GEOPHYSICAL CHANGES OF CHILIKA LAGOON IN POST NARAJ BARRAGE PERIOD

Synopsis of the Thesis Submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy

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Introduction

Asia’s largest brackish water lagoon the Chilika lake, (Ramsar site no 229), seprated from Bay of Bengal by a series of barrier spits, is situated in the State of Odisha, India. Siltation of the lake is become a matter of concern as this leaded to various geomorphologic changes, and affected the shape and size of the lagoon, receiving major portion silt through rivers Daya and Bhargovi, the southern branches of the Mahanadi River, via the Kathajodzi and the Kuakhai rivers. The Naraj barrage is constructed at the mouth of the river Kathajodzi to regulate the inflow, thus siltation, into the lagoon (Fig 1). Other major interventions such as (i) diversion of flood discharge directly into Bay of Bengal through the Mangala cut via Kanchi river, a sub-branch of the river Bhargovi, (ii) Gobkund cut in the Bhargovi river, and (iii) raising and strengthening of levees along the Daya and the Bhargovi river etc. have reduced flood flow and silt flushing efficiency of the lagoon into the sea. Various affects of siltation in the lagoon due to interventions by the barrage are analyzed considering its pre and post-construction situations. Considering different flood situations in the river Mahanadi, alternate strategies are studied for operation of the Naraj barrage aiming at minimization of siltation in the Chilika Lake. The geomorphologic, geoclimatic, hydrologic and sediment flux changes occurred in post Naraj period is focused in the research and future predictions were made by using field study, stochastic, and soft computing techniques.

1. Features of study

(a) Chilika Lagoon

Chilika, is a shallow, brackish, shore parallel, pear shaped wetland, the largest lagoon in Asia (19°28′–19°54′N and 85°05′–85°38′E), spreads adjacent to south Mahanadi delta. It had maximum spread area 1165 sqkm and minimum 906sqkm. (Sterling A., 1846)\(^1\). The lagoon had dimensions of length varying from 70.81km to 63.4km, width 32.2km to 20km and depth 0.38m to 4.2m. Historically, it was a gulf in past, separated from the Bay by sandy ridges of 3000-4000 years back to form a lagoon. Poor exchange and hydro-dynamic disparity distracted the ecology, biome and morphology of the marine-semi marine-fresh water environment by end of 20\(^{th}\) Century. The lagoon has four sectors; (i) Northern sector: maximum inland flow, shallow and least saline; (ii) Central sector: saline and deepest; (iii) Southern sector: Less siltation, stable in dimension and salinity; (iv) Outer channel: narrow,
parallel to coast, maintains the lagoon’s dynamics. The tidal inlets are maintained by flood in monsoon and the tides in the remaining period.

(b) Mahanadi river and its Delta system:

Mahanadi is the third largest river in Peninsular central India with its length 851km and catchment area 141589sqkm. River Mahanadi is bifurcated as the Mahanadi and the Kathajodi branches at Naraj, which further throws its southern limb as Kuakhai. The river Kuakhai further has sub-branches Kushabhadra (60km), Bhargovi (85.5km) and Daya 60km). Daya and Bhargovi are the major rivers debouching Chilika. Other major drainage systems are Gangua, Ratnachira and Luna having catchments of 741sqkm, 145.40sqkm and 445sqkm, respectively.

River Mahanadi has an arcuate shaped delta of area 9500sqkm with apex angle 140°. It has three distinct zone, Southern sector, Central sector and Northen sector. South Mahanadi delta (SMD) extends from Naraj to western bank of Chilika. Present study cover this area only. Upper Mahanadi basin in Odisha, possesses permeable soil of dense vegetative shield and has high resistance with low drainage density of value 0.022. Deltaic soil is SPSM type and in coast it is sandy. The delta has surface water potential of 66.88BCum at head and Ground water potential of 16.46 BCum. The average sediment carried by the river 29.77MMT. Sediment yield of the catchment was of order of 200-400 MT/km² annually (Delta Development plan 1986)[2].

(c) Naraj Barrage

Naraj Barrage is constructed at the head of river Kathajodi at its bifurcation from Mahanadi river to control its flow draining to Chilika lake. The 940m long barrage at Naraj 20 -24’ N lat and 86-57’ E was in operation from (2004), mainly aiming at providing threshold flushing flood so that sedimentation in Chilka can be reduced. Naraj Barrage having design discharge of 29500cumec also used for water supply to Cuttack and Bhubaneswar city.

2. Previous studies

The maximum dimensions of the lake were 70.81kms x 32.2kms. The average width was 8.05km with average depth 0.9 to 1.5 meters except some places more than 3meters (Cotton, 1858)[3]. Harrish,(1860) surveyed Mahanadi delta. Pearson,(1858)[5] had prepared the bathymetry map of Chilika. The flow distribution in the branches Daya and Bhargovi rivers were respectively 2.6% and 1.9% of total flow of parent river Mahanadi
The geomorphology, hydrology and hydrodynamic changes of the lake and in the SMD with time was reported by Das et al (2008)\[^7\]. Ecology and biodiversity was improved after dredging a mouth at Sipakuda, 17km downstream of depleted mouth at Motto (CDA reports 2012\[^8\], 2013\[^9\], Ritesh, K. 2010\[^10\], and Sahu et al., 2014\[^11\]). The geology of evolution and geophysical changes in morphology of the delta, the age of the lagoon and the geospatial transformation have been reported by Venkatratnam (2003)\[^12\], Mahalik et al (1996)\[^13\], Kadekodi et al, (1999)\[^14\], Nayak et al., (2006)\[^15\] and Lal et al (2009)\[^16\]. GIS studies of the lagoon, its LU/LC and the change in lake area was studied by Samal et al., (2013)\[^17\], Ojha et al., (2013)\[^18\] Gupta M.(2014)\[^19\] and Mahanti et al (2015)\[^29\]. Pattnaik et al 2000\[^27\], 2006\[^28\], Gupta GVM et al 2008\[^20\] have reported that decreasing of the dimension and change in morphodynamics of the lake may be due imbalance flow exchange and sediment transport. Sediment studies on the lake and South Mahanadi delta were done by W.R. Department, Odisha, 1986\[^2\], Gopi Krishna et al, 2014\[^21\], Gupta M. (2014)\[^22\], Chandramohan (1993)\[^23\], Abinash kumar (2014)\[^24\], Audin J. and B. (1950)\[^26\]. Though various aspects of chilika lagoon has been studied by many researchers, detailed Civil Engineering espects was not addressed.

3. The Problem Statement

During the last decade of 20\(^{th}\) century it is noticed that the productive ecosystem of Chilika was degraded. Brackish water species were diminished by 40\%, 393sqkm new land mass created by sedimentation and average depth was reduced from 3m to 1.6m by the year 2000. The aqua catch was reduced from 8924MT in 1986-87 to 1274MT in 1995-96. The tidal inlet in barrier spits outer channel were shifted to extreme north i.e. Village Motto. The tidal inlet at Magarmunha got silted up reducing exchange of flow. To augment flushing flow and enhance flow exchange to chilika, one direct inlet was dredged at 17km down stream of old inlet during the year 2000. A barrage was constructed at Naraj over river Kathajodi in 2004. Though catch, salinity and biodiversity in Chilika improved, but after the Naraj barrage, flow was decreased in Kathajodi reducing flushing flow in Chilika. Rivers passing through south mohanadi delta were declared as Class ‘C’ (OSPCB 2004). After renovation of Gobkund and Kanchi drain discharge in river Bhargovi was reduced by 65\%. Bhargovi became geriatric, causing reduction in agriculture yield and enhanced back water propagation. A detailed hydrologic study was warranted regarding the geophysical changes in Chilika lagoon concerning effect of Naraj barrage.
4. Materials and Methodology

To start with hydrologic boundary of the rivers and drains were marked and catchment area of drains planimetered from Toposheets. The measured catchment areas of south Mahanadi system and western catchments measured as respectively 1777sqkm and 2800sqkm were confirmed by satellite imagery results. Rainfall records are obtained from Government agencies. The physical G&D data of the SMD for monsoon periods are taken at 18.2km (Kanti) on Daya and 48km (Chandanpur) on river Bhargovi for the period 2000 to 2003 (pre-barrage), 2004 and 2012–2013 (post-barrage) by setting of observatories. Licensed SPSS package (2012), MATLAB, other free hydrologic and statistical packages were used for analysis. The remote sensing data, Advanced Wide Field Sensor (AWiFS) through IRS-P6 (NRSC) were utilized to study geophysical changes.

5. Research Contributions

Many geophysical transformations including changes hydrological, morphological, sedimentological and meteorological parameters of the area in and around the Chilika lagoon have occurred after operation of Naraj barrage. Various effects of hydrologic alternations were studied through appropriate GIS approach with data integration, and presented to address the anomalies of the identified research gaps. For study of the morphologic changes during pre and post Naraj Barrage a method was developed considering satellite imageries. The regression relationships were developed between flow and sediments of rivers Mahanadi, Daya and Bhargovi.

Fig 1 Index map of SMD showing river system and Chilika lagoon with position of inlets
5.1 Geophysical changes in Chilika: Some of the study results covering the following aspects have been presented as under.

**Water spread area:** The different study results for maximum (during flood) and minimum (summer) water spread areas of the lagoon were reported, for example; 1165 sqkm and 906 sqkm (Sterling, 1846)[1], 1045sqkm and 790sqkm (CDA report-2012) [8], respectively. The present study through Advanced Wide Field Sensor (AWiFS) conducted for the months Jan (Post monsoon), May (pre-monsoon) and August (active monsoon) for the period 2003-2012 revealed that the average minimum and maximum water spread area in post barrage period to be 775sqkm and 1011sqkm.

**Tidal Inlets:** Tidal inlets in the spits of the lagoon have undergone many changes spatially in number and dimension. After operation of Naraj barrage since 2004, the old mouths at Moto and Sipakuda were closed in 2004 and 2014, whereas four new natural inlets opened at villages Gabakunda, Mirzapur, Dahalabali and Chadachadi during 2008, 2010, 2012 and 2014, respectively. This resulted in coersion of the lagoon from Choked to Restricted one (Kejorve, 1996)[25].

**Geomorphological Changes:** Mouth of river Daya got silted up restricting floods to pass. Makara, a surrogated branch adjacent to Daya towards tail had widened and started carrying a major share of Daya flow after the barrage. A number of drainage channels in South Mahanadi Delta such as Ratnachira, Sunamunhi and Bhargovi became geriatric. A deltaic sub-system has built up towards south of the delta associated with Daya. Many a drainage channels emerging from Bhargovi left embankment became either defunct or silted up and became shallow during span of 1999-2012.

**Land use and Land cover:** Regarding LU/LC changes (1999-2012), it was observed that agricultural land and water body were decreased by 10.92sqkm and 1.32sqkm, whereas forests, swamps, urban area and human settlement were increased by 6.82sqkm, 3.16sqkm, 1.39sqkm and 1.69sqkm, respectively in SMD. The swamps, agricultural lands and water spread area of Chilika had decreased by 7.8sqkm, 7.4sqkm and 1.2sqkm, whereas prawn culture area and human settlement increased by 8.5sqkm and 2.3sqkm, respectively.

**Hydro-morphology:** Lal et al. (2009)[16] noted about three shifts of channel mouth at Talatala, Krishnaprasad Garh and Tichhini. But from AWiFS images show, a number of such geo-hydrologic shifts of symmetry extending from south to north. These shifts indicate the
Physical model
A physical model is developed for the study of geomorphologic and climatic changes of the lagoon considering the interventions and actions needed to restore the health of lagoon. [Fig 2]

5.2 Hydrological Data Analysis

Rainfall Analysis
Chilika receives runoff from its local catchment apart from Mahanadi flow. Rainfall data for the period 1993-2014 for eight blocks are collected and stochastic analysis was done. The procedures followed in analysis are: drawing of 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), and finding the parameters to fit equation. The regression equations were developed and validated. It was found that of the monsoon rainfall in catchment of Daya river show a linear increasing trend, whereas that in catchment of Bhargovi river and Chilika lake area show nonlinear trend. The prediction of rainfall by Gumbel method shows higher results than the Log Pearson Type III. (Fig 3, 4 and 5)
Flood Analysis:
The number of very high floods has increased after the construction year 2000. High floods were observed in the years 2004, 2006, 2008, 2010 and 2014. Historical flood of magnitude 44750 cumec was faced and caused havoc in South Mahanadi delta in the year 1982 and 2008.

Flow scaling
The linear and nonlinear regression relationship between discharge of Mahanadi and Kathajodi branch before 1982 followed sigmoidal relation with highest $R^2$ value 0.896. If $Y$ is the flow of the dependent river and $x$ is the flow of trunk Mahanadi River, the nonlinear regression fitting as:

Sigmoidal

$$Sigmoidal (1)$$

However the flow distribution has improved after the operation of Naraj barrage from 2004. The best fit nonlinear regression equation with $R^2$ value 0.947 is both the quadratic and sigmoidal function and the validated equations are:

Quadratic

$$Quadratic (2)$$
Sigmoidal \[ Y = 8.87 \times 10^4 \left[ e^{-(x-6.56 \times 10^4)/2.157 \times 10^4} \right] \] (3)

**Probabilistic prediction of flow distribution**

A probable output relation between the release from river Kathajodi and flow in its branches downstream Daya and Bhargovi debouching Chilika as given as follows (Table 5):

**Table 5 The flow distribution in different branches below Naraj barrage in cumec**

<table>
<thead>
<tr>
<th>Percentile</th>
<th>Release Naraj</th>
<th>Kuakhai</th>
<th>Daya - Kanti</th>
<th>Bhargovi Uttara</th>
<th>Bhargovi Chpur</th>
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<tbody>
<tr>
<td>1</td>
<td>3190</td>
<td>630</td>
<td>355</td>
<td>80</td>
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<tr>
<td>5</td>
<td>5131</td>
<td>1107</td>
<td>545</td>
<td>108</td>
<td>0</td>
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<td>11</td>
<td>5958</td>
<td>1649</td>
<td>646</td>
<td>494</td>
<td>298</td>
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<td>13</td>
<td>7250</td>
<td>1737</td>
<td>690</td>
<td>581</td>
<td>363</td>
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<td>17</td>
<td>8085</td>
<td>2038</td>
<td>698</td>
<td>620</td>
<td>404</td>
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<td>25</td>
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<td>2438</td>
<td>748</td>
<td>661</td>
<td>450</td>
</tr>
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<td>42</td>
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<td>2708</td>
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<td>68</td>
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<td>3277</td>
<td>1440</td>
<td>1420</td>
<td>620</td>
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<tr>
<td>75</td>
<td>13995</td>
<td>3454</td>
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<td>1459</td>
<td>700</td>
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<td>1948</td>
<td>2040</td>
<td>748</td>
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<tr>
<td>85</td>
<td>16481</td>
<td>4271</td>
<td>2010</td>
<td>2133</td>
<td>824</td>
</tr>
<tr>
<td>87</td>
<td>17178</td>
<td>4532</td>
<td>2094</td>
<td>2296</td>
<td>1082</td>
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<tr>
<td>93</td>
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<td>2285</td>
<td>2482</td>
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<td>5588</td>
<td>2492</td>
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<td>99</td>
<td>24488</td>
<td>5828</td>
<td>2776</td>
<td>2956</td>
<td>1543</td>
</tr>
</tbody>
</table>

**Regional flood Frequency analysis (D-INDEX METHOD)**

The extreme flood data of River Mahanadi (1858-2014) was analyzed and prediction made by D-index method. The common distribution functions like Normal, Log Normal, Pearson, Log Pearson type III, Gumbel, log Gumbel and Generalized Extreme Value were used and found the lowest D-index which is 0.1887 for GEV function (Table 6).
Table 6: Prediction of flood by Gumbel, LPT III and GEV (D-index) for Daya & Bhargovi (1958-2014) Discharge in Cumec

<table>
<thead>
<tr>
<th>Name of river</th>
<th>Return period (Years)</th>
<th>Probabi ty P %</th>
<th>Dis Gumbel II Daya</th>
<th>Dis LPT III Daya</th>
<th>Dis GEV (PWM) Daya</th>
<th>Dis Gumbel II Bhargovi</th>
<th>Dis L PTIII (Cumec) Bhargovi</th>
<th>GEV (PWM) method Bhargovi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daya &amp; Bhargovi</td>
<td>1.0</td>
<td>95.2</td>
<td>387</td>
<td>356</td>
<td>64</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.1</td>
<td>90.1</td>
<td>485</td>
<td>461</td>
<td>558</td>
<td>25</td>
<td>107</td>
<td>153</td>
</tr>
<tr>
<td></td>
<td>1.2</td>
<td>80</td>
<td>614</td>
<td>610</td>
<td>698</td>
<td>198</td>
<td>191</td>
<td>337</td>
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<tr>
<td></td>
<td>2.0</td>
<td>50</td>
<td>915</td>
<td>956</td>
<td>1109</td>
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<td>876</td>
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<td>1116</td>
<td>1415</td>
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<tr>
<td></td>
<td>10</td>
<td>10</td>
<td>1587</td>
<td>1541</td>
<td>1750</td>
<td>1499</td>
<td>1595</td>
<td>1719</td>
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<tr>
<td></td>
<td>25</td>
<td>4</td>
<td>1926</td>
<td>1740</td>
<td>2002</td>
<td>1951</td>
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<td>2177</td>
<td>1857</td>
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<td>2426</td>
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<td>2434</td>
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<td>3663</td>
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<td></td>
<td>500</td>
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<td>3002</td>
<td>2119</td>
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<td>3390</td>
<td>4260</td>
<td>2809</td>
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<td>1000</td>
<td>0.1</td>
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<td>2172</td>
<td>2675</td>
<td>3721</td>
<td>4698</td>
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<td></td>
<td>2000</td>
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<td>3497</td>
<td>2217</td>
<td>2760</td>
<td>4052</td>
<td>5117</td>
<td>3046</td>
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<tr>
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<td>5000</td>
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<td>3824</td>
<td>2257</td>
<td>2858</td>
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<td>5554</td>
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<td>4072</td>
<td>2297</td>
<td>2922</td>
<td>4820</td>
<td>6027</td>
<td>3259</td>
</tr>
</tbody>
</table>

5.3 Sediment Study

Mahanadi delta

Sediment received by the rivers Daya and Bhargovi is either from their own catchment or a part from basin flow. It was observed the sediment concentration has reduced from 0.288 gm/lit to 0.166gm/lit for river Bhargovi and 0.268gm/lit to 0.218gm/lit for Daya. This result may be associated with effective barrage operation principles. The average sediment concentration has been reduced from 0.252gm/lit to 0.227 gm/lit at u/s of delta. The average rate of decrease of sediment was 10%, whereas for non-monsoon flow the rate of precipitation...
Statistical Analysis

Linear and non-linear regression equations are developed from the data series and quadratic equation and third order logarithmic equations are found to be highly reliable with $R^2$ values 0.16 and 0.96 for non-monsoon and monsoon sediment data. (Table 7 and 8)

Table 7 The Nonlinear Regression Equations for Annual Cumulative Discharge/sediment of River Mahanadi (Non-Monsoon Period 1993-2009)

<table>
<thead>
<tr>
<th>S L</th>
<th>Equation type</th>
<th>Equation</th>
<th>Parameters</th>
<th>$R^2$ Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Linear</td>
<td>$Y = y_0 + ax$</td>
<td>$Y_0 = 0.206$, $a = 4.11 \times 10^3$, $b = 0.069$</td>
<td>0.069</td>
</tr>
<tr>
<td>2</td>
<td>Quadratic</td>
<td>$Y = y_0 + ax + bx^2$</td>
<td>$-0.048$, $a = 2.7 \times 10^4$, $b = -1.73 \times 10^4$</td>
<td>0.16</td>
</tr>
<tr>
<td>3</td>
<td>Power</td>
<td>$Y = ax^b$</td>
<td>$Y_0 = 0.00513$, $a = 0.518$</td>
<td>0.086</td>
</tr>
<tr>
<td>4</td>
<td>Exponential</td>
<td>$Y = y_0 + a (1 - e^{-bc})$</td>
<td>$Y_0 = 0.659$, $a = -0.00022$</td>
<td>0.106</td>
</tr>
<tr>
<td>5</td>
<td>ln (2para.)</td>
<td>$Y = y_0 + a \ln (x)$</td>
<td>$Y_0 = -2.02$, $a = -0.28$</td>
<td>0.107</td>
</tr>
<tr>
<td>6</td>
<td>ln (3para.)</td>
<td>$Y = y_0 + a \ln (x-x_0)$</td>
<td>$Y_0 = 0.765$, $a = 0.15$, $b = -1.66 \times 10^3$</td>
<td>0.119</td>
</tr>
<tr>
<td>7</td>
<td>ln (2nd order)</td>
<td>$Y = y_0 + a \ln (x) + b \ln (x)^2$</td>
<td>$Y_0 = -18.2$, $a = 4.122$, $b = -0.225$</td>
<td>0.133</td>
</tr>
</tbody>
</table>

Table 8 The nonlinear regression equations for annual cumulative discharge/sediment of river Mahanadi (monsoon period 1993-2009)

<table>
<thead>
<tr>
<th>S L</th>
<th>Equation type</th>
<th>Equation</th>
<th>Parameters</th>
<th>$R^2$ Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Power</td>
<td>$Y = ax^b$</td>
<td>$Y_0 = 1.6 \times 10^4$, $a = 1.68$</td>
<td>.955</td>
</tr>
<tr>
<td>2</td>
<td>Exponential</td>
<td>$Y = y_0 + a (1 - e^{-bc})$</td>
<td>$Y_0 = 8.14 \times 10^3$, $a = 3.91 \times 10^9$, $b = 0.767$</td>
<td>.767</td>
</tr>
<tr>
<td>3</td>
<td>ln (3para.)</td>
<td>$Y = y_0 + a \ln (x-x_0)$</td>
<td>$Y_0 = -1.59 \times 10^7$, $a = 1.08 \times 10^6$</td>
<td>-.228 \times 10^9</td>
</tr>
<tr>
<td>4</td>
<td>ln (2nd order)</td>
<td>$Y = y_0 + a \ln (x) + b \ln (x)^2$</td>
<td>$Y_0 = 1.98 \times 10^7$, $a = 3.91 \times 10^9$, $b = 1.93 \times 10^9$</td>
<td>.922</td>
</tr>
<tr>
<td>5</td>
<td>ln (3rd order)</td>
<td>$Y = y_0 + a \ln (x) + b \ln (x)^2 + c \ln (x)^3$</td>
<td>$Y_0 = -1.65 \times 10^7$, $a = 4.83 \times 10^9$, $b = -4.69 \times 10^9$, $c = 1.52 \times 10^9$</td>
<td>.969</td>
</tr>
</tbody>
</table>

Geotechnical studies

The bed load collected from silt traps of Bhargovi weighed 37.35 kg and 39.47 kg and that of Daya 12.25 kg and 17.45 kg in the monsoon months of 2012 and 2013, respectively. The average specific gravity of bed loads of Daya and Bhargovi were 1.42 and 1.916, respectively. Temperature correction factor considered were 0.9996 to 0.9998. The average moisture content was 9.8% for Bhargovi and 13.3% for Daya. As per laboratory classification of soil, txdot designation (TEX-142-Es and S), the trap material was clayey soil having sand with 5 to 12% fine silt. The bed load materials from both the rivers Daya and Bhargovi were of SP-SM type. The Cu Values of the soil collected from silt trap is about 4 and Cc are 1 > Cc >3. It was confirmed that both the rivers flowing in alluvium.
5.4 Sediment Prediction though Artificial Neural Network (ANN)

Prediction of sediment yield of river Daya and Bhargovi

To have an accurate prediction, Artificial Neural Network (ANN) was used. Transfer Functions used were hyperbolic tangent transfer function (tansig), Log-sigmoid function (logsig) and Linear transfer functions (purelin). They use perceptron of Multi layered NN and Back propagation training (Figure 7). It has input values \(\pm \infty\) and output values are \(\pm 1\).

\[
\alpha = \text{Logsig}(n) = \frac{2}{1 + e^{-n}}
\]

\[
\alpha = \text{Tansig}(n) = \frac{2}{1 + e^{-2n}} - 1
\]

\[
\alpha = \text{Purelin}(n)
\]

Fig 7 Functions in ANN (Tansig, Logsig and Purelin) Md. Dorofkiet Al. 2012

ANN method has advantages that previous knowledge is not essential for the underlying layer, faster processing and computation. Once data provided, computation and prediction is instantaneous (importance & complexity ignored). No statistical model or optimization technique is needed. Tansig is better and runs faster than Tanh function though the shape of output curve slight distorted. Purelin functions are applicable to data series for linear input output characteristics. Logsig perform better than Tansig with high correlation values.

Steps involved in NN for prediction, the design consists of steps: collection and compilation of data, normalizations of data, trimming outliers by data verification, creation of the network, configuration of the network [Input Layer, Hidden layer and Output layer], initialization of weights and biases, training, Validation of the network, (Fig 8 and Fig 9)

<table>
<thead>
<tr>
<th>#</th>
<th>River</th>
<th>Function</th>
<th>Performance Value</th>
<th>R-Value</th>
<th>Output Equation</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Daya</td>
<td>Tansig</td>
<td>0.91</td>
<td>0.955</td>
<td>(Y = 0.93 \times \text{Target} - 0.094)</td>
<td>Reliable</td>
</tr>
<tr>
<td>2</td>
<td>Daya</td>
<td>Logsig</td>
<td>0.85</td>
<td>0.072</td>
<td>(Y = -1.5 \times 10^{-5} \times \text{Target} + 1.7 \times 10^{-5})</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Daya</td>
<td>Purelin</td>
<td>0.874</td>
<td>0.024</td>
<td>(Y = 0.027 \times \text{Target} + 0.49)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Bhargovi</td>
<td>Tansig</td>
<td>0.026</td>
<td>0.761</td>
<td>(Y = 0.62 \times \text{Target} + 0.34)</td>
<td>Reliable</td>
</tr>
<tr>
<td>5</td>
<td>Bhargovi</td>
<td>Logsig</td>
<td>0.779</td>
<td>0.171</td>
<td>(Y = -5.8 \times 10^{-6} \times \text{Target} + 4.9 \times 10^{-6})</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Bhargovi</td>
<td>Purelin</td>
<td>0.91</td>
<td>0.273</td>
<td>(Y = 0.59 \times \text{Target} + 0.65)</td>
<td></td>
</tr>
</tbody>
</table>
On Analysis, Tansig function found to have highest $R^2$-value to be 0.95, 0.91 for rivers Daya and Bhargovi respectively. From the prediction for monsoon sediment, the Tansig transfer function proved a better result (Table 9).

**Post-Naraj Barrage (Daya River, Tansig)**

**Post Bhargovi: (Tansig)**

**Fig 8** ANN prediction results of Daya River -post barrage sediment: Activated function

**Fig 9** ANN prediction results of Bhargovi River -post barrage sediment: Activated function (Tansig)
It has been predicted for sediment flow to Chilika by SMD rivers by ANN (Tansig) method and the results for July, August and September and October 2015 were 305MT, 107233MT, 63951MT and 171489MT, respectively for river Bhargovi. The predicted corresponding results for river Daya in 2015 were 1988MT, 255896MT, 443301MT and 701185MT respectively for river Daya. The results of sediment prediction for rivers Daya and Bhargovi seem to be reliable.

6. Results and Conclusion

1. Assessment of pre-barrage to post barrage situation reveals that the sediment concentration of rivers has reduced from 0.268mg/lit to 0.218gm/lit in Daya and from 0.288gm/lit to 0.166gms/lit in Bhargovi while comparing pre barrage to Post barrage period. It can be considered as the result of efficient operation of the Naraj barrage.

2. The average sediment concentration in Mahanadi at Naraj during the period 1980 to 1984 of 0.775gm/lit was reduced to 0.252gm/lit during the period 2000-2003, i.e, -67.5% and from 0.252gm/lit to 0.227 gm/lit i.e. -10% during the period 2004-2012. The non-monsoon sediment concentration decreased from 0.091 mg/l to 0.231mg/lit, i.e. -66%.

3. Log Pearson Type III probability distribution function are the best fit probability distribution function for sediment flow in Mahanadi deltaic channels both for monsoon and Non-monsoon period.

4. (a) For non-monsoon flow, nonlinear regression equations u/s of delta follows a quadratic equation as the highest R² Value = 0.16.

\[ Y = -0.048 + 2.7 \times 10^{-4}x + 1.73 \times 10^{-8}x^2 \ (x = \text{Discharge in Mm}^3/\text{sec and } Y \text{ sediment in MMT}) \]

(b) For monsoon flow, the best fit equation is the log 3rd order equation with highest R² value of 0.969 is given by

\[ Y = -1.65 \times 10^7 + 4.83 \times 10^6 \log x - 4.69 \times 10^5 (\log x)^2 + 1.52 \times 10^4 (\log x)^3 \]

A simple power equation can give almost equal result with R² value of 0.96 and the equation is given by

\[ Y = 1.6 \times 10^{-4} X^{1.68} \ (\text{Where, } X = \text{Discharge in Mm}^3/\text{sec and } Y \text{ sediment in MMT}) \]
5. The bed load is clayey soil of sand with 5 to 12% fine silt. The bed load materials from both the rivers Daya and Bhargovi for the year 2012 and 2013 is of SP-SM type. The Cu Values of the soil collected as bed load from silt trap is less than or just exceeding 4 and Cc are 1 > Cc > 3. Higher bed load flow in River Bhargovi than River Daya.

6. a. From the nonlinear regressions, the $R^2$ value of the power function was the highest as 0.86. The relation between the sediment and discharge for the river Daya during monsoon period was given by

$$Y_{TSS} = 1.412 \times X^{0.004}$$

b. From the above nonlinear regressions, the $R^2$ value of the Exponential function was the highest and was 0.58. The relation between the sediment and discharge for the river Bhargovi during monsoon period was given by

$$Y_{TSS} = 0.0035(1 - e^{-6.98 \times 10^{-5}x})$$

7. Among Tansig, Logsig and Purelin, the Tansig prediction of results are reliable and found for the years 2015, 2020, 2030, 2040 and 2050.

8. Suggested management strategy of Naraj Barrage:

The proposed operational procedures of Naraj barrage are as stated below.

**Situation I: Pre-Barrage condition**

All gates of Naraj barrage shall be opened during flood period to maintain pre-barrage condition only when the discharge of Mahanadi river is beyond 38500 cumec.

**Situation II: Average flood period**

In an average flood period, the Naraj barrage shall be operated except the first flood up to discharge of 15500cumec initially in Mahanadi to avoid excess sediment flow to Chilika through Kathajodi.

**Situation III: High flood Period**

The Naraj barrage shall be operated for the floods exceeding 18500cumec in main branch of river Mahanadi and the extra amount of flood would be allowed to pass through the Khathajodi branch up to discharge of 31300cum. This can ameliorate flood havoc in the downstream of the river for any high flood beyond discharge of 35000 Cumec, all the gates of the Naraj, and all other barrages shall be kept open for free flow in respective rivers.
Situation IV: Draught year
To maintain minimum flushing flood into the Chilika, during the draught years a discharge of about 1500 to 2500 cumec is essential in river Kuakhai. In drought year entire discharge of river Mahanadi is to be diverted to the Chilika through the Naraj barrage, leaving aside only the riparian right in the Mahanadi and the irrigation requirements in its downstream.

8. Organisation of chapters in Thesis

The Organization of Chapters in the thesis is as follows:

Chapter 1: Introduction

The introduction chapter contains overall view of the features of the study area, Importance of the study, Research objectives, Materials and Methodology, Outcome of study and chapter wise planning of the Thesis report.

Chapter 2: Review of Literature

Brief summary of the previous research works pertaining to the study is described in this chapter. Reviews of available literatures related to Geomorphology, Hydrology, Sedimentology and Lake geology are presented.

Chapter 3: Study Area

Description of the study area is presented in this chapter. Details of river systems, South Mahanadi Delta, Chilika lagoon and the interventions are discussed. Detailed data are presented in tabular form.

Chapter 4: Geophysical Studies

This chapter contains information regarding morphological changes of the lagoon, the river basin, morphology of offshore, anastomosis in lower delta, growth of south Mahanadi delta and historical information of formation of the lagoon etc. Detailed study of the geophysical changes of lagoon such as; study of water spread area, in the barrier spits, tidal inlets sectoral transformations etc.

Chapter 5: Rainfall Analysis of South Mahanadi Delta and Lagoon

Rainfall analysis of the south Mahanadi delta and the lagoon area, and changes of few climatic parameters such as Temperature, Lightening, runoff, and change of bio-diversity in the area are described in this chapter. Rainfall analysis of the area has been done in details.
Chapter 6: Flood analysis of major inflowing rivers into Chilika lagoon

Flood frequency analysis and stochastic modeling is presented in this chapter. Regional extreme flood analysis of Mahanadi, Flow scaling in various branches of river Mahanadi, Stochastic analysis of extreme floods of rivers Daya and Bhargovi are presented.

Chapter 7: Sedimentation study

Sedimentation studies of various rivers, i.e, Mohanadi, Daya and Bhargovi are narrated here. Details of physical study through observatories and geotechnical studies are described. Stochastic analysis for the fluvial system of in South Mahanadi Delta and Chilika lagoon are also presented.

Chapter 8: Prediction of Sediment inflow

This chapters shows the prediction of sediments in rivers Daya and Bhargovi transported to chilika lagoon. It also summarizes the prediction methods of future sediment influx to Chilika lake via rivers using soft computing from 2015-2050.

Chapter 9: Summary and Conclusion

This chapter narrates the concluding remarks of the whole study and states the pertinent results of the study.

References


