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RESEARCH ARTICLE

Hydro-morphology of Cuts in Coastal Rivers debouching Chilika; South Mahanadi Delta, Odisha, India

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Abstract

Bhargovi, the split deltaic branch of southern Mahanadi River, runs parallel to Bay of Bengal for last 48.5km and debouches in the northern swamps of Lagoon Chilika joining branch Daya. Though not wide, the river discharges 1100 to 1450cumec which is 3-4% of floods of river Mahanadi. Proximity to coast, alluvial flat topography, sinuosity and mild gradient posed a constant threat to lives and property. Early release of floods to lessen havoc to Puri district during early 20th century was considered urgent. Three cuts were officially provided in the Bhargovi system at. Mangala cut (1937), Siaro cut (1942) and Gabakund cut (1984-2007). After Gabakund cut in 2007, Chilika received 70% less flow of Bhargovi. Sedimentation and imbalance in the flow exchange downsized lagoon area. Each cut plugged one river and made them geriatric or defunct. The present paper studies the spatial impact of these cuts. Stochastic modeling with regression analysis is done to establish a relation between the stages of Gabakund cut vs. discharges at delta head by considering travel time. Field observations are taken to predict the impact of the submerged weir and pilot channel after renovation of cuts.

Introduction:-

The River Mahanadi has complex and different hydro-morphology in its southern delta than in others. Erosion, inundation and sedimentation are the basic river processes. Avulsion, meandering, bypassing and splitting are normal river mechanics. The basin characteristics are change in geodynamics of river cross section, base level, alluvial terraces and revetments. High to very high floods change the river/channel courses. The Mahanadi delta is sinking, shrinking and subsiding due to paucity of sediments after construction of dams in the upstream. The coast is protruding with regular sediment erosion/deposition with MSL rise. The off shore currents are becoming violent causing strong long shore drift.

At Naraj, the delta head, the river Mahanadi is bifurcated and forms south branch, Kathajodi. Further six km d/s, Kathajodi throws the spilling limb, Kuakhai, where South Mahanadi Delta (SMD) starts. The river Kuakhai throws the river Kushabhadra and then, bifurcates into Daya and Bhargovi 15km downstream.

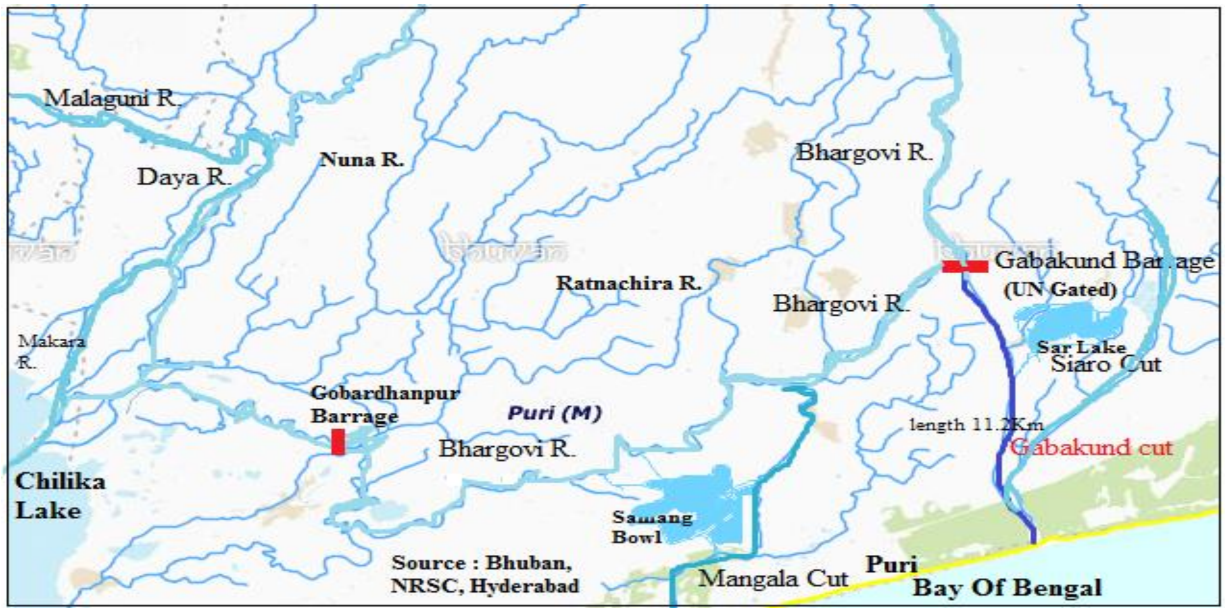


Fig 1: The index map of the river Bhargovi, Mangala , Gabakund and Siaro cut Source: Google, Bhuvan,NRSC, Hyderabad.

Bhargovi, at 37.5km, near the village Gabakund has a sharp concave rectangular bend turning SW-ly. Thereafter, the river runs parallel to the coast and debouches in the swamps of Chilika lagoon after joining Daya (Fig 1:a&b).

The river also discharges directly to the Bay via Siaro, Mangala or Gabakund cuts. A few shore perpendicular drainage channels (East Kania, Buxi Kania, Nua Nai and Bali Nai *etc*) are either falling directly in sea or Chilika. There are two lakes, *i.e.* Samang and Sur in the sub basin of Bhargovi (Fig 1) acting as detention reservoirs. Bhargovi has four shore perpendicular major distributaries emanating from left bank, i.e. Kanchi near Chandanpur (47km), East Kania at 56km, Nua Nai the officially dredged channel at 64km, Boxi Kania at 72km of the river. Kanchi discharges through Gabakund and Mangala cut. East Kania dwindle in the northern swamps of Chilika, whereas Nuanai and Boxi Kania join a shore parallel river, Sunamunhi and join sea 6km from Chilika.(Fig 1)

Review of literature:-

Arnott M. H. 1905[1], reported that flood damages in Puri district for inundation outweighs the benefit except some land near Jatni right of Daya. **Einstein A., 1926** [2], reported that rivers in northern hemisphere erode mostly to right and in southern hemisphere it is to left as per Bayer's law. **Paul F. Macar, 1934,** [3] has argued that a cut in a meandering channel generates a drop or cascade which propagates to the head causing erosion in the channel. He suggested excavation of a cut from Bhargovi to Bay for amelioration of floods in Puri District. Surlake was 51.8sqkm in rains and 10sqkm during summer where as Samang Lake was 16sqkm **(J Shaw, 1928)** [4]**. The Orissa flood committee Report, 1928**[5], suggested the Mangala cut to be dredged through Bhargovi-Kanchi- Dhaudia – Mangala link, to divert flow to Bay of Bengal. **Rangaiya R et al. in their 1st, 2nd and 3rd Reports, 1938**[5], 1940[6] and 1942[7] reported that a flood of 2000cumec in Kuakhai River, Bhargovi and Daya shares 25.4% and 47.6% respectively. At higher discharges in Kuakhai, river Bhargovi carries 29.5% where as Daya shares 50.2%. A direct cut from Gabakund to sea at Beldal was felt to be excavated to release fast the floods in south Mahanadi delta... The management of recurrent flood problem in deltas, In the district Gazetteer of Cuttack is recorded that, Odisha is not to think how to prevent floods but how to pass them early to the sea, told by **O' Milley L. S. S. 1933**[8]**.** A straight, 12.5km long cut from Bhargovi to Bay of Bengal and renovation of old Siaro cut from Sur Lake to sea was decided in 1962. Irrigation and power Dept. Odisha, 1972 decided Gabakund to have independent identity and no relation with Siaro cut (**Tripathy J. 1984**) [9]. The runoff of the channel and yield of sediment in basin of ARNO river, Italy had appreciably reduced due to the anthropogenic interventions made for channel adjustment than natural changes made for last 70 years as reported by **Paolo B., et al., 1997**. [10] When a diversion/cut was made along the bend of a river there was unequal discharge. If the cut takes off along the tangent then the cut carries less sediment than the original river**. (Garde and Ranga Raju 2000)**[11]. **Matsuda I., 2004**[12] reported that the meandered channels exist in alluvial reach. When the river bends, pools are formed in the stretch where depths of river flood plains are larger than alluvial fans. **Jonathan d P. et al 2006**[13] have classified river mouths on the basis of channel network, morphology, hydrology, hydrographic and sediment logy. **Camporeale et al 2008**[14] have reported that when a cut is made in a river that is meandering, it may either remove whole pattern of the river removing old meandering channels or change the dynamics of the whole river to bring the river hydrodynamics to a steady state. **Nayak et. al., 2010,**[15] **2012**[16] have claimed that wave set up, tropical climatic actions and corresponding geomorphologic processes developed formation of submerged spits in front of some river mouths of west coast of India. **Sandra D P., 2014**[17], mentioned that the confluence area of river and sea is highly rich in nutrient and highly productive ecosystem and biologically rich. **Maren et al., 2015**[18] reported that the concentration of suspended sediment by deepening a channel may increase with the estuarine circulation.

Causes for study:-

After the excavation of the cuts with a pilot channel, the observations are:

1. Discharge of about 50-60% is diverted from Bhargovi to Bay of Bengal directly depriving Chilika from its flushing flow. The river users downstream are deprived of their riparian rights during summer if canal supply is off.
2. A fresh water body of area 52sqkm, called Sur Lake, was draining directly to sea via Siaro cut. The lake is downsized and converted to a huge swamp at present.
3. The active Sunamunhi river during early 19th century became defunct within 3 to 4 decades after the Mangala cut. The Samang swamp (16sqkm) dried up after construction of barrage at Gobardhanpur.
4. East Kania, Kanchi, and other drainage branches of Bhargovi got detached from Chilika lagoon which had reduced flushing flow due to Gabakund cut. The hydrodynamics of tidal inlet of the lagoon has disturbed large aqua fauna, guest avifauna, productive ecosystem and ecstatic beauty of Chilika lagoon.
5. During neap and spring tides, the back water in Gabakund cut progressed via deeper pilot channel up to 10km u/s. It is apprehended that the back water may reach the river.
6. The hydrogeology of the coastal area towards north Puri has become brackish due to salinity intrusion resulting poor yield and shortage of drinking water.
7. Below 47km, the river was silted up downstream. But during rabi crops water is needed for irrigation for a patch of 18000Ha in Bramhagiri block.
8. Some drains originating from Bhargovi were discharging in Samang bowl in past and acting as balancing reservoir for Chilika. Presently the lake is no longer in existence.
9. The area around Gabakund and Siaro cut areas have been vulnerable during flood but Puri district was flood dependent in past.

Methods and methodology:-

The objective of the study lies upon unveiling the impact of all the cuts from river Bhargovi to Bay of Bengal. Now the river Bhargovi is geriatric below 38km. River mechanics involved with the geomorphic changes have been investigated. Field surveys were conducted, satellite imageries were taken and old literatures consulted to find the causes. A gauge post was set up at 4.00km of the cut having zero value and danger value as 2.95m and 6.20m. The field studies were conducted, gauge values were taken from 2006-2011 and spatial developments were examined for the last centuries. The corresponding daily stage and discharge values at Mundali, at the head of the delta are collected from W. R. Dept., Government of Odisha.

The time series for the discharge at Mundali and corresponding stage after considering the travel time is taken. Statistical Packages is being used for hydrologic modeling and data analysis. Linear and non-linear regressions are developed after conducting the outlier test with 95% confidence limit. The R^2 values of the fit equations are considered for the goodness of fit of the model equation. A reference curve is prepared for the stages at cut corresponding to the discharge of the trunk river at Naraj.

River Bhargovi:-

River Bhargovi, an ephemeral river solely flows in Puri district and falls in northern swamps of Chilika Lake. It is connected to Bay of Bengal via ever nomadic tidal inlets. Though not wide, the river discharges in maximum 1100 to 1450cumec which is 3-4% of floods of trunk river Mahanadi. Proximity to coast, alluvial topography, sinuosity, low gradient and configuration posed a constant threat to lives with heavy pecuniary losses The hydro-morphologic parameters of the cuts and the river Bhargovi is in Table 1.

Table 1: Important hydrological parameters of River Bhargovi, a branch of River Mahanadi

Hydrologic parameters		Hydrologic parameters	
Length of the river	85.5km	Gabakund cut Siaro cut Mangala cut from Sunamunhi River	15.93km 16.8km 4.77km
Drainage area	640sqkm	Length of northern shift after 2004 at outlet (Gabakund + Siaro Cut) Mangala Cut	1.354km 0.956m reduced to 0.524Km
Mean discharge (Long Term)	1212cumec	Gradient a. Gabakund b. Siaro cut c. Mangala cut	1:8000 1:12500 1:6000
Mean discharge after cut At Chandanpur (1995-2012)	155cumec	Minimum discharge	31cumec (1999)
Maximum discharge 1982	2553cumec	Av rainfall in mm	1500mm
Year of excavation Siaro cut Mangala cut	 1930 1937	Construction status of Gabakund	Phase I: 1964-67 Phase II: 1983-87 Phase III: 1995-02 Phase IV: 2005-07 (Pilot Channel)

Floods in River Bhargovi:-

River Bhargovi was competent to discharge the floods within its flood plains as they were unbanked till 1942 before construction of double embankments. The high floods received thereafter could not be discharged smoothly. There were frequent high floods in Mahanadi delta from 1928 to 1941. Almost every year 40% to 50% area of Puri district was remaining inundated. The peak flood statistics of 160years (1855-2015) reveals that the south Mahanadi basin had undergone dry spells towards second half of both 19th and 20th century, but strong wet spell prevailed from 1911 to 1947 and from 2001 to 2014. Floods at Naraj can be classified as low, medium, high and very High with flood volume 17-20, 20-34, 34- 40 and above 40 thousand Cumec. Time series peak floods of Mahanadi at Naraj from 1855 -2015 are in Table 2:

Table 2: The different types of floods in (Thousand m3/Sec) in the river Mahanadi (1855-2015)

Type Flood	Year of flood (Mahanadi River)	Freq
Low (17-20)	1867,1869,1886,1887,1906,1956,1964,1979,1981,1987,1988,1989,1999,2000,2002,2010,2012,2013	18
Medium(20-34)	1856,1862,1863,1871,1875,1876,1877,1880,1881,1884.1885,1891,1893, 1894,1900,1904,1907,1908,1909,1910,1912,1913,1915,1917,1918,1921, 1928,1930-32,1935,1936,,1942,1943,1945,1948,1950,1952,1953,1958-63, 1967-69,1971-78,1981, 1983-86, 1990, 1991, 1993-95,1997,1998, 2002, 2004, 2005, 2007,2009,2011,2013,2014	78
High (34-40)	1866,1874,1879,1895,1911,1914,1919, 1925,1934,1939, 1944,1946, 1947, 1955,1967, 1980,1992,2001,2003,2006,2011	20
Very high(>40)	1855,1872,1892,1896,1920,1926,1929,1933,1937,1940,1982,2008	12
Dry Year	Rest period from 1855 to 2015 <17000cumec (Years not mentioned above)	32

Siaro Cut:-

The high floods in 20th century inundated regularly four blocks in Puri district within the Kushabhadra and Bhargovi Doab (Land between two rivers) for days together. Floods remained stagnated within Surlake for months causing disasters. As per directives of flood committee report 1928 Siaro cut was excavated. It was dredged to discharge floods of Bhargovi- via Dhanua- Surlake - Nuanai link to Bay of Bengal. The river Dhanua was causing huge pecuniary loses due to flash floods. After Siaro cut, the area got relief from floods and the agricultural yield increased as the area is well irrigated by Mahanadi Delta Stage II (MDS II). But coastal lake, Sar was absorbing floods and slowly realising to Chilika through local drains. (Fig 3(a) and Fig 3(b)).

Mangala Cut:-

Siaro cut was inadequate for smooth discharge of flood of the sub-basin in the south of Puri. So Mangala cut was excavated from old Mangala River to sea. The link diverted 10-20% of flood discharge of Bhargovi to sea via Kanchi-Dhaudia- Mangala river link. .

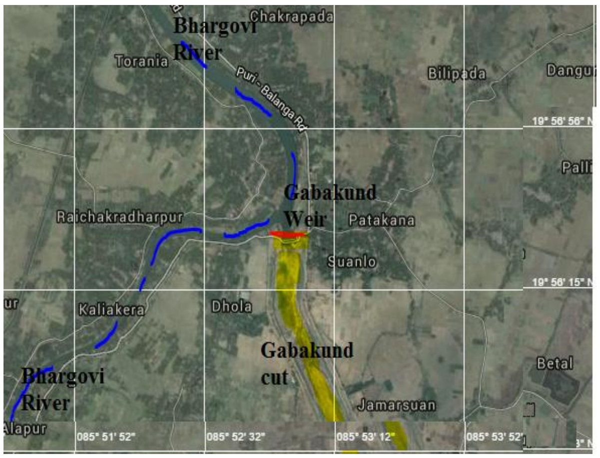


Fig 2 (a): The Gabkund cut to Bay of Bengal Fig 2(b): The Siaro cut joining Gabakund (Source: Google)

The Samang bowl (Lake) of area 15-20sqkm was acting as balancing reservoir for Chilika and was absorbing part of floods of river Bhargovi. There was dredged channel between Sunamunhi river and Samang bowl was called Nua Nai. By the year 2000, the Samang bowl was depleted after construction of a barrage at Gobardhanpur downstream. The connecting channel Nuanai between Samang and Sunamunhi River got depleted. The Sunamunhi river which was active during 1970-1980 is now dead Fig 5(a, b and c).

Gabakund Cut:-

The Siaro and the Mangala cuts were dredged over branches of Bhargovi and were inefficient to moderate the flood viz. Flood Committee 1938-1942, Flood Enquiry committee 1962, Departmental committee 1972, Consultants report-1984, 76th, 99th and 100th High level Technical Advisory Committee of the state etc..They reported modifications in the drainage system with various changes, flood allocations depending upon funds availability and contemporary decisions from time to time. (Fig 2 and Fig 3)

Fig 3(a): The origin of Mangala cut (Kanchi R.) (L) Fig 3 (b): Gabakund cut (origin) (R),

Initially in 1962, Gabakund cut was excavated over an age old breach on Bhargovi left embankment at 37km for a length3km and width 288m. The cut remained partially functional till 1972.The cut was diverting 283cumec with a free board of only 0.9m. The cut remained redundant till 1980 as it was dry period in the basin (Tripathy J.1984).

But the Surlake bowl remained lacustrine by surplus water of Bhargovi via river Dhanua. The Surlake remained heavily flooded from 1972 to 1980 as Siaro cut was carrying both the water of Gabakund and Surlake. The Gabakund cut was renovated piece meal to discharge flood more than 500cumec and assured irrigation to 20000Ha during Khariff through its sluices.

However the neighbouring villages were in panic during high floods. The recurrent chronic high floods in the Mahanadi delta had variable impact depending on the duration and peak discharge. The duration of floods in the delta was higher in 21st century than 20th century (Table 3). More damages have incurred in the area during the floods 2001, 2003, 2008 and 2011

Fig 4: (a) The outlet of the Mangala cut from Sunamunhi R. 4 (b) Siaro and Gabakund cut from Bhargovi

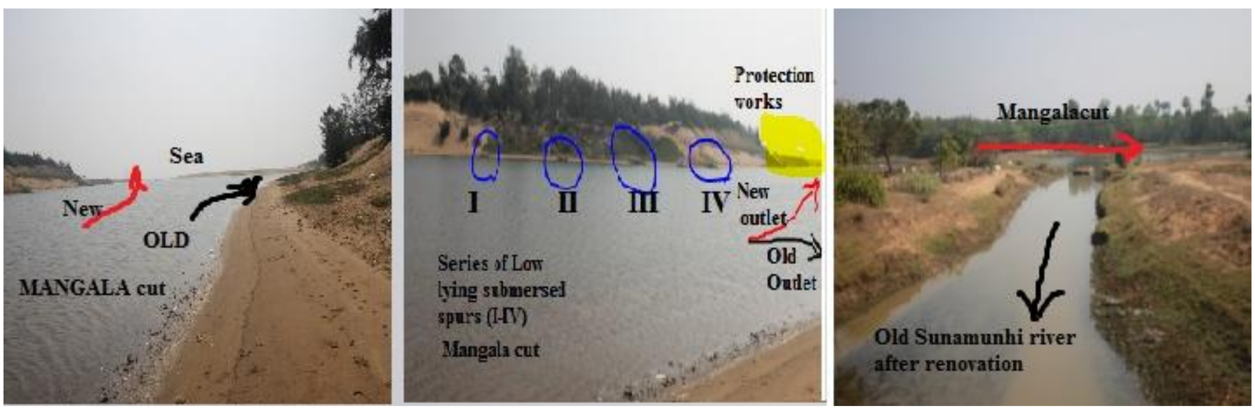


Fig 5 (a) Outlet of Mangala cut (b) Spurs that protected beach erosion (c) Geriatric Sunamunhi River

Table 3: Status of High and very high floods in river Bhargovi and Mahanadi that affected South Mahanadi Delta

Sl No	Year	Stage in (m)	Dates of peak flood	Peak in Cumec	Duration in days	Peak Bhargovi Uttara m^3/sec
		Mahanadi River at Naraj (Delta head)				
1	1958	27.43	15.9.58	34013	13	1062
2	1959	27.48	18.8.60	35573	9	1268
3	1961	27.2	30.9.61	36422	10	1282
4	1980	27.08	22.9.80	34748	12	1947
5	1982	30.39	31.8.82	44750	06	2185
6	1985	26.63	07.08.85	25853(exception)	04	1595
7	1991	27.37	14.8.91	34219	10	1174
8	2001	27.37	20.7. 01	39887	19	1392
9	2003	27.74	30.8.03	38223	19	862
10	2006	26.7	01.9.06	36340	12	1175
11	2008	30.45	20.9.08	44777	15	1599
12	2011	27.55	11.9.10	38677	10	1480

A designed channel of clear width (Toe-Toe) 290m long, 11.2Km wide with double embankments was excavated piece meal basis by 2002. During 2005-06 the cut was renovated with double embankments, bed level at 1.00m, cut width 335m. A pilot channel was excavated with bed width 60m from 7Km to 10km to pass floods. Further in 2006-07 the cut was renovated for the portion 4.0km to 7.0km where the pilot channel width was maintained at 40m. The cut worked successfully but back water was propagated in the Pilot channel Fig 6(a). Salinity ingress in the ground water table has propagated 5km more than the past. The diversion of flood quantity increased. To avoid salinity intrusion to the river Bhargovi, a low level submerged weir, without gates was constructed during 2014 Fig 6 (b).

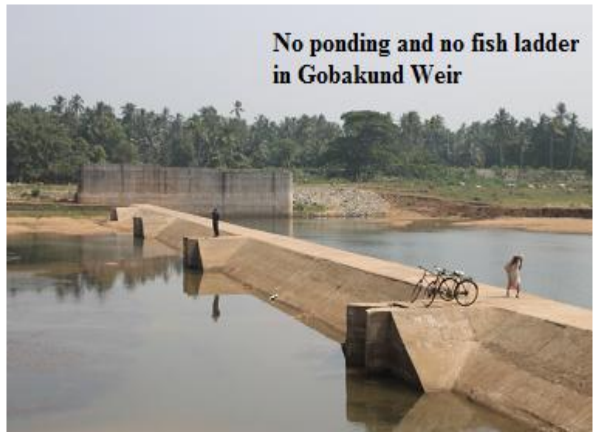


Fig 6(a): Back water propagation till 9.2km (High tides) Fig 6(b): Submerged Weir at Gabakund mouth

North Bending of Channel Outlets:

Shoreline is an interface of coast, sea and air where energy transfer is continuous. Eustatic forces responsible for Coast shaping are tides, waves, currents, MSL changes, long shore drift, stream flow, tectonic and tsunami forces. Sediment Transport in coastal processes is due to wave action, beach drifting and coastal deposition. The recent changes in coastal land are formation of estuaries or emergences along east coast of India. The shore line from Gabakund mouth to Mangala cut mouth of Puri coast is fragile. Erosion and deposition along the mouths of Gabakund cut and Mangala cut had turned northward shift of outlets after the Sumatra tsunami-2004 Fig 4 (a) and (b). The possible causes for formation of long shore bars and diversion of outlet to north due to littoral drift, Coriolis force, rip current, tectonic effects etc..

Stochastic studies:-

After completion of renovation works of Gabakund cut with its pilot channel during 2006-07, it was found that the discharge of high floods has less impact on the stage of flood within Gabakund cut. A relation has been established between discharge at Naraj and the stages of Gabakund cut Fig 6.

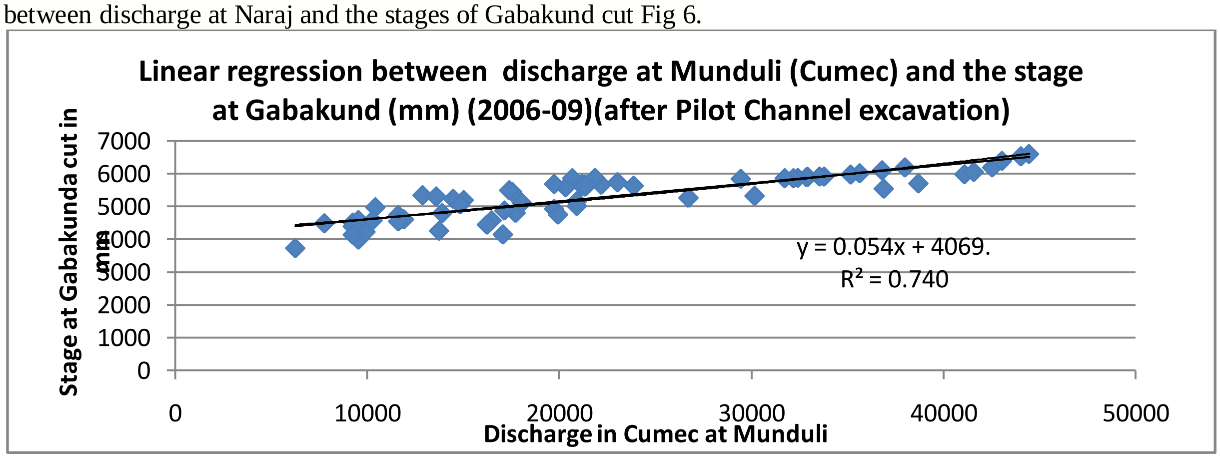


Fig 7: Linear regression between main river delta head discharge and the stage at Gabakund (2006-09)

Normal P-P and Q-Q plots:-

Normal probability-probability plot is a graphical technique to assess whether the data considered is normally distributed. To get the normal probability plot (PP plot and Normal quartile plot (QQ plot) and to check whether the data possesses normal distribution, model used was Blom's fractional rank estimation method with standardized normal distribution for a series of data size 67. From the normal QQ-plot of the data it can be interpreted that the data is slightly tailed from both ends. Similarly the normal PP-plot is a normal distribution with slight hump. However the present data series can be considered as of normal distribution series.

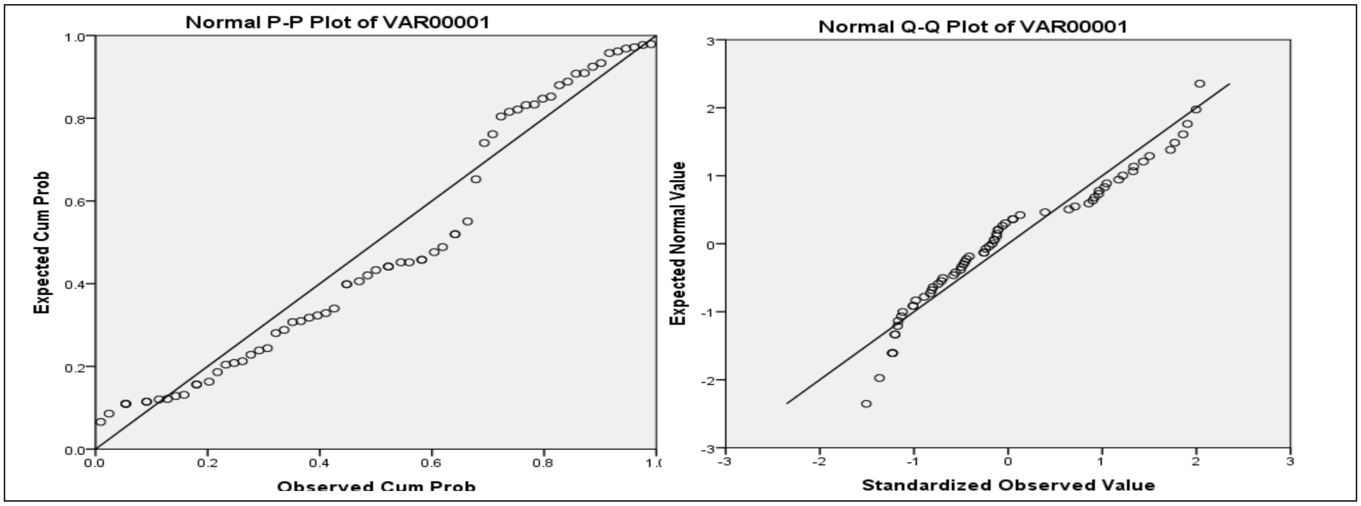


Fig 9: Normal PP and QQ plot of the discharge data at Mundali and gauge data at Gabakund (2006-2009)

From the normal QQ-plot of the data it can be interpreted the data is slightly tailed from both ends. Similarly the normal PP-plot is a normal distribution with slight hump. However the data series can be considered as of normal distribution.

Regression model:-

For the data series a non linear regression is developed between the discharge at delta head at Naraj and corresponding stage at Gabakund barrage to the effectiveness and future prediction. From the above curve fitting models it is found polynomial quadratic equation having the highest R^2 value as 0.7899. From different linear and nonlinear regression models the nonlinear polynomial quadratic models are the vest fit when tried with various regression equations. The data series have shown 75% data accuracy. The model relation between the discharge at Mahanadi and stage at Gabakund is given by

$$Y = 7.24 + 495\, x^{0.224}$$

Table 6: The Nonlinear Regression Equations for Discharge at delta head (Cumec) of River Mahanadi vs. stage at Gabakund in mm (Monsoon)

#	Equation type	Equation	PARAMETERS					R^2 Value
			Y_0	a	b	c	X_0	
1	Linear	$Y = y_0 + ax$	4069	0.054				0.74
2	Power (2P)	$Y = a x^b$		501	0.2237			0.789
3	Power (3P)	$Y = Y_0 + ax^b$	7.24	495	0.238			0.7899
4	Polynomial quadratic	$Y = y_0 + ax + bx^2$	3397	0.122	-0.000013	-	-	0.788
5	Exponential	$Y = a(1-e^{-bx})$		5945	0.0001			.71
6	Inverse	$Y = y_0 + a/x$	6423	1.9*106				0.74
7	logistic	$Y = y_0 + a \ln(x)$	-6628	1025				.0.78
8	Hyperbolic	$Y = ax/b+x$		6942	5941			0.778

Discussion:-

The cuts are either natural or anthropogenic. They are dredged in deltaic rivers to sea to save the people downstream from flood inundation and disasters. The manmade cuts in alluvial reaches are generally excavated at the concave bends where the flow directly hits the embankments. River mouth exhibits various changed features in long run when cut outlets are opened to sea.

Siaro cut, Mangala cut and Gobkund cut were excavated in phases as per need and availability of funds. Scientific and modeling aspects were least considered during their excavation. Gobkund cut became ineffective due to sediment plugging from 1972 to 1980 and further in 1990's. As per studies of Park K., 2013[20], the aspects like changes in channel width, meandering, the bed roughness, perching or flood discharges, sediment concentration and back water of bay of Bengal are to be considered for studying their longevity. . Channel width adjustment is given by Park is $W(t) = W_e\ (W_0\ - W_e\ )\ e^{-kt}$, Where W_0 , W_t , are the channel width initially, after t years and K, a constant. (Shin et al, 2010). Channel slope Adjustment in channel gradient with width is given by $S(t) = S_e\ (S_0\ - S_e\ )\ e^{-kt}$ where S_0 was the initial channel slope and S_e is the changed slope after the channel reaching equilibrium after t years. At equilibrium stage, the slope shall be seventh power of the width, Leon et al, 2009[21]. To achieve the equilibrium stage the channels take appreciable period. The channel undergoes constant changes in its geometric profile. The equation for time span for achieving an equilibrium hydraulic shape is $T_p\ =\ \frac{-1}{K}\ [\ln(1 - 0.1\ P)]$ where K is a constant or the relation coefficient expressed exponentially, T in years and P is the percentage of adjustment done. The slope adjustment considering P= 50%, and K= 0.1 we have:

$$T_{50} = \frac{-1}{K}[\ln\ (1 - 0.1\ P)]\ =\ \frac{-1}{0.1}\ \ln[\ 1 - 0.01 * 50]$$

$$T_{50} = -10 \ln \frac{1}{2}\ =\ -10 *\ -0.69315 = 6.9 years$$

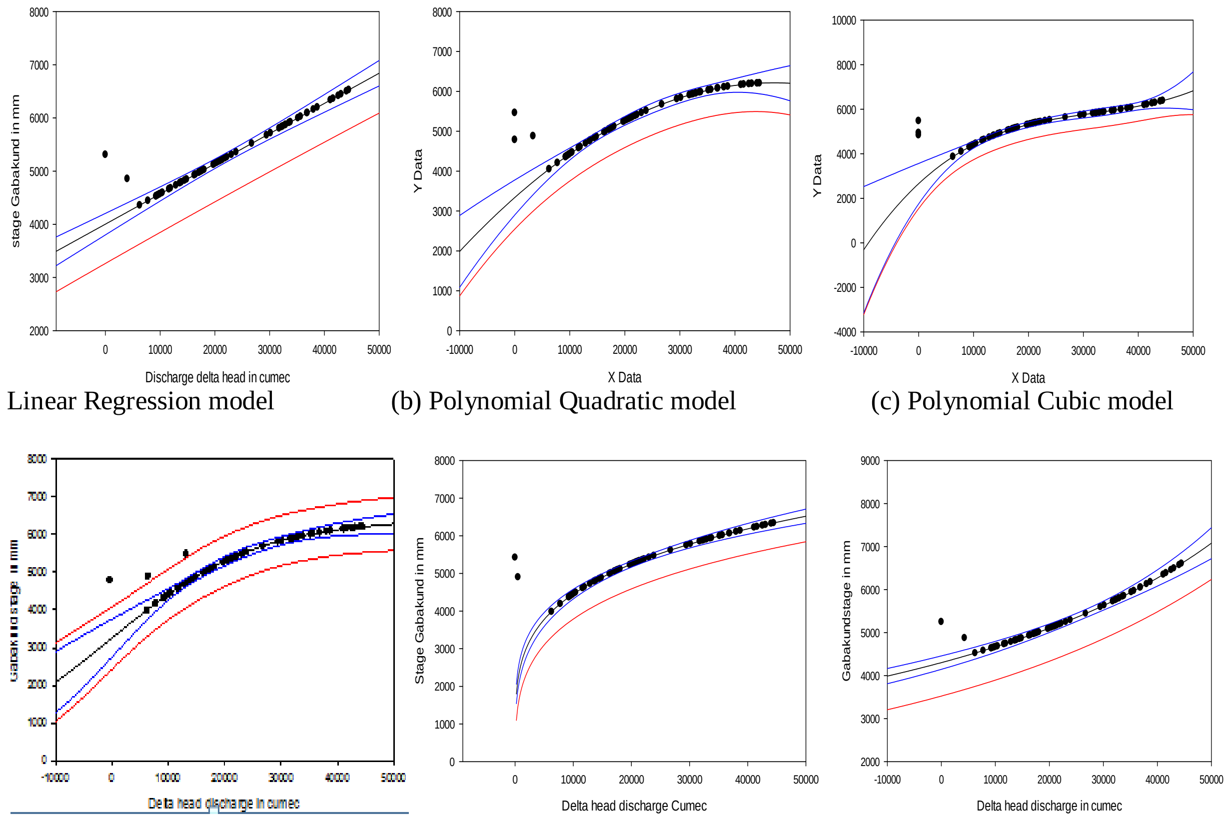
For P=90%, cut may take 23years to adjust the slope. For final slope adjustment of the cut we have to wait for a long period to reach at a decision where the effectiveness of the cut. Gabakund Channel is exhibiting both slope and section adjustment and had effective plugging of channel from 1964 to 1972.

Impacts after artificial cuts:-

Rise in MSL, frequent storm impacts, long term climate changes and migration of outlets had changed the morphology of the all the cuts. The anthropogenic interventions such as sand mining, explosives used for fishing, permitting untreated sewage, reclamation with improper designed structures had added to the changes

Excess sand mining has lowered the bed and movement of vehicles on embankments has stressed on the levees. Erosion and deposition on bed had changed the cut and the river dimensions regularly. Both bar skimming and pit dredging had caused channel incision and erosion of the side slopes. During floods, the sediment starved water scoured both bed and slopes. The scoured matters get deposited after some distance and settle down causing haunch in the bed. The hydrogeology of the area was deteriorated with time. The salinity intrusion invaded up to a distance of 20-25km from the cut outlet. The back water has propagated gradually up to the submersed weir which is 300m from the center of Bhargovi river [fig 6 (a)].

The Mangala cut was constructed to get relief from regular flood submergence of Puri Sadar block. The Samang bowl, a balancing reservoir for Chilika lake which has been depleted. It may be taken as a cause for sedimentation of the Asia's largest brackish water lagoon Chilika.



Linear Regression model (b) Polynomial Quadratic model (c) Polynomial Cubic model

(d) Sigmoidal regression model (e) Power function model (2P) (f) Rational function model

The Mangala cut has dried up the coast parallel river Sunamunhi. The river became defunct and dead. Many a drainage channels emanating from left bank of river Bhargovi could not discharge flood and made the area water logged by converting ground water brackish. Mishra et al (2015)[22] .It was observed the gauge reading during 2005 flood (21500Cumec in trunk river Mahanadi) before pilot channel excavation was 7.1m and having 0.9m free board. The flood caused a breach at 5.8km and there was heavy flood damages and 10days inundation. The Gabakund gauge record was 6.2m during 2006 when the flood volume was 31000cumec in trunk Mahanadi, confirming excellent working of the pilot channel.

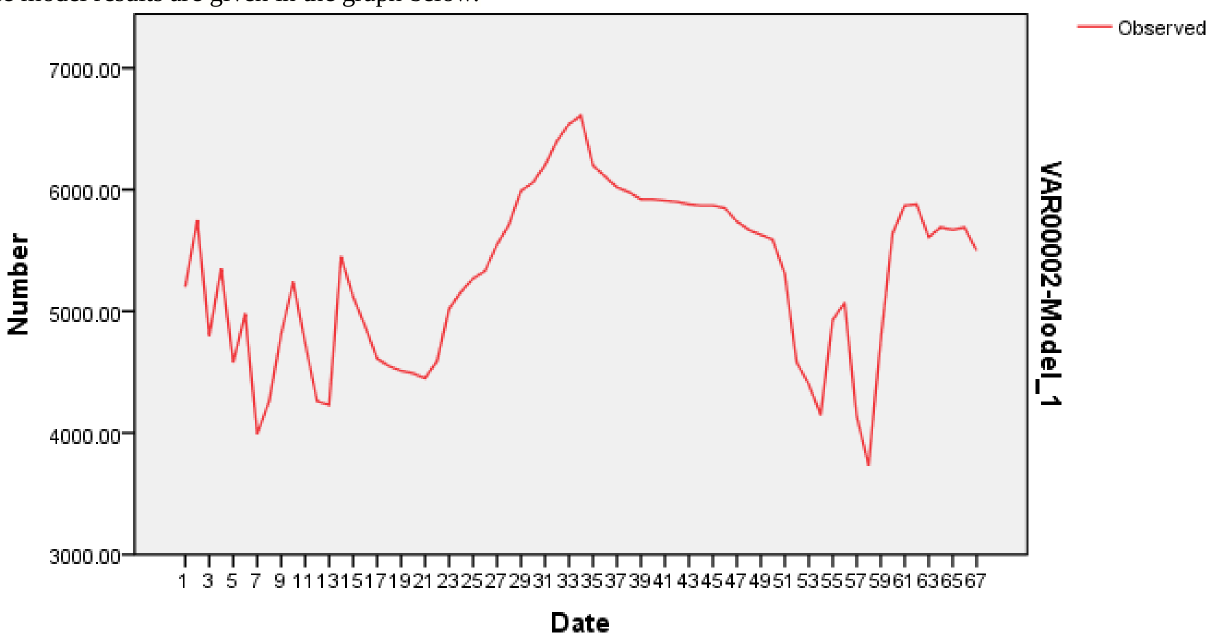
A submersed weir was constructed at 200m distance from the centerline of river during 2014 within the gorge of the channel. It was aimed to divert 10 to 15cumec irrigation water for irrigation in Bramhagiri block during Rabi crop and to prevent saline water intrusion.

Model study:-

Arima Exsmooth model was applied to study a series plot for observed forecast of the gauge of Gabakund cut at various stages of discharge at head of the delta as follows.

Model Fit											
Fit Statistic	Mean	SD	Minimum	Maximum	Percentile						
					5	10	25	50	75	90	95
Stationary R-squared	.862	.	.862	.862	.862	.862	.862	.862	.862	.862	.862
R-squared	.862	.	.862	.862	.862	.862	.862	.862	.862	.862	.862
RMSE	269.261	.	269.261	269.261	269.26	269.26	269.26	269.26	269.26	269.26	269.26
MAPE	3.653	.	3.653	3.653	3.653	3.653	3.653	3.653	3.653	3.653	3.653
Max APE	21.281	.	21.281	21.281	21.281	21.281	21.281	21.281	21.281	21.281	21.281
MAE	183.303	.	183.303	183.303	183.30	183.30	183.30	183.30	183.30	183.30	183.30
Max AE	849.126	.	849.13	849.13	849.13	849.13	849.13	849.13	849.13	849.13	849.13
Normalised BIC	11.577	.	11.577	11.577	11.577	11.577	11.577	11.577	11.577	11.577	11.577

The model results are given in the graph below.



Adverse effects:-

The adverse effect of Gabakund cut, the river Bhargovi became geriatric below 37km after the renovation of the cut with a pilot channel. Back water has propagated along pilot channel up to head of the cut. Very high floods may change the river course besides the weir making the massive construction a futile effort Fig 6 (b).

Uneven distribution of bed load and the suspended sediment was prevented during low floods. The reduction in discharge has augmented the deposition of sediments and proliferation of algal blooms, ipomeas and water Hyacinth along the river Bhargovi. The accumulations of sediments and aquatic weeds have raised the base level of the river Bhargovi. The competence and the capacity of the river have reduced resulting in deposition of sediment in the bed cumulative manner. The shoal formation shall discontinue flow at the railway bridge and the road bridge near Chandanpur establishes the fact. It is observed that at the mouth of the cuts near sea sand bars have developed after tsunami 2004 and restricted direct discharge to sea and the river outlets moved north by 500m Fig.4 a & b.

The impacts of the cuts may be physical (flushing or choking), fluvial (degrading or aggrading), chemical (anthropogenic or natural or both). It increases eutrophication. Seasonal variation in flow may decrease in discharge but increases human origin discharges, reduction in supply of sediment and inadequate recruitment of fish species due to their obstructions in migration.

Predicted problems:-

The two cuts i.e., Siaro and Mangala cuts were indirect cuts may have little effect on the main river Bhargovi. But Gabakund cut may stand penetration of tides through the estuary to main river in future. The water users below Gabakund cut shall encounter the problems of brackish water.

Lowering of bed by dredging depletes the river water level with increase in brackish water intrusion. The ground water of the area has turned more saline which may affect agriculture, natural habitats flora, fauna and mainly fishery. The Rabi crops shall be affected drastically in the area. The lowering of water level during high and medium floods shall be smoothly discharged. The construction of the new submersible weir may be a barrier for salinity propagation to the river Bhargovi but salinity of the coastal areas shall increase gradually. The coastal lacustrine areas shall become prone to human encroachment at the cost of aquatic habitats in absence of regular annual flooding.

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