Fretful longevity of Upper Kolab Reservoir, Odisha by GIS study

Abstract:

Background: The nonrenewable energy source, hydropower reservoirs are the yardstick that scales up developing countries around the globe including India. The multipurpose Upper Kolab project is housed at the Kondhan Hills of the north Eastern Ghats mobile Belt range near Koraput Town. The dam is of length 630.5m with a height of 54.50m, and an average annual flow1803 M cum in operation since 1986. The project was built for 320MW generation, about 445000Ha CCA, and water supply to nearby towns.

Objective: Climate Change and anthropogenic stresses have resulted in depleting the major reservoir's capacity by sedimentation, hence irrigation and power generation. The southern part of the Northeastern Ghats belt is worst affected. The present study is about the rate of capacity loss of Upper Kolab Reservoir in south Odisha.

Methodology: The present study involves the collection of data from the Landsat 4, Landsat 5, and Landsat 8 OLI Operational land user image of 30 m resolution was downloaded from either SRTM data or Earth Explorer data, and the digital elevation model (DEM) was prepared for the same period of the years 1996, 2002, 2013, 2017 and 2021. The TOPO geological map (1:500,000 scale) of 1983 was used to digitize geological formations. The ArcGIS 10.2 software is used for the topographic constraints of the water body and its watershed. The maps generated are slope maps, aspect maps, and various differentials sediment values in volume and water spread area.

Results & Conclusion: The inference is the fast rate of annual sedimentation @3.542mm/yr which is much higher than its mother basin Godavari (@2.22mm/yr. The longevity of the Upper Kolab Reservoir and power generation shall be affected earlier before it is designed life. Sedimentation needs prioritization, as caused by the anthropogenic and climate-induced huge sediment entry to the upper Kolab reservoir warranting a secondary reservoir downstream.

Keywords: Aspect map, Arc GIS, DEM, SRTM data, Upper Kolab Reservoir, sedimentation,

Introduction:

Reservoirs behind dams are anthropogenic water bodies that have multifarious services like water supply, Irrigation, hydropower generation, etc. The width and depth of the reservoir, soil, rainfall, and the climate of the basin govern the storage capacity by sedimentation. The trap efficiency controls the sediment accruing, hence the decline of the reservoir efficiency. Also, sediment distribution through accumulation on the reservoir bed is based upon the viscosity, fall velocity and flow velocity, and rate of silt entry. The geology, geomorphology, hydrology, and hydrogeology of the terrain of the basins contribute to sediment and promote/deteriorate the reservoir capacity. The sedimentation of the reservoirs depletes the quantum of usage, increases downstream erosion, and river flow obstruction later dwindling its useful life projected to be about 22 years and the cause is sedimentation, (Mohammad K., 1987[1], Obialor et al., 2019[2]). India has conducted sediment surveys of 264 reservoirs out of 369 major multipurpose reservoirs and reported 141 reservoirs to have a yearly average loss of gross storage, live and dead 0.95%, 0.67%, and 2.39 % respectively (CWC-2020[3])

The Sabari River, a tributary of the River Godavari, the boundary between Odisha and Chhattisgarh, in its upper reaches is called the Kolab River. In the Sabari system, several hydropower projects have been developed both in Odisha and in the adjoining state of Andhra Pradesh. The Upper Kolab Project (UKP) is one among those dams constructed like Balimela, Machhakund, Satiguda, Sileru, etc. The UKP is due to its positioning in the Sankaran Knolls part of the Kondhan Hills Range of southwest EGB Hills, Odisha. But as a multi-purpose project, the UK reservoir has rarely controlled or moderated floods. The project is at Lauriguda, 5Km SE of Jeypore town in Koraput districts (at lat. of 18^0 47' N and long. of 82^0 37' E (as per SOI Topo sheet Number 65/J11) (Fig 1). The river Sabari is the boundary between Odisha and Chhattisgarh states of India.

The benefits of this project are hydropower generation, irrigation, and municipal water supply (CCE, UKP, 2020[4]). Upper Kolab Hydro Electric Project (UKHP), Koraput, Odisha, started excavation in 1976 by the I&P Dept., Government .of Odisha (GoI). This multipurpose project is operational with 4 x 80 MW units 320 MW (completed 1993), utilizing the water potential of 11089MCM the Kolab (through major Golagad, Guradi, and Kanger Nallah) a tributary of the river Godavari (Choudhry et al, 2016[5]).

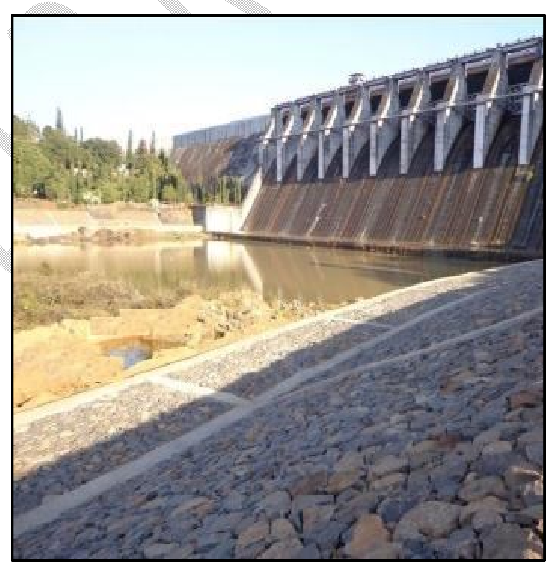


Fig1(a): The Survey of India map of the Upper Kolab Project, (1983) Fig 1(b) The Down Stream of UKHE Project

The UKP provides irrigation to an ayacut area of 44544 ha. in Khariff and 26700 ha during Rabi in the blocks such as Jeypore, Boriguma, and Kotpad in Koraput District. The UKP provides municipal drinking water to Damanjodi, Sunabeda, Koraput, and Jeypore townships. The project was completed in two stages. Stage I comprises 3X80MW and was completed in 1987 and stage II later in 1993. The 646m long and 55m high Kolab dam was constructed as stone masonry at the village Korenga, the Kondhan Hills as a part of the Eastern Ghats belt (EGB) range, in Koraput. The project is situated at Bariniput which is 19km from Jeypore city and 27km from district headquarters.

The SOI TOPO map has been downloaded to find the physical parameters from the geo-referenced map of the Koraput district as shown in Fig 1(a). Because of the suitable huge hydropower potential, the Upper Kolab basin at Upper Kolab and Jalaput projects was built. A water conductor system was excavated to transport water to the powerhouse that was under operation from 1987 for 240 MW (3 x 80 MW) having a firm power of 95MW, with annual energy designed 668MU. A Pumped Storage HE Project (HEP) was completed under AIBP 2003-2004. The tail waters from the powerhouse are stored in a balanced reservoir through a dam at Satiguda used for the water supply of Koraput township and created the irrigation potential **Fig 1(a), Fig (b), and (Table 1).** The UK basin has a population density n 2011 of 128 per/Km^2 and 41% of the total area is used as agricultural land (Choudhry 2016[5]).

Review of Literature

Hydropower is a source of renewable energy generation of 15000MW (17%) of the total in India and globally 4327TWh (28%) till 2021 (WEO 2022[6]). That can relieve the climate change (CC) strategies and can address the snowballing energy stresses (Ali et al., 2018[7]). Sedimentation accrued from its catchment is accompanied by gradual change in grain size distribution in low drawdown, and sediment pollution cause depletion in the life span of the reservoir, making Hydropower generation uneconomical in aged and geriatric reservoirs, (Bogen et al., 2001[8]). Dams interject the link of sediment conveyance from the basin through the rivers upstream and downstream. Consequently, there is a loss of reservoir storage capacity and reduced reservoir's design life, concurrently causing deficient in the regular building of the luxuriant delta and ecosystem (Kondlof et al., 2014[9], Mishra S P, 2016[10]), India covers about 113.3 Mha of land exposed to soil erosion and ≈5334 MMT of soil is detached yearly due to various causes, (Javed et al., 2016[11]).

The sedimentations of rivers where sediment flow is only alleviated through the catchment treatment plan and the ratio of sediment in the water of a reservoir (Wang et al., 2022[12]), GIS methodology like RASTER can be effective software to assess the sedimentation of reservoirs (Cortis 2023[13]). Reservoirs generally trap sediment flowing from the basin, trailing the storage capacity, making the D/S of the reservoir become sediment starved, and the dams are constructed based on the design and operation concept that all influx sediments efflux with the outflow, (Kondolof et al., 2014[14]). The gross, live, and dead storage of the UKP reservoir during 1986 (designed) are 1215, 935, and 280M. cum whereas when studied by the expert reservoir surveyors were 1073.95, 859.19, and 214.76M.cum with a gross capacity loss of 141.05M.cum (cumulative 11.61%). The observed rate of sedimentation since surveyed last (2019) was 3.461Th.cum/km^2/year (Compendium reservoir sedimentation CWC – 2020[15]).

India has conducted a sediment survey of 264 reservoirs out of 369 major multipurpose reservoirs and reported 141 reservoirs to have a yearly average loss of gross storage, live and dead 0.95%, 0.67%, and 2.39 % respectively rest of the 126 reservoirs have negative percentage values loss in live/dead storage per year. The survey of the reservoirs is time-consuming, cost involved, and may involve errors, as an alternative the GIS, Remote sensing, and modern survey techniques can be considered effective tools to assess sedimentation (CWC compendium 2020[15]).

Hydropower generation is affected by anthropogenic stresses on the ecosystem and climate change. To mitigate energy demand for the rising population, and the available high potential that can be harnessed generating from reservoir units, the demand for low-carbon energy (SDG-7), development, and hydropower would seem to have a significant role in South Asia's energy future. Small hydropower stations (SHPs) are less hazardous to the environment. Societal, biological, environmental, climatic, and anthropogenic negative impacts through sediment accretion have closed many hydropower stations in the 21st century, (Morana et al., 2018[16], Ibrahim et al., 2020[17], Amasi et al., 2021[18])

The globe has a 6800 km^3 volume of water behind the dams and its annual loss of capacity is about 1-5%. Consequently, the global reservoir storage/person has briskly declined from the initial days of the golden spike of the Anthropocene epoch (1980). Contemporary storage/capita has gone up to the 1960 level, (Schellenberg et al., 2017[19]). Sedimentation of the UKP reservoir has raised in the last decade and even is much higher than its neighboring Deccan reservoirs.

The present study is an attempt to study the sedimentation of the Upper Kolab Reservoir using the GIS and Rs data encrypted from the satellites for the years 1996, 2002, 2013, 2017, and 2021. The results are to institute compatibility with the previous sediment survey results of UKP.

Geomorphology, Geology, and soils:

The UKP basin is housed within dense forest, rugged hills interspersed by valleys of elevation ranging from 900 -1400mm. The soil of the basin is a stretch of alluvium in the flood plains, e flat-topped hills (Mesa), Denudation Hills with shallow aquifers, pediments, structural hills, intermontane Valleys, dissected plateaus with red loamy soil, and red Sandy Soil good source of soil erosion for the sedimentation in the reservoirs in the area, **Fig 2(a) and Fig 2(b).**

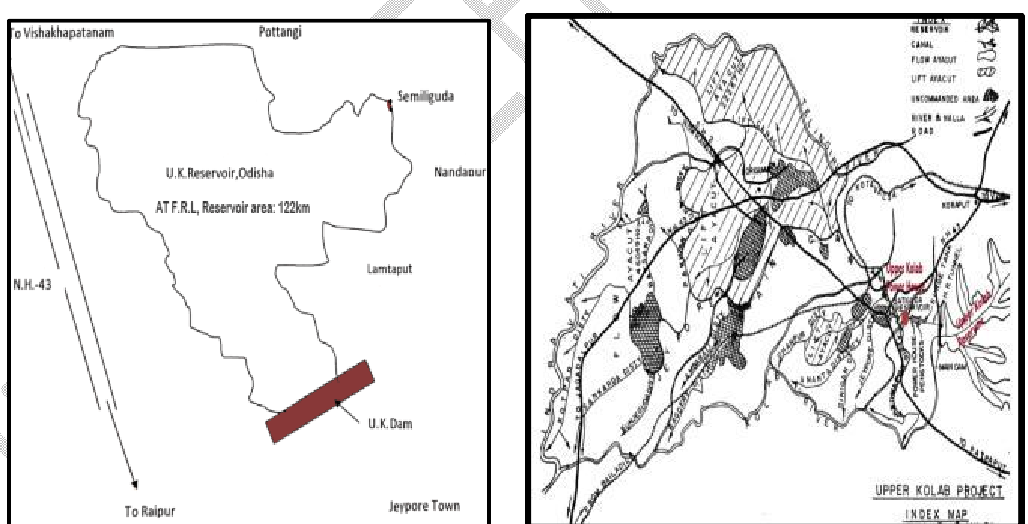


Fig 2(a): The sketch map of Upper Kolab Reservoir, Fig 2(b): U K Project, Koraput, Odisha

The limnology and the rock type encountered in the dam axis mainly consist of quartz-feldspar, charnockite or Pyroxene granulite, and meta dolerite. The general foliation direction of the rocks is N 55^0 E- S 55^0 with a dip 55^0 to 75^0 towards NW trending across the dam axis. These rocks are moderately fractured and exhibit two continuous sets of joints. One is vertical across the foliation. The other is oriented paralleled to the foliation trend with dips 25^0 to 30^0 against the dip of foliation. The rocks are folded and faulted in NE-SW trending (Project report UKP).

The climate:

The UKP basin enjoys a hilly; tropical climate and is comprised of scorching summers (Mar to June), long chilled winters (late Nov to Feb) & rainy seasons (SW monsoon). The average maximum and minimum temperatures are about 100C and 400C respectively. About 80% of the annual rainfall occurs from mid-June to mid-Oct. Under influence of SW, NE monsoon, and the ITCZ (Intertropical convergence zone), erratic rainfall occurs in the UK basin from 2007-2008 onwards, (**Fig 3**).

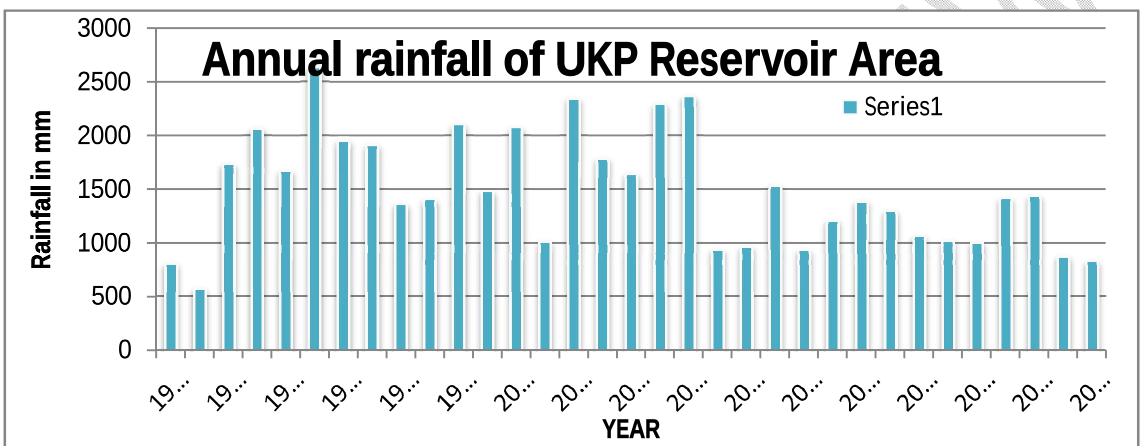


Fig 3: Annual rainfall (Cumulative) of Upper Kolab Area for the period 1989 to 2018-19 (Data Source: Operation manual, UKP, WR Dept. Odisha 2020[20])

Salient Features:

The HEPs have three compartments large (>30 MW), small (100 kW to 30 MW), or micro (<100 kW), and the reservoirs can be impounded, pumped storage, and run off the river. The Upper Kolab hydroelectric project is large and the pumped-storage reservoir has a spread area is 122 km^2 at FRL, and receives drainage water from a 1630 km^2 basin. All the salient features like the basin, hydrology, dam, dyke, spillway; Power House of the Upper Kolab Dam project is in (Dubey et al., 2014[21], UKP report, WR Odisha 2020[22]). An earthen dyke of length 526m and 7m in height exists at Jatiguda village. The live storage capacity at zero elevation level is 935Mcum, **Table 1**.

Table 1: The salient features of the UKP Multipurpose Project with basic data

#	Characteristics	Quantity/	#	Characteristics	Quantity/
A	Hydrology	Unit	C	UKP DAM/ DYKE	Unit
i	Catchment area	1630 Km^2	i	Gravity dam Conc/ RR masonry /Straight	
ii	Max & Min rainfall/year	1560/980mm	ii	The total dam length	646 m
iii	Av Annual Rainfall	1270mm	iii	Maximum dam height	55 m
iv	Design Flood of UKP	10020 cumec	iv	Top width	7.50 m
B	UKP Reservoir		v	Dyke (length/ top width)	526m/ 7m
i	Gross storage cap. at FRL	1215 MCum		Ogee spillway from RD 193 m - 350 m	

ii	Dead storage at DSL.	280 MCum	i	No bays and width	11m/12.2m
iii	Live storage capacity	935 MCum	ii	Spillway Crest level	845.80 m
iv	FRL/ MWL	858m	iii	Flood release Aug/2006	425.5Mm^3/
v	DSL	844 m	iv	Irrigation from Satinallah	47985 ha
vi	Submergence area at F.R.L.	164.95 km2	ii	HE power generated	95MW
vii	Top-level of Dam	861 m	iii	WSA at FRL at 858m	114.56Km^2
viii	WS area at MDDL 844m	33.88Km^2	iv	Capacity at FRL 858m	1073.95MCum
ix	Capacity at MDDL 844m	214.76MCum			

M/S Toja Vikas int. PVT Ltd, the consulting engineers for the project, New Delhi had conducted the sediment from 26th June 2011 to 21st Sept. 2011 the sediment survey to assess the capacity and inferred that the amount of sediment trapped in the reservoir from the year 1986 to 2011 was 5462MCum, or 34.61 Ham /100m^2/annually (**Table 2**).

Table 2: The areas and capacity of Upper Kolab Reservoir from the years 1986 to 2011;

Elevation	Preimpounding-1986		Survey-2011		Elevation	Preimpounding-1986		Survey-2011	
	Area	Capacity	Area	Capacity		Area	Capacity	Area	Capacity
m	Km^2	MCum	Km^2	MCum	(m)	Km^2	MCum	km^2	MCum
810.4	0	0	0	0	834		70	7.14	28.27
811		0.5	0	0	835	11.6	80	8.69	36.185
812		1.5	0	0	836		95	10.89	45.975
812.5		2	0	0	837		112.5	12.93	57.885
813		2.5	0.003	0.002	838		127.5	14.96	71.83
814		3.5	0.007	0.007	839		146	17.31	87.365
815	1	4.5	0.01	0.015	840	22.98	162.46	20.22	116.73
816		6.5	0.03	0.035	841		188	23.52	128.6
817		7.5	0.08	0.09	842		215	27.1	153.91
818		8.5	0.16	0.21	843		246	30.36	182.64
819		9	0.21	0.395	844	35	280	33.38	214.76
820	1.11	10	0.35	0.65	845	37.648	312.51	36.75	250.275
821		11	0.39	0.995	846	42.5	361.34	39.72	288.312
822		12	0.48	1.43	847	46.67	410.79	42.96	3329.85
823		13	0.56	1.95	848	51.25	459.02	45.69	374.275
824		14	0.73	2.595	849	55.83	507.86	49.42	421.72
825	2.45	15	0.86	3.39	850	60.901	556.7	53.09	472.985
826		17	1.05	4.345	851	66.25	631.56	57.18	523.122
827		20	1.27	5.505	852	71.25	706.42	61.66	637.51
828		26	1.48	6.88	853	77	731.28	66.43	851.525
829		30	1.84	8.54	854	33.75	856.14	72.14	720.81
830	4.41	35.76	2.43	10.675	855	99.59	931.01	78.12	795.94

831		44	3.08	13.39	856	97.5	1025.33	85.93	877.985
832		62.5	4.26	17.02	857	105	1120.33	95.74	968.3
833		62.5	5.55	21.925	858	114.32	1215	114.56	1073.95

The gross capacity loss in the reservoir within 25 years was @0.46% and dead and live storage capacity was reduced by @93% and 32% respectively. The reservoir is undergoing sedimentation in its upper reaches. There is a recommendation to modify the originally designed area capacity curve for useful utilization of the services fixed during pre–reservoir operation table planning and strategy. The overall change capacity of the reservoir between the years 1986 and 2011 (25 years), (CWC report 2020[15]) is given in Table 2.

Reservoir operation rule

The sequence of gate operations is given in Table 3. As per the reservoir gate operation norms gates no 4, 5, 6, 7, and 8 are prioritized numbering from left to right. Closure of the gates in the final is the skillful gradual lowering of the gates by 0.3m to 0.5 m sequence mentioned in Table 2 above with precaution to avoid flooding downstream settlements. As per the Water, resources management, Upper Kolab Dam the rate of siltation calculated at 3.461mm /year or 5.642MCum/ year calculated from 1986 – 2022 (in 25 years) from the date of impound.

Table3: The sequence of gate operation during flood when needs to overflow through the gates

Gate operation Number from left to right	1	2	3	4	5	6	7	8	9	10	11
Operation sequence	nil	nil	2	3	4	5	6	7	8	9	10

The frequency-wise percentage of rate of siltation top to bottom (100 - 90% …. 0-10% elevation wise) estimated in the year 2011 were 12%, 27%, 13%, 10%, 9%, 10%, 7%, 6,5%, 3.5%, and 2.2% respectively. The sedimentation rate after 25 years was the periphery of the reservoir than the close vicinity of the Dam.

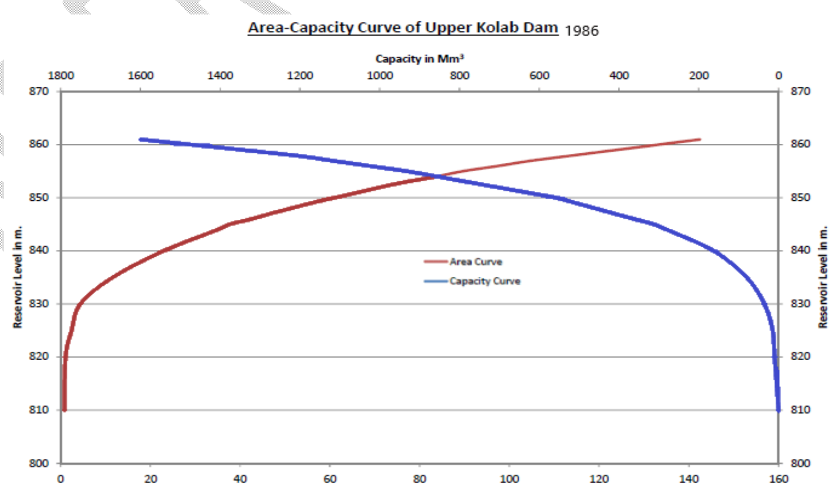


Fig 4: The Area - capacity curve of the UKP dam (WR dept-2020[20])

Methodology:

Reservoir sedimentation measurement is done either by capacity survey or stream flow analysis. The stream flow analysis rests on the difference in the quantum of sediments that remain within the reservoir after evaluating the inflow (tributaries) and outflow (spillways and tailrace channels). But the capacity survey is conducted within the water body, where the sediment volume is estimated regularly by hydrographic survey and the available capacity is ascertained. Both methods are cumbersome, time-consuming, costly, and demand technological expertise. The current high-tech method of evaluation of sedimentation of reservoirs can be done by use of geographical positioning system (differential mode), Echo-sounder and Transducer (variance in-depth measurement), and soft computing devices. The present methods may be the use of a robotic boat survey with help of DGPS, or GIS,(data acquisition by drone or LiDAR). The present study is involving data of 30m resolution, yet it is fast, economic, accurate, and reliable. More importance is stressed on the GIS technique and use of big data under a cloud platform to assess the sedimentation of 369 reservoirs in India by CWC (120 reservoirs attempted).

Reservoir sustainability plays a significant role in sedimentation quantity that occurs when the flow is variable like flood passes, flash floods, storm surges, and tidal waves (Tsai et al, 2021[23]), Annual sedimentation of a reservoir can be estimated by the RS expertise after knowing the concentration of suspended particulate materials (SPM) inflowing reservoirs behind the dams and carried by floods during the lifespan of the dam and its annual approximation, (Kolbadi et al., 2021[24], Mishra et al., 2022[25]). Sediment yield from an area is mostly governed by land and soil factors. The land factors include slope, aspect, physiography, LULC, soil, vegetation, and concurrent erosional status, (Jain et al., 2010[11], Javed et al, 2016[26]. The soil factors include soil type, texture, the effective depth of the soil, soil erosivity, and mineral content, Jazouli et al., 2017[27], Mishra et al, 2017[28]).

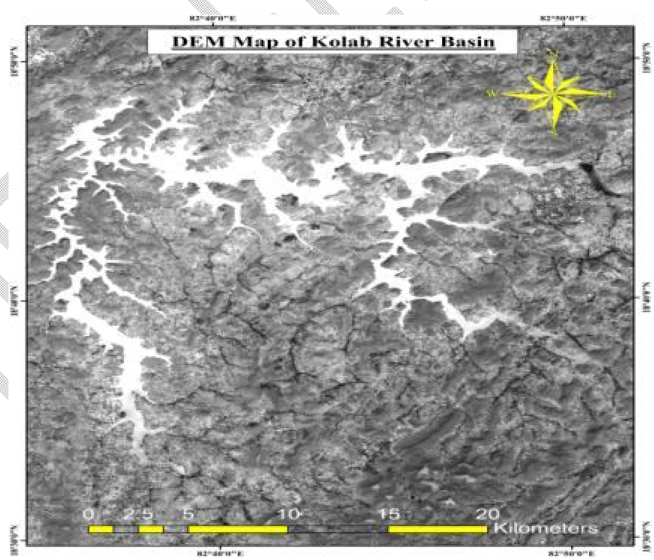


Fig 5: The digital elevation model (DEM) of the Upper Kolab River Basin

Remote sensing SRTM (Shuttle radar topography mission) data were downloaded from USGS which is in the digital elevation model platform (http://www.earth explorer. usgs. gov.in), and used for the map preparation. After geo-referencing, these maps were mosaicked and delineated for the Upper Kolab dam watershed boundary of 30-meter resolution. The Ground Control points (GCPs) were later used and were projected into Universal Transverse Mercator (UTM zone 44

N.) projection, considering the datum from World Geodetic System (WGS84). The slope, and aspect map has been constructed using arc GIS software (NASA SRTM data 2013[29]).

Contour/Slope/Aspect Map of UKP:

Contours are lines of equal altitude; provide the topographic, limnologic, and various terrain geologic information along with the gradient wise and cross-section of interest like drains, roads, settlements, ponds, vegetation, sewer lines, etc. The slope is the degree of inclination of the topography of an area. To know the slope physiognomies of the Upper Kolab watershed, the slope map was prepared from DEM (Digital elevation Model) later by Raster or TIN (Triangulated Irregular Network) but not by LiDAR (Light detection and ranging) methodologies.

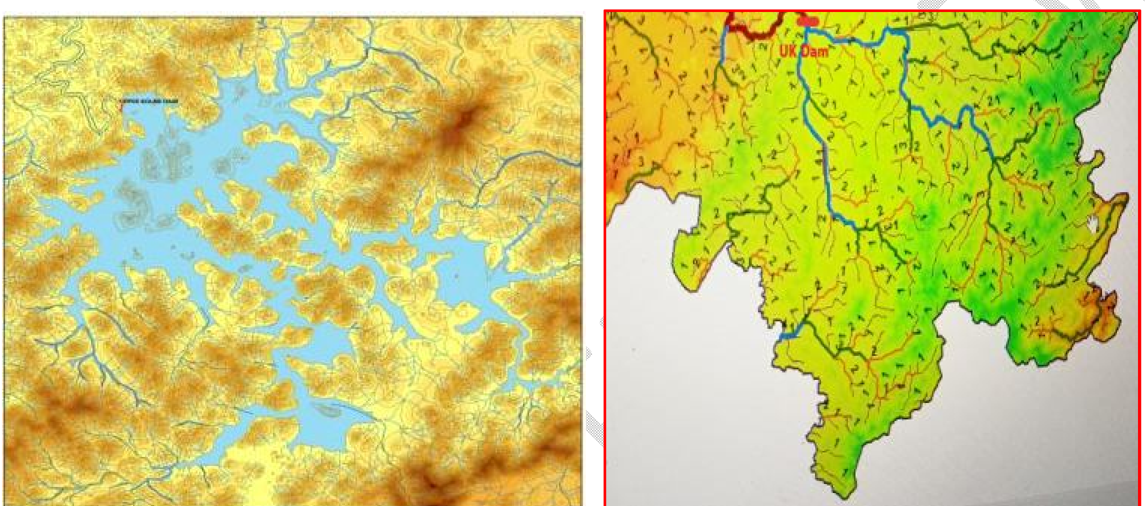


Fig 6: The contour map and the stream order Map of the UPPER KOLAB River

The UKP basin lies in the mountainous region; the slope map shows slopes in all directions i.e. east, west, north, and south. Using the customary technique to calculate the slope in degrees, three classes gentle (0˚ - 13˚), moderate (13˚ - 25˚), and steep (25˚ - 38˚) were assigned (Fig 5 a-e), (Bhavsaar et al, 2015[30], Dadoria et al, 2016[31], Mishra et al, 2022[32]).

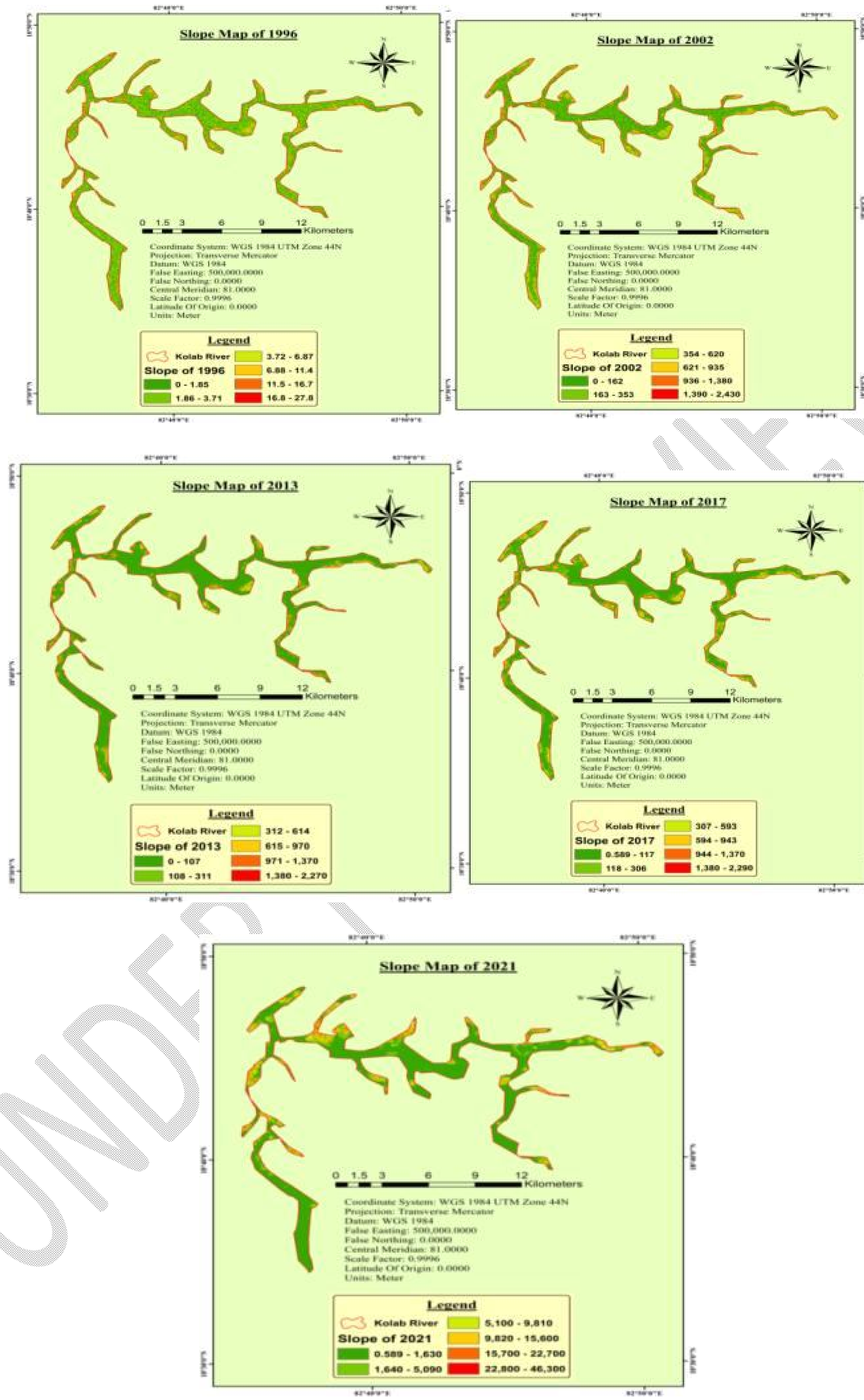


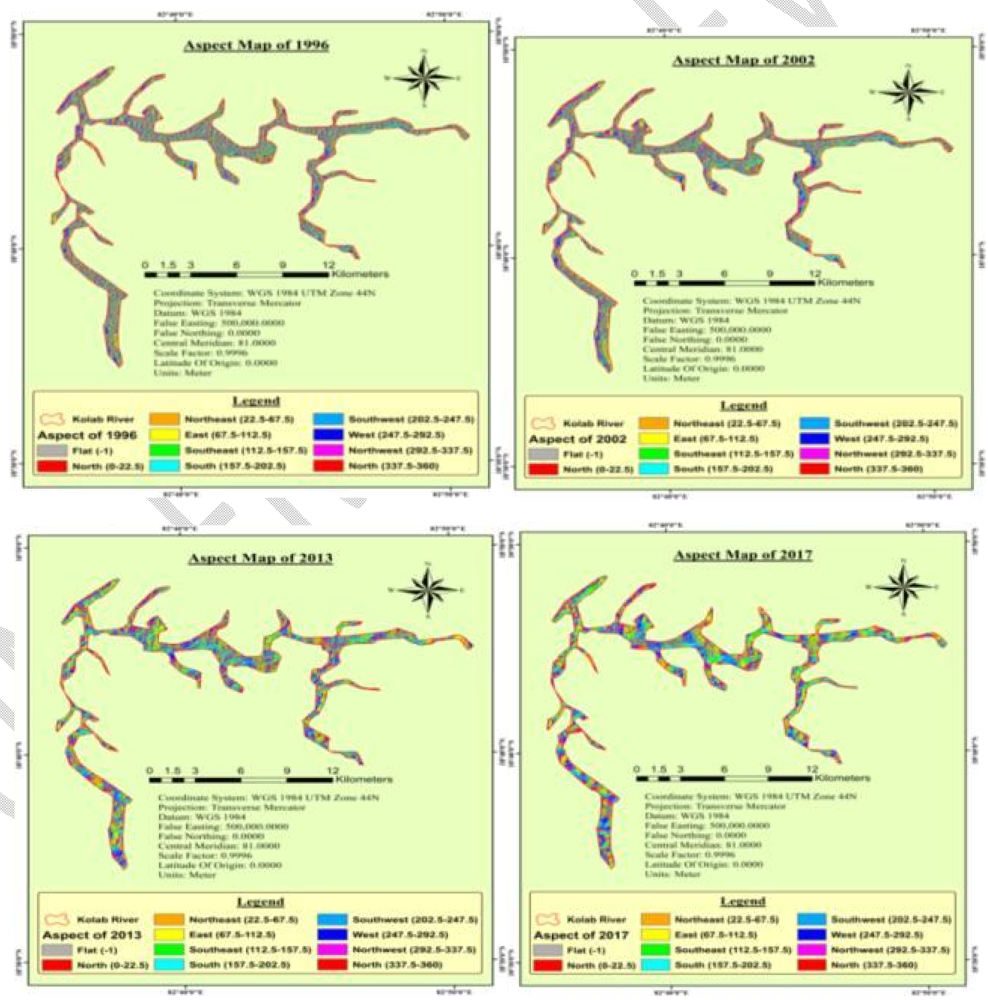
Fig 7 (a – e): The slope map of the UKP Reservoir FYs: 1996, 2002, 2013, 2017, 2021

The direction shown by the compass that the slope faces is known as its aspect. Mountainous areas have steep slopes in all directions. The aspect values (dip direction) obtained from the map indicate the slope's face directions physically. Vegetation along with the north and south-facing hilly areas vary owing to divergent insolation incidence, snow depth, soil development, and Pedi plains, characteristically use ground differences dependent on the aspect of the terrain.

The aspect-slope map presents the aspect, direction, slope, or steepness of an unbroken surface like the terrain signifying DEM (digital elevation model). Such a map is beneficial to identify the landscape topographies i.e. ridges and valleys, shaping the extent of solar radiance on the surface. These maps can strike the visualizations in it, **Fig 7 (a-e).**

The Aspect map:

The slope maps and the aspect maps for the years 1996, 2002, 2013, 2017, and 2021 are made and indicate the basin is becoming flattered and aspect ratio is reducing gradually and the quantum of sedimentation (1996-2002, 2013-2017, 2017-2021) is increasing year after year Fig 8 (a-e) and Fig 9 (a-e) respectively.



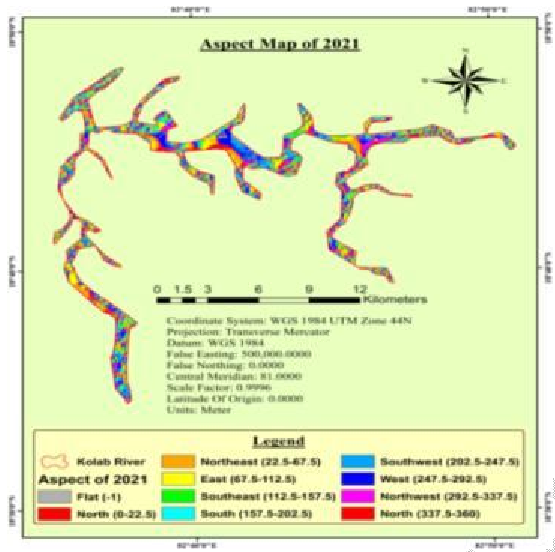
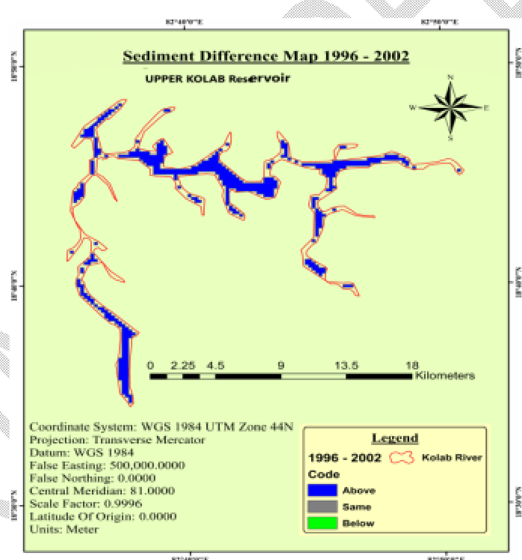


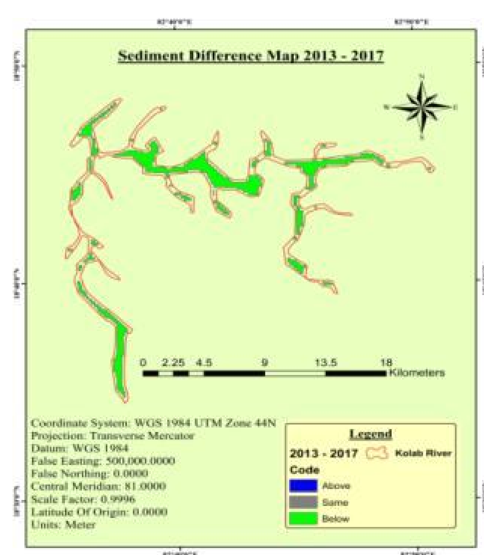
Fig 8 (a – e): The aspect map of the UKP Reservoir FYs: 1996, 2002, 2013, 2017, 2021

RESULTS

Estimation of sedimentation

The Universal Soil Loss Equation (USLE) or Revised Universal Soil Loss Equation (RUSLE) methods are used for the calculation of soil loss/accretion of a watershed, present study of sedimentation of UKP reservoir involves uses the GIS methodology, Mishra et al., 2017[33], Patil et al., 2021[34], Shahiri et al., 2022[35]].





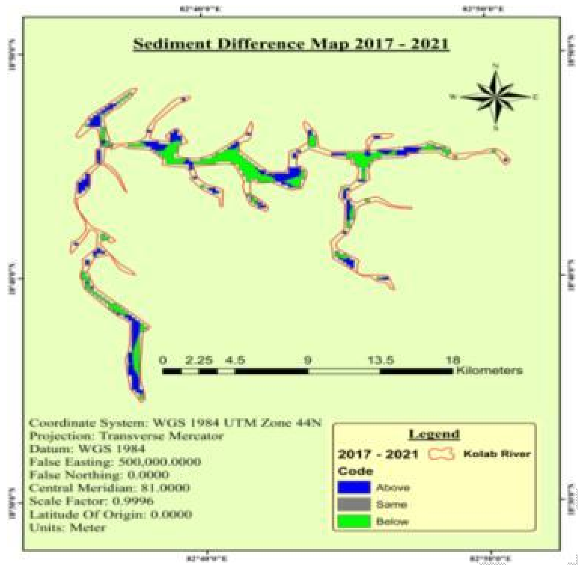


Fig 9 (a-c): The sediment contrast map of UKP Reservoir FYs: 1996 - 2002, 2013- 2017, 2017 – 2021

Table 4: The inference about sedimentation of the reservoir with the calculation of errors

Years	*Volume*	*Catchment Area*	*Total Siltation*	*Total Scouring*	*Water Spread Area*
	MCum	*(km²)*	*(MCM)*	*(MCM)*	*(Km²)*
1996-2002	*1179.22*	*1782.35*	*1603.21*	*190.27*	*103.32*
2013-2017	*1056.39*	*1689.71*	*1498.30*	*189.74*	*99.36*
2017-2021	*1012.96*	*1511.26*	*468.41*	*1042.49*	*100.65*
The reference data observed by CWC; GOI and the observed period 2011-12					
2011	*1073.95*	*1630.00*	*NIL*	*NIL*	*113.50*
Calculation of error					
Years	*Volume (%)*	*Catchment Area (%)*	*Siltation (%)*	*Scouring (%)*	*Water Spread Area (Km²)*
1996-2002	*13.52*	*9.34*	*NIL*	*NIL*	*8.96*
2013-2017	*7.67*	*3.66*	*NIL*	*NIL*	*12.45*
2017-2021	*5.67*	*7.28*	*NIL*	*NIL*	*11.32*

Estimation of sediment accumulation in UKP:

A comparative study has been made for the sedimentation of the Upper Kolab reservoir to assess the loss of gross storage capacity as follows:

a. The reservoir capacity during pre-impounding (1986): 1215 MCum

Capacity at FRL after operation of UKP (1999): 1179.22 MCum

Loss of storage in 13years (1986 – 2002): (1215 – 1179.22) = 35.78 sq km

Rate of yearly sedimentation (1986- 2002) = 35.78/16 = 2.2363MCum/year

Rate of sedimentation during (1986-2002)= (2.2363*1000)/1630 = 1.3721 Ha.m/Km^2/year or

= 1.372mm/yr

The reason for the lower rate of sedimentation during the initial operation period of the reservoir is due to the bed slope and flow velocity being so designed that there shall be no sedimentation within the reservoir. However, quantities of sediment/debris deposits occur in the reservoir periphery. With sedimentation the bed slope, and flow velocity change with the time of operation.

ii. Loss of storage capacity after 29years (1986 to 2017)= (1215 – 1051.39) = 163.61MCum

Yearly rate of sedimentation in first 29years = 163.61/ 29 = 05.631MCum/year

Rate of sedimentation = (05.631* 1000)/1630 =3.455 Ham /Km2/year

or **= 3.455mm/yr**

It is calculated that the rate of change of sedimentation gradually increases with the Anthropocene stressed basin and reservoir characteristics, the rate of sediment accrue has changed to 3.455mm/year.

iii. Loss of storage capacity after 35years (1986 to 2021)= (1215 – 1012.96) = 202.04MCum

Yearly rate of sedimentation in first 29years = 202.04/ 35 = 5.7726MCum/year Rate of sedimentation = (05.7726 * 1000)/1630 =3.542 Ha.m/Km2/year or

or = 3.542mm/yr

As per the New Indian Express on 01st May 2022 at 09:36 AM, the power generation has been cut down to 240MW instead of 320MW (95MW, firm) (and the water is to be charged to the canal for irrigation on a priority basis, (to maintain 42000 ha in Khariff instead of 47985 Ha, and 25000 ha during Rabi season. The reduction

Generation of Hydropower UKHEP:

The cumulative plant availability factor achieved during the year is the availability for generation in hours to the total hours in a year. The substantial generation may be higher or less than the specified capacity of the hydropower plant. Design Energy for UKHEP approved for the year 2020-21. The total predicted generation during the year 2020-21 as per DoWR& DoE was scheduled as 733.82 MU against the actual cumulative generation of 789.31 MU.

Table 5: Monthly Generation Particulars (MU), P.A.F.M, max and Min generation during F.Y. 2008-09 to 2021-22 of the UKHEP

Financial Year	No of units	Capacity (MW)/generation,(MU)	Cumulative P.A.F.M (%)	Max generation (MU)	Month	Minimum generation (MU)	Month	Yearly generation in MU
2008-09	4	320/564	84.64	55.4	Oct	35.06	Feb	585.85
2009-10	4	320/564	90.61	57.22	Aug	07.2	Dec	407.79
2010-11	4	320/564	84.6	74.02	Mar	25.16	July	563.59
2011-12	4	320/564	94.61	88.65	Apr	09.74	Dec	605.21
2012-13	4	320/564	88.53	69.23	Mar	19.02	June	464.09
2013-14	4	320/564	84.8	133.85	May	28.81	Dec	871.89
2014-15	4	320/564	92.56	74.86	June	42.54	Dec	718.27
2015-16	4	320/564	92.97	95.05	Mar	16.94	Nov	727.82
2016-17	4	320/564	83.18	81.92	Mar	09.62	Dec	620.01
2017-18	4	320/564	65.06	86.36	Apr	20.83	Dec	676.00
2018-19	4	320/564	73.195	156.03	Sept	45.57	July	923.88
2019-20	4	320/564	72.4	92.67	Aug	51.08	July	827.96
2020-21	4	320/564	68.98	103.32	Sept	29.02	Oct	789.31
2021-22	4	320/564	85.98	65.22	Mar	6.46	Dec	451.22

Source: http://admin.ohpcltd.com/Siteupdate/MonthGen/MonthlyGen2008.pdf

The HE plant data of UKHEP from 2008 to 2021 informs that as per demand the monthly generation has an increasing trend (The peak monthly maximum energy harnessed 156.03 MU and the lowest minimum in 2021-22 was 6.46MU from an installed capacity from four units 320MW (4*80MW). Annual generation was lowest in the year 2009-10 (407.79MU) and the highest generation was 923.88MU in the year 2018-19 and 827.96 MU during the pandemic COVID 19 period confining all at home with increased domestic consumption.

Discussion:

Around 1-5% capacity of reservoirs is lost per year out of the total volume of 6800 km^3 in the globe due to sedimentation at present at par with 1960'. As per Schellenberg et al, 2022[19], in hydro review content directors – 2017, the global reservoir storage/ capita has briskly declined since its uttermost quantum in 1980. On 20th Oct 2021, it is reported in The New Indian to express that hydropower generation is a concern for the depleted reservoirs, particularly in southern Odisha reservoirs. The low water level in Upper Kolab Reservoir, in the last two years, is about 800mm (av about 1270mm) that have dwindled the power generation by less than 50% (43% live storage in UK reservoir in 2021) (**Table 5**)

It is imperative that sedimentation of reservoirs, causes water storage loss, energy capacity loss with turbine impairments and downstream basin faces sediment starvation, causing deltaic erosion, (Mishra et al, 2022[36])), Reservoirs of small capacity with large transportation rate, deposit less sediment than that of a reservoir of huge capacity. The rate of Sedimentation of a reservoir is based upon the basin characteristics like shape, size, soil erosion rate, sediment harvest, vegetation, and soil characteristics. The retrospective reservoir characteristics are trap efficiency, accommodation, bottom layer topography, sediment flux rates, substrate mobility, and sand-mud content, Dutta S., 2016[37], Prather B.E., 2020[38]. Mishra et al., 2022[39], Since the date impounding of the UK reservoir, very heavy floods occurred during the years 1990 & 2006. The high reservoir capacity enabled spill flood flow of more than 50% of live storage volume. For the rest of the years, the sustainability of reservoir operation was in jeopardy. In the years 2003 & 2018, water have been released in expectation of high floods as per meteorological forecasts but could not fulfill the expectations. The spillway data reveals that storing up to 858.18m could be possible only once and twice within 36 years of the operation of the reservoir.

The UKHEP is a part of all 10 hydroelectric projects of Godavari Basin 2715.45MW installed capacity with an overall generation of 6412MU with HEP performance (MU/MW) in Godavari basin 2.36. The HEP performance of the Godavari basin has been studied by SUNDRP from 1985-1986 to 2010-2011 was 2.53 to 2.36 with a decreasing trend. The generation is dropping gradually in the basin to drop in performance of the reservoirs. The UK HEP was contemporary to the study period i.e. from 1986, the hydropower generation of UKHEP must be depleting gradually. The attributes may be a rise in sediment influx to the reservoir and reducing the reservoir capacity, (SANDRP- 2011[40])

Sedimentation of a reservoir involves basin erosion, sediment entrainment, gullies, drains, silt transportation via the inflowing rivers, deposition, and settlement within the reservoir behind the dams. Dams are designed to have zero sediment balance as it depletes the reservoir capacity and consequently the hydropower generation. It is the result of the reduction of the velocity of flow, and bed slope gradient that instigates the accelerating sedimentation.

The sedimentation rate of reservoirs across east-flowing rivers in Odisha and the north Andhra coast (Up to the River Godavari), is about 1.638 Th. Cum./Km^2/yr (hydrographic survey results) below the rate increases abruptly. The most probable model of peak flow and transportation of sediment through the east-flowing river from the Huguli River to Vansadhara was studied by the author and found to follow a similar pattern that differs from the rest of the east-flowing rivers originating from the Deccan Plateau (Mishra S. P. 2017[41]). The average sedimentation rate from 1986 to 2011 (25 years) in upper Kolab Reservoir was 3.461 Th. Cum/Km^2/yr as estimated by CWC for the operation period of the UKP dam from 1986 to 2011. But the average estimated rate of annual sediment accruing during the period 1986 to 2021 has increased to 3.542mm /year. The other similar dams in region IV as estimated at 0.76mm/year for the east-flowing rivers on the east coast of India and the neighboring Deccan peninsular region reservoirs project have average sedimentation of 2.22 Th. Cum/Km^2/yr. The calculated sedimentation of the present UKP is 3.542 Th. Cum/Km^2/yr, which indicates much above the regional average.

Conclusion:

The river is the carrier that transports sediment from the upper reaches of the basin and is carried to the delta but is obstructed by a dam. Sediment is deposited within the reservoir by squeezing its storage capacity, hence usage value in long run is based upon the basin and the reservoir characteristics such as slope, stream order, aspect and terrain characteristics of the basin, and the effect of reservoir siltation on power generation loss.

The present paper envisages the sedimentation of the upper Kolab reservoir (UKR) and corresponding power generation loss based on the pumped-storage reservoir operation rules and concurrent energy demand. The results obtained are as follows:

i. The rate of sedimentation calculated by the GIS method is found to be compatible with the hydrologic survey method.
ii. The sedimentation in the UKR is gradually increasing threatening its lifespan. The rate of sedimentation in UKR is 3.542mm/year is much higher than the average rate of sedimentation in the adjacent reservoirs in the Godavari Basin i.e. 2.22mm/year.
iii. The cause of sedimentation is attributable to Anthropogenic activities, inefficient management of the sedimentation in the upper basin, and lack of various catchment treatment plans rather than the reservoir de-sedimentation.
iv. The strategies related to reservoir capacity building to be well judged and a new reservoir operation plan needs to be chalked out as meeting the grid demand of the Orissa Hydropower Corporation (OHPC) the federal authority.
v. The dynamism of flow and the water the active water in the reservoir and water consumption efficiency has a strong correlation. If the water usage rate reduces, the prolonged storage of the quantum of a flood shall aggravate sedimentation.
vi. Sediment management in the reservoir needs prioritization which affects the power generation of the Upper Kolab Project.
vii. Considering the rate of sedimentation, and deterioration of vegetation in the upper basin it is desired to have another dam warrant be designed and made functional below the existing UKP as the middle Upper Kolab Project before the Kolab River joins the Saberi River.

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