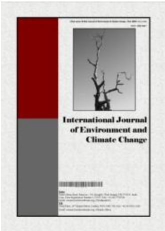

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Estimation of Sediments in Rengali Reservoir, Odisha (India) Using Remote Sensing

Siba Prasad Mishra [a*], Chandan Kumar [a], Abhisek Mishra [a], Saswat Mishra [a] and Ashish Patel [a]

[a] *Civil Engineering Department, Centurion University of Technology and Management, India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Reservoir sedimentation is a regular process and sequential path of sedimentation in reservoirs comprising of erosion, entrainment, transference, deposition and compaction of dregs carried into artificial lakes formed behind the dams. India houses 5334 large dams in function (2329 numbers before 1980) and 411 dams are in pipeline. The Rengali dam, functioned from 1984, that traps 50% of the total sediment load of the Brahmani River continues to thwart the growth and buffering of the Brahmani delta.

Remote sensing (RS) and Geographical Information System (GIS) have emerged as powerful tools to create spatial inventory on Hydro-Bio-geo resources and the state of the environment. The RS/GIS and process-based modelling employed in spatial and dynamic assessment of loss in live storage of the reservoir by developing contour, aspect and slope map by using data received from LANDSAT sources.

The sedimentation of the Rengali reservoir (functional from 1984) studied for three decades 1990-2000; 2000-2010 and 2010- 2020 by constructing contour, aspect and water spread area maps by using web based data (satellite downloads). The web based water spread area data analysed by GIS tool for integration, spatial analysis, and visual presentations.

The results revealed that the decadal rate of sedimentation of Rengali reservoir is reducing with

**Corresponding author: E-mail: 2sibamishra@gmail.com;*

age. An appropriate reservoir operation and management system as per defined protocols considering sediment related problems is essential for controlling the ageing processes that may diminish the safety and shorten the reservoir life.

Keywords: Contour/aspect map; geospatial; remote sensing; Rengali reservoirs sedimentation; web-based data.

1. INTRODUCTION

Climate change, erratic rainfall, off time onset and withdrawl of monsoon, coastal changes along with anthropogenic interventions on the regime have altered the fluvial status of the rivers and sediment status [1]. Under the exponential demographic growth and sustained hydroelectric power demands rise in crop yield, the deltas accommodating about 322 people/km^2 in 2000 to estimated population density of 422 people/km^2 in 2020. South Asian countries like India, Bangladesh, China, Vietnam, Indonesia, Thailand, and the Philippines etc., is house to about 73% of the people of the country. The immediate adversities that the dams cause are encroachment of productive land, forests, ecosystem, properties, more oustees, sinking, shrinking and subsidence of coastal deltas as long-term effect. About 85% of coastal areas are heavily flooded superseding the multipurpose reservoir benefits, which has warranted construction of dams across river course [2,3,4,5, 6,7,8,9].

India possesses 5334 large dams in action and 411 numbers are in the pipeline with gross storage area above 257.812BCM. Out of the in operation dams, 80% have lost 50% of its life span and unsafe, [10]. They demand their renovation by either improvisation or restoration to protect the national assets, ecosystem, people and property. The scheduled operation rule curve of a reservoir to augment its water for irrigation, hydropower, flood control, navigation or recreation has become controversial in various conflicting issues like space, time and discharge. As a result, majority of old, reservoirs have turned geriatric and warrant to be modified in view of sediment administration for its sustainability based on catchment characteristics, [2,11,12,13]. Rengali Reservoir over river Brahmani in Odisha is one such example (Fig. 1).

The terrigenous sediment are the natural organic, earthy and minerals transported by the rivers as bed load, suspended load and wash load. The upper soil of the earth or weathered rock was detached from their parent source by air; rain or snow forms rills and gulley and finally to the river via the anastomosed drains. In boulder (mountainous) reaches as pebbles to coarse sand, transforms to fine sand and silt while reaching the delta and estuaries. The transportation of the particles uses the river gradient, the flow velocity, gravity, size of the involved particles and other enacting forces. The modes of transportation are traction (rolling), saltation (uplift and later fall) and suspension. The dissolved solutes have less contribution to sedimentation as is a long-term dissolution process [14].

Fig. 1. Map of Bramhani River Basin showing its reservoirs and Rengali dam (source: Internet)

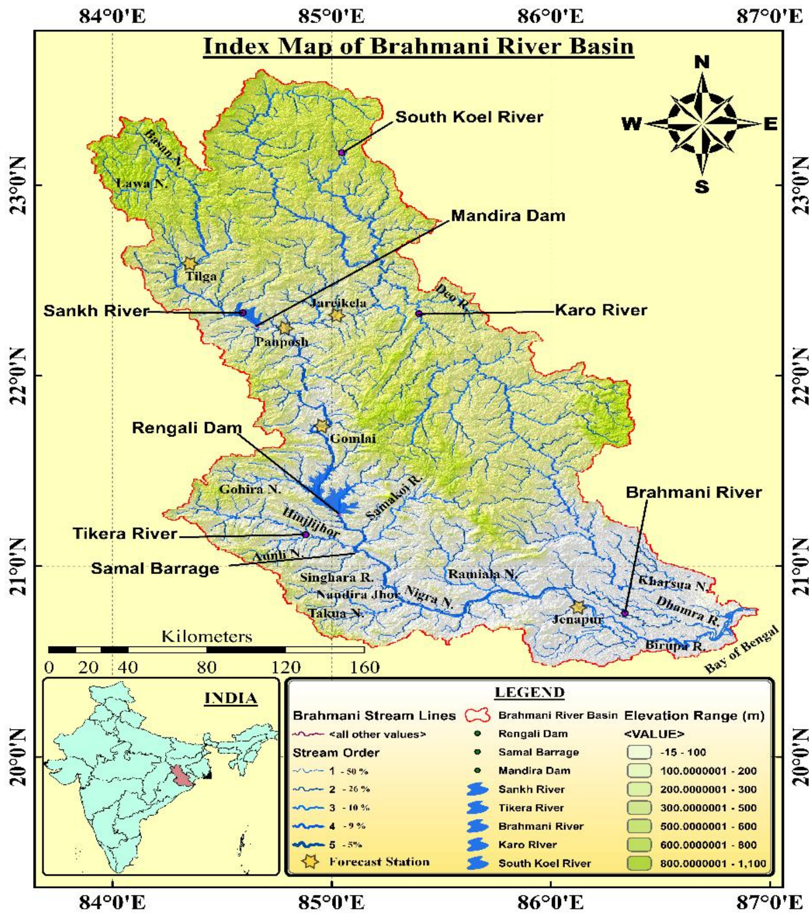


Fig. 2. Index map of Bramhani Basin with the reservoirs

Indian peninsula, the land of ridges and valleys has network of rivers. The east flowing major rivers in India, due to their large basins, and deltas, the sediment load during monsoon period is high. soil erosion from the geological unstable basins are vulnerable, especially during floods where huge sediment is elated, and deposited in the reservoirs. Examples are the Godavari, the Mahanadi, the Bramhani, the Krishna, the Subarnarekha, the Vaigai, and many others. The Bramhani is one of such rivers Brahmani is of 799km in length, basin catchment 39,116km^2, at delta head (Catchment 33955km^2) with annual discharge (1986-2011) was 17.43Bcum and average sediment flow (1993-2012) was 5.23MMT at Jenapur [15]. Rengali Dam in the upper reaches of Brahmani river has stream order five is in (Fig. 2).

2. REVIEW OF LITERATURE

Globally, the rivers in south East Asia have rivers with large deltas and their sediment yield are large and posing problems to the reservoirs [16,17,18,9]. Southeast Asia considered the region with the largest sediment yields [8]. Dams constructed across rivers changes its flow and sediment regime, [19]. Sinking, shrinking and subsidence in deltas in downstream of are caused by dams shall affect the terrain and fluvial management, sediment supply, catchment characteristics [20,21,22]. Present dams are acting as mid-sediment traps and causing sand paucity for the yield rich deltas. The reserve storage capacity affected by sediment yield, and hydrologic variability, soil erosivity of the basins and watersheds [23,24,25,26,27]. Reservoir sedimentation is a sequential course of sedimentation in reservoir comprising of erosion, entrainment, transference, deposition and compaction of sediment carried into reservoirs formed behind the dams.

The sediment accretion in rivers and trapping in reservoirs can be calculated using channel flood plain geometry and satellite imagery, GIS and Remote Sensing, [28,29,13,30]. The sediment analysis and prediction of reservoir sedimentation is possible by soft computing like; ANN, SVM or GIS/RS, proved to be an effective tool used throughout the globe, [31,32,33,34,35]. Sedimentation and depletion of the storage capacity at FRL is common in Indian Reservoirs and utility in long run, [36,37,38,39,40]. The sedimentation of adjacent old reservoirs in the state comparable to Rengali have identical sediment concentration in the Hirakud reservoir in Mahanadi system [41].

The sedimentation survey of Rengali reservoir conducted during the year 2006 by Central Water Commission (CWC). The old process is monotonous, time consuming and disposed to inaccuracy though modern technologies like Robotic boat survey using echo sounder and transducers used. Present work deals with spatial analysis of sedimentation of the Rengali Reservoir for three periods i.e. 1990-2000, 2000-2010 and 2010-2020 over the last 3 decades, using GIS Based Web-platform, and compared with statistical approaches.

2.1 Scope of Study

The Landsat data for 1990, 2000, 2010 and 2020 downloaded considering the same month of the year and contour, elevation, aspect and water spread area maps made, and compared for three decades and the amount of sedimentation accrued compared.

1. The entry of flow and sediment to the reservoir and the same at apex of the delta as available analysed and concentration study conducted for the period 1986 to 2014.
2. After inception, during initial 6 years (1984 - 1990), the reservoir found was heavy scouring indicating continuous and uninterrupted flow through the reservoir. The sediment, the weathered and decayed uprooted tree roots are at the peripheral banks.
3. Sedimentation in the next three decades i.e. 1990-2000. 2000-2010 and 2010- 2020 computed and compared the cumulative deposits
4. Discussed the probable causes in the trend of increase.
5. Some desilting prospective in the upper reaches of the basin of the reservoir discussed.

2.2 Location

The river Bramhani originates at the confluence of the rivers South Koel and Sankh at Vedavyas near Rourkela (22 15' N and 84 47' E). The Sankh emerges near the Jharkhand-Chhattisgarh border (near Netarhat Plateau) whereas the South Koel and Karo rises from Lohardaga in Jharkhand opposite side of the Damodar River in the Chhotanagpur Plateau. Small tributaries of the river Brahmani are Kansa-Bansa, Lawa, Karo, Rukura, and Gohira. The basin have typical physiognomies that the Brahmani River emerges near the origin of the Mahanadi River from the same hills at Nageri. The Tikira, and the Samakoi, are the tributaries joining the Brahmani River below the Rengali Dam until Samal Barrage. At the outfall, the river carries the riverine flow of adjacent the Baitarani River and finally debouch to Bay of Bengal, (Fig. 2).

2.3 The Rengali Dam and Reservoir

The medium dam is 70.5m above MSL and length is 1040 m. The second largest manmade reservoir having catchment area 25250 km^2 in Odisha spreads over 37840ha at FRL and 28000 ha at the Mean level. It stores 4494.77Mm^3 of water with average (av.) annual inflow of 14900 MCM. The dam has 464m overflow section (24 gates), spilling capacity of 47000m^3, and maximum reservoir level 125.4 m. The Rengali dam impounded from 1984, and 35km downstream, the Samal barrage (1994) is in operation with catchment area at barrage site 30,030 km^2. The barrage provide irrigation to gross command area is 3364 km2 and the dam finally power generation in five units to a tune of 250MW (1992). The reservoir is type I (lake type) and in the process of shift towards Type II (Flood Plain-Foot Hill) at high depth as per [42].

The major tributaries of this river are Sankh, Karo (Koel), Mankada Nallah before dam, and Tikira before barrage. The maximum peak water level recorded was 378.83 m in Tilga site on 27.07.2017 (base period 2019-20), CWC Data Boo 2021. At Gomalai, at apex of the Rengali reservoir, the river has catchment of 19820 km^2 and run off was 0.68 Cu .Km. during the period June-Nov and corresponding suspended sediment transported 6.527MMT, India waterportal org/ sites/default /files/iwp2/Water_Data_Complete_Book_CWC_2005.

2.4 Brahmani Basin

The basin is a conjugate canopy the Brahmani and the Baitarani mixing bowl, (Fig. 3). The climate of the basin is Savanna tropical with hot summer and moderately cold winter. The basin influenced by southwest monsoon from June to October, (2019-20). The basin spreads over Jharkhand (U/S major tributaries), Chhattisgarh (least), and Odisha States. The Brahmani River totally flow in Odisha from Vedavyasa to Bay of Bengal. The river receives runoff from 50015 km^2 (about 1.7% of the geographical area) of the country. The travel time of flood is 13-15hours from Vedavyasa (Panposh) to Rengali, 3 hrs. from Rengali to Talcher and 16-18 hrs. to reach delta head at Jenapur. The Upper reaches of the basin houses the Rourkela city and mining areas of Sundergarh, Deogarh and Keonjhar areas of Odisha (Fig. 3).

2.5 Soil Erosion in Brahmani Basin

The anthropogenic land degradations and the respective gulley erosion have made the upper Bramhani basin fragile and unstable. The bald landscape has yearly erosion rate varies within the range 8.12–24.01 kg m^{-2} y^{-1}. Heavy rainfall trigger initially along with the local topography such as slope morphometry, land use, barren soil cover and soil-plant characteristics control the triggering of gully erosion. The annual erosion rate beyond the soil tolerance limit (T-value – 1.0 kg m^{-2} y^{-1}) obtained from potential erosion map of area. River Brahmani had a dry period and reservoir levels depleted by 33.1% between May 2014 to 2019, [43].

The minerals available in the basin are limestone, dolomite, lead, fire clay, bauxite and china clay. The towns and industries are steel plants, cement, aluminum, explosive, and chemical plants. The soil in the upper basin area are red and yellow soils, red sandy and loamy soils, mixed red and black soils. The Rengali reservoir has the live storage capacity at full reservoir level (FRL) is 3.432BCM and on 25.03.2021 the capacity has reduced to 1.159BCM and the average decadal live capacity 1.934BCM. Within 40 years, the depletion of volume was 1.348BCM is due to sedimentation. In comparison to Hirakud reservoir, considering the design live storage capacity at FRL and in the adjacent, the Mahanadi basin, the rate of flow is higher and immediate action is pertinent to monitor the loss of the life of the reservoir, [44]. The basin covers three states Chhattisgarh, Jharkhand and Odisha. The distribution of catchment area, length of the rivers is in (Table 1).

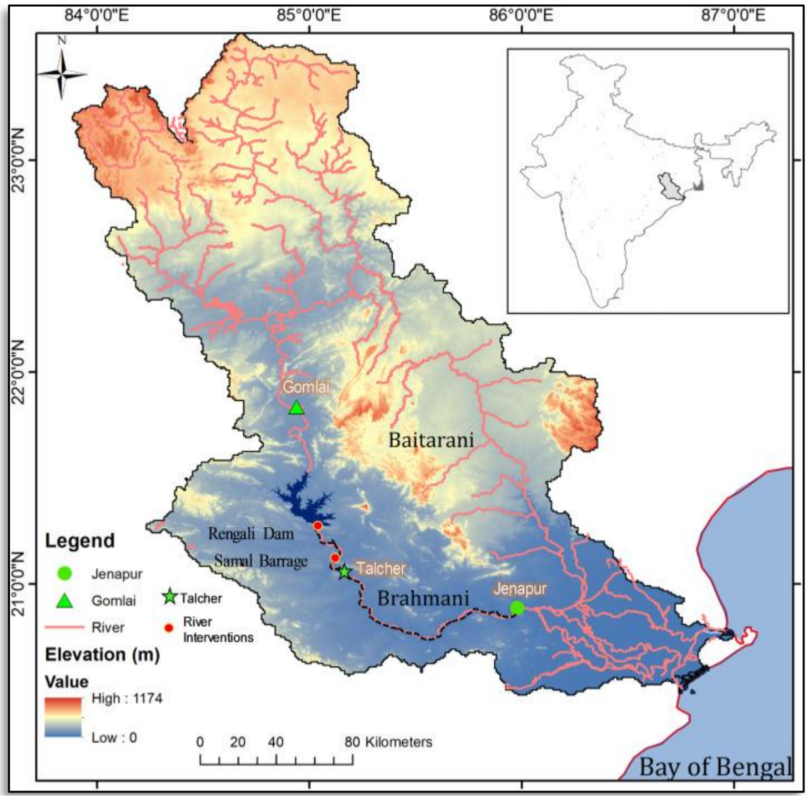


Fig. 3. The origin/debouch of the Bramhani and the Baitarani rivers to Bay of Bengal

Table 1. The state wise coverage of geographical, basin area of 799m long Brahmani River

#	The state in India	Geographic area (Km^2)	Catchment area (Km^2)	%of area	Area/districts
1	Jharkhand	23173	15,769	40.4	Loherdega, Simdegam Gumla, Ranch, Singhbhoom (W)
2	Odisha	43982	22,364	57.3	Sundargarh, Keonjhar, Deogarh, Angul, Dhenkanal, Jajpur, Kendrapada
3	Chhattisgarh	28491	900	2.3	Sarguja, Jashpur
	Total	95646	39,033	100	

3. METHODS

Reservoir sedimentation estimated from river sediment flow and reservoir surveys by using the trap efficiency and sediment distribution either by manual survey (BIS: 12182: 1987) or by web based technologies. Reservoir sedimentation survey methodologies based on mapping of water-spread area at the time of satellite overpass is one of the better option. Multi-date satellite data is needed which covers the operating level of reservoirs at close interval. Water spread area is the water level contour at that level. Using different contours, capacity between them is calculated. The water spread area and the elevation information are the source to calculate the volume of water stored between different levels. These capacity values then linked with the previously calculated capacity values to find out the change in capacity at different levels.

The sediment carried by rivers trapped by the reservoir together with bed load. The gauge and discharge observations are for calculating discharge and sediment at the specified section. Robotic boat surveys, echo sounder or transducers are modern gadgets to take physical observations, which yield series of observational data. The present method employed for assessing the reservoir sedimentation is by GIS/ GNSS/RS methodologies, which gives thematic information directly. These big data can have fast and accurate analysis with economy. Various models, software's, and computer devices employed to arrives at the sedimentation rate of a reservoir geospatially.

The GIS/RS gathering data about terrestrial attributes and earth's feature based on water spread area for time to time. These attributes emit electromagnetic waves based on the terrain geology, and temperature and emissivity from the emitted radiation. All these features received from the satellites recorded by the sensors on board of GNSS satellite and transmitted back to the earth. Difference between features are vegetation, soil, etc. Data received at ground stations, digitally or visually interpreted to generate thematic maps. Satellites data such as Landsat, SPOT and IRS are more useful for mapping and monitoring the land resources for better water management planning.

Any reduction in water spread area at a specified elevation over a period is indicative of sediment deposition at this level. This when integrated over a range of water stages helps in computing volume of storage lost by sediment deposit. A systematic process provided in the methodology section provided below:

1. Site selection and acquisition of digital data i.e. Landsat data.
2. Created the Composite map by combining the bands available in the Landsat data.
3. Mapping out our area of focus from the Composite Map, which is the Rengali Reservoir.
4. With help of the elevation data, created contour map of the study area.
5. Then converted the Composite Map i.e. the transformed the topographical data to Raster Map.
6. Following the creation of Raster Map, IDW (inverse distance weighted) Map was made using the interpolation tool under Arc Toolbox.
7. The IDW Maps and Raster Maps exported into a different layer for further processing.
8. All the exported files were then converted, using the conversion tool under Arc Toolbox, to TIN (Triangulated Irregular Network) format.
9. The TIN formatted Maps then compared using the surface tool under Arc Toolbox.
10. Post comparison, a difference map created to show the results.
11. The resulting difference map, attribute values are noted and the data exported to MS Excel file.

12. The exported data then used to analyse the sediment percentage increase or decrease.

Present Satellite data is of five optimal dates corresponding to various water stages from minimum to maximum draw down levels used in estimating the water spread areas. Simple ratio (NIR/RED) image generated to identify the water pixels and then verifying the standard FCC. The non-water pixels identified with the ratio (GREEN/NIR) image and removed to have the total water spread. The water spread area on different satellite overpass dates and corresponding elevations used to find the total reservoir storage capacity with the help of Elevation area curve.

The limitations in the research are (i) estimation works between MDDL and FRL only possible as these are the levels between which reservoirs operates. Changes estimated only in the live capacity of reservoir. For capacity estimation below MDDL corresponding to dead storage conventional hydrographic survey techniques are used. (ii) Availability of cloud free data throughout reservoir operations also poses limitations in the analysis. The lacunae evaded by combining data from different water years to get full operative range.

3.1 Sediment Yield of Indian/ Brahmani Reservoirs

The weight of sediment transported across a cross-section of river/ reservoir during a stated period is its Sediment yield, which estimated annually ([45]). Various models, (empirical or conceptual) are in use to address the problem of soil and water planning and management. The required parameters are land use, vegetation, soils, slopes, drainage density, rainfall intensity etc. Empirical models in Indian scenario for sediment yield [46,47] for reservoirs are:

$$V_s = 1.067 * 10^{-3} * P^{1.384} * A^{1.292} * D_d^{0.392} * S^{0.129} * F^{2.51} \quad (1)$$

$$F = \frac{0.21\,F_1 + 0.2F_2 + +0.6F_3 + 0.8F_4 + F_5}{\sum_{i=1}^{5} F_i} \quad (2)$$

Where $V_s =$ the sediment yield Mcum/year; P = Annual rainfall in cm; A= Sub water sed area in Km^2 $D_d =$ drainage density Km/Km^2 ; S = Average slope and F is the vegetative factor where F_1 = Reserved and protected area; F_2 = unclassified forest area; F_3 = Cultivated area; F_4 =area belonging to grass & grazing area; F_5 = fallow area and waste land all in Km^2.

But the reservoir storage capacity (S in m^3) and the reservoir level (H_{res}) follows the relation

$S = 652600 * (H_{res} - 92.423)^{2.566}$ where H_{res} lies between 109.7m to 125.4m

The trap efficiency is the ratio of deposited sediment quantity to the total inflow sediment. The dependant variables for trapping of silt are size of the sediment particles, fall velocity and the flow rate through the reservoir.The rule curve for the Rengali reservoir is as follows (Table 2).

The above attributes can be available in the drainage map, LULC map, slope and contour maps that can be available with better accuracy and faster period by GIS/ RS methodology. Present research utilizes the methodology to assess the sediment deposition in Brahmani reservoir.

3.2 Climate, Past Studies on Rengali Reservoir Sedimentation

The basin enjoys scorching summer (max 47°C), and soberly winter (even 4-5°C due to altitude effect), and receive rainfall (av. 1305mm) from southwest monsoon from June to October months (Fig. 4). The Rengali reservoir before impounding (1984) designed without sedimentation modelling. The designed dead and live reservoir capacity at FRL - 125m were 988.8, and 3505.9Mcum respectively. After 27 years, the Rengali reservoir capacity were 619.24 MCum and 3130.51MCum respectively in the year 2006. The reservoir lost its capacity of 745.02cum within 27years with average rate of silting 1.229 Th. Cum/Sq.km/ yr., or 1.229 mm/yr., or, 31.043 MCum /yr. in 27 years (1982 to 2006), [42,48].

Table 2. The rule curve for reservoir operation plan for Rengali River during various months

Date of year	1st july	1st Aug.	1st Sept.	9th Sept.	22nd Sept.	1st Oct	1st Nov
MRL+MSL (m)	109.72	116.00	122.0	122.3	123.5	123.5	123.5

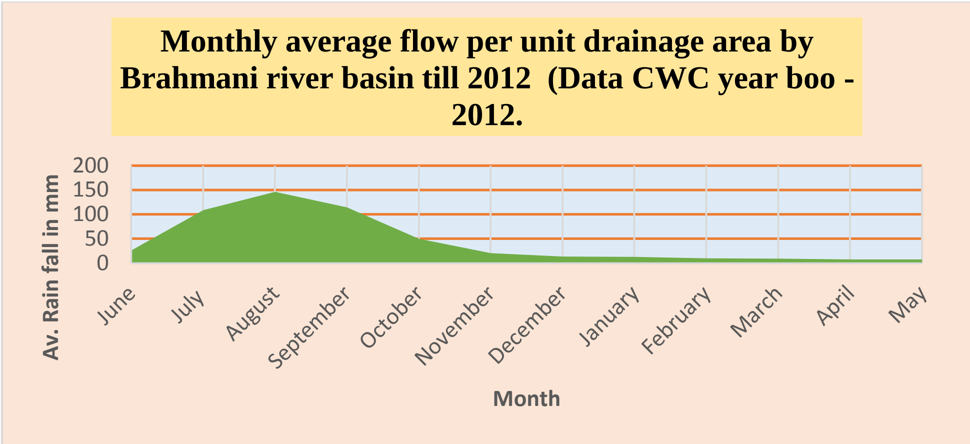


Fig. 4. Monthly av. flow/unit drainage area by BRB until 2012 (Data CWC yearbook -2012)

The flow (1987-2014) and suspended sediment (1993-2014) data before entry at station (Pan posh or Gomlai) and after release from the dam at station and at the apex of the delta at Jenapur (for the same period) gathered from various handbooks issued by Central Water commission, a pioneer Government India Organisation. The compendium of data made a time series and was analysed for flow, sediment discharge of the river Brahmani before and after the Rengali reservoir. Using CWC gauge and discharge observation data for non-classified rivers 2021, [49].

The inferences observed are:

1. The average inflow at Gomlai or Pan posh before entry for the period 1987-2014 were 10.861Bcum and average sediment entry was pre-reservoir was 9.299MTM. The average out flow (1987-2014) from the river downstream at Jenapur was 17075.32Bcum and average corresponding sediment flow (1993-2014) was 4.861MMT respectively.
2. The sediment concentration at upstream of the reservoir ranges from 2.434 MMT/Bcum (1994) when flow was 9.045BCum to 0.324MMT/Bcum during the year 1995 when flow was 22.059Bcum respectively.
3. We may infer that generally at low volume of flow the sediment concentration is higher and vice versa.

The web-based study of Brahmani R. Sedimentation:

Remote sensing and Geographical Information System (GIS) have emerged as powerful tools to create spatial inventory, integration of data and information on natural resources, their spatial analysis, and for visual presentations. RS and GIS are process-based modelling that plays crucial roles in spatial and dynamic assessment of surface area. The RS methods have great advantages in observing actual picture i.e. the synoptic view, wide area, non-destructive, and/or real time bases. The sensor technologies, nonvisible signals such as in near infrared, thermal-infrared and microwave wavelength domains can segregate the thematic layers.

The Landsat data acquired from the public USGS site used to create Band Combination. The Composite Map inherited by using the Composite Tool, from which the study area masked out. Later the Land use and land cover Map, Aspect Map, Contour Map, Slope Map and the Raster data Map created from the Topography data. The Inverse Distance Weighted (IDW) interpolation map, by use of interpolation tool, created. The flow and sediment data collected by CWC is shown in Fig. 5 and Fig. 6.

The major land use and land cover area in the upper Brahmani basin in the year 2020 has mountainous region 37%, built up area 31%, and barren land covered 30%. The land can be more vegetative growth in the area on implementation of pertinent action plans (Fig. 7).

3.3 The Contour Map of Rengali Reservoir

The creation of surface difference map created by exporting the attribute Table data of Surface Difference Map into MS Excel and doing sedimentation analysis. The Slope aspect and contour maps of the Brahmani reservoir created (Fig. 8 a, b, c, d).

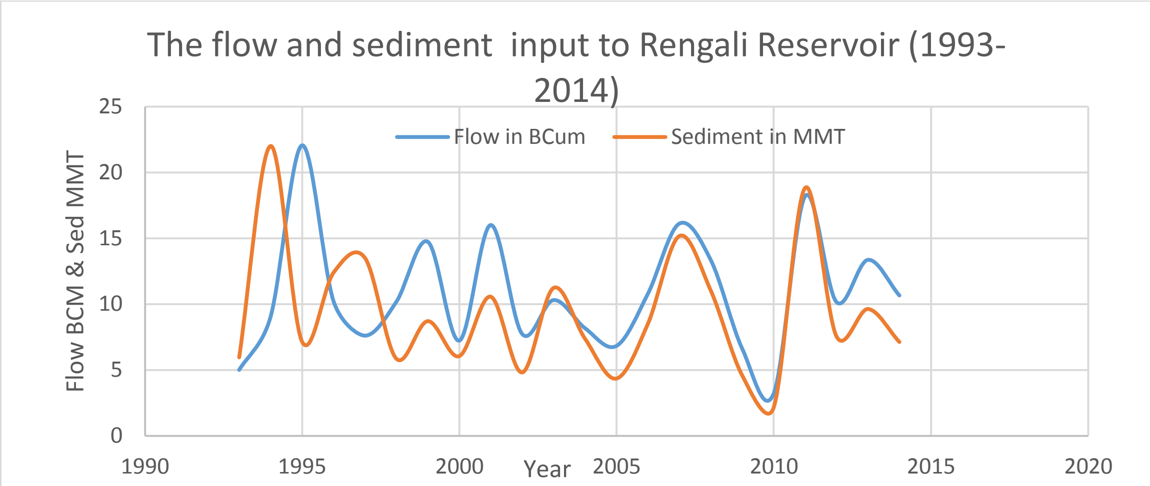


Fig. 5. The flow and sediment inflow near entry point of Rengali Reservoir (1993-2014)

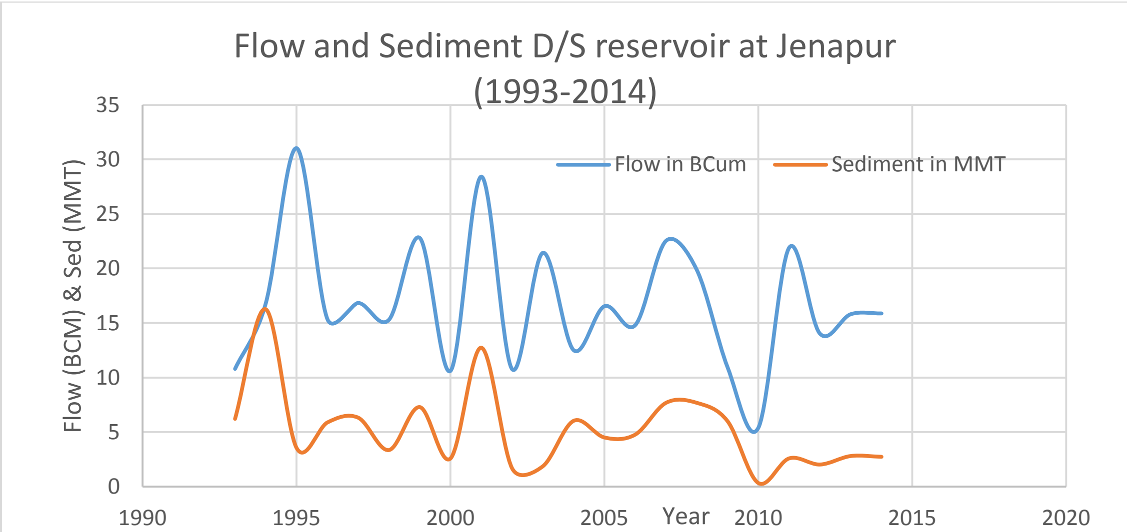


Fig. 6. The flow and sediment outflow near exit point of delta head at Jenapur (1993-2014)

3.4 Slope Maps

The slope is an important topographical attribute responsible for degradation of watershed. The steep slope causes more soil erosion resulting development of gullied lands; loose the moisture holding ability of soils. For generation of slope map, the contour map, and elevation map of Upper Brahmani basin considered. Using the inbuilt sub-routine of ILWIS, the slope map for the region generated. Using the iff statement, the slope map for each of sub-watershed have been generated and using statistics of that map, the average soil loss from sub-watersheds computed separately (Fig. 9 a, b, c, and d).

3.5 Aspect Map

The aspect map (breadth to depth ratio) principally states to the bearing of the mountain slope faces, an important attribute indicating the influence of sun i.e. the distribution of vegetative area in the basin prompted. The aspect map obtained from the SRTM DEM. It represents the direction of the aspect. The values 0-22.5 represent north; 67.5-112.5 denote true east. The upper Brahmani basin displaying slopes east facing. These slopes have high moisture so possess dense vegetation compare to west faced slopes, [50], (Fig. 10. a, b, c, d).

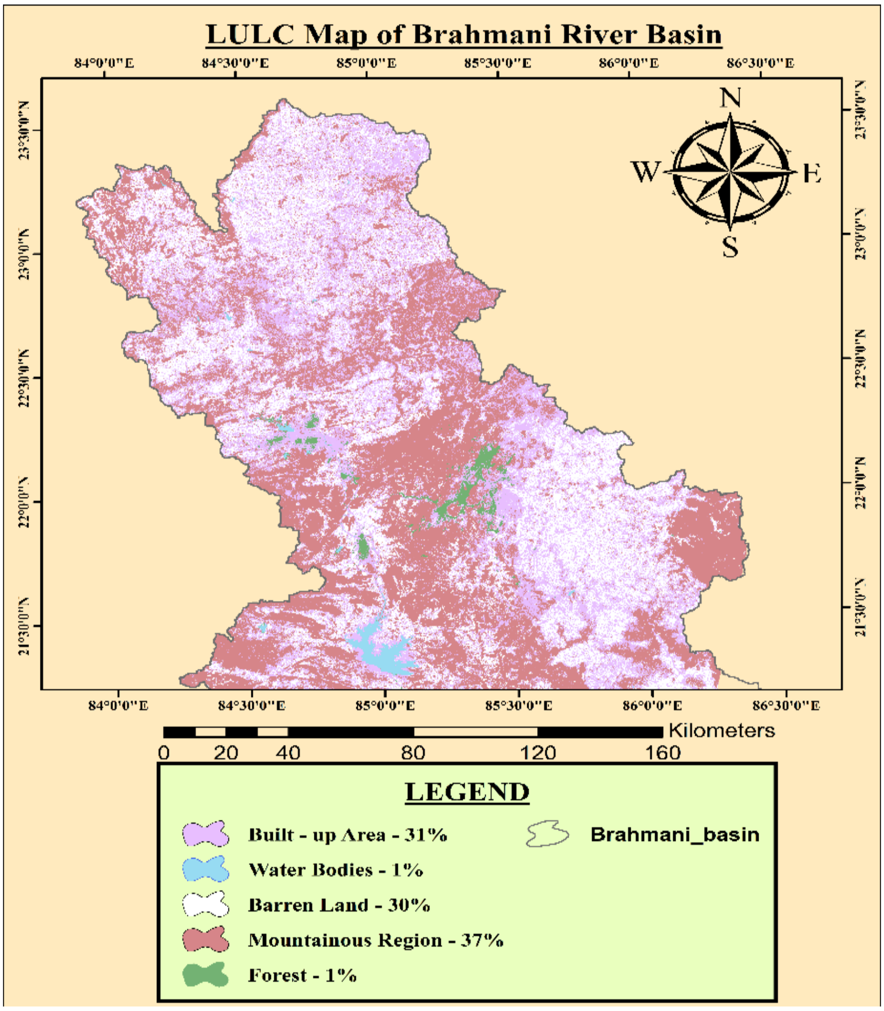
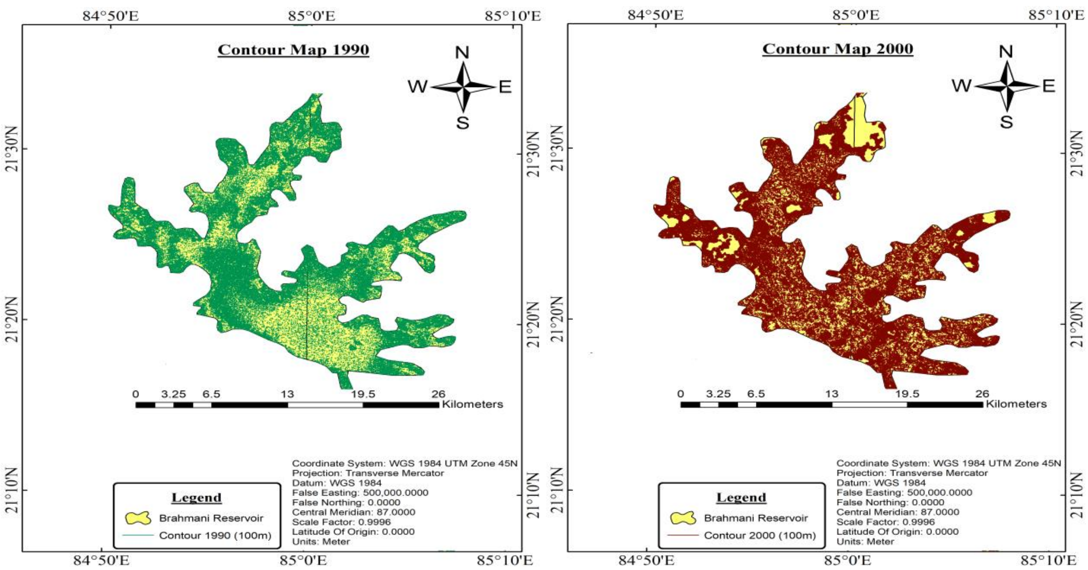


Fig. 7. The land use and Land cover map of the upper Brahmani basin



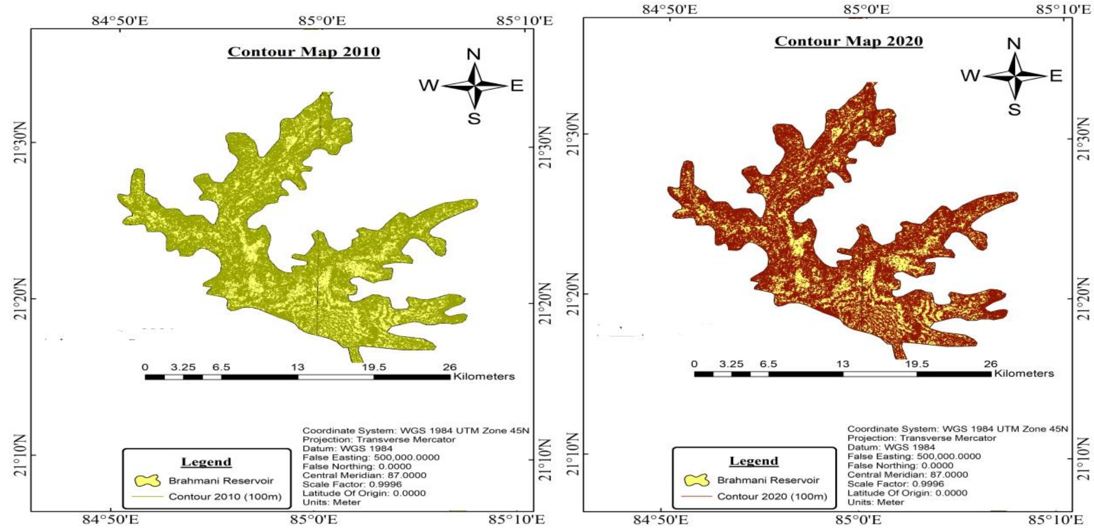


Fig. 8. (a, b, c, &d). The contour map of the Rengali reservoir during 1990, 2000, 2010 and 2020)

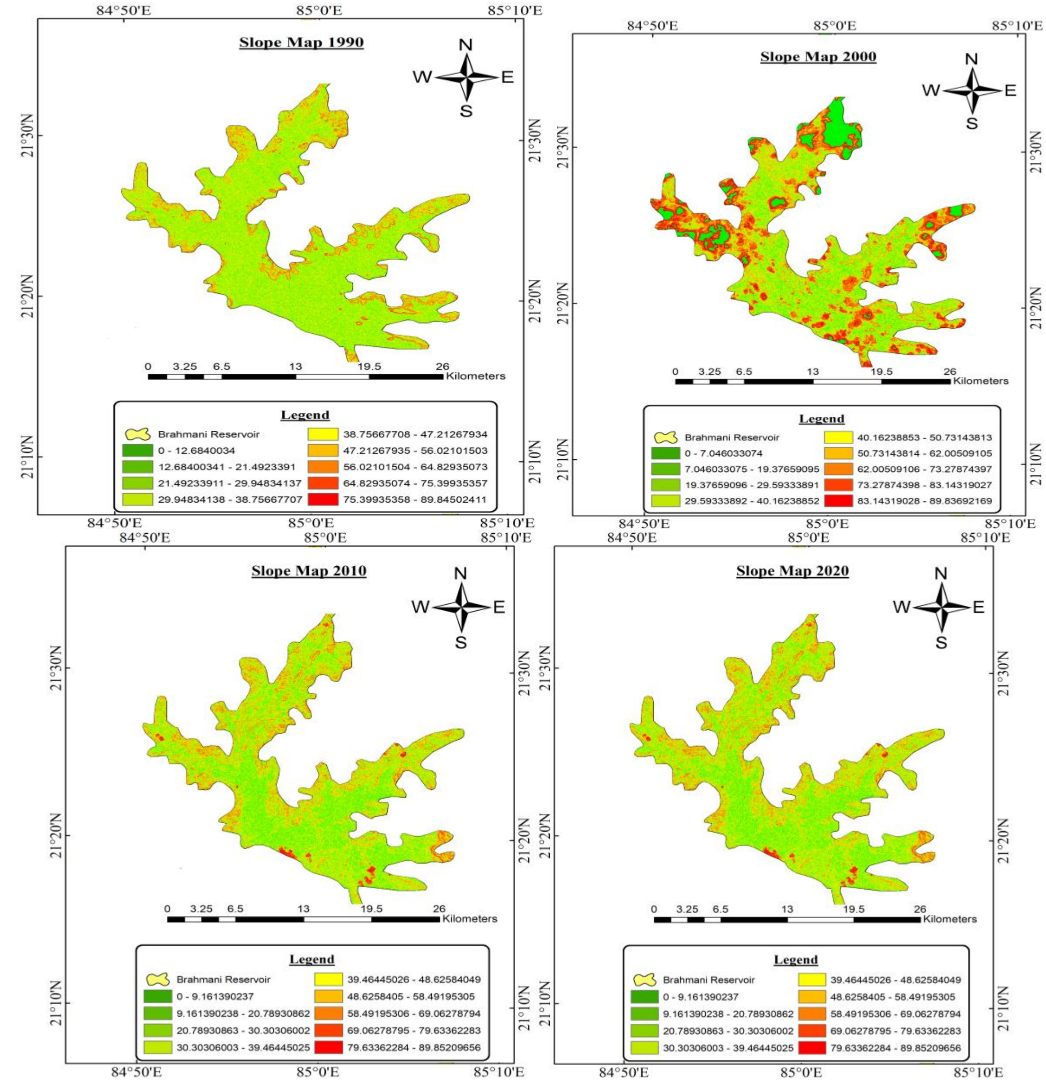


Fig. 9. (a, b, c &d). The slope map of Rengali reservoir area during 1990. 2000, 2010 and 2020

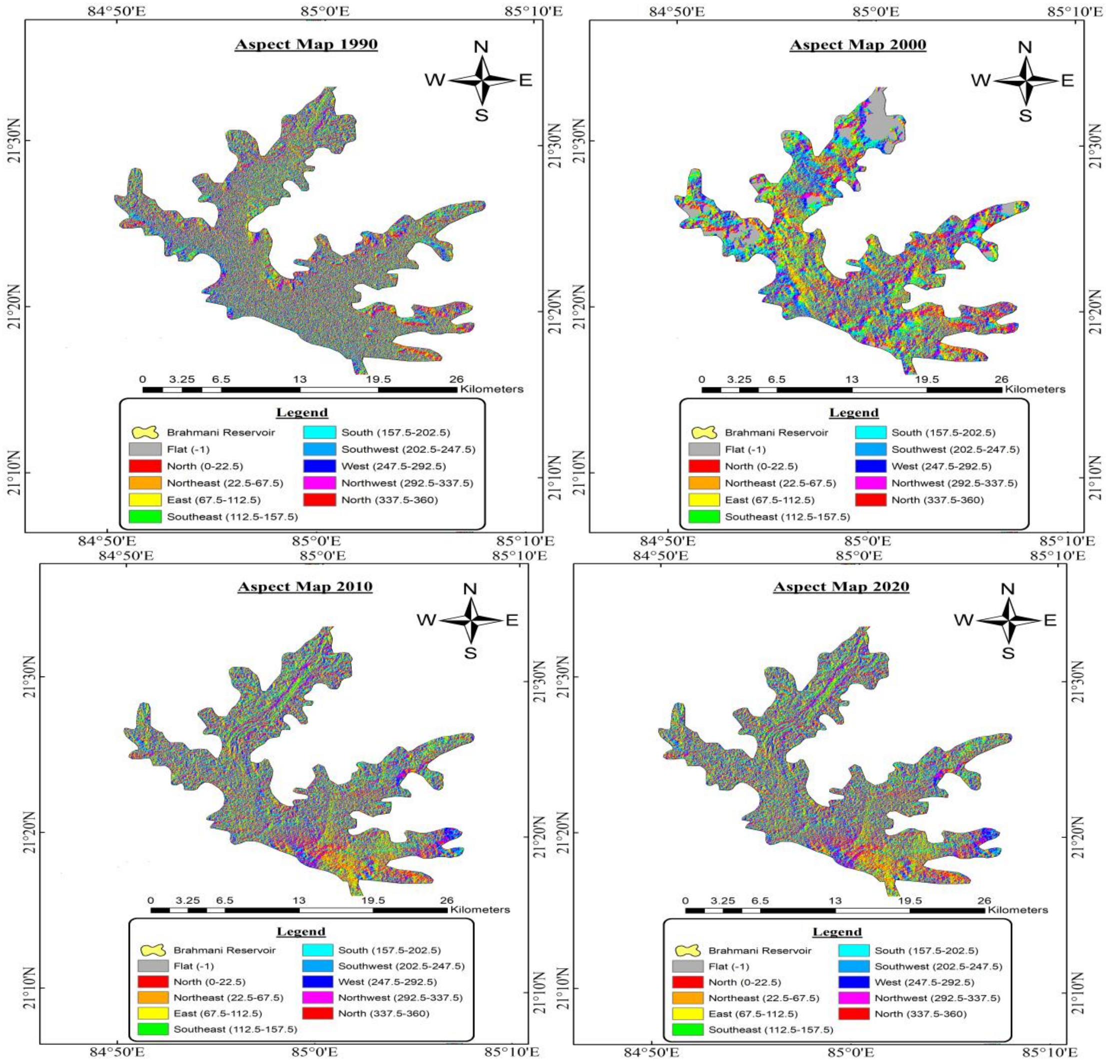
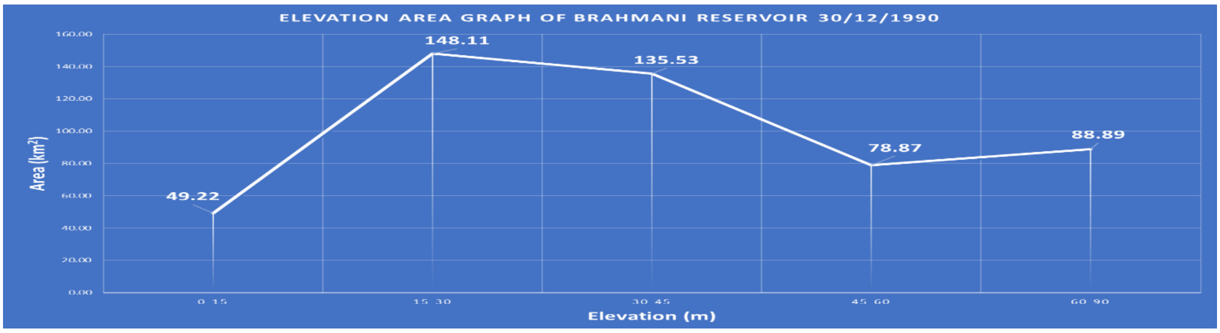


Fig. 10(a, b, c &d). The aspect map of the Rengali reservoir area (1990. 2000, 2010 and 2020)

Table 3. The water surface area vs. the elevations comparative changes in the Rengali reservoir

Elevation Range (m)	Area (km^2) 2020	Area (km^2) 2010	Area (km^2) 2000	Area (km^2) 1990
0-15	88.63	62	85.09	49.22
15-30	137.65	123.36	63.03	148.11
30-45	103.79	127.57	93.2	135.53
45-60	95.49	94.85	76.45	78.87
60-90	153.12	97.46	182.57	88.89



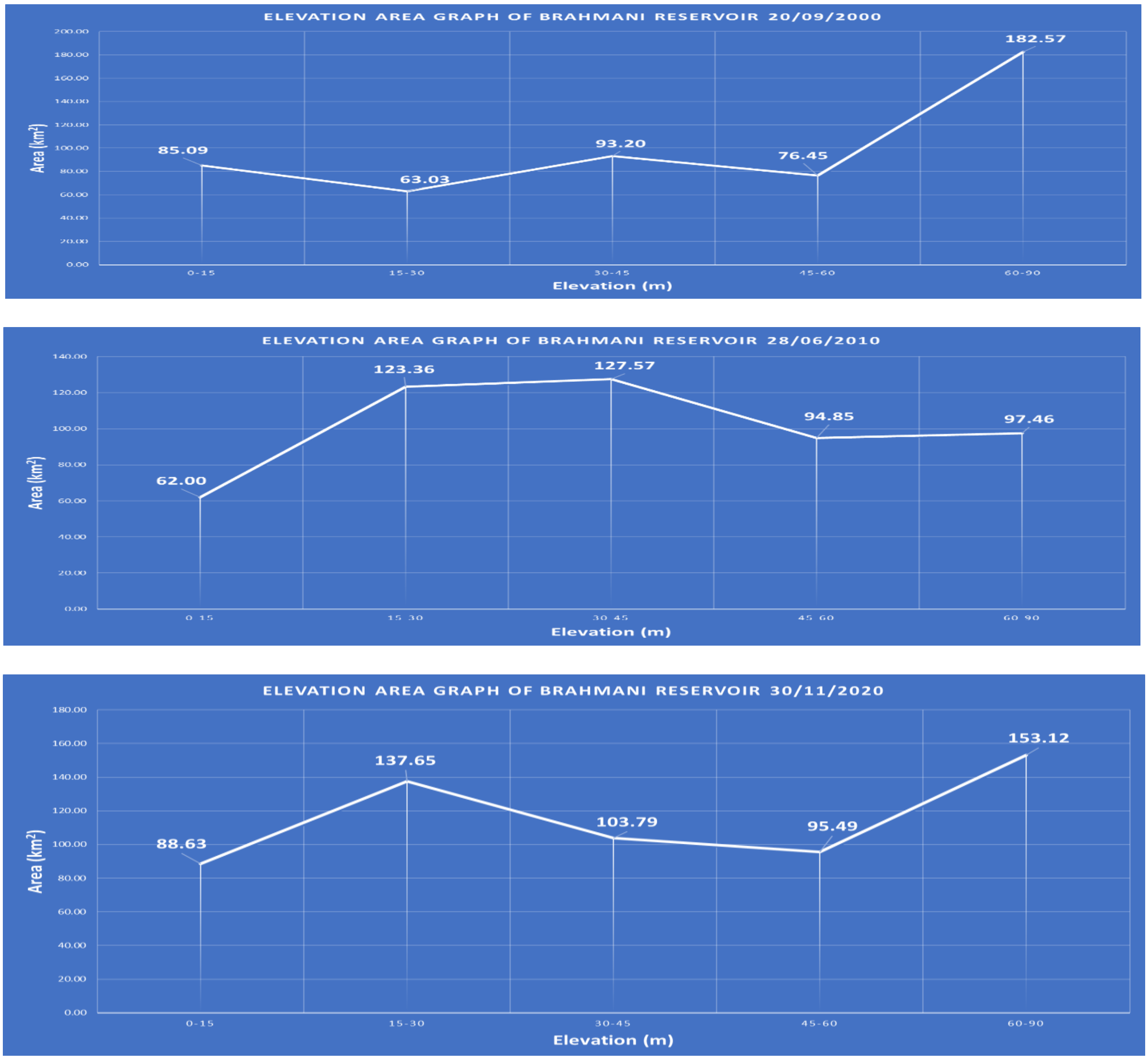


Fig. 11(a, b, c, & d). The elevation area map in the years 1990, 2000, 2010 and 2020

3.6 Elevation vs. Area Map of Rengali Reservoir 1990, 2000, 2010 & 2020

All Raster data files further converted to TIN format and comparison between the TIN files done by the use of Surface Tool.

A Surface Difference Map acquired by comparison and further analysis done by exporting the Attribute Table data into MS Excel. The elevation, volume, area, siltation and scouring details were analysed. The resulting Elevation-Area graphs and area capacity curves obtained (Fig. 11).

The water surface area in the year 2000 was least as the SW monsoon was extremely poor in the Brahmani basin and the upper catchment of the reservoir. The horizontal sectional area in 2020, the elevation range 15-30m and 30-45m is less than the year 1990 indicating that the volume is reducing in the three decades Fig. 12 (a, b) and Fig. 13.

3.7 Error Calculation in Sediment Estimation Rengali Reservoir

Vicissitudes in storage capacity in a reservoir is the volume sedimentation accrue within the reservoir. GIS tool and the interpretation methodology is moderately easy and used with proper judgement in deciding the results due to incorporation of errors from various sources, which can bias the result.

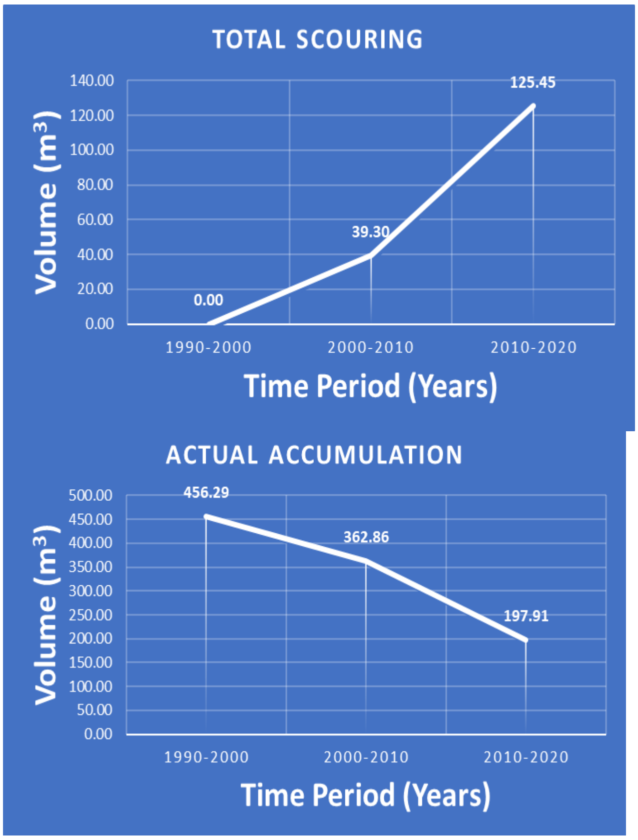


Fig. 12(a, b). The scouring & deposit in Rengali Reservoir (1990-2000, 2000-2010 & 2010-2020

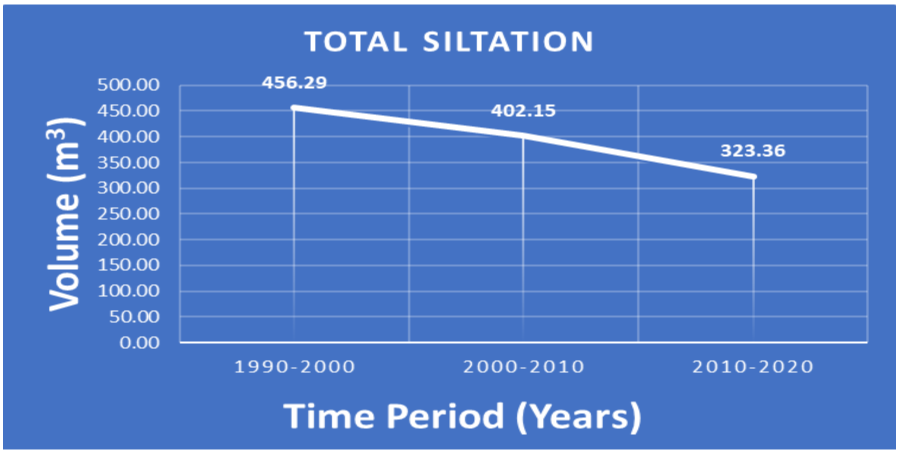


Fig. 13. The total sedimentation in Brahmani Reservoir (1990-2000, 2000-2010 & 2010-2020)

Table 4. Water spread area estimation and interpretation of sediment accretion with

		Acquired Data			
Years	**Volume**	***Total Calculated Area***	**Total Siltation**	**Total Scouring**	**Actual Accumulation**
	(m3)	**(m2)**	**(m3)**	**(m3)**	**(m3)**
1990-2000	456.29	888.54	456.29	0	456.29
2000-2010	441.45	850.48	402.15	39.3	362.86
2010-2020	448.87	869.43	323.36	125.45	197.91
Known data					

Years	Volume	Total Calculated Area	Total Siltation	Total Scouring	Actual Accumulation
	(m3)	(m2)	(m3)	(m3)	(m3)
2006	474.7	745.02	Nil	Nil	346.46
For every 474.7 m³ volume of water, the error calculations are:					
Error Calculation					
Years	**Volume**	**Total Calculated Area**	**Siltation**	**Scouring**	**Actual Accumulation**
	%	**%**	**%**	**%**	**%**
1990-2000	8.09	19.26	Nil	Nil	31.72
2000-2010	7.08	14.15	Nil	Nil	4.73
2010-2020	5.44	16.69	Nil	Nil	42.87

In the present study, the percentage range of error found to be 5.44 to 8.09% in calculation of volume, which is within the permissible range up to 10%.

3.8 Area Elevation Curve of Brahmani Reservoir

The elevation area curve of the Rengali reservoir for the period 1990-2000, 2000-2010 and 2010-2020 is in Fig. 14. The reservoir is showing a stable area capacity curve from 2000 to 2020.

3.9 The sedimentation Anomalies of Rengali Reservoir

On analysis and comparative study of the results, observations are that initial stages there was heavy scouring and decay of organic left out materials within the reservoir. They trashes were disposed in the peripheries and banks for first 5 to 6 years after impounding (Fig. 15).

Table 5. Change in reservoir capacities in three periods 1990-2000, 2000-2010 & 2010-2020

Years	Volume (m^3)	Total Calculated Area (m^2)	Total Siltation (m^3)	Total Scouring (m^3)
1990-2000	456.29	888.54	456.29	0.00
2000-2010	441.45	850.48	402.15	39.30
2010-2020	448.87	869.43	323.36	125.45

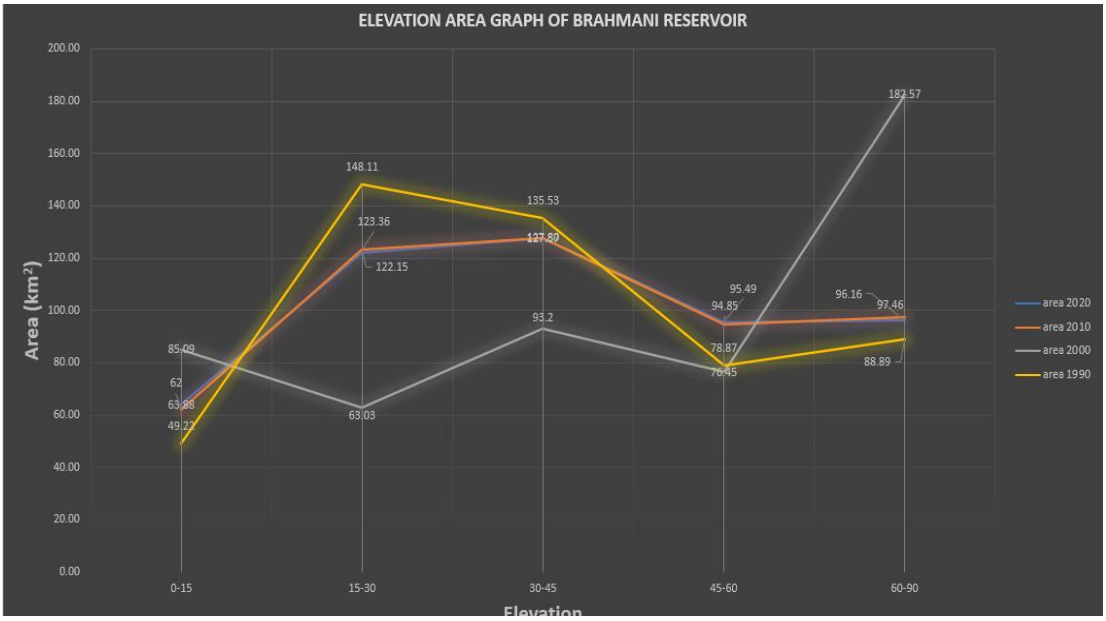


Fig. 14. The area capacity curve of Rengali reservoir for the periods 1990. 2000, 2010 and 2020

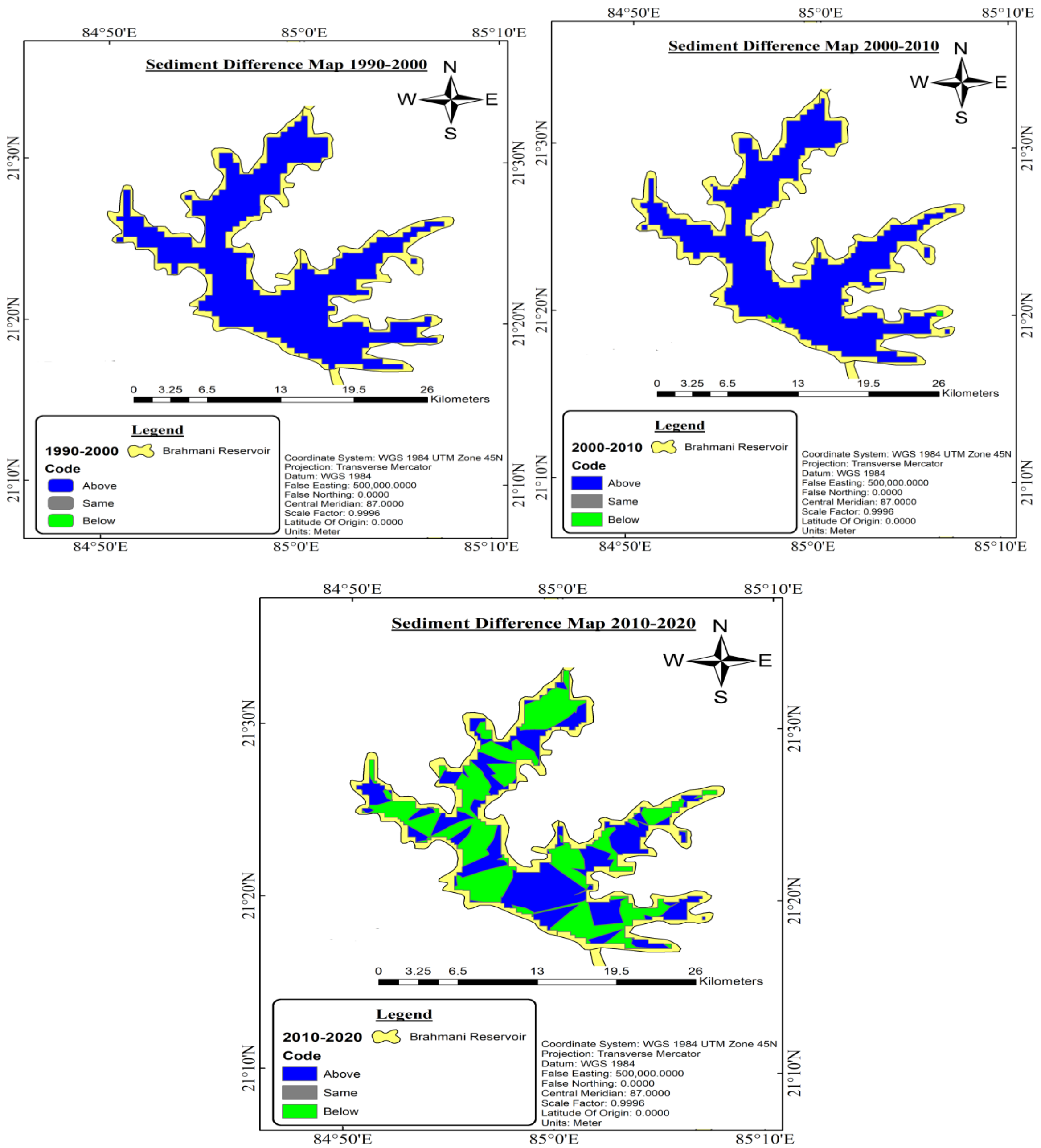


Fig. 15. The decadal sedimentation differential maps of Rengali Reservoir 1990-2020

During the years 2000-2010, almost equal amount of sedimentation and scouring occurred indicating the irregularities in the flow of Bramhani River. The present decadal scenario high rate of sedimentation the bottom level has raised significantly and the base reference level risen up.

4. DISCUSSION

Considering life of a reservoir as 50-200years, the rate of sedimentation is about 0.5% to 2%/ annum, [51,52]. Natural contribution for the reservoir silting are meteoric dynamics (e.g., Wind, Rainfall, snow, and hail), upper basin topography, geology, vegetation, floods etc... The methodologies are hydraulic condition (e.g., reservoir capacity to inflow volume, the shape, specifications of bottom outlets, reservoir operation rule, the trap efficiency, flow turbulence, and reservoir inflow. Anthropogenic players are overexploitation of forests, modern agriculture, grasslands, and LULC changes induced by human activities that build up soil erosion and augments reservoir sedimentation rates. Main players of reservoir sedimentation are Slope of Stream, Reservoir dimensions (shape, length, and aspect ratio), reservoir constriction, sediment size, volume ratio, capacity inflow, and outlets, vegetation, reservoir operation rule.

All dams are unique, so possesses different profile of management. In India, the reservoirs silted by ≈ 10% deposited in reservoirs, which reduces 1 to 2% of storage capacity annually. The best reservoir operation assigned to the basin managers is pre- defined by assigning its area capacity curve and reservoir operation schedule by optimized flood routing and sediment management.

The comparison of different studies on Rengali reservoir by various researchers summarized with the present study (Table 6).

Table 6. The comparison of different studies on Rengali reservoir by various researchers summarized with the present study

Author	River	Model	Work done
Konhauser et al., 1997 [53]	Rivers in Mahanadi tri-delta	Field data & Lab analysis	The high element conc. of element found in the Brahmani River, followed by the Baitarani and the Mahanadi due to high anthropogenic interventions (industry and mining).
Das B. P. et al., 2005 [48]	Brahmani River	BHIWA model and basin study	The total inflow & outflow to the basin is 51586 MCum The consumptive Use (CU) (69%), and river flows (31%). The total CU, ET at 2000 is 34,138 MCum. Consisting of ≈ 64% (forests, pastures and barren lands), 35% farm sector (rain fed and irrigated) and 1% anthropogenic beneficial ET is ≈28% of total CU.
Central water commission, GOI; 2015 [42]	Brahmani Reservoir	Observations, GIS/RS	Reservoir Capacity (MCum): *In 1984*: Gross: 4494.77; Live: 3505.9; Dead : 988.87 *In 2006*: Gross: 3749.75 Live: 3130.51 Dead: 619.24; Loss in gross capacity 745.02 (16.58%); Av. rate of silting in 24 yrs., was 1.229 (Th.Cum/SqKm/yr)
Paul P. K., 2013 [54]	Brahmani & Baitarani	SWAT model	Brahmani basin has 26 sub-watersheds, The UKMO-HADCM3 model applied to stream flow and sediment yield at their delta head has decreasing trend in stream flow increasing trend in the sediment yield.
Asa S. C. et al., 2015 [55]	Brahmani R.	Silt quality Heavy metals	The av. Conc. of heavy metals Fe (2%), Mn (515.46 µg/g), Co (30.65 µg/g), Ni (33.69 µg/g), Cu (21.66 µg/g), Zn (52.86 µg/g), Cr (216.90 µg/g), and Pb (21.47 µg/g) in sediments of the river. Conc. of Fe, Mn and Cr was high in the rivers.
Nath T. K. 2018[56]	Brahmani River	Field obs ervation & Lab analysis	Cluster- III mainly includes Rengali Dam, and Talcher U/S. The river was highly polluted in 80's & early 90's. Actions improved the quality now.
Mishra S. P. 2017 [15]	Brahmani River	Stochastic modelling Flow 1987-2012& Sed. (1993-2012)	The annual flow (av. 17.433Bcum) and sediment (av. 5.23 MMT) statistically studied and follow the best-fit equation Sine (4P) and sediment and inverse 3rd order equation and dissimilar to fit equations of other rivers in Odisha.
Mishra S. P. et all (present Study)	Rengali Reservoir (Brahmani River)	Web based Technology Flow 1987-2014 & Sed. (1993-2014)	The annual flow (av. 17.075Bcum) and sediment (av. 5.86 MMT) at Jenapur; Rengali reservoir at head reach 10.86BCum and 9.30MMT. The sediment accrued 456.29m^3 (1990-2000), 402.15m^3 (2000-2010), and 323.36m^3 (2010-2020), which is reducing gradually in last three decades.

5. CONCLUSION

Reservoir sedimentation is regular and vital concern to all water bodies behind dams in the globe that contribute gradual loss of storage potential. The reservoirs generally designed and functioned to control silting by various methods, but that is threatening the safety, utility and becoming geriatric before designed life period of the dam and reservoir both. The potential risk is surging up to serving society, environment, and fetching economic benefits. The present study pointing out to the basin managers of Rengali basin to speculate perfect strategies to get a picture for future sedimentation glitches and to its sustenance. Various sediment management strategies nurtured for the project, for modifications that should have done during planning, design and pre & post construction stages. Regular survey are necessary and pertinent actions taken not to allow the reservoir to allow to prominently reducing its benefits, but operation to continue as economically beneficial. The reservoir disallowed to silt up to such an extent so that the channels get jammed and even turbines choked up. For the young Rengali reservoir, a comprehensive action plan is essential as last studied during 2005 for its assessment and management of sediment-induced problems. It is desirable to document the safety related records, and associated stresses in engineering, hydraulics, social and economics related problems

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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