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Modeling of Flow/Sediment Input at Delta Head of Rivers in Odisha, India

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Abstract: **Odisha, a state in the East coast of India, allows six east flowing major river systems, i.e. the Subarnarekha,the Budhabalanga, the Baitarani, the Bramhani, the Mahanadi and the Rushikulya debouching into the Bay of Bengal .The Mahanadi being the largest river have reduced average annual flow of 47.97 Bcum from 66.88 Bcum and average annual suspended sediment load 11.34MMT from 27.07MMT at its delta head, Naraj. The statistical study of the trend analysis of flow and sediment of the six rivers has been tried in the present paper. The regression analysis of the flow data (25 years) and sediment data (20 years) have been conducted. The fitting of polynomial, peak, sinusoidal, waveform, power and rational functionsto the data series was tried for the best curve fitting considering the highest coefficient of determination (R2). It is observed that 63% of flows of rivers in Odisha follow rational functions. The common Gumbel and Log-Pearson Type III probability distribution functions have been used to estimate annual flow and accompanying suspended sediment load at the delta head of the rivers along Odisha coast. The statistically estimated annual flow and sediment were calculated at various return periods and compared. It is found that at lower return periods the Gumbel methods are suitable and for higher recurrence periods Log Pearson Type III methods give better result. Sustenance measures to reduce flood havoc have been worked out to rejuvenate the sink of the deltas**

Key words: **Mahanadi, Discharge, Sediment, PDF Functions, Odisha Rivers, Trend analysis, Statistical Modeling**

1. INTRODUCTION

Odisha, (170 27’ to 220 34’ N lat. and 81027'E to 87029'E long.) is a peninsular state lies in the northern part of east coast of India. It has an area of 155707sqkm, coastline of 480km and a demographic population 0f 0.42 Billion. Odisha is the land of east flowing Hexa deltaic rivers i.e. theSubarnarekha, the Budhabalanga, the Baitarani, the Bramhani, the Mahanadi and the Rushikulya(Fig 1). The first five rivers originate from the ChhottanagpurPlateau and the last one from EGB hills. They are of different size, shape, length and form various types of deltas. (Table 1) The other small east flowing rivers draining to Bay of Bengal (BOB) are contributing negligible amount of the total flow and sediment. The rivers originating in Odisha but join the BOB along Andhra Pradesh coast are the Bahuda, the MahendraTanaya, the Vansadhara and the Nagavali.
The state is in a tropical climate having maximum temperature of 450 C and minimum 200C. All the rivers are ephemeral and fed by Southwest monsoon during June to October. The average precipitation of the state is 1450mm in average 78rainy days. The average Monthly evapo-transpiration of the basin is 40mm in winter and 300mm in summer.
The basins in north Odisha were of pre-Cambrian origin. They were originateddue to volcanic, tectonic activities. The rivers flow along the easterly slope. The rocks in the area are formations of Archean to recent. The consolidated rocks are igneous and crystalline, semi-consolidatedformations of Archean to recent. They are upland, the river valleys and

subdued Plateaus. The 75m contour line delimits the coastal deltaic range from the middle mountainous region. The consolidated rocks are igneous and crystalline, semi-consolidated. They are formations of old and recent of both Gondwana and alluvium.

Geographically the state has five physiographic units i.e. the coastal Plains, the middle mountainous country, the rollingclastic sediments of Eastern Indian Tectonic Zone (EITZ), North Singhbhum Mobile Belt (NSMB), and eastern fringe of Chhotanagpur Genesis (CGC).They have formed the basin of the rivers from Subarnarekha to southern fringe of Mahanadi delta. The southern part of the Mahanadi and Rushikulya basins resembles the traits of Eastern Ghats Hills and 850 ridges with a shallow shore. Nayak et al (2012)[1], Mishra et al (2015)[2].

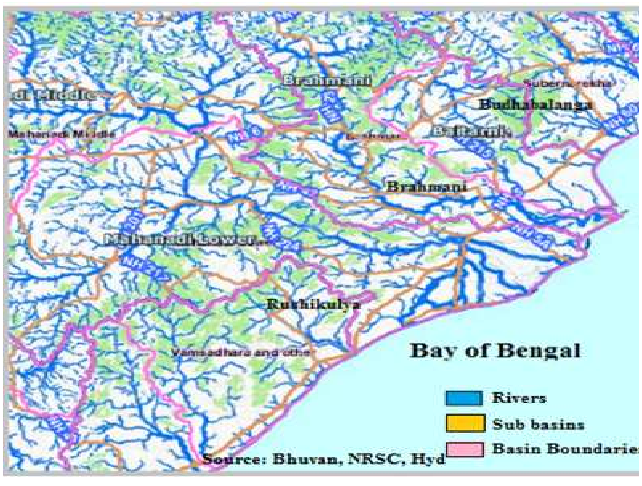

Fig 1: Index map of the study area showing rivers (source Bhuaban)

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2. REVIEW OF LITERATURE

Audin J. B.,(1950)[3], stated that 76% of suspended sediment (SS) in Mahanadi river in the year 1947 was fine (<0.075mm), 13% was medium sand (0.075 mm< d< 0.2mm) and balance 11% were coarse materials (>0.2 mm). Khosla

Dams (major, medium and minor) and BWA's (barrages, weirs and anicuts) in Odisha along these rivers are 180 and 43 respectively (Water Resources Dept., Odisha). The ground water potential of the state to a tune of 381251Ham has been explored for irrigation purposes. The annual average sediment yield of the catchment was 200-400MT/km^2/year (Mohanty et al 2006)[5]

Nnaji et al 2014[6], reported Gumbel and Log Pearson Type III (LPT III) and Weibull distributions can reasonably predict of flow frequency. LPT III distribution can be used and are more appropriate. Rechard A. Vogel , (1993)[7] reported LPT III method of flood flow modeling was recommended by United states as flood frequency guide lines.Olofintoye et al (2009)[8] reported LPT III methods are adoptable for many Nigerian rivers of Africa. Al-Awadi (2016)[9] reported that LPT III method is prioritized over log normal, Gumbel and simple average methods.[10]

3. METHODS

Presently the deltas of rivers are sinking, shrinking and subsiding due to anthropogenic interventions like dams and BWA's basing on sediment study for large rivers like Ganges, Mahanadi, Godavari, Krishna etc., Syvitski et al., (2009)[10] and (2011)[11], Gamage et. al.(2009)[12], Gupta et al (2012)[13], Dandekar (2014)[14]. Less research works are done on the sediment flows of small river basins in Odisha. This paper is an attempt to study the influx of sediment and flow in six major rivers in Odisha and their impact on the deltaic system. Annual discharge of monsoon/non-monsoon flow and sediment (colloidal argillaceous matter) were collected from Integrated hydrological data book (non-classified basins), 2005, 2006, 2009, 2012 and 2015[15]. The data were compiled to a time series. The statistical analysis of the time series of flow/sediment for the major six rivers in Odisha falling in BoB was done in the present study.

A time series is a data filethat represents continuous physical data with a fixed specified time interval**.** It is aimed at to find a trend in the phenomenon and used to predict future values of the time series. Trend analysis is done by smoothening and fitting a function or a curve to the series of data.

Multiple regression models (both linear and nonlinear) were applied to the time series annual flow and corresponding sediment data of the rivers at 95% confidence limits. The coefficient of determination R^2 values was used to determine the % rate of fitting to the observed data. The types of fitted curve, the probability distribution functions, the parameters of the best fit equation and coefficient of determination were found.

A.N. 1953[4]Khosla A.N. 1953[4]reported that the concentration of sediment were 90% of the total annual sediment loadflow downstream retaining only 10%in the upper catchment. The suspended load at Sambalpur before construction of Hirakud Dam (1947-51) was 0.081%.

The prediction for these parameters can be done statistically, using soft computing methods and Fuzy logic and machine computing. In the present study the prediction of flow and sediment of rivers at their delta head has been done by using common statistical methods (Gumbel and LPT III) by statistical tools and packages. A comparison was done for the obtained results and their suitability was assessed.

4. FLUVIAL SOURCES:

Basin flow, the reservoir discharges and run off from the basin are the main sources of water. The amount of precipitations received by the basin is 75 to 80% during SW monsoon. The total catchment area/drainage area in Odisha is 150460sqkm/143729 sqkm and annual flow is 99.876 Mcum, Patiet. al.(2010)[17]. The ground water potential is 2.1Mha. The yields from the wells are @10-35 cum/hr in granite strata, @5-18cum/hr in crystalline genesis and @20-115cum/hr in semi consolidated rocks CGWB, MoEF (2015)[18]. In 21st century the statistics of climate have changed the statistics due to erratic monsoon, geo-tectonics and sun earth geometry[Fig-2].

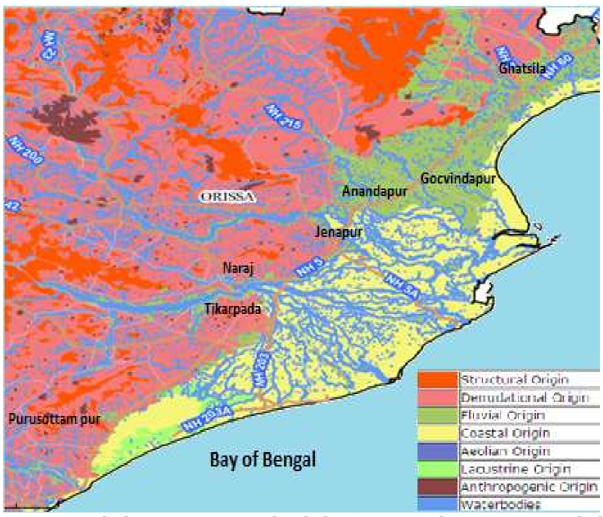

Fig 2: Geomorphologic map Coastal Odisha (Source: Thematic maps Bhuban)

The sources for sediment are from classic gullies, infrastructural development sites, urban storm water, agricultural field excesses, flood plains etc. The links between runoffs and sediments are through ravines. The soil discharge rate (T) of the state is varying in different physiographic zones of Odisha from 2.5mg/ha/yr. to 12.5g/ha/yr. The inland reaches of EGB hills and upper Mahanadi basin have a soil erosion rate is less (T<7.5 mg/ha/yr.) Lenka et al., (2014)[19].

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5. STATISTICAL TOOLS

The statistical equations used for curve fitting are polynomial, peak, sigmoidal, wave form, power and rational. The probability distribution functions tried are linear, quadratic, cubic, inverse, sigmodal, Sine, Lorenzian etc. The basis for consideration of the fit of curves is the correlation coefficient (R), the coefficient of determination (R^2) and coefficients of skewness etc.

5.1 CORRELATION COEFFICIENT (R):

It is a measurement that how the data in a time series are linearly related i.e. how a time series close to the mean value. It is the ratio of standard deviation to covariance. If σ_x and σ_y are the standard deviations, and σ_{xy} is the covariance then the the coefficient of correlation (R) is

$$R = \frac{\sigma_{xy}}{\sigma_x \sigma_y}.$$

$$\Rightarrow \quad R = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{[n(\sum x^2) - (\sum x)^2]\,[n(\sum y^2) - (\sum y)^2]}}$$

It's values lies between -1 < R < 1. When R is zero or near zero there is almost zero correlation, +1 is a perfect fit with same slope and the time series is positively and linearly related. For –ve values of R, it indicates a perfect negative fit with opposite slope and the series is not correlated.

5.2 COEFFICIENT OF DETERMINATION (R^2)

Coefficient of determination is a measure of how the regression line fits the data. It is the % of explained variation to the total variation. The R^2 (When not adjusted) value is given as $R^2 = \frac{SSR}{SST} = 1 - \frac{SSE}{SST}$, Where SSR= sum of the squared regression, SST= sum of squared total and SSE = sum of squares due to error. The values lie between 0-100% and represents the % of data lies close to the best fit line. R^2 values are the predictors in ordinary least squared regression. The –ve values obtained indicate the regression line does not fitting the data.

5.3 RATING CURVES

Flow, sediment rating curves are empirical methods used to correlate the suspended sediment quantity (Mcum) against flow is given by Bcum). Both the parameters have a linkage. The relationships formats are a many. The relations between the sediment concentration (C) and flow (Q) was C=a Q^b where a and b are the rating coefficient and exponent, respectively (Syvitski et al., 2005)[20]. The other rating curves used are polynomial, peak, sigmoidal, wave form, power and rational of different parameters. Flow and sediment rating curves are empirical methods used to correlate the suspended sediment quantity (Mcum) against flow is given by Bcum). Both the parameters have a linkage. The relationships formats are a many. The relations between the sediment concentration (C) and flow (Q) was C=a Q^b where a and b are the rating coefficient and exponent, respectively (Syvitski et al., 2005)[20]. The other rating curves used are polynomial, peak,sigmoidal, wave form, power and rational of different parameters. .

Since the shape, size and characteristics of the basins are different, the most appropriate linear and nonlinear regression equations used are Polynomial, Peak, Sigmoidal, wave types, power and rational. For prediction of flow and sediment the commonly used PDF were Gumbel and Log Pearson type III (LPT III) used against various recurrence intervals.

6. PREDICATOR METHODS

6.1 GUMBEL METHOD

Gumbel's method for predicting flood and sediment are one of the commonly used methods. The equations is given by: Q_T = Q (l+ K* Cv), where Q_T = the probable discharge with a return period of T years, Cv = standard deviation of logarithms of annual total discharge, Q = mean flood, K = frequency factor =(y_T - y_n)/σ_n, σ_n = standard deviation of data series,The reduced variate= 〖 y〗_T= –0.834–2.303loglog (T/T–1)=–0.834–2.303XT,.WhereX_T=loglog (T/T–1), y_(n) and σ_n = expected mean and standard deviations of reduced extremes to be found from Gumbel's table. The data prediction by Gumbel's method is cumbersome and time consuming and predicted values sometimesdo not matchwith the trend of the observed data (Al-Mashidani et al 1978)[21]

6.2 LOG PEARSON TYPE III METHOD

The LPT III method is a recommended tool to predict flood and sediment of a river at various return periods with available time series. It is helpful in assuming future flood and sediment data of a stream for design of structures. Nnaji et al 2014 reported LPT III distribution is excellent for low flow analysis. Rivers in Odisha are of low annual flow LPT III method can be used for prediction.. The general equation is given by: log x=(logx)¯ +K σ_log x , where (log x)¯ is the average of logarithms of the data, K is the frequency factor and is function of skewness coefficient and recurrence interval and the value is found from the log Pearson factor table (Harters table 1969)[22].

6.2.1 COEFF. OF SKEWNESS (LOGARITHMS)

In probability statistics, skewness measures the asymmetry of the probability distribution of an observed data from the mean. It can be positive or negative. In Pearson's distribution the first and 2nd Pearson'sskewness coefficient are C_s=(mean-mode)/σ and C_s=3((mean-mode)/σ) respectively. But in LPT III method the coefficient of skewness of the logarthims is given by C_s=(n∑▒〖((〖Y_(i - Y¯))〗^3 〗)/((n-1)(n-2) 〖S_Y〗^3) Where n= no of variants, Yi = log x (variants), Y¯is the mean of the Log x,, Sy3 = σ_(logx) = Standard deviation of the log x values.

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7. DISCUSSION

The lengths, catchment areas and the place of origin of the six major basins in Odisha are given in Table 1. The annual average flow and corresponding sediment at the delta heads are also calculated for the available data (Table 1). The average annual flow of Mahanadi, (Bramhani + Baitarani) and Subarnarekha basins at delta head had reduced from 66.88Bcum, 28.48Bcum and 12.37Bcum to 46.969Bcum, 22.224 Bcum and 7.208Bcum respectively. The reasons for decrease in discharge were due to erratic monsoon, hydrologic interventions and anthropogenic activities. The average annual suspended sediment load was 27.07MT during 1980-1985 reduced to 11.02 MMT during 1993-2012 (Delta Dev plan, W R Dept., Odisha 1986)[23].

Table 1: The major six rivers and their origin, length, area, sediment and deltaic shape in Odisha

sl	Name of River	Origin (hills range)	Delta head		Length Km /Basin catchment (sqkm)	Years of flow observation	Av. annual disch.(Bcum)	Years sediment obsns	Av sed (MMT)
			(G&D site)	area					
1	Subarnrekha	Chatnagpur	Ghatsila	5101	446/19277	1986-2011	7.208	1993-2012	2.64
2	Budhabalanga	Similipal	Govindpur	2196	189/6691	1986-2011	3.122	1993-2012	1.249
3	Baitarani	Gonasika	Anandpur	5748	365/14218	1991-2011	4.791	1993-2012	2.24
4	Brahmani	Ranchi	Jenapur	5161	799/39116	1986-2011	17.433	1993-2012	5.23
5	Mahanadi	Amarkantak	Tikarpada	9500	891/141589	1986-2011	46.969	1993-2012	11.02
6	Rushikulya	Rushyamala	Purrusottampur	588	165/8963	1988=2011	2.334	1999-2012	1.998

8. REGRESSION EQUATIONS

From various trials with different types of curves and probability distribution functions, those equations were selected for the annual stream flow at the delta head basing on the highest value of R^2 (Table 2). Similarly the sediment discharges for the rivers were tried with linear and nonlinear regression model curves and corresponding R^2 values obtained. The equation with the highest R^2 value was considered as the best parametric equation. The regression analysis of the flow series and the sediment series of rivers are given in table 2 and Table 3.

From regression analysis of annual flow series it is found that 67% rivers follow rational PDF. Bramhani is following the wave form model (Sine, 4P). The largest river Mahanadi fitted with Rational PDF and R^2 value 0.6 and Baitarani Log normal PD function and R^2 value 0.38.

Table 2: The model fit to the time series for flow to Bay of Bengal via East coast rivers at the delta head.

Name of river	PDF	Equation	Parameters for Equations						R^2 in %
			Y_0	a	b	c	d	X_0	
Subarnarekha	Rational (7P)	$Y = \frac{a + bx + cx^2 + dx^3}{1 + ex + fx^2 + gx^3}$		6.434	-1.33	0.081 e=-0.20 f=-0.012	d=-1.5E-7 g=-2.2E-4		54%
Budha balanga	Rational	$Y = \frac{a + bx + cx^2 + dx^3 + xe^4}{1 + fx + gx^2 + hx^3 + ix^4}$		2.23	-1.04	0.14	d=-6.3E-2 e=-8.0E-5 f=-0.478		44%
Baitarani	Log Normal	$Y = y_0 + \frac{a}{x} e^{[-0.5 \frac{\ln \frac{x}{x_0}}{b}]^2}$	2.88	42.2	0.05			.17 .	38%
Brahmani	Sine (4P)	$Y = y_0 + a\sin(\frac{2\pi x}{b} + c)$	1.79	4.22	2.23	0.601			30%
Mahanadi	Rational (6P)	$Y = \frac{a + bx + cx^2}{1 + dx + ex^2 + fx^3}]$		39.6	-6.67	-0.25	d=-0.177 e=0.008 f=-4.9E-5		60%
Rushikulya	Rational (7P)	$Y = \frac{a + bx + cx^2 + dx^3}{1 + ex + fx^2 + gx^3}$		2.06	-.048	0.034 e=-0.24 f=-0.02	d=--7.25E-4 g=-3.7E-4		58%
Vansadhara	Damped Sine	$Y = y_0 + a e^{-\frac{x}{d}} \mathrm{Sin}[\frac{2\pi(x)}{b} + c]$	2.76	1.52	1463	4.85	117.1		36%
Nagavali	Rational (5P)	$Y = \frac{a + bx + cx^2}{1 + dx + ex^2}]$		2.47	-0.34	0.01	d=-0.138 e=0.0042		43%

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The trend of annual sediment series fits mainly Peak type (Lorenzian or Gaussian PDF). The sed. series of the river Mahanadi fits to damp sine curve. The annual sediment flow pattern of rivers of Odisha does not follow any regular distribution curve. It may be due to irregular rainfall, extreme meteorological phenomenon and passing of storms.

Table 3: The model fit to the time series for sediment influx to Bay of Bengal via East coast rivers.

Name of river	PDF	Equation	Parameters for Equations						R^2 value in %
			Y_0	a	b	c	d	X_0	
Subarnarekha	Mod.Gaussian	$Y = y_0 + a\,e^{[0.5\,(\frac{x-x_0}{b})^c}$	1.97	1.09	0.52	3.93		1.56	54%
Budha balanga	Modi damp Sine	$Y = a\,e^{-\frac{x}{c}}\,\mathrm{Sin}\,\frac{\pi\,(x-x_0)}{b}$		1.99	8.96	1.37E6		-0.18	92%
Baitarani	Logistic	$Y = y_0 + \frac{a}{1+[\frac{x}{x_0}]^b}$	1.53	1.97	173			.93	31%
Brahmani	Inverse 3rd order	$Y = y_0 + \frac{a}{x} + \frac{b}{x^2} + \frac{c}{x^3}$	5.24	23.5	139	-114			37%
Mahanadi	damped Sine	$Y = y_0\,a\,e^{-\frac{x}{d}}\,\mathrm{Sin}[\frac{2\pi\,(x)}{b} + c]$	8.69	977	4.16	4.77	0.66		86%
Rushikulya	Mod Gaussian	$Y = y_0 + a\,e^{[0.5\,(\frac{x-x_0}{b})^c}$	1.26	4.23	1.11	8.03		8.84	80%

9. ESTIMATION OF FUTURE FLOODS

Trials have been taken to forecast the longterm prediction of floods upto 1000 years. The methods employed are the Gumbel and Log Pearson method III.The steps used in LPT III methods are (a) Transform n (no of observations) to logarithmic values Y_i =Log x_i (b), Compute mean $(\overline{Y})$ and std. deviation (σ_{logx}) of the logarthimic values. Compute coefficient of skewness of the logarithms$C_s = \frac{n\sum((Y_{i-\overline{Y}})^3}{(n-1)(n-2)S_Y{}^3}$. Then find $Y_T = \overline{Y} + \sigma_{logx}K_y$ where K_y is found from Harter's table. Finally X_T = Antilog ofY_T. The flow/sediment of the six rivers of Odisha is given in Table 4.

9.1 Prediction (LPT III method)

Table 4: Thestatistically estimated flow and sediment of six rivers in Odisha by LPT III method at various return periods

i	Return period (T)	Probability (P)	Predicted floods in rivers of Odisha at various recurance interval LOG Pearson III Method (C_s = skew coefficient [of the logarithms) Flow : Mm^3 and TSS : Th. MT											
			Subrnarekha		Budhabalanga		Baitarani		Bramhani		Mahanadi		Rushikulya	
	(yr)	(%)	flow	TSS	Flow	TSS	Flow	TSS	flow	TSS	Flow	TSS	Flow	TSS
1	1.05	95.2	2558	89	1659	69	2102	251	8259	812	23793	2862	820	491
2	1.11	90.1	3145	177	1907	195	2509	413	10044	1294	26587	3479	1008	591
3	1.25	80	4024	384	2246	576	3085	718	12424	2133	30724	4493	1277	760
4	2	50	6369	1439	3012	2754	4474	1773	17428	4636	41901	7814	1921	1349
5	5	20	9934	4364	3949	7362	6306	3634	22489	8126	59819	14832	2736	2724
6	10	10	12455	7198	4509	10176	7459	4940	24937	10099	73452	21506	3225	4151
7	25	4	15786	11600	5160	12851	8850	6530	27283	12114	92803	32901	3786	6799
8	50	2	18353	15330	5610	14228	9838	7634	28627	13301	108840	43993	4166	9577
9	100	1	20978	19330	6033	15196	10787	8655	29705	14259	126345	57771	4516	13254
10	200	0.5	23689	23533	6437	15867	11712	9591	30593	15044	145522	74813	4844	18089
11	500	0.2	27393	29308	6945	16457	12896	10702	31530	15858	173794	103592	5245	26870
12	1000	0.1	30298	33847	7315	16745	13774	11455	32098	16343	197607	131142	5531	35873
13	2000	0.05	33303	38365	7673	16940	14632	12153	32568	16730	223785	164829	5798	47583
14	5000	0.02	36791	43344	8059	17051	15573	12817	32982	17054	256949	212601	6077	65325
15	10000	0.01	40645	48964	8467	17192	16578	13505	33400	17393	295093	274296	6370	89681
	C_s		-0.12	-0.61	-0.29	-1.5	-0.59	-0.8	-0.97	-1.5	0.49	-1.1	-0.51	-0.71

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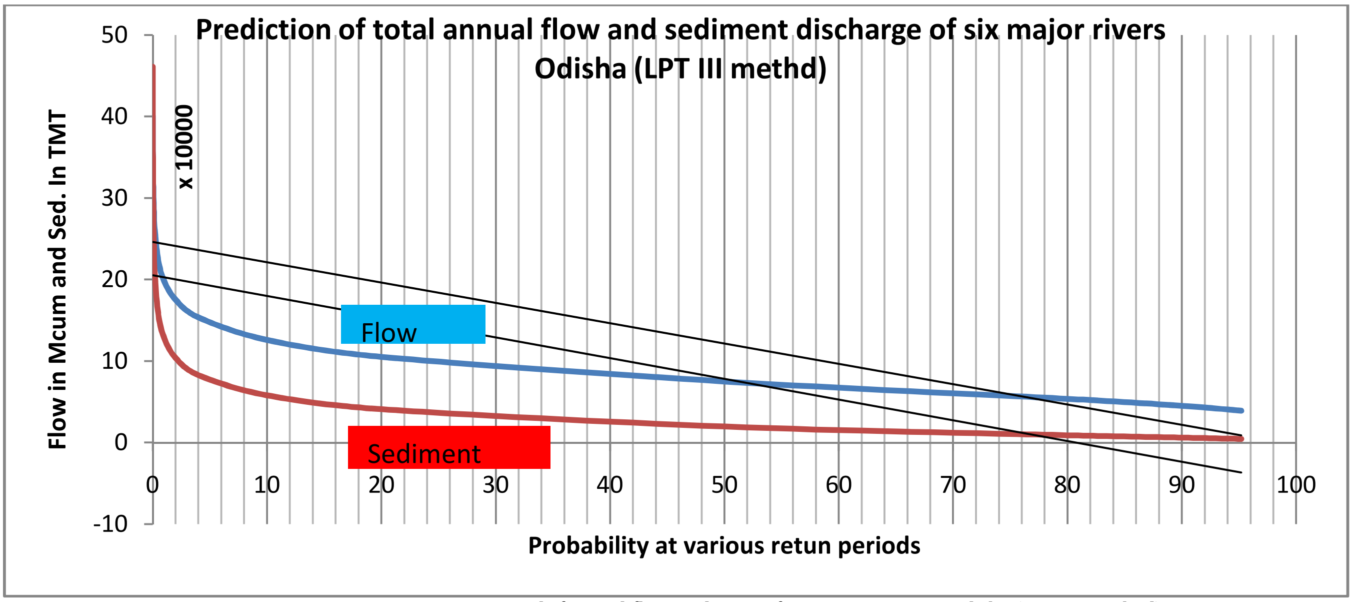

Fig 3: Estimation at various return periods for total flow/ sediment of six major rivers in Odisha (LPT III method)

9.2 GUMBEL METHOD

Table 5: The statistically estimated flow and sediment of major six rivers in Odisha by Gumbel method at various return period

i	Return period	Prob. (P)	Predicted floods in rivers of Odisha at various recurance interval by Gumbel's method											
			Subrnarekha		Budhabalanga		Baitarani		Bramhani		Mahanadi		Rushikulya	
	(yr)	(%)	flow	TSS	Flow	TSS	Flow	TSS	flow	TSS	Flow	TSS	Flow	TSS
			Mm^3	TMT	Mm^3	TMT	Mm^3	TMT	Mm^3	TMT	Mm^3	TMT	Mm^3	TMT
1	1.05	95.2	1468	-2001	1582	-3888	1619	-395	8779	-656	14548	-6576	780	-781
2	1.11	90.1	2429	-1219	1841	-2526	2150	48	10228	333	19978	-3616	989	-310
3	1.25	80	3693	-192	2181	-735	2848	630	12134	1635	27115	276	1264	311
4	2	50	6634	2198	2973	3433	4473	1983	16567	4662	43723	9330	1904	1754
5	5	20	10590	5413	4039	9040	6659	3805	22531	8736	66067	21513	2765	3695
6	10	10	13210	7542	4744	12752	8107	5011	26480	11433	80862	29578	3334	4980
7	25	4	16519	10233	5635	17443	9935	6535	31470	14841	99554	39770	4054	6605
8	50	2	18975	12228	6296	20923	11292	7666	35171	17369	113421	47330	4589	7809
9	100	1	21412	14209	6953	24377	12639	8788	38846	19878	127186	54835	5119	9005
10	200	0.5	23840	16183	7607	27818	13981	9906	42506	22378	140900	62312	5647	10197
11	500	0.2	27044	18787	8469	32359	15751	11381	47336	25677	158994	72177	6344	11769
12	1000	0.1	29466	20755	9121	35790	17089	12496	50986	28170	172669	79632	6871	12957
13	2000	0.05	31886	22722	9773	39221	18426	13611	54635	30662	186339	87085	7397	14145
14	5000	0.02	35085	25322	10635	43754	20194	15084	59458	33955	204406	96935	8093	15715
15	10000	0.01	37505	27288	11286	47184	21531	16198	63106	36447	218072	104386	8620	16902
	No of	year	26	20	21	14	26	20	26	20	26	20	24	14

The flow and sediment discharge of all the six major rivers in Odisha has been analyzedby using Grumbles probability distribution and the results are in Table 5

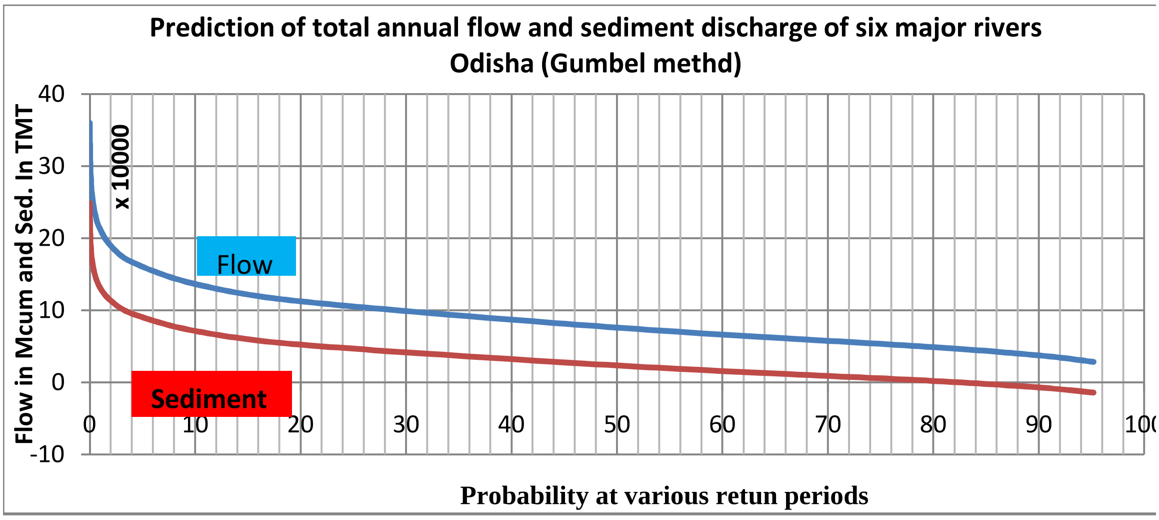

Fig 3: Estimation at various return periods for total flow/ sediment along six major rivers in Odisha by Gumbel method

10. SUSTAINABILITY OF FLOW AND SEDIMENT

The delta- inland interface is complex and ever changing. The area is influenced by a multifaceted environment of Marine – brackish- clastic/ mountainous. The interdependent system consists of two subsystems i.e. Anthropogenicand Socio-economic. They are ever transforming sub-systems. To keep pace with the change, sustainability studies become Univocal. In geographic scale these subsystems are of recent origin (6500- 8500 years BP) of post Holocene era.

Erratic climate in past 2 to 3 decades have resulted in changing water resources scenario. Wet lands and surface flow system are under stress and drying. Anthropogenic interventions to hydrologic controls have stressed deltaic alluvium to deplete. Sea level rise as a result of Global warming are squeezing the delta and there is shift in strandline.

The monsoon fed hexa-deltaic rivers in Odisha have high discharges with active monsoon and storm passages. But rate of sediment are mainly depending upon the number of floods in a year or the duration.

To have a sustainable sedimentary environment in and upstream of the deltas, it is high time conserve the sediment in the deltas for a sustained economic system. The possible curative measures are:

1. The sediment load in floods have shown decreasing trend in rivers of Odisha. The small rivers having less dams and BWA's have maintained the rate of sediment flow.
2. Basin disorder is resulted from deforestation without forestation, changes in land use and land cover issues due to population explosion and particularly sand mining from river beds.
3. Sedimentation of wet lands and lagoons has reduced the capacity of balancing reservoirs. The largest lagoon of Asia along Odisha coast must get its flushing flow to avoid sedimentation and downsizing.
4. Flood plains are only explored but not loaded with sediment laden water by flood routing through confined channels after construction of double embankments. The delta has become flood dependent than flood vulnerable.
5. Profuse erosion and deposition along beaches have changed the land form specially along coasts of Gopalpur, Puri, Astarang and Sataviya*etc*.. Formation of new spits and bars in front of estuaries along Mahanadi and Bramhani and Subarnarekha river mouth after Sumatra Tsunami 2004 are the prominent features.
6. Increase in Habitation and settlements along the coasts and encroachment of levees have reduced the sand dunes which is increasing the impact of storms and storm surges. The change in slamming of Indian tropical cyclones in 21st century indicates hard days ahead.
7. Urban flooding due to urbanization and industrialization is an issue of the century. Floods at Bombay-2005, Bhubaneswar 2014, and Madras 2015 were notable.

Sediment traps, the reservoirs should be provided with adequate under sluices and silt excluders as silt input of lower Mahanadi system have reduced by 66.6%. As per Ministry of Environment and forests (MoEF) and Ministry of Water Resources (MoWR) have no provision for Sediment studies during administrative approval of water resources projects (MoEF Guidelines for EIA clearance 2006, 2009 and 2012). Construction of large dam is not to be cleared by the federal institutions without proper sediment studies and environmental impact assessment. The urban flooding should be handled with care as glass by the planners for safety and security.

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CONCLUSIONS

Annual flow and corresponding rate of Sediment discharge varies geospatially with fluctuating hydrologic parameters, meteorological extremes and tectonic activities. Rivers in Odisha have unique sediment sources/sinks, sediment activities in their basin area and hydrologic changes. One major and five medium rivers in Odisha falling Bay of Bengal were statistically investigated for flow (1986-2011) and sediment (1993-2012).Data series indicate the flow in rivers of Odisha depends upon the SW monsoon activity,cyclonic disturbances inland and passage of storm and their intensity.

The rational type equations are fitted to the flow series. The peak type (Gaussian and Lorenzian) fits to the sediment series. The largest river Mahanadi of Odisha has produced good predictions with high correlation coefficient R^2 for flow (60%) and sediment 86% respectively. From prediction by Gumbel method the trend fits better with the series at lower recurrence period but LPT III method prediction has a comparable fitting at high return periods.

Nature has its own governance and sustainability. Unnecessary impeding on nature's activities for human development without proper attention may lead todevastation.

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