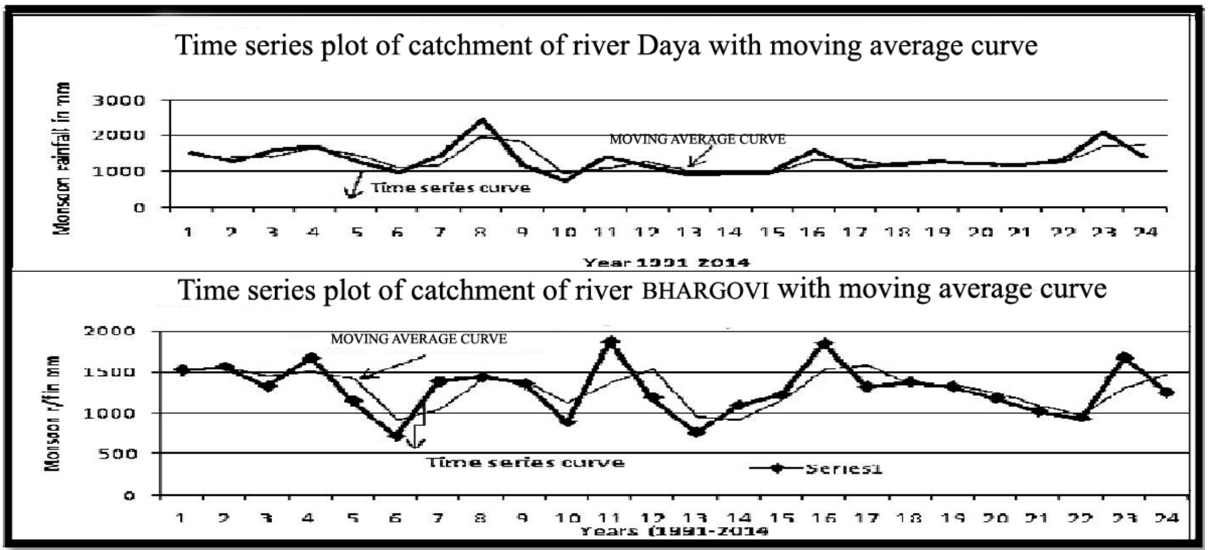

Fig 2 : Time Series and Moving Average Curve for the Monsoon R/F Data of Rivers Daya and Bhargovi (1991-2014)

2.2 General Statistics

Basic statistics are widely required for validation and reporting. Mean, median, mode, standard deviation, Kurtosis and the quartiles are common basic statistics used for validation of time series rainfall data. (Table 2)

Table 2: General statistics of monsoon rainfall of rivers Daya-Bhargovi Doab

Sl No	Parameter Values	River Daya	River Bhargovi	Chilika lagoon
1	Year of data	1991-2014	1991-2014	1991-2014
2	Sample range (Years)	24	24	24
3	Minimum (mm)	734	722	465 (1996)
4	Maximum (mm)	2458 (1998)	1878 (2001)	2743 (2013)
5	Range (mm)	1724	1156	2278
6	Arithmetic mean (mm)	1322	1299	1075
7	Mode (mm)	1255	1188	
8	Median (mm)	1256.5	1326	896
9	Variance	1.456×10^5	94752	
10	Standard deviation	381.6	307.8	509
11	Skewness	1.358	.025	
12	Kurtosis	2.639	-.286	
13	Percentile Min. (25% Q_1)	1103	1110	784
14	Percentile max (75% Q_3)	1500	1878	1210
15	Standard error	77.89	62.8	
16	Coefficient of variation	.289	.237	

From the above statistical values it can be inferred that the annual monsoon rainfall of the catchments of river Daya, Bhargovi, Doab VII and the lagoon area are spatial and there is a wide variation in monsoon rainfall amount. During 1996 there was scanty rainfall in the lagoon resulting in abnormal aqua catch and heavy siltation in the lagoon. During 1998, the rainfall of the Daya catchment was abnormal due to very high SAT and the cause of rainfall attribute to very high Sat and regular convective rainfall in the mountainous zone of EGB area Khordha and Puri Districts. Similarly the maximum rainfall of 2013 in the lagoon area may be related with the storm (Phailin) has slammed the area.

2.3 Hypothesis

The hypothesis for the commonly used goodness of fit tests (Kolmogorov-Smirnov test (K-S), Anderson-Darling Test (A2) and χ2 test) taken as

H_0: The data follow the specified distribution.

H_A: The data do not follow the specified distribution.

2.4 Homogeneity of data:

All the rain gauge station considered in the catchment area of the rivers Daya and Bhargovi are taken from 1970’s. Their location, orientation have not been changed during the period of observation considered. Hence the data is homogeneous.

2.5 Outliers:

Fig 3, Fig 4, and Fig 5 exhibit the Probability plot for outliers for monsoon rainfall in catchment of rivers Daya, Bhargovi and lagoon. From the probability plot, it is observed that the monsoon rainfall data has one lower outlier each in the Chilika lagoon. This shows the time series data is consistent.

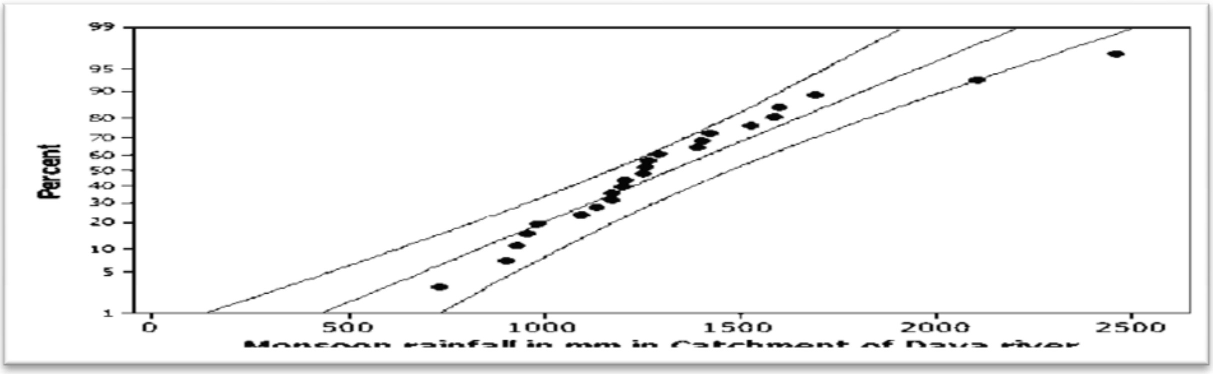

Fig 3:Prob. Plot of Monsoon r/f in Catchment area of Daya River, Confidence Limit 95% (1991-2014).

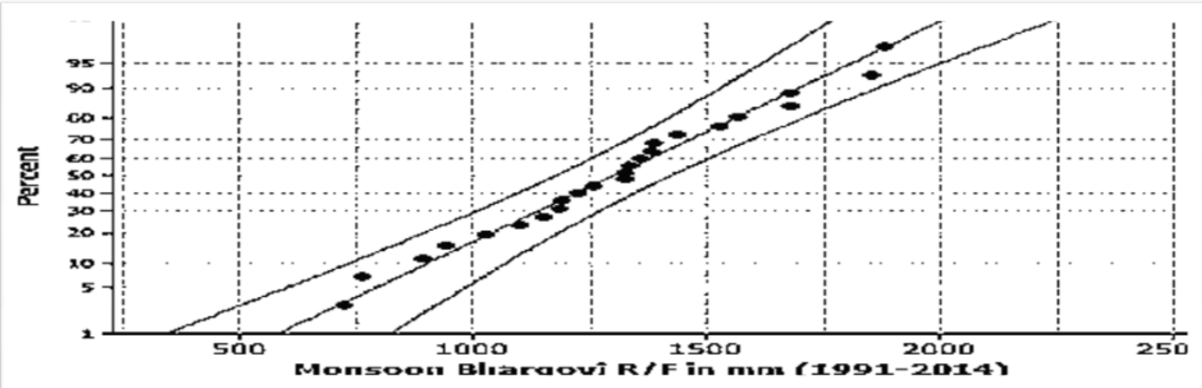

Fig 4:Prob. Plot of Monsoon r/f in Catchment Area of Bhargovi River, Confidence Limit 95% (1991-2014).

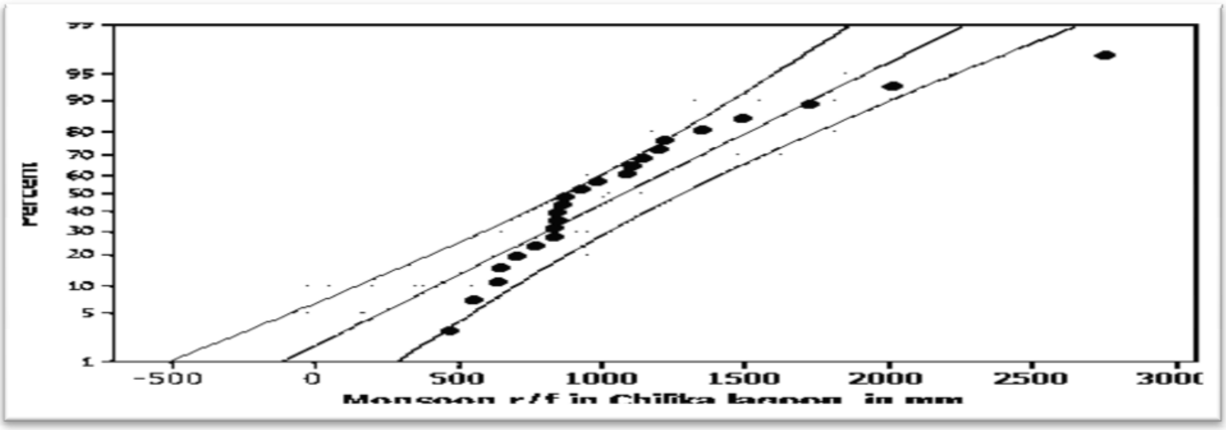

Fig 5:Prob. Plot of monsoon r/f in Chilika Lagoon, Confidence Limit 95% (1991-2014).

Empirical Cumulative Distribution Functions

Empirical CDF functions are used for finding the quartile values of precipitation for the data set. In such a distribution X-axis denote the rainfall in mm and Y axis the percentile values varying between zero and one. Fig 6, Fig 7 and Fig 8 exhibit the empirical CDF function for the monsoon rainfall time series for the catchment R/F of river Daya and Bhargovi and the Chilika. From the empirical cumulative distribution functions it can be inferred that the time series of monsoon rainfall in the catchment of river Daya, Bhargovi and Chilika lagoon fitting nicely with the Cumulative distribution function.

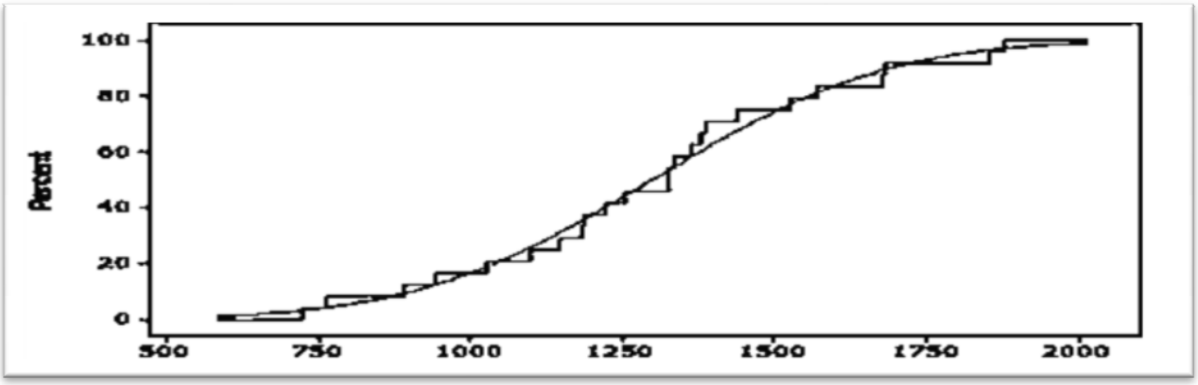

Fig 6: Empirical CDF Function (normal) of Monsoon r/f in Catchment of River Bhargovi (data 1991-2014)

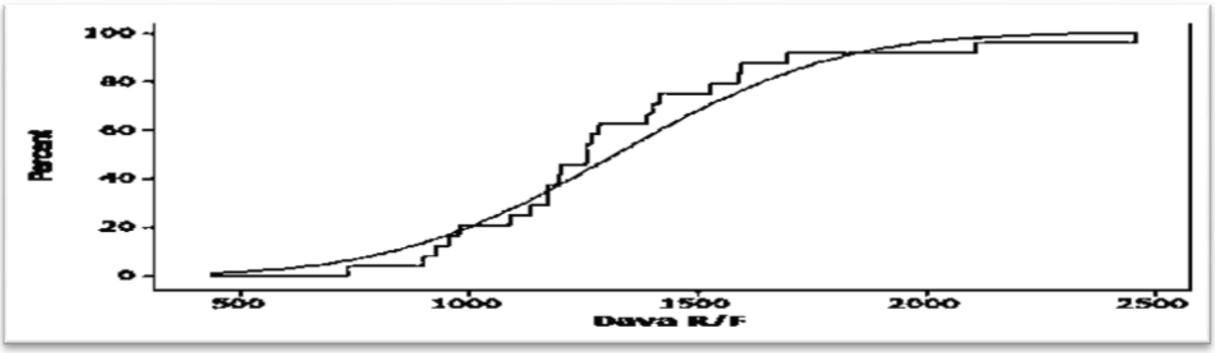

Fig 7: Empirical CDF Function (Normal) of Monsoon r/f in Catchment of River Daya (data 1991-2014)

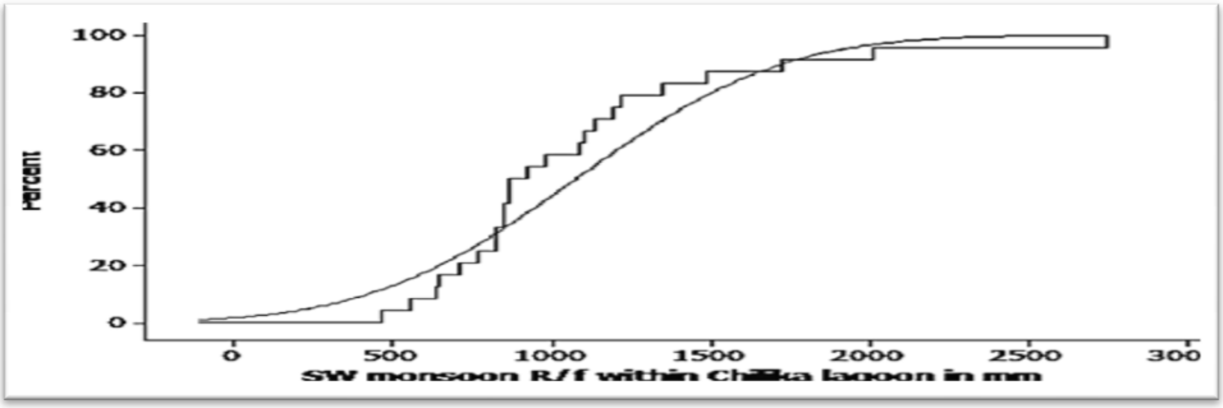

Fig 8: Empirical CDF function (Normal) of monsoon r/f in catchment of Chilika Lagoon (data 1991-2014)

2.6 Goodness of fit tests

Goodness of fit test is conducted for a time series data provides information about representation of observed data to a particular distribution and calculate expected frequencies for a particular Probability model. Models are Discrete probability model, (Binomial or Poisson), Continuity Probability models(Normal and exponential). Other tests used are Chi-square test, Kolmogorov-Smirnov test, Anderson-Darling test. (Table 3) However the χ2 test is considered for best GoF distribution for Hydrologic large data series of univariate distribution and fits a theoretical distribution.The probability distribution function used for the tests are given in table 3. The probability distribution functions of monsoon rainfall with their ranks of river Daya and Bhargovi is given in table 4.

Table 3: The Probability distribution functions for various Goodness of Fit (GoF) tests

Sl	GOF type	PDF Equation	Range	Remark
1	Kolmogorov-Smir-nov (K-S)	D_n= Sup mod [(F_n (x) – F (x)]	X=$x_1, x_2, \ldots x_n F_n(x)$ =1/n(No of obsns≤x	Confidencedistri. Func. CDF F(x)
2	Anderson-Darling (A^2)	A^2=-n-1/n Sum((2i-1)[ln F(x_i) + ln (1- F (X_{n-i+1})]	Sig level α ≥ Critical value	Lower the rank no best is fit
3	χ2 test	$\sum_{i=1}^{n} (Oi - Ei)^2 / Ei$ where E_i= F (x_2) - F (x_1)	Oi=Observed Ei= Expected	Best for analysis

Table 4: Probability distribution function for monsoon rainfall of Daya and Bhargovi rivers

#	Distribution	*Kolmogorov Smirnov*		*Anderson Darling*		*Chi-Squared*		Parameters
		Stat	Rank	Stat	Rank	Stat	Rank	
	River Daya							
1	Frechet (3P)	0.099	8	0.234	2	0.088	15	α=39.9 β=11134 γ=-9979.5
2	Log-Logistic	0.089	1	0.183	1	0.102	19	α=6.5773 β=1240.1
3	Pearson 5	0.095	3	0.241	5	0.082	11	α=13.34 β=15360 γ=77.6
4	Pearson 6	0.095	2	0.242	6	0.080	8	α_1=245.53 α_2=16.11 β=81.3
5	Gen. Gamma	0.099	6	0.270	13	0.079	6	k=0.65 α=12β=17.5 γ=506
	River Bhargovi							
1	χ^2 (2P)	0.09	11	0.178	6	0.157	9	ν=45396 γ=-44098.0
2	Fatigue Life (3P)	0.09	8	0.178	5	0.160	11	α=0.017 β=17395 γ=-16099
3	Gamma (3P)	0.09	5	0.185	11	0.003	4	α=96.8 β=30.92 γ=-1694.6
4	Lognormal (3P)	0.99	4	0.179	7	0.168	14	σ=0.044 μ=8.82 γ=-5493.5

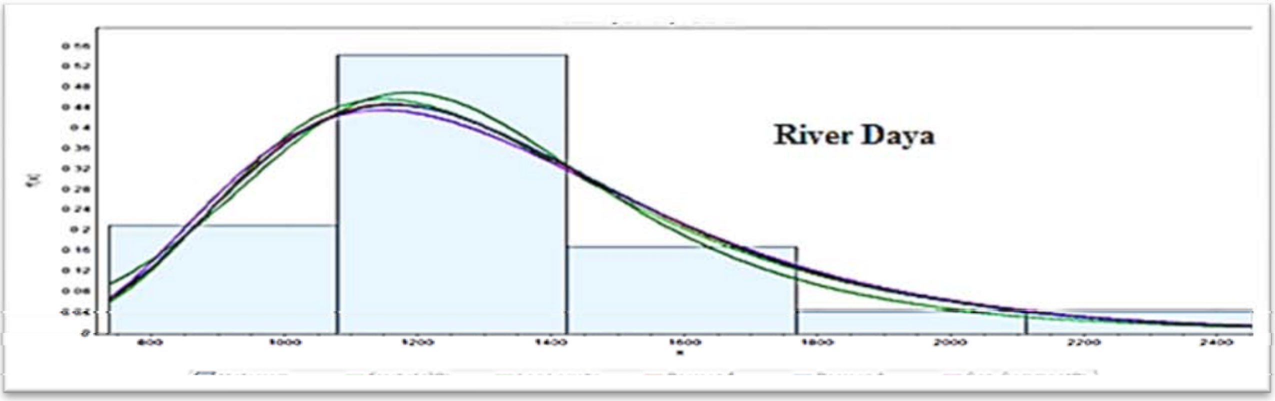

Fig 9 (a): Gof Plots of Various PDF Functions for Monsoon Rainfall for River Daya and Bhargovi

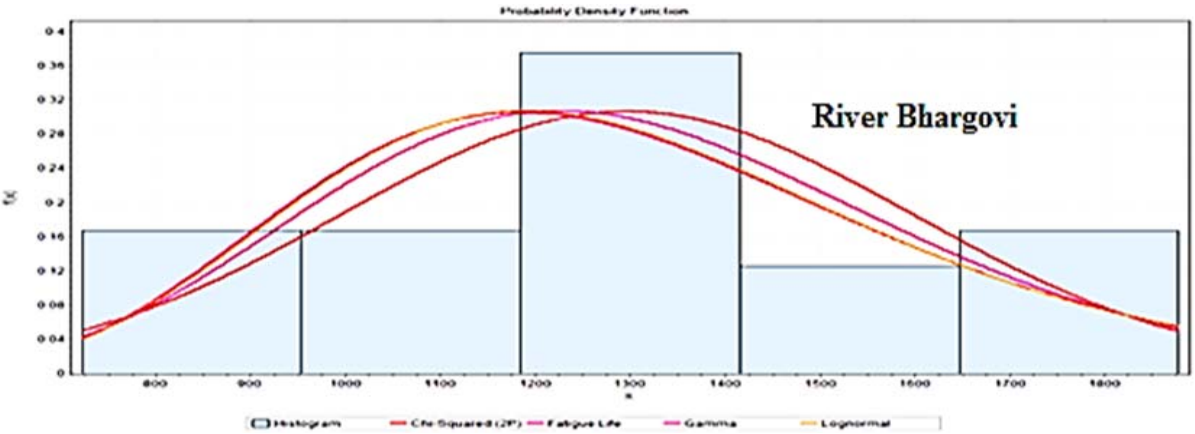

Fig 9(b): Gof Plots of Various PDF Functions for Monsoon Rainfall for River Daya and Bhargovi

GoF plots are observed that the PDF function for the monsoon rainfall time series for the catchment of river Daya and Bhargovi. The best fit PDF function is Gamma Function [Fig 9(a) and Fig 9(b)].Since the river Daya is contributing higher discharge and have major area providing monsoon rainfall an empirical relation has been drawn by CDF function for discharge of Daya river against catchment rainfall and the graph is shown in fig 10.

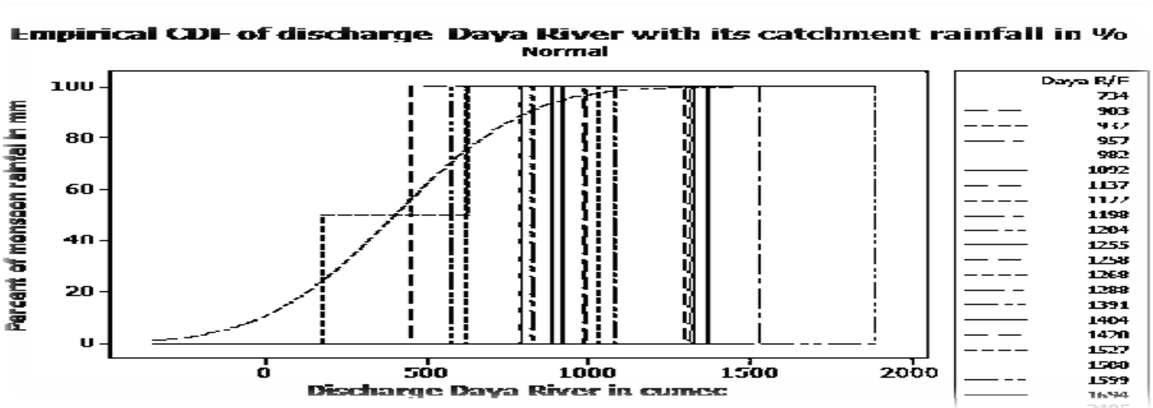

Fig 10: The Empirical CDF of Monsoon Discharge of River Daya with its Catchment Rainfall (%)

3.1 Regression with Discharge and catchment rainfall

A regression equation has been tried to draw between the rainfall in the catchment of river Daya and river Bhargovi a relation has been drawn as both the sub catchments are adjacent to each other. The regression equation is

Daya catchment R/F = 322 + 0.771 R/F in Bhargovi Catchment R/F (monsoon in mm)

3.2 Prediction of Catchment R/F of river Daya and Bhargovi

For prediction of future rainfall of the catchment the distributions considered are the Gumbel distribution and Log Pearson Type III (LPT III).

3.2.1 EV Type I: Gumbel distribution is the Extreme value type I distribution (1941) and it is unbounded and independent of shape parameter. This distribution has wide application in hydrology and meteorology.The probability density function of this EV I is

$$F(x) = 1/\sigma\ [\exp^{(-z - \exp(-z))}]$$

$$\text{Where}\ \ Z = \frac{x-\mu}{\sigma}$$

Whereμ, the location parameter and $\sigma > 0$are the scale parameters respectively.

3.2.2 Log Pearson Type III:

The LPT III distribution is a development of the family of Pearson Type 3 distributions. It is the3 parameter Gamma distribution. Similar to GEV LPT III uses 3 parameters, location, scale and shape. A problem arises with LP3 as it has a tendency to give low upper bounds of the precipitation magnitudes, not desirable for the analysis.The simplified expression for this latter distribution is given as follows:

1. $P = Log\ (Pi)$ Eqn 1
2. $PT = Pav + KT\ S$ Eqn 2
3. $P_{av} = 1/n\sum_{i=1}^{n} P$ Eqn 3
4. $S = [1/n\ \sum_{i=1}^{n}(P - Pav) * 2]\hat{}1/2$ Eqn 4

Where P is the size of data, the Frequency precipitation PT (in mm) with a specified recurrence interval T (year), Pave is the average monsoon precipitation (1991-2014) and S is the standard deviation.

K_T = the Pearson frequency factor which depends on return period (T) and skewness Coefficient (Cs).where

$$C_s = n\ [\text{Sum of}\ (P_i - P_{av})^3]\ /\ (n-1)\ (n-2)\ S^3$$

3.3.1 Discharge of river Daya under influence of catchment rainfall

The data is arranged in descending order and a rank (m) is assigned as per position. The return period is evaluated considering T = m+1/n (where n is the length of the time series). The return period and % of probability are calculated (for 2, 5, 10, 25, 50, 100, 500 and 1000, 2000, 5000, 10000 years). The Gumbel distribution function and Log Pearson Type III distribution are used for rivers Daya and Bhargovi to find the probable flood using the statistical packages. Table 5, Table 6 and table 7 show the forecasted table for monsoon rainfall of River Daya, River Bhargovi and Chilika Area computed by Gumbel and LPT III methods. Corresponding graphical representation have been shown in fig 11, fig 12 and Fig. 13 respectively.

Table 5: Forecasted Table for Monsoon Rainfall of River Daya by Methods Gumbel and LPT III

Sl No	Return period in years (T)	Probability (%) P	Gumbels Variate (Y)	Predicted Rainfall in mm	Frequency factor K	y = log (R)	Predicted Rainfall in mm
		Method of Moments (Gumbel)			PWM methods(Log Pearson III)		
1	2	50	0.367	1265	-0.069	3.098	1253
2	5	20	1.5	1665	0.815	3.201	1588
3	10	10	2.25	1929	1.318	3.259	1817
4	25	4	3.199	2263	1.885	3.326	2116
5	50	2	3.902	2511	2.27	3.37	2346
6	100	1	4.6	2757	2.628	3.412	2582
7	200	0.5	5.296	3003	2.966	3.451	2827
8	500	0.2	6.214	3326	3.388	3.501	3167
9	1000	0.1	6.907	3571	3.693	3.536	3436
10	2000	0.05	7.601	3815	3.987	3.57	3718
11	5000	0.02	8.517	4138	4.312	3.608	4057
12	10000	0.01	9.21	4382	4.639	3.646	4428

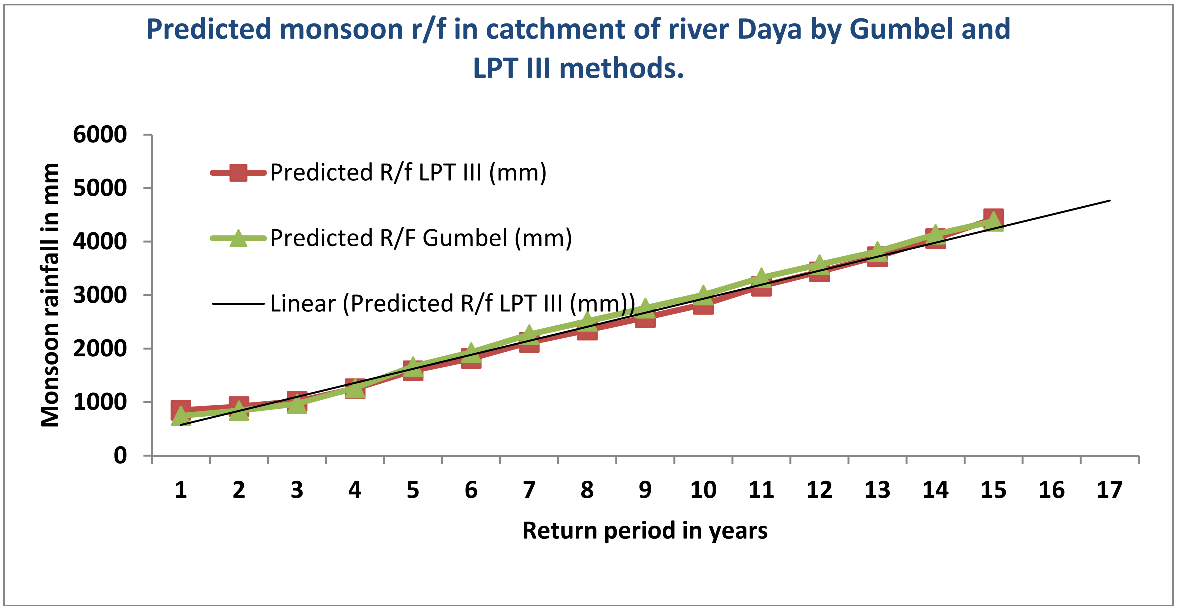

Fig 11: Comparison of Monsoon Rainfall in Catchment of Daya River Predicted by Gumbel and LPT III methods for 2, 5,…….10000 years return period with trend line

3.3.2 Discharge of river Bhargovi under influence of catchment rainfall

Table 6: Forecasted table for monsoon rainfall of river Bhargovi by methods Gumbel and LPT III

Sl No	Return period in years (T)	Probability (%) P	Gumbels Variate (Y)	Predicted Rainfall in mm	Frequency factor K	y = log (R)	Predicted Rainfall in mm
		Method of Moments (Gumbel)			PWM methods(Log Pearson III)		
1	2	50	0.367	1253	0.095	3.111	1292
2	5	20	1.5	1575	0.857	3.194	1565
3	10	10	2.25	1788	1.204	3.232	1707
4	25	4	3.199	2058	1.537	3.269	1856
5	50	2	3.902	2258	1.733	3.29	1950
6	100	1	4.6	2456	1.897	3.308	2032
7	200	0.5	5.296	2654	2.037	3.323	2105
8	500	0.2	6.214	2915	2.195	3.34	2189
9	1000	0.1	6.907	3112	2.298	3.352	2247
10	2000	0.05	7.601	3309	2.389	3.362	2299
11	5000	0.02	8.517	3570	2.479	3.371	2351
12	10000	0.01	9.21	3767	2.568	3.381	2405

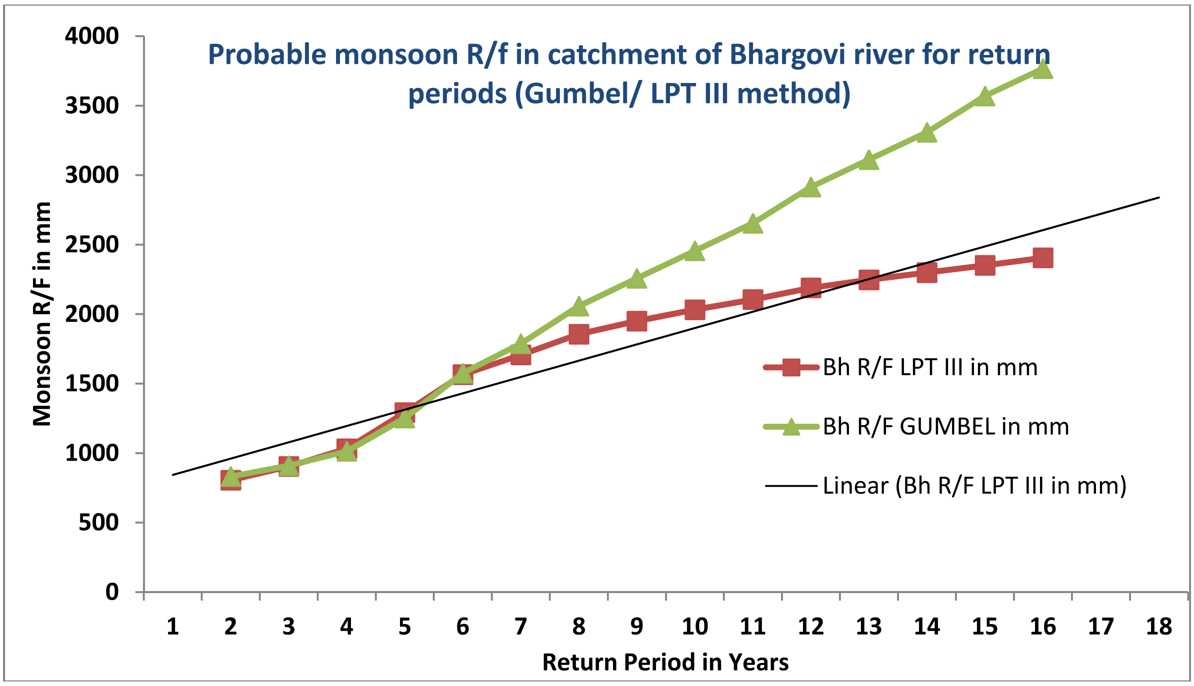

Fig 12 Comparison of Monsoon Rainfall in Catchment of Daya River Predicted by Gumbel and LPT III Methods for 2, 5,…….10000 Years Return Period with Trend Line

Table 7: Forecasted Table for Monsoon Rainfall of Chilika Lagoon by Methods (Gumbel and LPT III)

Sl No	**Return period in years (T)**	**Probability (%) P**	**Gumbels Variate (Y)**	**Predicted Rainfall in mm**	**Frequency factor K**	**y = log (R)**	**Predicted Rainfall in mm**
Method of Moments (Gumbel)					**PWM methods(Log Pearson III)**		
1	2	50	0.367	998	-0.069	3.098	1253
2	5	20	1.5	1531	0.815	3.201	1588
3	10	10	2.25	1884	1.318	3.259	1817
4	25	4	3.199	2330	1.885	3.326	2116
5	50	2	3.902	2661	2.27	3.37	2346
6	100	1	4.6	2990	2.628	3.412	2582
7	200	0.5	5.296	3317	2.966	3.451	2827
8	500	0.2	6.214	3748	3.388	3.501	3167
9	1000	0.1	6.907	4075	3.693	3.536	3436
10	2000	0.05	7.601	4401	3.987	3.57	3718
11	5000	0.02	8.517	4832	4.312	3.608	4057
12	10000	0.01	9.21	5158	4.639	3.646	4428

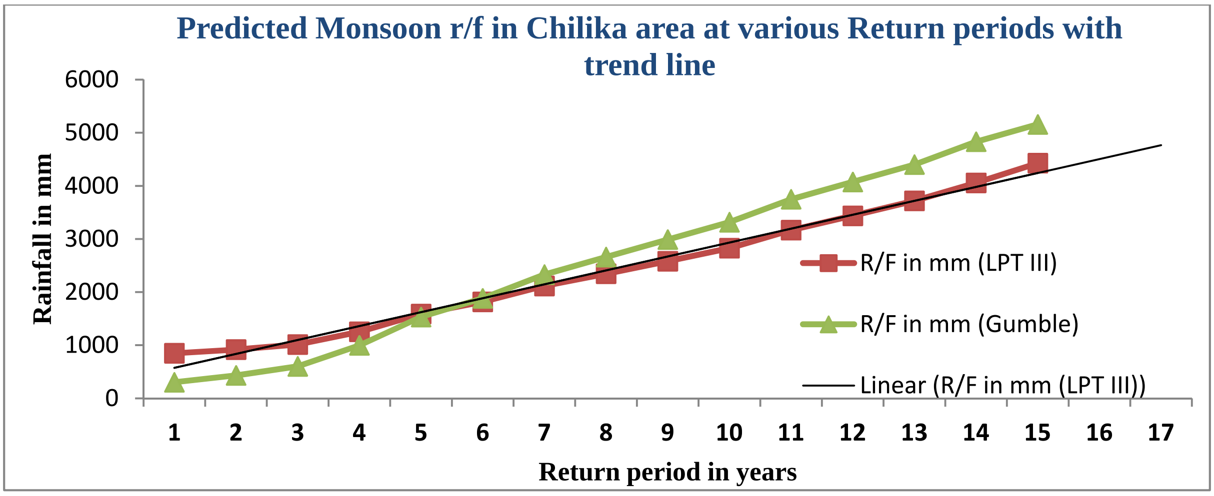

Fig 13: Comparison of Monsoon Rainfall In Catchment of Chilika Lagoon Area Predicted by Gumbel and LPT III Methods For 2, 5, …….,10000 Years Return Period With Trend Line

Conclusion:

Analysis of meteorological predictors is prerequisite for a changing climate. Rainfall is controlling factor for geomorphologic changes of an area. Rainfall in catchment of rivers in south Mahanadi delta and their receiver, the lagoon Chilika command the economy, biodiversity, flora, fauna and avifauna of the area. Statistical analysis of the monsoon precipitation with long term prediction has been studied in the paper.

The monsoon trend exhibits few changes. The total rainfall in the area shall increase slowly in future. The Gamma distribution shows a best fit PDF function. Log Pearson Type III method is applied to predict monsoon rainfall. The monsoon rainfall in catchment of Daya River shows a linear increasing trend. Whereas the monsoon rainfall trend in catchment of Bhargovi River and Chilika Lake area are showing anomalies in the behavior of predicted values made by Gumbel and LPT III methods. There shall be change in rainfall in the Chilika area in future. The prediction of rainfall by Gumbel method is showing higher results than the Log Pearson type III.

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