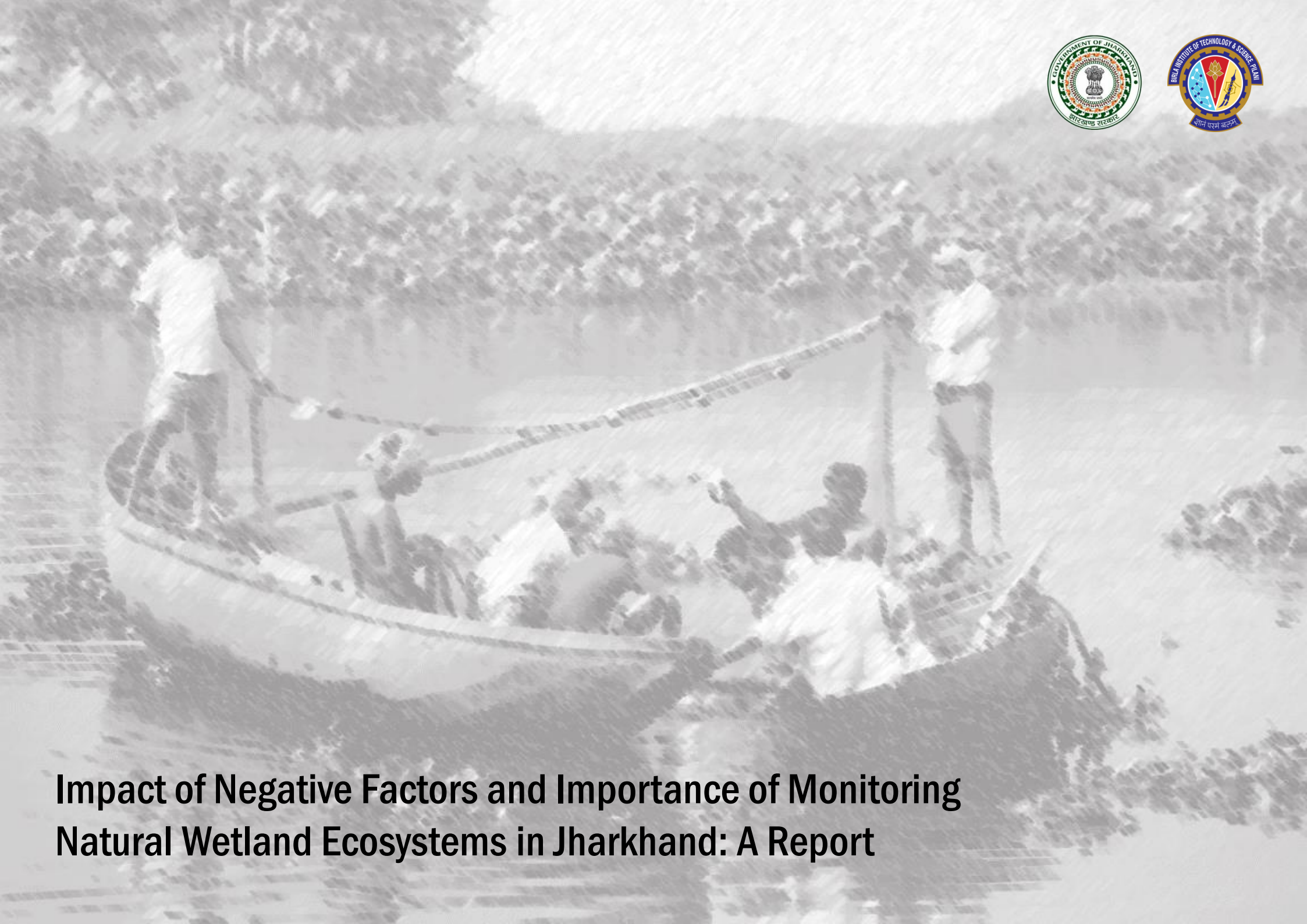

Impact of Negative Factors and Importance of Monitoring Natural Wetland Ecosystems in Jharkhand: A Report

Principal Investigator: Srikanth Mutnuri, BITS Pilani, India

Lalita Baragi and Rakshit Mittal, BITS Pilani, India (Biology)

Rajeev K. Chaturvedi, BITS Pilani, India (Economics)

Mohan Bera, BITS Pilani, India (Sociology)

Project funded by State Government of Jharkhand, India.

Editing and Layout by Rakshit Mittal

Cover picture: Brett Cole Photography

Impact of Negative Factors and Importance of Monitoring Natural Wetland Ecosystems in Jharkhand: A Report

Contents

1. Introduction

What is a wetland?

According to the Ramsar Convention on Wetlands of International Importance:
"Areas of marsh, fen, peatland, or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish, or salt, including areas of marine water, the depth of which at low tide does not exceed six meters"

1.1. District Map of Jharkhand and Wetlands Considered

Jharkhand state has 24 districts as given in the state-district map given in Fig. 1. We have considered the major wetlands grouped district-wise in this report.

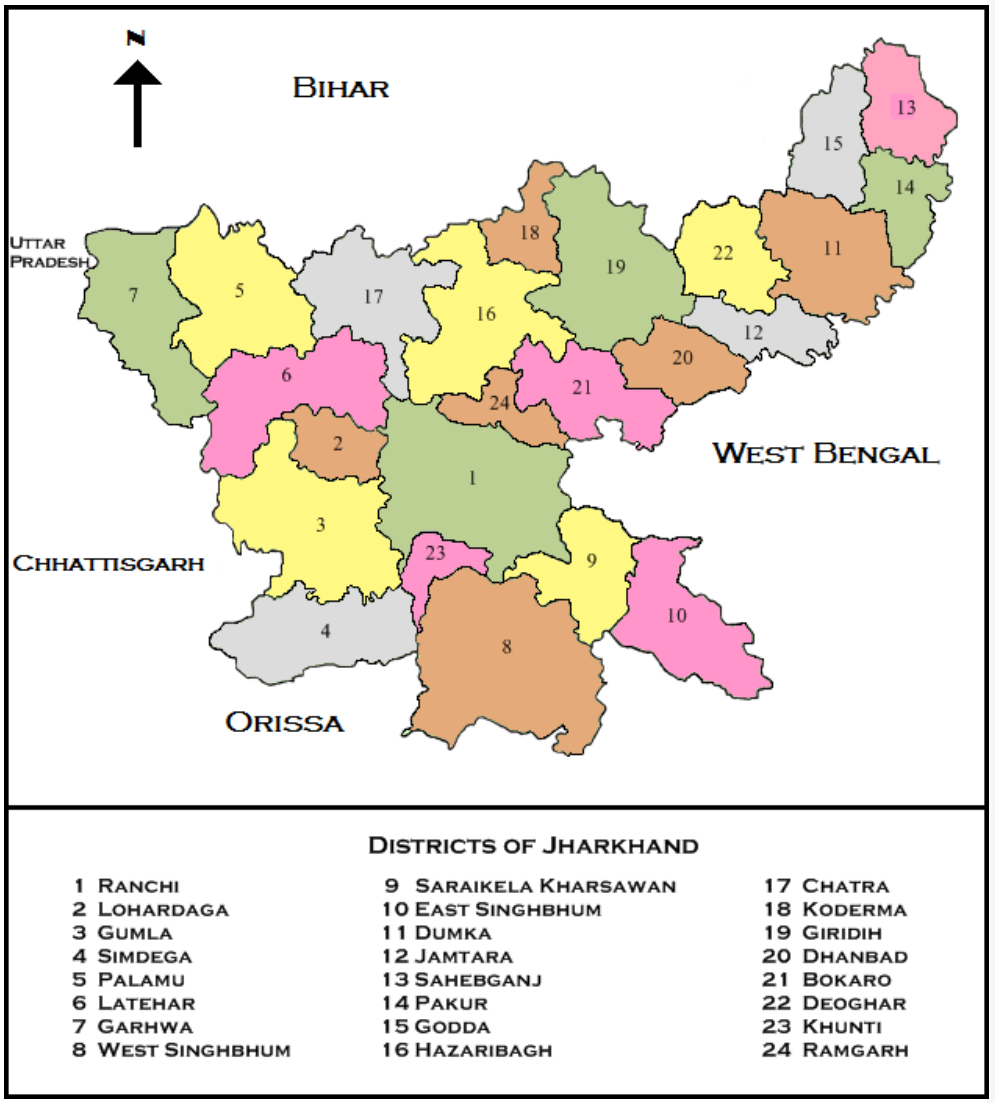

Fig. 1 Study Area, Jharkhand Map with different districts

1.2. Monitoring of Wetland over time

In order to monitor the wetlands in Jharkhand we propose to use Multispectral satellite data/ Geographic information system (GIS). This will provide us with data on water body area, vegetation and manmade structure (roads, buildings) cover on temporal scale. Based on this data we can calculate different indices such as Normalized Difference Vegetation Index (NDVI) associated with vegetation content, Normalised Difference Water Index (NDWI) associated with water content, and Normalized Difference Built-up Index (NDBI) associated with urban pattern (building cover). Satellite data i.e. Landsat provides data from 1972 till now to calculate all the above indices.

The datasets used and methodology are described in Appendix 1.

1.3. Biological Aspects Considered

- We collected information from literature on
  - water quality parameters such Temperature, pH, Dissolved Oxygen, Transparency, Turbidity, Nitrate, Phosphate, Silicate, Gross Primary Production and Net Primary Production.
  - diversity of organisms [flora (plankton, vegetation) and fauna (plankton, fish)].

- We compared the water parameters with the permissible limits given by Bureau of Indian standards guideline values for drinking water, in order to know whether water is suitable for drinking (human consumption), domestic, and irrigation purposes

- Based on the collected data we calculated Water Quality Index (WQI), which is valuable and unique rating to depict the overall water quality status in a single term that is helpful for the selection of appropriate treatment technique to meet the concerned issues. A WQI is also a means by which water quality data is summarized for reporting to the public in a consistent manner. WQI calculation produces a score between 0 and 100. The higher the score the better the quality of water. The scores are then ranked into one of the five categories described in Table 2

WQI range	Quality		Concern
91-100	Excellent water quality	Support a high diversity of aquatic life, suitable for all forms of recreation	meets expectations — lowest concern
71-90	Good water quality		
51-70	Medium or average water quality	Have less diversity of aquatic organisms and frequently have increased algae growth	Moderate concern
26-50	Fair water quality	Only able to support a low diversity of aquatic life and are probably experiencing problems with pollution	does not meet expectations - highest concern
0-25	Poor water quality	Only be able to support a limited number of aquatic life forms, and it is expected that these waters have abundant quality problems.	

Table 1: Water Quality Index (WQI) and description

1.4. Economic Aspects Considered – InVEST Models

We use the InVEST models to quantify and analyse the economic ecosystem services offered by wetlands. InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) is a suite of models used to map and value the goods and services from nature that sustain and fulfill human life. It helps explore how changes in ecosystems can lead to changes in the flows of many different benefits to people. InVEST models are spatially-explicit, using maps as information sources and producing maps as outputs. InVEST returns results in either biophysical or economic terms. nVEST models are based on production functions that define how changes in an ecosystem's structure and function are likely to affect the flows and values of ecosystem services across a land- or a seascape. The models account for both service supply and the location and activities of people who benefit from services. We are using the following InVEST models for analyses:

i) ***Carbon Model:*** The InVEST Carbon Storage and Sequestration model estimates the current amount of carbon stored in a landscape and values the amount of sequestered carbon over time. First it aggregates the biophysical amount of carbon stored in four carbon pools (aboveground living biomass, belowground living biomass, soil, and dead organic matter) based on land use/land cover (LULC) maps provided by users

ii) ***Forest Carbon Edge Effect Model:*** The InVEST carbon edge effect model extends the approach of the InVEST carbon model to account for forest carbon stock degradation due to the creation of forest edges. It applies known relationships between carbon storage and distance from forest edge to calculate edge effects in carbon storage, and combines these estimates with carbon inventory data to construct the overall carbon map.

iii) ***Sediment Retention Model:*** The InVEST Sediment Retention model estimates the capacity of a land parcel to retain sediment by using information on geomorphology, climate, vegetative coverage and management practices.

iv) ***Urban Flood Risk Mitigation Model:*** The InVEST model calculates the runoff reduction, i.e. the amount of runoff retained per pixel compared to the storm volume. It also calculates, for each watershed, the potential economic damage, by overlaying information on flood extent potential and built infrastructure.

v) ***Annual Water Yield:*** InVEST estimates the annual average quantity and value of hydropower produced by reservoirs, and identifies how much water yield or value each part of the landscape contributes annually to hydropower production. The model has three components: water yield, water consumption, and hydropower valuation. The biophysical models do not consider surface – ground water interactions or the temporal dimension of water supply.

The data sources and other constant factors and indices used as inputs for these models are described in Appendix 2.

***Other Valuations*:**

i) ***Water Storage*:** Water storage is an important value of a wetland/reservoir. We calculate the water storage valuation on a per-annum basis. We assume the cost of storage of one meter-cube of water to be 1 USD for one year. The wetland provides us with this water storage service and that is how we calculate its value by considering the wetland storage capacity data.

ii) ***Science and Education*:** The Govt. of India, in Strategy 1.4 of its National Water Mission of 2013, allocated 900 crore to develop an inventory of wetlands in India. We calculate the per kilometer-square value of a general wetland in India in terms of this expenditure and then calculate the total value of the particular wetland by considering its actual area.

iii) ***Sediment Retention*:** The InVEST Sediment Retention model estimates the capacity of a land parcel to retain sediment by using information on geomorphology, climate, vegetative coverage and management practices. We use soil nutrient data to identify the amount of nutrients sequestered. This amount is valued by considering the market price of N-P-K fertilizer.

iv) ***Crop Production*:** We calculate the value generated by crop production from three major crops – Wheat, Maize, and Rice. We have only calculated the crop production in areas surrounding the wetland and not the entire watershed area dependent on the wetland for irrigation. To value the crop produced, we consider the Minimum Support Price set by the Govt. of India.

v) ***Hydroelectric Power*:** We consider data from various sources to identify hydroelectric power plants, the wetlands they are associated with and their annual power generation capacity to value a wetland in terms of the hydroelectric power generated by it. We consider the average cost of one unit of electricity (1 kWh) in Jharkhand, provided by the Jharkhand State Electricity Board, to value this particular service.

1.4. Sociological Aspects Considered

Wetlands are socially important. They form a part of the indigenous/local population's identity. Other than their dependence on it for economic reasons and sustenance, wetlands also provide a wide range of social services. Often they are the centres of social activity. We have considered two InVEST models to model the social services of wetlands, namely:

i) ***Scenic Quality Model:*** The InVEST Scenic Quality model assesses the visual quality of a landscape based on sited or planned features that impact visual quality. The model allows you to value scenic quality in a variety of ways, such as the number of "viewer days" per year or the monetary value of a change in scenic quality using valuation functions from peer-reviewed literature.

ii) ***Recreation Model:*** Recreation and tourism are important components of many national and local economies and they contribute in innumerable ways to physical wellbeing, learning, and quality of life. To quantify the value of natural environments, the InVEST recreation model predicts the spread of person-days of recreation, based on the locations of natural habitats and other features that factor into people's decisions about where to recreate. In the absence of empirical data on visitation, we parameterize the model using a proxy for visitation: geotagged photographs posted to the website flickr.

In historical times many great civilizations had flourished along the wetland. The development and growth of civilizations highlights the importance of wetlands in the world. However, there has been gradual change in human relationship with wetlands. The value of wetland depends on location of wetland, settlement pattern, climatic condition and its contribution in terms of livelihood. As a complete ecosystem, a large number of people find their livelihood from wetlands. Although, wetlands cover 7% percent areas of the earth surface, but it provides about 45% ecosystem services to the world (ISRO 2001). It contributes in supplying drinking water, water for irrigation, replenishing groundwater, flood control, promote tourism, fishing, transport, food production and reduce climate impacts. Wetland has also great significance in socio-cultural mobilization. However, McCartney et al. (2006) warned that the communities highly dependent on wetland are in stress because of over exploitation of resources. Although

wetlands are the most productive livelihood generating ecosystem in the earth, it is observed that a large area of wetlands has been transformed into wasteland. Therefore in-depth study on wetland is urgently required.

The process of sustainable development of wetlands began after the Ramsar Convention in 1971. The Ramsar Convention's focused on how wetlands are significant for people. In 2018, the Ramsar Convention Secretariat published 'Global Wetland Outlook: State of the World's wetlands and their services to people' by focusing on the contribution of wetlands to achieve the Sustainable Development Goals (SDGs). A number of studies have already been carried out in the context of its physical, biological and socio-economic importance, but quite limited works has been ventured in terms of combination of all these aspects in the context of Jharkhand. The study has adopted an interdisciplinary approach by involving the biological, social, and economic aspects in relation to wetlands and people and government for the sustainable development of wetlands. The main objectives of the study are:

a) To understand the dependency of people on wetland resources and in what ways the dependency has been changing in Jharkhand;

b) To investigate alternative livelihood opportunities generated from wetlands in Jharkhand; and

c) To understand the role of wetland based livelihood strategies of the government to achieve SDGs.

1.5. Study of Trade-offs and Synergies

Different ecosystem services respond differently to management, there are inevitable trade-offs among some of these services, and understanding these trade-offs has gradually become a research hotspot. As the research on trade-offs has deepened, it has become possible to quantify them.
Trade-offs among multiple ecosystem services occur when an improvement in one ecosystem service is achieved at the expense of a decrease in another; conversely, when an improvement in one ecosystem service leads to an increase in another, the relationship is a synergy. We quantify the trade-offs and synergies between different ecosystem services by calculating Pearson's correlation coefficient over temporal data.

1.6. High Resolution Inventory of Wetlands

In recent times there has been a dramatic advance in both spatial resolution and availability of Earth Observation (EO) data with the potential for wide application in the field of wetland monitoring and mapping. EO provides improved thematic and geographical accuracy, high revisiting capability and data consistency, all in a cost effective manner. To this end EO is nowadays increasingly used for wetland mapping, and consequently in assessment and monitoring activities. At the same time, advanced image processing techniques have been developed and tailored specifically for wetland and habitat mapping in order to process data from raw to higher levels producing added-value maps and to provide frequently updated baseline and trend information.

Mapping wetlands are essential for natural resource management at both regional and national levels. However, accurate wetland mapping is challenging, especially on a large scale, given their heterogeneous and fragmented landscape, the highly dynamic and remote nature of wetland ecosystem, as well as the spectral similarity of differing wetland classes. These issues result in fragmented, partial, or outdated wetland inventories in most countries worldwide. Nevertheless, as mentioned earlier, innovative and powerful tools are now available in the fields of EO and Spatial Data Infrastructures that could facilitate the adoption and implementation of a standardized, consistent methodology on wetland mapping and assessment.

Although India has one of the most comprehensive wetland inventories (published by NWIA using optical imagery from LISS III for the year 2006-07), these are not up-to-date, also incomplete and have considerable limitations related to the resolution and type of data, as well as the developed methods. These differences make the existing inventories incomparable and highlight the significance of long-term comprehensive wetland monitoring systems to identify conservation priorities and sustainable management strategies for these valuable ecosystems.

2. Biological Aspect Case Studies

2.1. Getalsud Reservoir

2.1.1. Site Description

Getalsud reservoir situated across the river Subarnarekha (50 km from the origin of the Subernarekha River), 40 km east of Ranchi city.

Fig. 2: Region of Interest – Getalsud Reservoir

Watersheds / Catchment Area

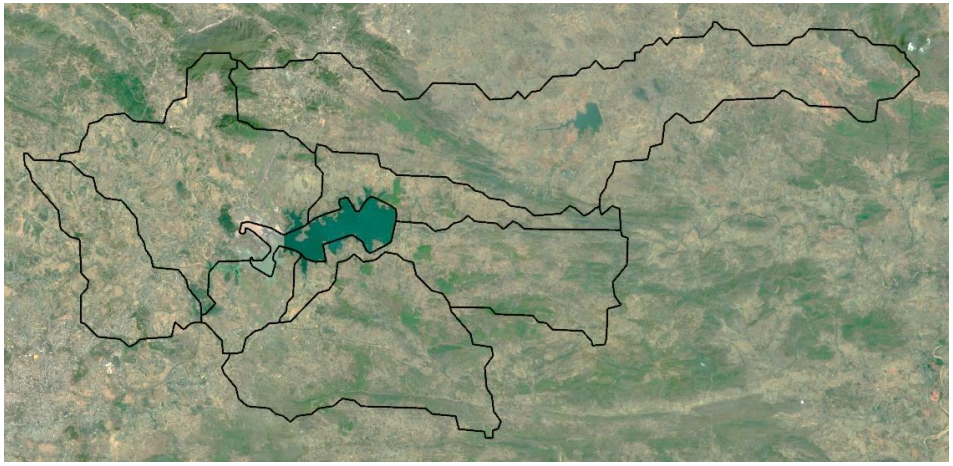

Fig. 3: Watershed regions associated with Getalsud reservoir marked with black boundaries

Latitude (N)	23°27'24.75"
Longitude (E)	85°31'29.70"
Area (km^2)	18.57
Maximum depth (m)	32.6
Mean depth (m)	8.46
Catchment area (km^2)	716.80

Table 2: Geospatial details – Getalsud Reservoir

2.1.2. Threats

The river Subarnarekha receives factory effluents from the Heavy Engineering Corporation and sewage wastes emanating from the industrial township. A drop in dissolved oxygen, accompanied by decrease in plankton, has been reported below the discharge point. The water recovers its quality further downstream. Recently, in 2019 around 30 quintals of adult fish were found dead at Getalsud dam, some 30 km away from capital limits in Angara block, the probable cause was the discharge of effluents from industrial units in close proximity to the dam.

2.1.3. Values

✓ **Direct use value**

- Agriculture:
- Wetland products (fishing): The dam provides a small-scale fishing opportunity to the local people of Rukka. Water is used to fulfill the drinking water requirements of the residents of Ranchi. Apart from that, it is also used for industrial purposes and generating electricity.
- Recreation (tourism): The nearby areas to dam are also user for picnic spot by the people of Ranchi and Ramgarh.

✓ **Indirect-use value**

✓ **Non-use value**

- Cultural and heritage value: There is huge rush during the time of New Year and Chhatt pooja.

2.1.4. Monitoring of wetland over time

The results show that there was increase in number of manmade structures (Fig 4), urban build-up (Fig. 5) and reduction in vegetation cover (Fig 6) around and in Getalsud reservoir. There is reduction in the area cover of wetland from 2000 (27.47 km^2) to 2020 (18.57 km^2) and perimeter of wetland from 2000 (66.79 km) to 2020 (60.09 km). In Fig 5, Red colour shows urban build up areas. There is increase in urban build up in 2020. Red colour in Fig 6 shows water bodies and buildings, while the Green colour is vegetation cover. There is decrease in vegetation cover in 2020

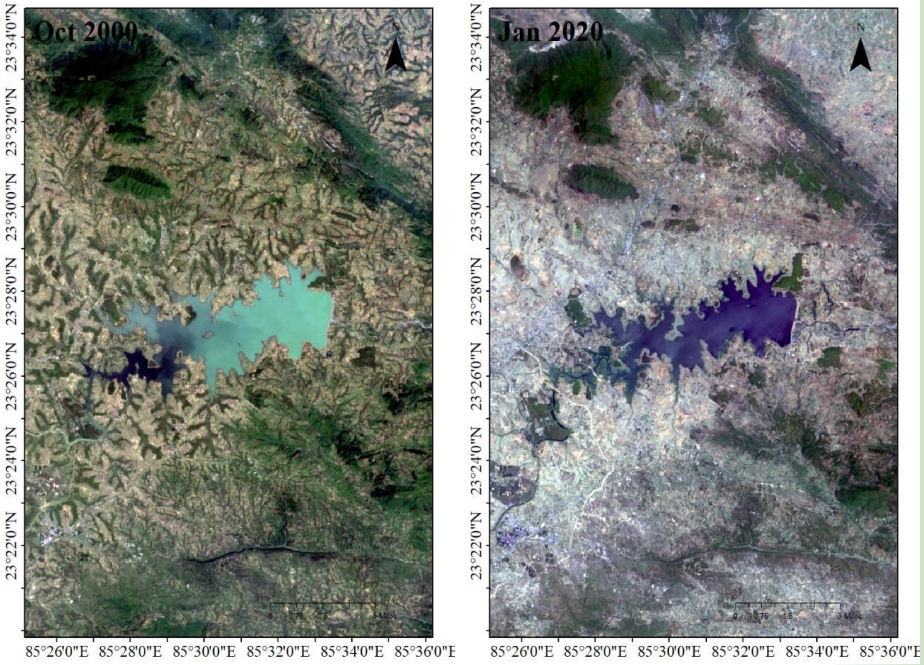

Fig. 4: Satellite data over time – Getalsud Reservoir

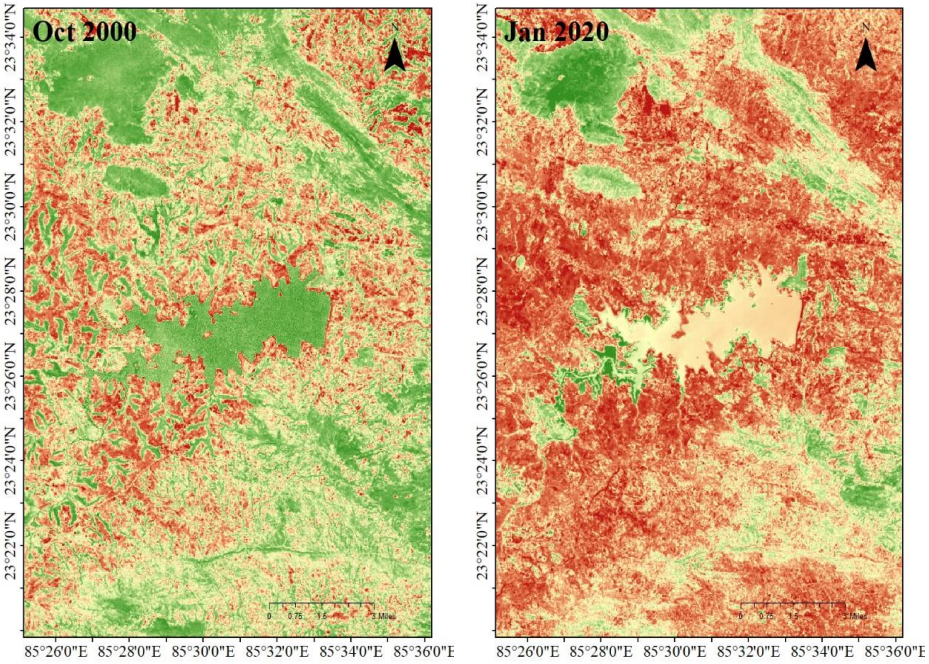

Fig. 5: Normalized Difference Build-up Index – Getalsud Reservoir

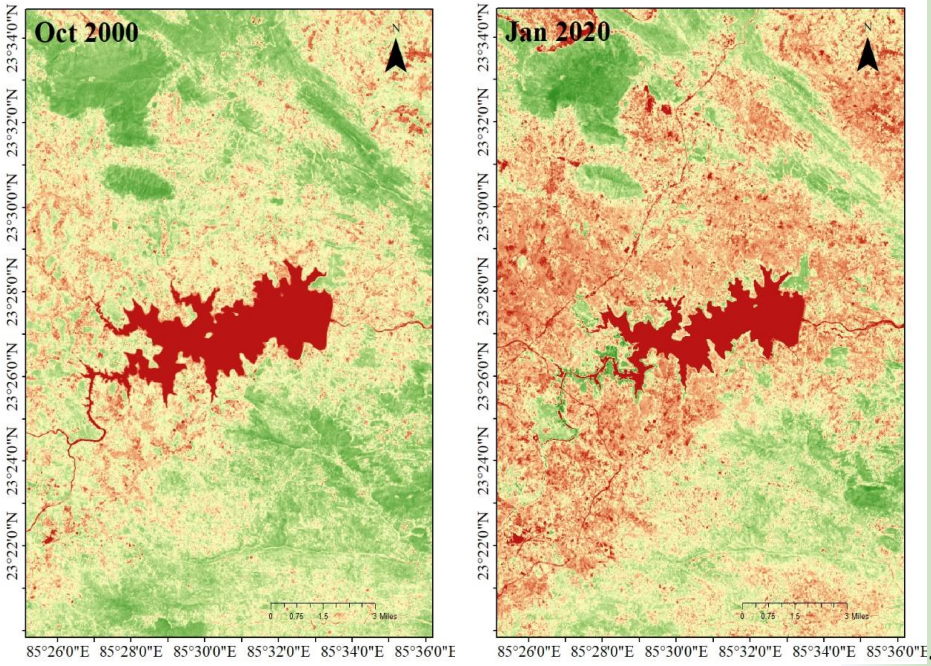

Fig. 6: Normalized Difference Vegetation Index – Getalsud Reservoir

2.1.5. Biological Aspects

Results

- **Water quality:** Water quality was found "*Good (WQI score=83)".* The water was considered good in this wetland mainly due to low chemical parameter values contributing to lower composite effect on water quality.

Water temperature (°C)	**16.0–28.5**
pH	**7.3–8.2**
Transparency (cm)	**10–176**
Turbidity	**Moderate**
DO (mg l^{-1})	**5.8–9.6**
CO2 (mg l^{-1})	**0.6–15.1**
Calcium (mg l^{-1})	**5.3–18.8**
Nitrate (mg l^{-1})	**0-0.36**
Phosphate (mg l^{-1})	**0.001–0.12**
Silicate (mg l^{-1})	**2.8–18.2**
Organic carbon (%)	**1.0–4.3**
Gross Primary Production (mg C m^2 d^{-1})	**281.07**
Net Primary Production (mg C m^2 d^{-1})	**147.4**

Table 3: Water quality – Getalsud Reservoir

- **Soil quality:**

Organic Carbon (%)	**0.46–0.60**
Available P (mg 100 g^{-1})	**2.45–6.08**
Available N (mg 100g^{-1})	**24.38–35.06**

Table 4: Soil quality – Getalsud Reservoir

- The water parameter values are within the permissible limits given by Bureau of Indian standards guideline values for drinking water.

- Based on the water quality index *(WQI score=83)*, the wetland overall water quality was found "*Good".* The water was considered good in this wetland mainly due to low chemical parameter values contributing to lower composite effect on water quality. However, at some places there are point discharges of industrial waste ,which affects the organisms and thus the ecological and economical value of wetland. In 2019, due to industrial discharge the water quality deteriorated, as a result the water pH increased to 12.5 which affected the fish by damaging their gills, eyes or skin, and death.

Interpretation

- ***Because of the good water quality (based on WQI score), it meets the expectation and is of least concern. This wetland is able to support a high diversity of aquatic life.***

Due to good water quality, wetland has high primary productivity. In wetland, diatoms have the maximum species diversity, followed by Chlorophyceae and blue- greens. Zooplankton is represented by 12 genera of rotifers, 6 of protozoa, 5 cladocerans and 2 of copepods. Density of benthic organisms is also high.

The average annual fish catch is 4000 kg. Different species of fish are Rohu (L. Rohita), Catla (Catla catla), Mirka (Cirrhinus mrigala), Reba (Cirrhinus reba), Calbasu etc.

There are 2 important factors for migratory birds:
(a) food – wetland is rich in fish, insects and algae which are source of food for migratory birds, notable among which are Little Grebe, Bank Myna, Pied Myna, Common Crane, Cattle Egret, Tufted Pochard,

Cotton Teal, Shoveller, Little Grebe, Palm Swift etc.

(b) Breeding - vegetation around wetland are habitat and breeding grounds for migratory birds. Based on GIS (NDVI index) it was observed that the vegetation cover around wetland has decreased from 2000 to 2020.

- ***The water is also suitable for drinking (human consumption) domestic, and irrigation*** purposes as water parameters are within the permissible limits given by Bureau of Indian standards guideline values for drinking water.

- ***In addition, the water would also be suitable for all forms of recreation, including those involving direct contact with the water.***

Recommendations

- ✓ Even though the overall water quality of wetland is good, there are some places where industrial effluents discharge occur. Its recommended that at these places water treatment should be done by using the latest yet economically viable treatment method such as constructed wetland. The size of the constructed wetland will be based on the water flow rate and the quantity of water to be treated.

- ✓ Jharkhand State Pollution Control Board has a zero-tolerance policy toward pollution. If we identify the industry, which is causing pollution the agency can take action and if necessary, the plant can also be shut down to prevent further harm to the wetland.

- ✓ Since the vegetation cover around the wetland, an important factor for migratory birds, has been decreased, we need to take some actions. We can reduced the urban activity and do afforestation around the wetland.

2.1.6. Economic Aspects

Carbon Sequestration

2010	2012	2014	2016	2018
2.340	2.419	2.526	2.524	2.524

Table 5: Carbon sequestration over time, in MegaTonnes

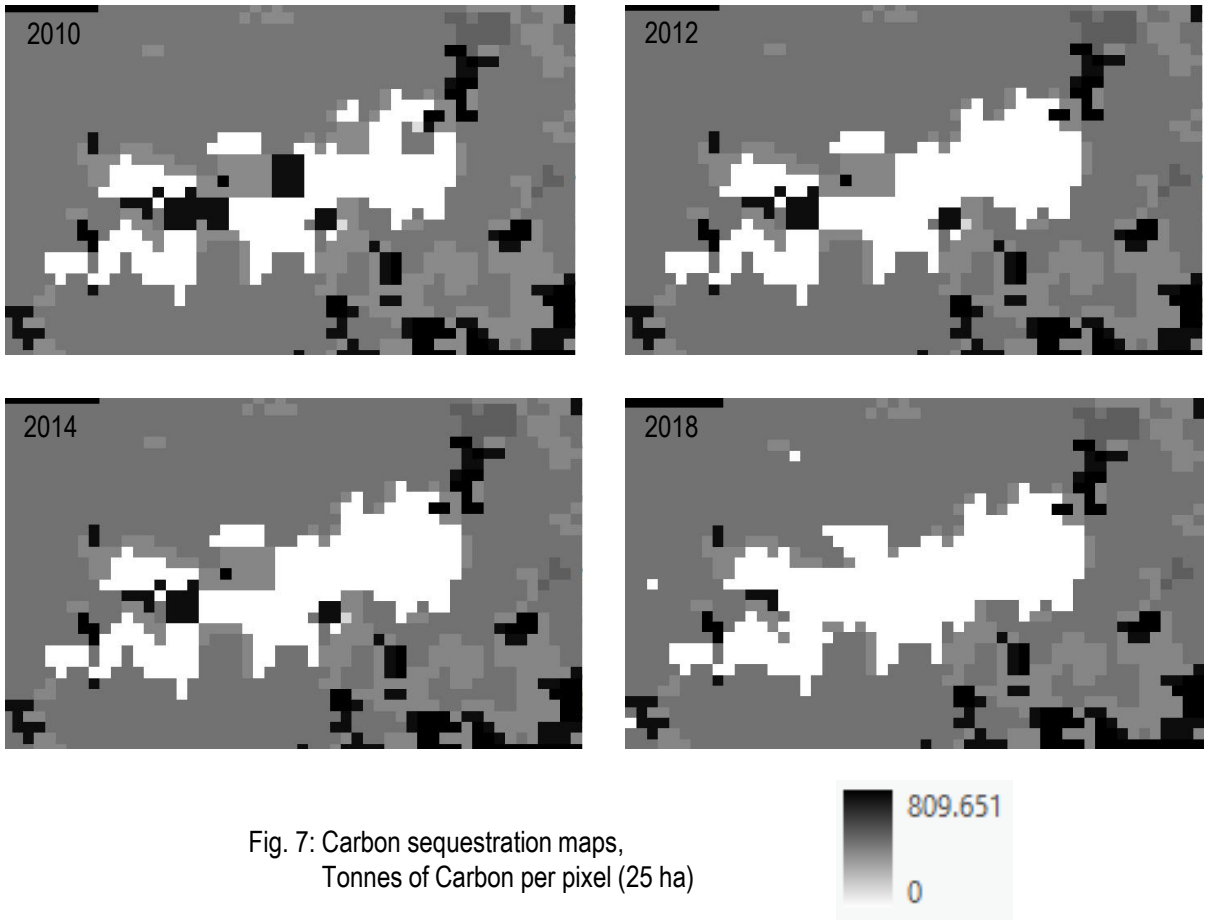

Fig. 7: Carbon sequestration maps,
Tonnes of Carbon per pixel (25 ha)

Flood Risk Mitigation

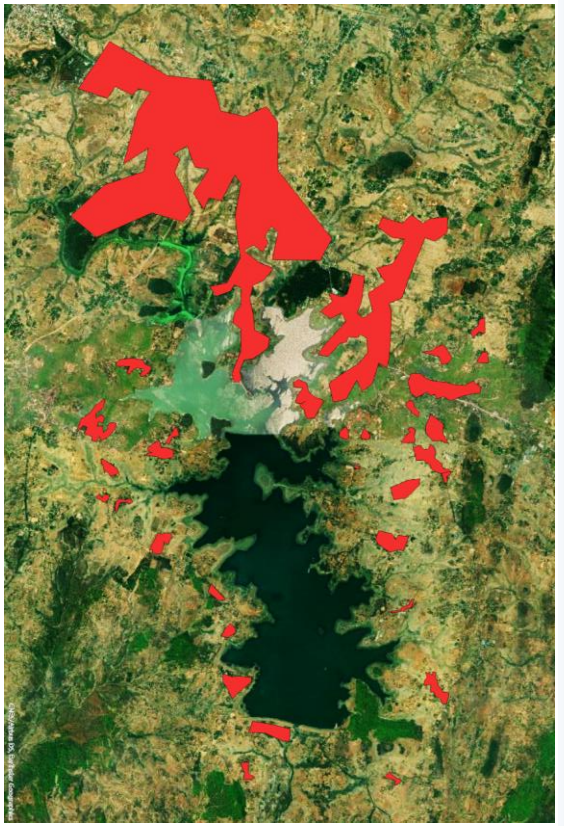

Fig. 8: Human settlements and built up area (marked in red) around the Getalsud reservoir

For a design storm with depth of rainfall 80mm spread over two days, modelling the Phailin Cyclone of 2013, it was found that the economic losses due to flooding came to nearly **26.08 million**.

Table 5 takes into account soil carbon, but the carbon maps only account for carbon above ground, considering edge effects.

Water Yield

2010	2012	2014	2016	2018
69.79	248.84	226.52	208.84	196.15

Table 6: Combined water yield in associated watersheds (billion litres)

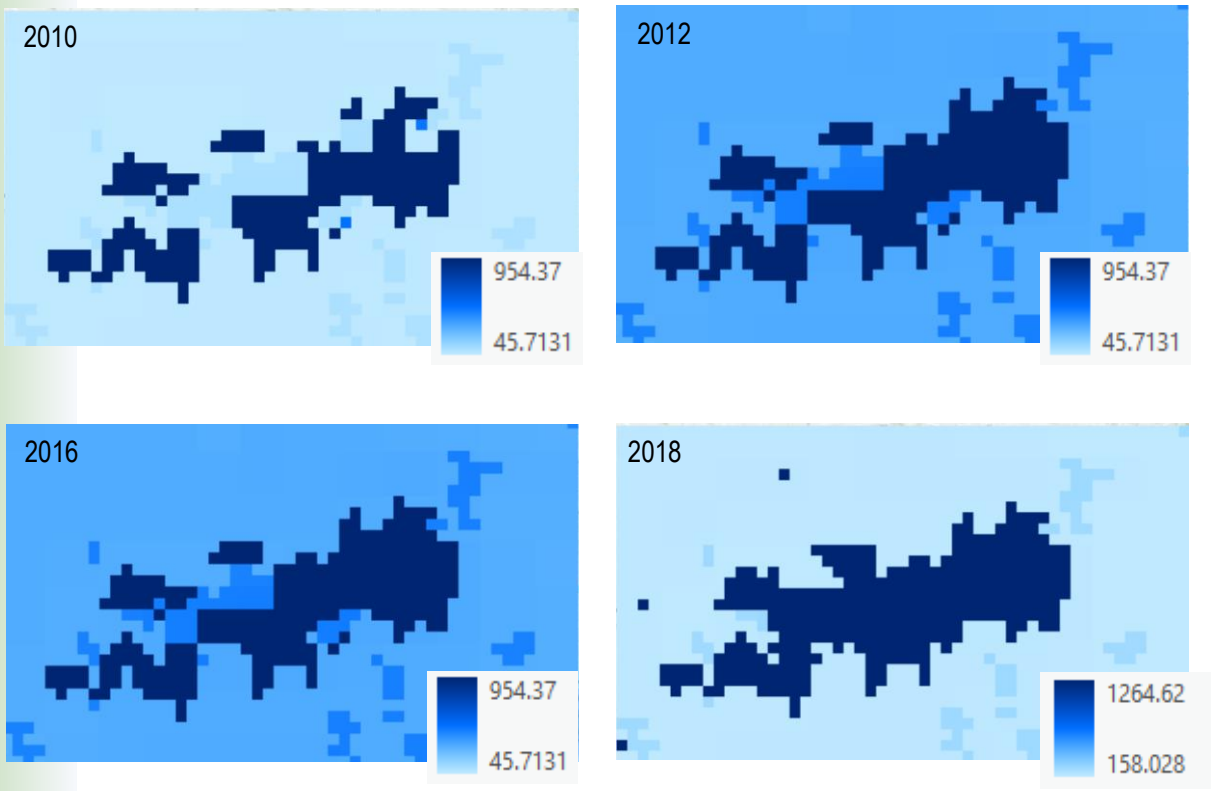

Fig. 9: Annual Water Yield Maps

Soil Sedimentation/Erosion

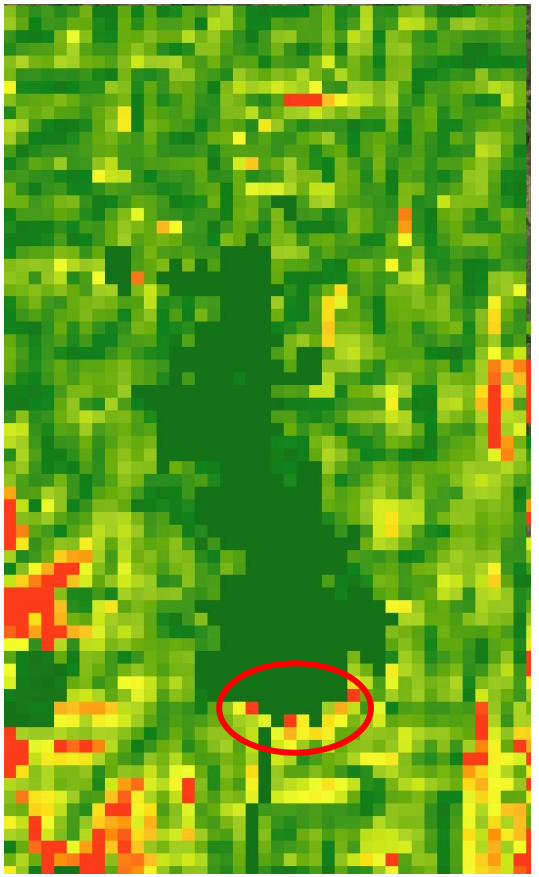

Fig. 10: Predicted soil erosion vulnerability maps. The red circles mark areas recommended for embankment to reduce soil erosion and loss of soil as a resource.

Regression Analysis

There is a weak positive correlation between the carbon stock and the area of the lake which signifies that the lake is an important sequestration zone for Carbon. There is a negative correlation between recreational index and Carbon storage and similarly between recreational quality and lake area which signifies that as human visitation to the lake has increased, it has been detrimental to the area of the lake and Carbon storage as well. The Water Yield is positively correlated with Carbon sequestration that doubly signifies the importance of carbon sequestration in the lake.

x	Carbon	Lake Area	Water Yield	Recreation
Carbon	x	0.23	0.87	- 0.50
Lake Area	0.23	X	- 0.36	- 0.91
Water Yield	0.87	- 0.36	X	0.46
Recreation	- 0.50	- 0.91	0.46	X

Table 7: Correlation coefficient between the different ecosystem services.

Current Valuations

a) Water Storage: The amount of water stored in the reservoir approx. = 288.5 Hm^3
Taking the annual price of water storage as 1 USD = 74 INR/m^3
The annual value of water stored in the reservoir = **2.14 billion INR**

b) Carbon Sequestration: The amount of Carbon sequestered in the wetland approx. = 2.524 MT
The social cost of Carbon in India is 86 USD = 6400 INR/T*
The value of Carbon sequestered in the wetland = **16.15 billion INR**

c) Science and Education: Project estimate of Strategy 1.4 (by inflation, 2020) approx. 13.7 billion INR **
The total area of wetlands in India = 153000 km^2

* https://www.downtoearth.org.in/dte-infographics/social_cost_corbon/index.html#:~:text=India's%20country%2Dlevel%20social%20cost,per%20tonne%20of%20CO2%20emission.

** http://nwm.gov.in/?q=strategy-14

Approx. investment in science and education of wetlands = 90,000 INR/km^2
The area of concerned wetland = 18.57 km^2
Value of scientific investment in reservoir = **1.67 million INR**

d) Sediment Retention: The total amount of soil retained in watersheds (by InVEST) = 393711.7 T
The average concentration of N and P in soil = 0.027%
The average quantity of retained nutrients = 106.3 T
The price of NPK approx. = 20,000 INR/ T
The value of sediment retention = **2.13 million INR**

e) Crop Production: Major annual crop production = Wheat (140 T), Maize (200 T), Paddy (6250 T)
Min. Support Price = Wheat (19250 INR/T), Maize (18500 INR/T), Paddy (18680 INR/T)
Approx. major crop value: 2,695,000 + 3,700,000 + 116,750,000 = **123.14 million INR**

f) Hydel Power: Annual generation of electricity = 237 GWh (Dam, 2008*) + 204 GWh (powerhouse, 2014**)
Average cost of electricity per unit in Jharkhand = 6 INR / kWh
Total value of electricity produced = **2.65 billion INR**

* http://globalenergyobservatory.org/geoid/5577

** http://59.179.19.250/wrpinfo/index.php?title=Subernrekha-I_Power_House_PH00800

Recreational Index

2010	2012	2014	2016	2018
5	9	12	13	17

Table 8: Annual no. of distinct photo user days – Getalsud reservoir

The lake is highly impacted by human settlements in terms of scenic quality. The south eastern shore of the lake still retains scenic quality due to low build-up index. The wetland has high cultural and social value. There is huge rush observed during Chhatt Pooja and New Year. The annual no. of distinct photo user days, an output of the InVEST model is taken as the proxy for level of human activities near the lake

Interpretations and Recommendations

- The carbon sequestration increased from 2010 – 2020 but there was an overall decrease from 2000 to 2020. This is mainly because of the shrinkage in the size of the lake. ***It is advised to reduce hum activity near the lake and to stop reclamation practices around the lake to reduce the negative impact and increase carbon storage value.***

Scenic Quality

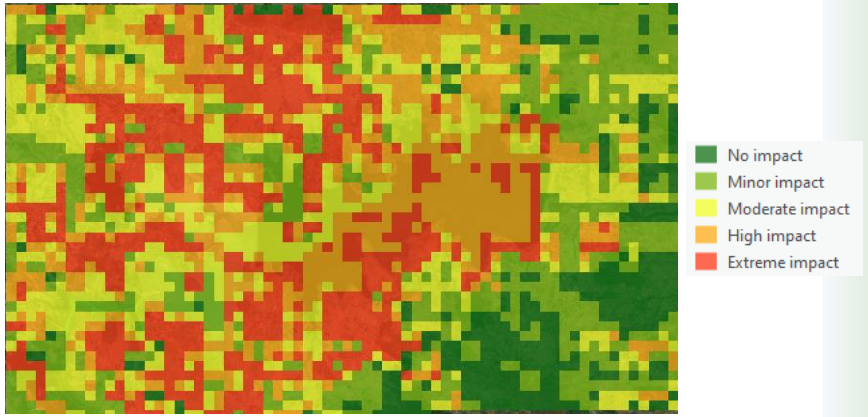

Fig. 11: Scenic Quality per pixel – Getalsud Reservoir

- There is high probability of soil erosion on the eastern edges of the lake. Soil erosion reduces th capacity of water storage of the lake, which is undesirable. ***Mitigation factors such a reforestation on those parts and building artificial banks can help reduce that.*** Soil is also a important non-renewable resource and it should be conserved at all costs.

- The scenic quality of the lake is highly impacted by man-made structures on the western coast of th lake. ***Corrective steps need to be taken to raze these structures and reforest these part with indigenous plant species.***

- Reduction in size of the lake negatively impacts scenic quality as well. Adequate steps should be take in this direction. There is a trade-off between recreational quality and carbon sequestratior Recreation and human activities negatively impact the valuation of the lake. ***Adequate balance steps need to be taken to develop responsible modes of tourism which do not harm th lake's fragile ecosystem.***

2.2. Tenughat Reservoir

2.2.1. Site Description

Tenughat reservoir was constructed on Damodar river. It is about 8 miles west to the Bokaro thermal power station in Bokaro district.

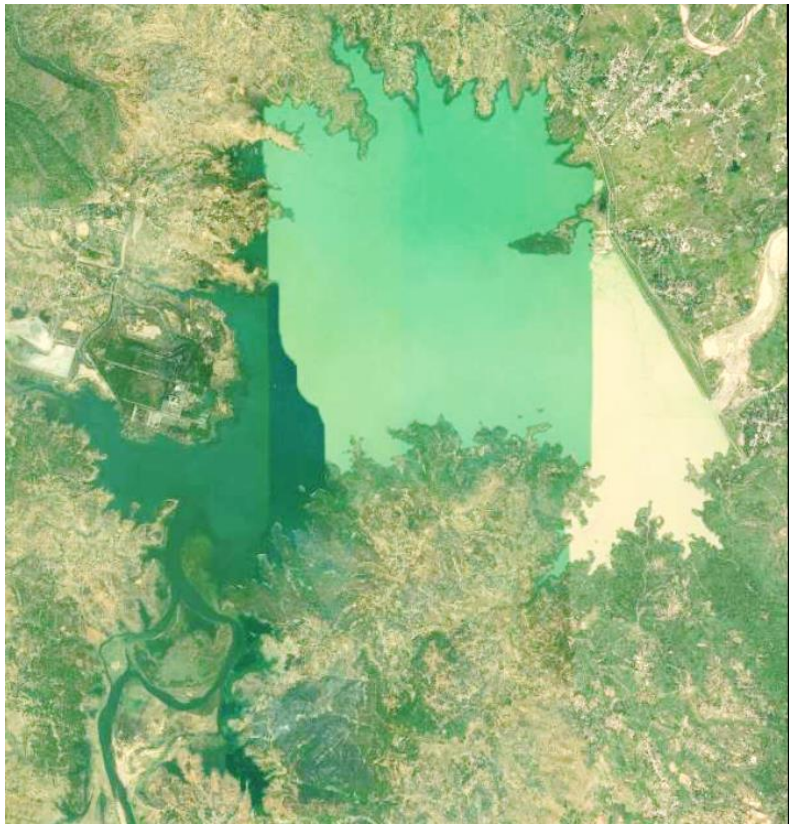

Fig. 12: Region of Interest – Tenughat Reservoir

Watersheds / Catchment Area

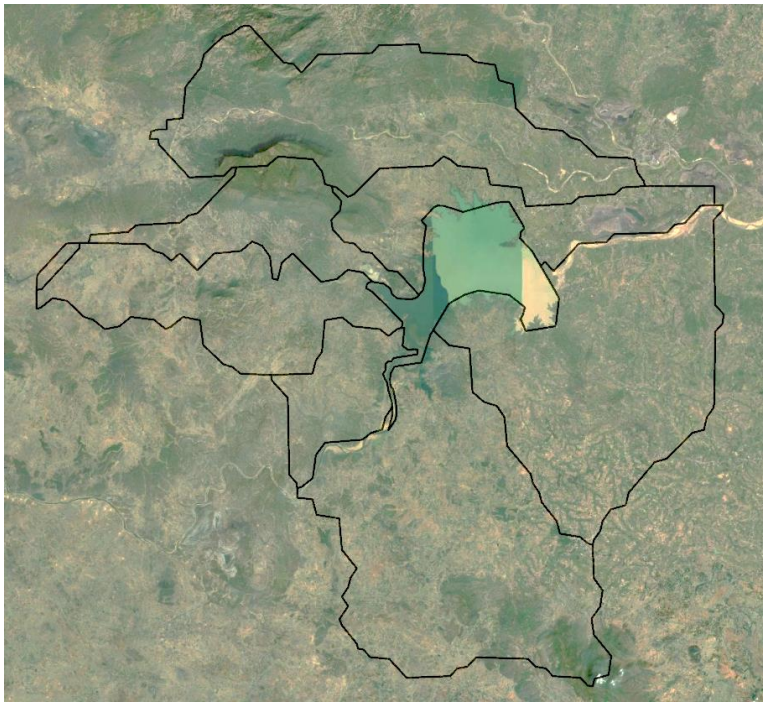

Fig. 13: Watershed regions associated with Tenughat reservoir marked with black boundaries

Latitude (N)	23°43'51.68"
Longitude (E)	85°50’01.09"
Area (km^2)	35.77
Maximum depth (m)	na
Annual Rainfall (mm)	1320
Catchment area (km^2)	4480.68

Table 9: Geospatial details – Tenughat Reservoir

2.2.2. Threats

Threatened by agricultural and industrial (coal washers, steel and fertilizer plants) effluents, mining, siltation, soil erosion, sedimentation, and overfishing. Total Suspended Solid (TSS) count is 40-50 times higher than the permissible limit and higher sulphate concentration. This is due to coal industries located near the river. Its entire surface is coated with a greenish-yellow film (oil and effluents from industries), while its bed, is a mixture of coal dust and soil. The ash generated by all the power stations seriously affects the ecology of the area.

2.2.3. Values

✓ **Direct use value**

- Agriculture:
- Wetland products (fishing, mining and aquaculture): The dam provides a small-scale fishing opportunity to the local people. Water is utilised to fulfil the needs of Bokaro Steel Plant and the Bokaro industrial area, and local population
- Recreation (tourism)

✓ **Indirect-use value**

✓ **Non-use value**

- Cultural and heritage value:

2.2.4. Monitoring of wetland over time

The results show that there was increase in number of manmade structures (Fig 14), urban build-up (Fig. 15) and vegetation cover (Fig 16) around and in Tenughat reservoir. There is reduction in the area cover of wetland from 2000 (34.95 km2) to 2020 (33.89 km2) and increase in perimeter of wetland from 2000 (68.31 km) to 2020 (76.28 km). In Fig 15, Red colour shows urban build up areas. There is increase in urban build up in 2020. Red colour in Fig 16 shows water bodies and buildings, while the Green colour is vegetation cover. There is increase in vegetation cover in 2020

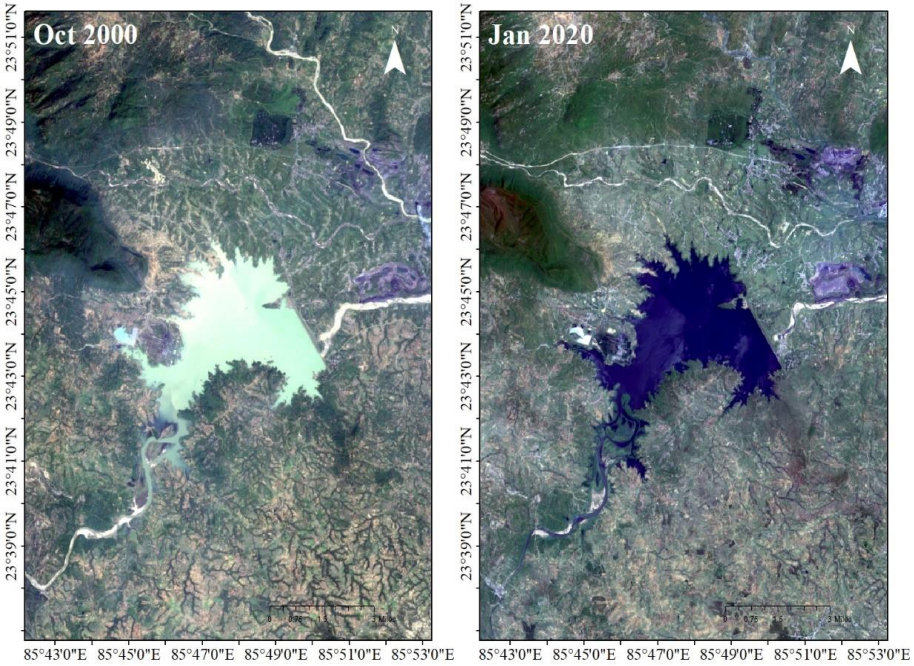

Fig. 14: Satellite data over time – Tenughat Reservoir

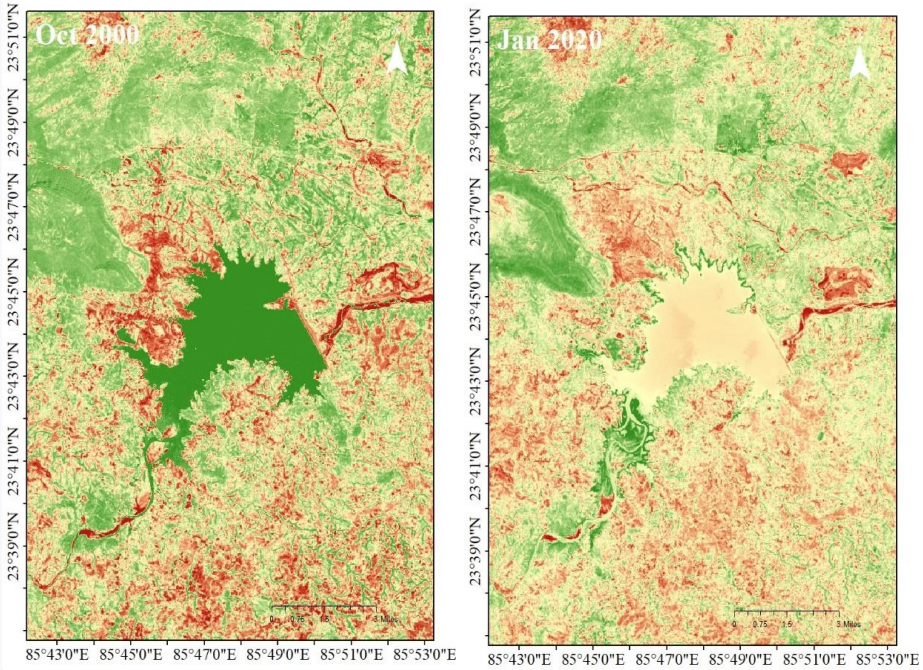

Fig. 15: Normalized Difference Build-up Index – Tenughat Reservoir

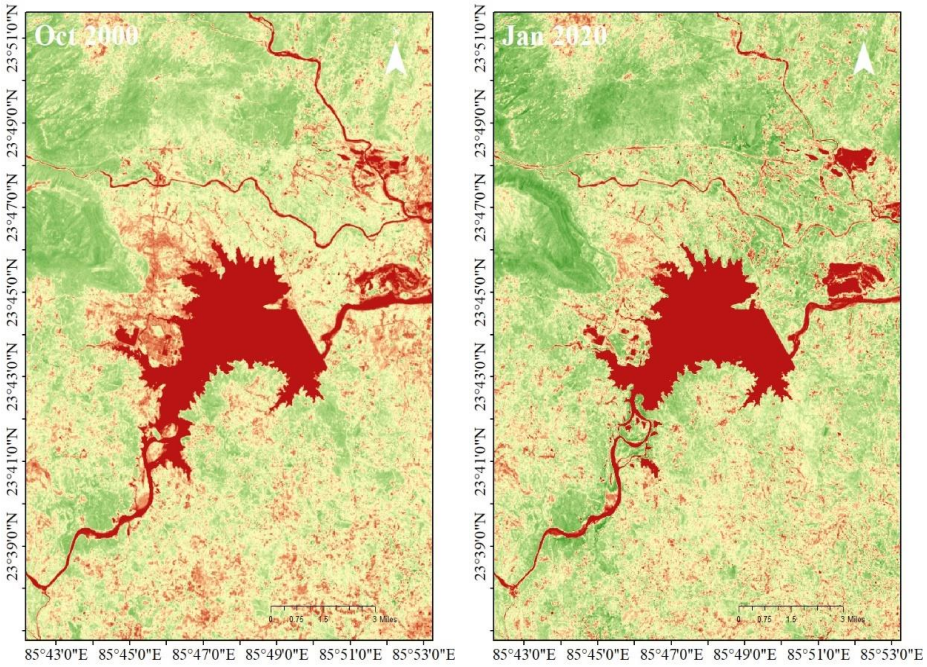

Fig. 16: Normalized Difference Vegetation Index – Tenughat Reservoir

2.2.5. Biological Aspects

Results

- **Water quality:** Water quality was found "*Good (WQI score=81)".* The water was considered good in this wetland mainly due to low chemical parameter values contributing to lower composite effect on water quality.

Water temperature (°C)	23
pH	7.5-8.6
BOD	0.7-3.1
Turbidity	Moderate
Total Dissolved Solids (mg l-1)	122-215
Total Suspended Solids (mg l-1)	90-118
Total Alkalinity (mg l-1)	240-280
DO (mg l-1)	7.4-8.3
Chloride (mg l-1)	21- 25.3
Nitrate (mg l-1)	1.7-25.1
Sulphate (mg l-1)	5.59-17.9
T-Coliform (cells/100ml)	4
Gross Primary Production (mg C m2 d-1)	
Net Primary Production (mg C m2 d-1)	

Table 10: Water quality – Tenughat Reservoir

- Based on the water quality index *(WQI score=83)*, the wetland overall water quality was found "*Good".* The water was considered good in this wetland mainly due to low chemical parameter values contributing to lower composite effect on water quality. However, at some places Total Suspended Solid (TSS) count is 40-50 times higher than the permissible limit and higher sulphate concentration. This is due to coal industries located near the river. Its entire surface is coated with a greenish-yellow film (oil and effluents from industries), while its bed, is a mixture of coal dust and soil. The ash generated by all the power stations seriously affects the ecology of the area.

- The water parameter values are within the permissible limits given by Bureau of Indian standards guideline values for drinking water.

Interpretation

- ***Because of the good water quality (based on WQI score), it meets the expectation and is of least concern. This wetland is able to support a high diversity of aquatic life.***

Due to good water quality, wetland has high primary productivity. In the Reservoir free floating phytoplanktons and zooplanktons were having a good growth. The phytoplanktons found in the reservoir were Spirogyra, Chlamydomonas lemna, Ajola, Hydrilla, Vacillinaria, Chara, and potamojiton. This vegetation was good food for major craps.

Different species of fish are Catla (C. catla), Mirka (C. mrigala), Rohu (L. rohita), L. calbasu, Bata (L. bata), C. carpio, P. sarana, M. aor, W. attu, B. bagarius etc.

More than 20,000 migratory birds such as ducks and coot visit these reservoirs.

There are 2 important factors for migratory birds:
(a) food – wetland is rich in fish, insects and algae which are source of food for migratory birds.

(b) Breeding - vegetation around wetland are habitat and breeding grounds for migratory birds. Based on GIS (NDVI index) it was observed that the vegetation cover around wetland has increased from 2000 to 2020. Indicating that the quality of wetland has increased for migratory birds.

- ***The water is also suitable for drinking (human consumption) domestic, and irrigation*** purposes as water parameters are within the permissible limits given by Bureau of Indian standards guideline values for drinking water.

- ***In addition, the water would also be suitable for all forms of recreation, including those involving direct contact with the water.***

Recommendations

- ✓ Even though the overall water quality of wetland is good, there are some places where industrial effluents discharge occur. Its recommended that at these places water treatment should be done by using the latest yet economically viable treatment method such as constructed wetland. The size of the constructed wetland will be based on the water flow rate and the quantity of water to be treated.

- ✓ Jharkhand State Pollution Control Board has a zero-tolerance policy toward pollution. If we identify the industry, which is causing pollution the agency can take action and if necessary, the plant can also be shut down to prevent further harm to the wetland.

2.2.6. Economic Aspects

Carbon Sequestration

2010	2012	2014	2016	2018
2.552	2.551	2.624	2.612	2.609

Table 11: Carbon sequestration over time, in MegaTonnes

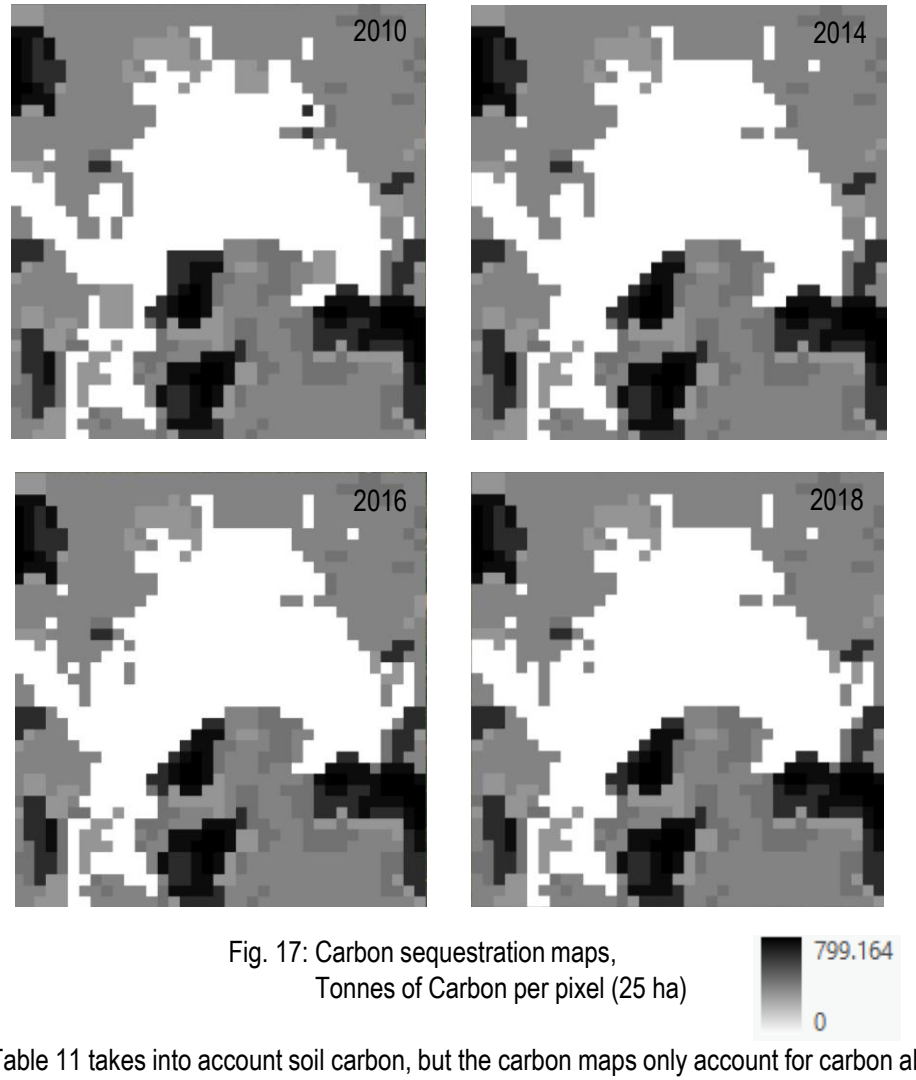

Fig. 17: Carbon sequestration maps, Tonnes of Carbon per pixel (25 ha)

Flood Risk Mitigation

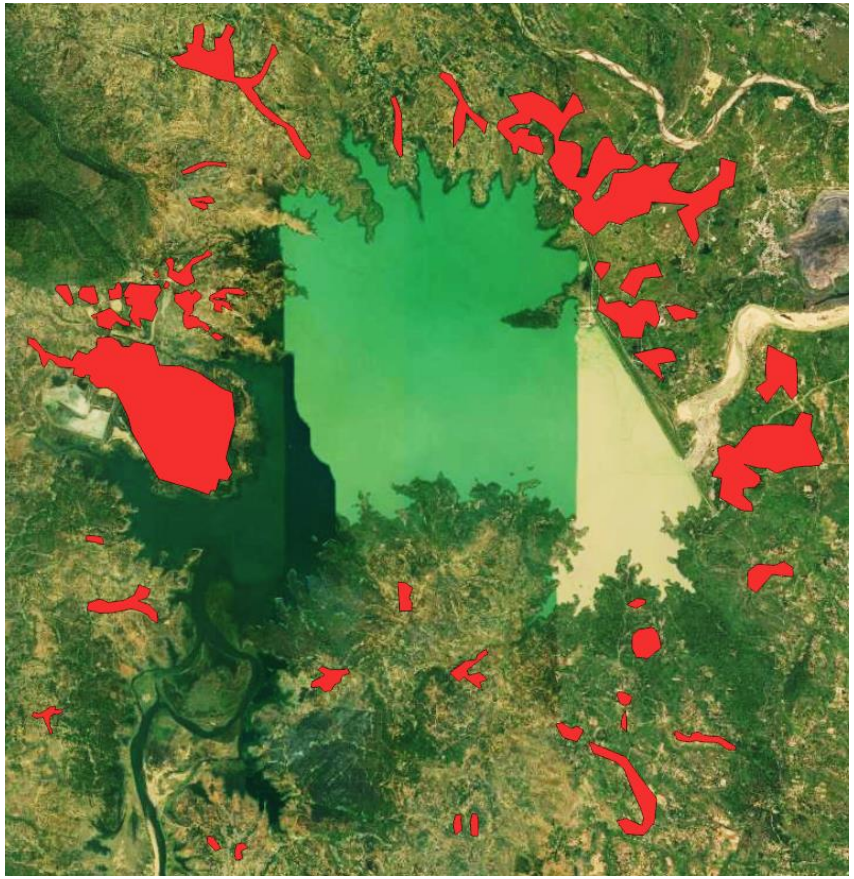

Fig. 18: Human settlements and built up area (marked in red) around the Tenughat reservoir

For a design storm with depth of rainfall 80mm spread over two days, modelling the Phailin Cyclone of 2013, it was found that the economic losses due to flooding came to nearly **13.35 million**.

Table 11 takes into account soil carbon, but the carbon maps only account for carbon above ground, considering edge effects.

Water Yield

2010	2012	2014	2016	2018
104.88	262.06	196.68	327.16	318.87

Table 12: Combined water yield in associated watersheds (billion litres)

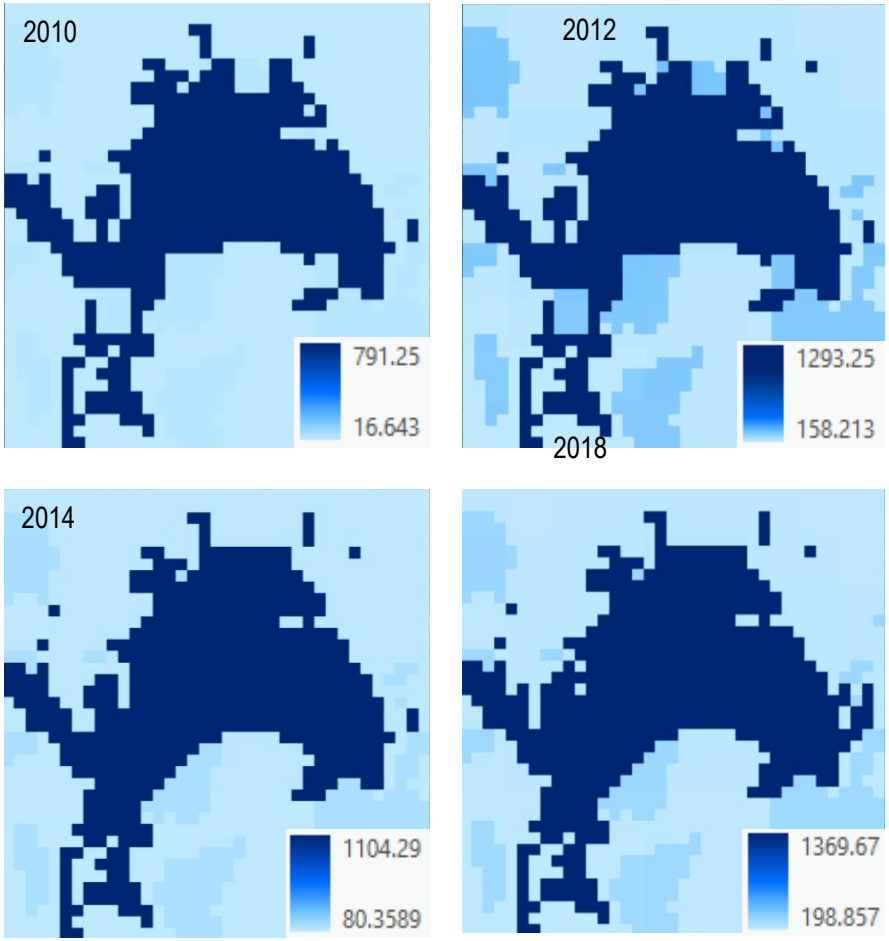

Fig. 19: Annual Water Yield Maps

Soil Sedimentation/Erosion

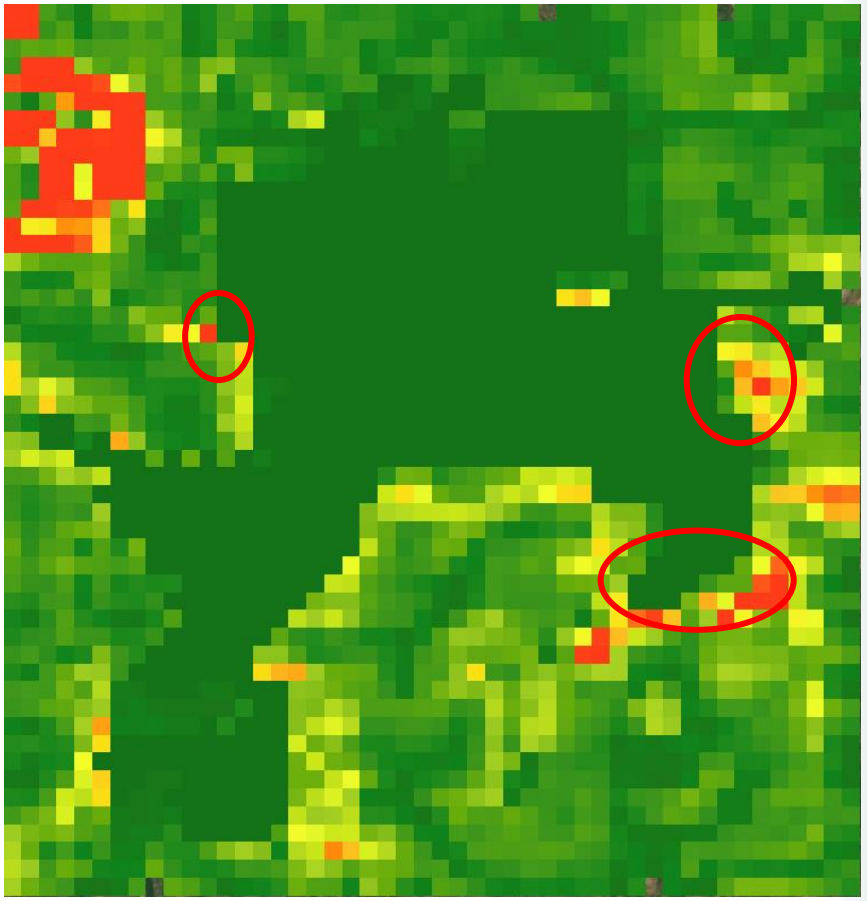

Fig. 20: Predicted soil erosion vulnerability maps. The red circles mark areas recommended for embankment to reduce soil erosion and loss of soil as a resource.

Regression Analysis

There is a weak positive correlation between the carbon stock and the area of the lake which signifies that the lake is an important sequestration zone for Carbon. There is a negative correlation between recreational index and Carbon storage and similarly between recreational quality and lake area which signifies that as human visitation to the lake has increased, it has been detrimental to the area of the lake and Carbon storage as well. The Water Yield is positively correlated with Carbon sequestration that doubly signifies the importance of carbon sequestration in the lake.

x	Carbon	Lake Area	Water Yield	Recreation
Carbon	x	0.23	0.87	- 0.50
Lake Area	0.23	X	- 0.36	- 0.91
Water Yield	0.87	- 0.36	X	0.46
Recreation	- 0.50	- 0.91	0.46	X

Table 13: Correlation coefficient between the different ecosystem services.

Current Valuations

a) Water Storage: The amount of water stored in the reservoir approx. = 7.77 Hm^3
Taking the annual price of water storage as 1 USD = 74 INR/m^3
The annual value of water stored in the reservoir = **575 million INR**

b) Carbon Sequestration: The amount of Carbon sequestered in the wetland approx. = 2.609 MT
The social cost of Carbon in India is 86 USD = 6400 INR/T*
The value of Carbon sequestered in the wetland = **16.70 billion INR**

c) Science and Education: Project estimate of Strategy 1.4 (by inflation, 2020) approx. 13.7 billion INR **
The total area of wetlands in India = 153000 km^2

* https://www.downtoearth.org.in/dte-infographics/social_cost_corbon/index.html#:~:text=India's%20country%2Dlevel%20social%20cost,per%20tonne%20of%20CO2%20emission.

** http://nwm.gov.in/?q=strategy-14

Approx. investment in science and education of wetlands = 90,000 INR/km^2
The area of concerned wetland = 35.77 km^2
Value of scientific investment in reservoir = **3.22 million INR**

d) Sediment Retention: The total amount of soil retained in watersheds (by InVEST) = 537913.2 T
The average concentration of N and P in soil = 0.027%
The average quantity of retained nutrients = 145.2 T
The price of NPK approx. = 20,000 INR/ T
The value of sediment retention = **2.90 million INR**

e) Crop Production: Major annual crop production = Wheat (64 T), Maize (85 T), Paddy (4434 T)
Min. Support Price = Wheat (19250 INR/T), Maize (18500 INR/T), Paddy (18680 INR/T)
Approx. major crop value: 1,232,000 + 1,572,500 + 82,827,120 = **84.52 million INR**

f) Hydel Power: Annual generation of electricity = 8 GWh (Tenu-Bokaro Link Canal)
Average cost of electricity per unit in Jharkhand = 6 INR / kWh
Total value of electricity produced = **48 million INR**

2010	2012	2014	2016	2018
1	0	3	5	8

Table 14: Annual no. of distinct photo user days – Tenughat reservoir

Recreational Index

The lake is highly impacted by human settlements in terms of scenic quality. The southern and western shores of the lake are highly impacted by human settlements, built infrastructure, like the Bokaro Steel Plant. The northern, eastern, and north-eastern shores are better in terms of scenic quality but still, highly impacted. The wetland provides water for agricultural activites and the Steel Plant. The ministry of tourism aims to develop the reservoir as a tourist hotspot which could develop into guided tours of the Plant. The lake is not be viable to be used for eco-tourism due to the presence of polluting industries.

Interpretations and Recommendations

- The carbon sequestration was fairly constant from 2010 – 2020 but there was an overall decrease from 2000 to 2020. This is mainly because of the shrinkage in the size of the lake. ***It is advised to reduce hum activity near the lake and to stop reclamation practices around the lake to reduce the negative impact and increase carbon storage value.***
- There is low susceptibility to soil erosion around the lake. ***Mitigation factors such as building artificial banks can help reduce it even further.*** Soil is also an important non-renewable resource and it should be conserved at all costs.

Scenic Quality

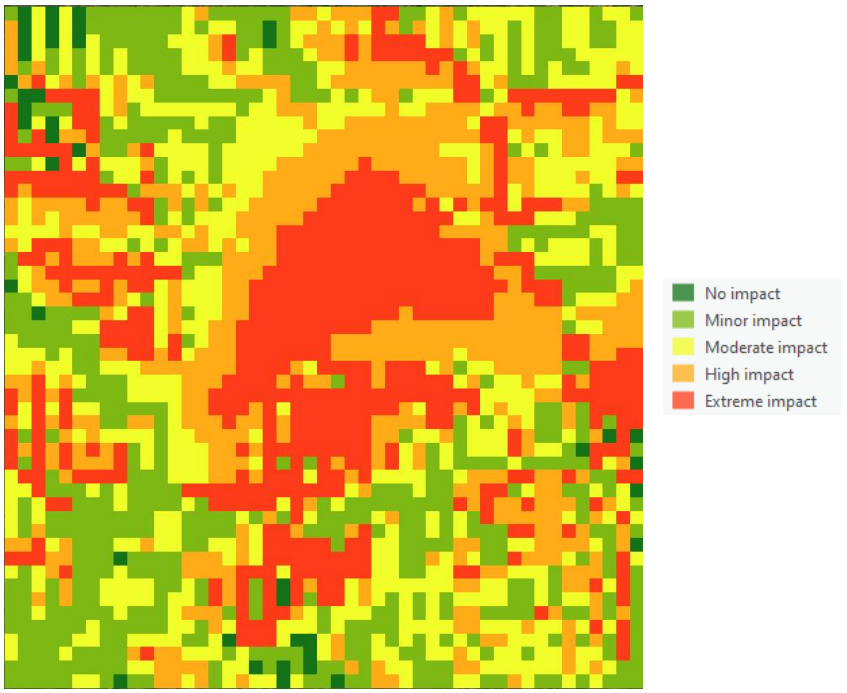

Fig. 21: Scenic Quality per pixel – Tenughat Reservoir

- The scenic quality of the lake is highly impacted by man-made structures on all sides. ***Corrective steps need to be taken to raze these structures and reforest these parts with indigenous plant species if the natural scenic beauty is to be restored.***
- Reduction in size of the lake negatively impacts scenic quality as well. Adequate steps should be taken in this direction. The govt. has zeroed in on this reservoir to develop tourism in the area. ***Adequate balanced steps need to be taken to develop responsible modes of tourism which do not harm the lake's fragile ecosystem.***

2.3. Chandil Reservoir

2.3.1. Site Description

Chandil reservoir is standing on the Subarnarekha River. It is situated in Saraikela Kharsawan district.

Fig. 22: Region of Interest – Chandil Reservoir

Watersheds / Catchment Area

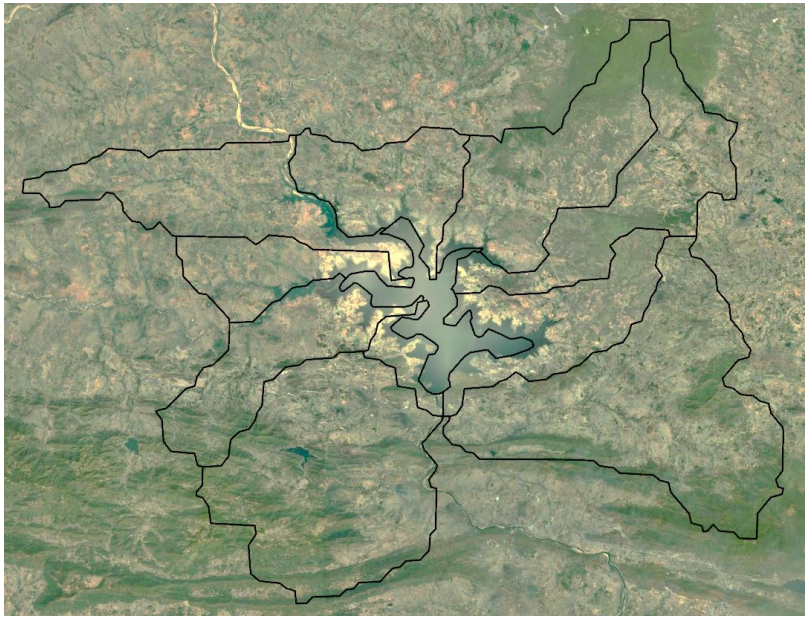

Fig. 23: Watershed regions associated with Chandil Reservoir marked with black boundaries

Latitude (N)	23° 1'23.15"
Longitude (E)	86° 1'12.64"
Area (km^2)	64.08
Maximum depth (m)	
Annual Rainfall (mm)	1192
Catchment area (km^2)	

Table 15: Geospatial details – Chandil Reservoir

2.3.2. Threats

2.3.3. Values

✓ **Direct use value**

- Agriculture:
- Wetland products: Reservoir water is used for irrigation, fisheries, drinking water supply, and electricity generation.
- Recreation (tourism): The museum located close to the Chandil dam has scripts written on rocks, which are 2000 years old. This dam is a 'tourist hotspot' as tourists visit to enjoy boating and the natural environment in and around the dam.

✓ **Indirect-use value**

✓ **Non-use value**

- Cultural and heritage value: Chandil was also found to be a major Palaeolithic site. This is an area of immense cultural and archaeological importance that has willfully been flooded without any proper scientific examination.

2.3.4. Monitoring of wetland over time

The results show that there was increase in number of manmade structures (Fig 24), urban build-up (Fig. 25) and vegetation cover (Fig 26) around and in Chandil reservoir. There is reduction in the area cover of wetland from 2000 (47.71 km2) to 2020 (64.80 km2) but increase in perimeter of wetland from 2000 (119.38 km) to 2020 (127.93 km). In Fig 26, Red colour shows urban build up areas. There is increase in urban build up in 2020. Red colour in Fig 27 shows water bodies and buildings, while the Green colour is vegetation cover. There is increase in vegetation cover in 2020

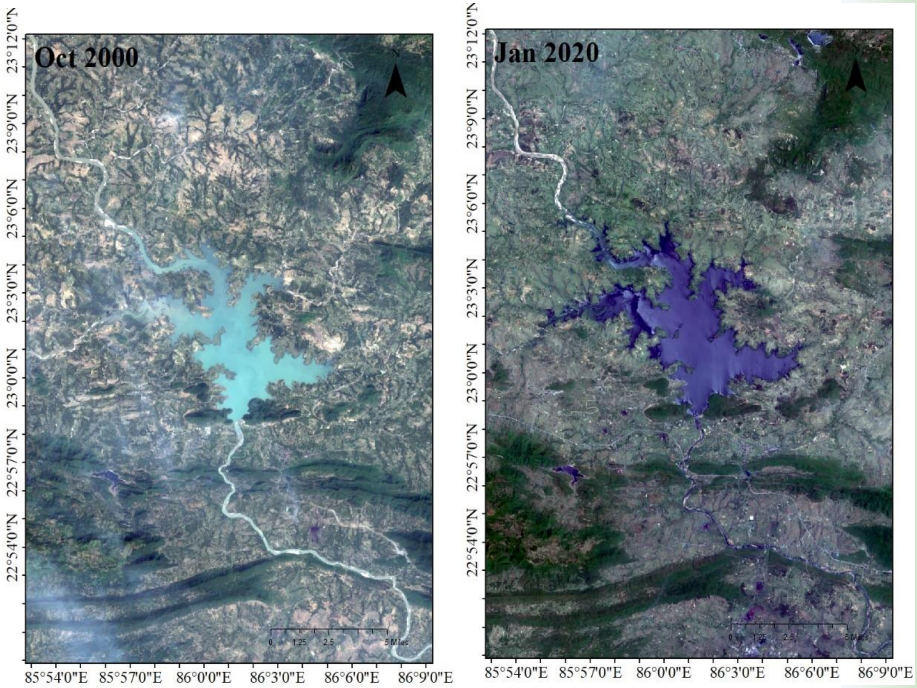

Fig. 24: Satellite data over time – Chandil Reservoir

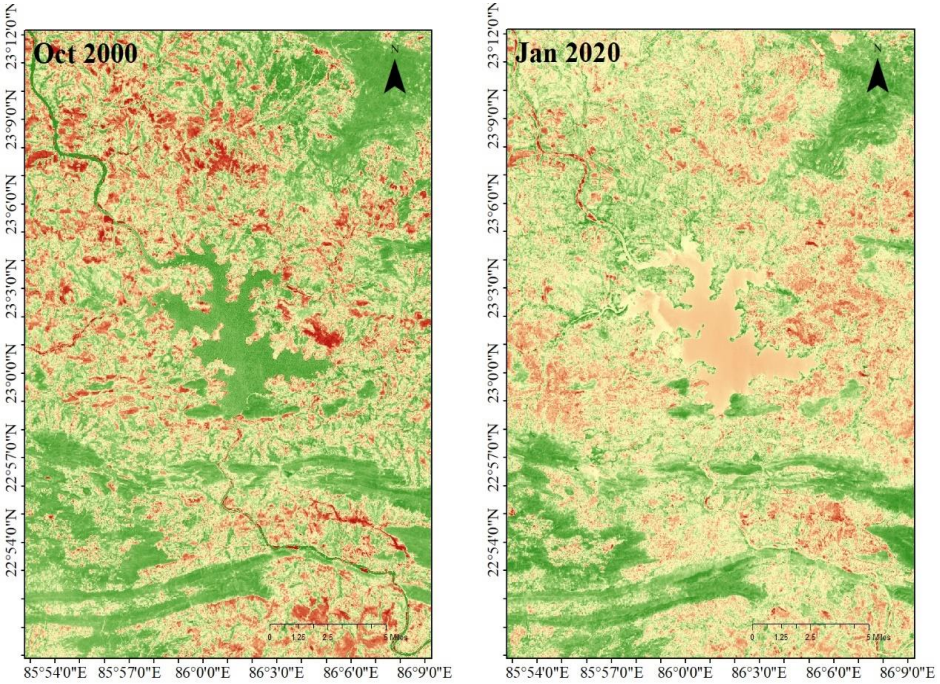

Fig. 25: Normalized Difference Build-up Index – Chandil Reservoir

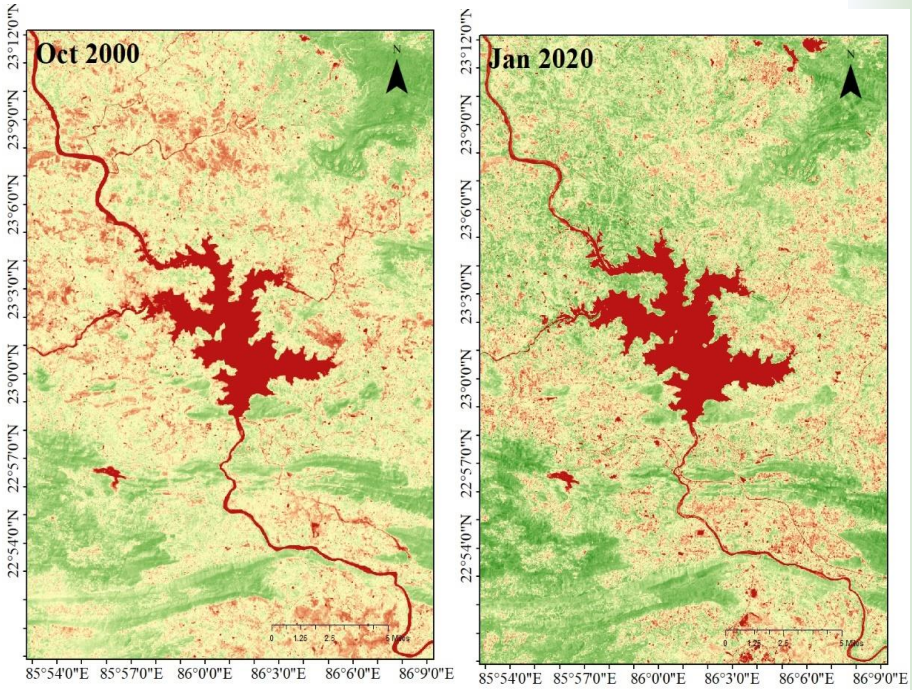

Fig. 26: Normalized Difference Vegetation Index – Chandil Reservoir

2.3.5. Biological Aspects

Results

- **Water quality:** Water quality was found "*Medium or average water quality (WQI score=68)".* The water quality is average due to high chemical parameter values (especially total solids) contributing to higher composite effect on water quality.

Water temperature (°C)	27.4 - 33.7
pH	6.8-6.9
BOD	3.7- 4.1
Total Dissolved Solids (mg l-1)	405- 485
DO (mg l-1)	5.4-5.6
Nitrate (mg l-1)	2.6 -3.1
Phosphate (mg l-1)	0.6-0.7
Gross Primary Production (mg C m2 d-1)	
Net Primary Production (mg C m2 d-1)	

Table 16: Water quality – Chandil Reservoir

- The water parameter values are within the permissible limits given by Bureau of Indian standards guideline values for drinking water.

Interpretation

- ***Because of the medium or average water quality (based on WQI score), this wetland has less diversity of aquatic aquatic life; and is of moderate concern.***

Due to Medium or average water quality, wetland has less diversity of aquatic organisms and frequently has increased algae growth.

Altogether, 42 fish species belonging to 30 genera were recorded from the reservoir, including two exotic species: pangas, Pangasianodon hypophthalmus, and Nile tilapia, Oreochromis niloticus.

- ***The water is also suitable for drinking (human consumption) domestic, and irrigation*** purposes as water parameters are within the permissible limits given by Bureau of Indian standards guideline values for drinking water.

Recommendations

- ✓ The overall water quality of wetland is medium or average, and is of moderate concern. In order to make the water quality good, we need to reduce the total solids in the wetland. Its recommended that water treatment should be done which removes the solids from the water.

- ✓ Jharkhand State Pollution Control Board has a zero-tolerance policy toward pollution. If we identify the industry, which is causing pollution the agency can take action and if necessary, the plant can also be shut down to prevent further harm to the wetland.

2.3.6. Economic Aspects

Carbon Sequestration

2010	2012	2014	2016	2018
4.761	4.971	5.245	5.248	5.252

Table 17: Carbon sequestration over time, in MegaTonnes

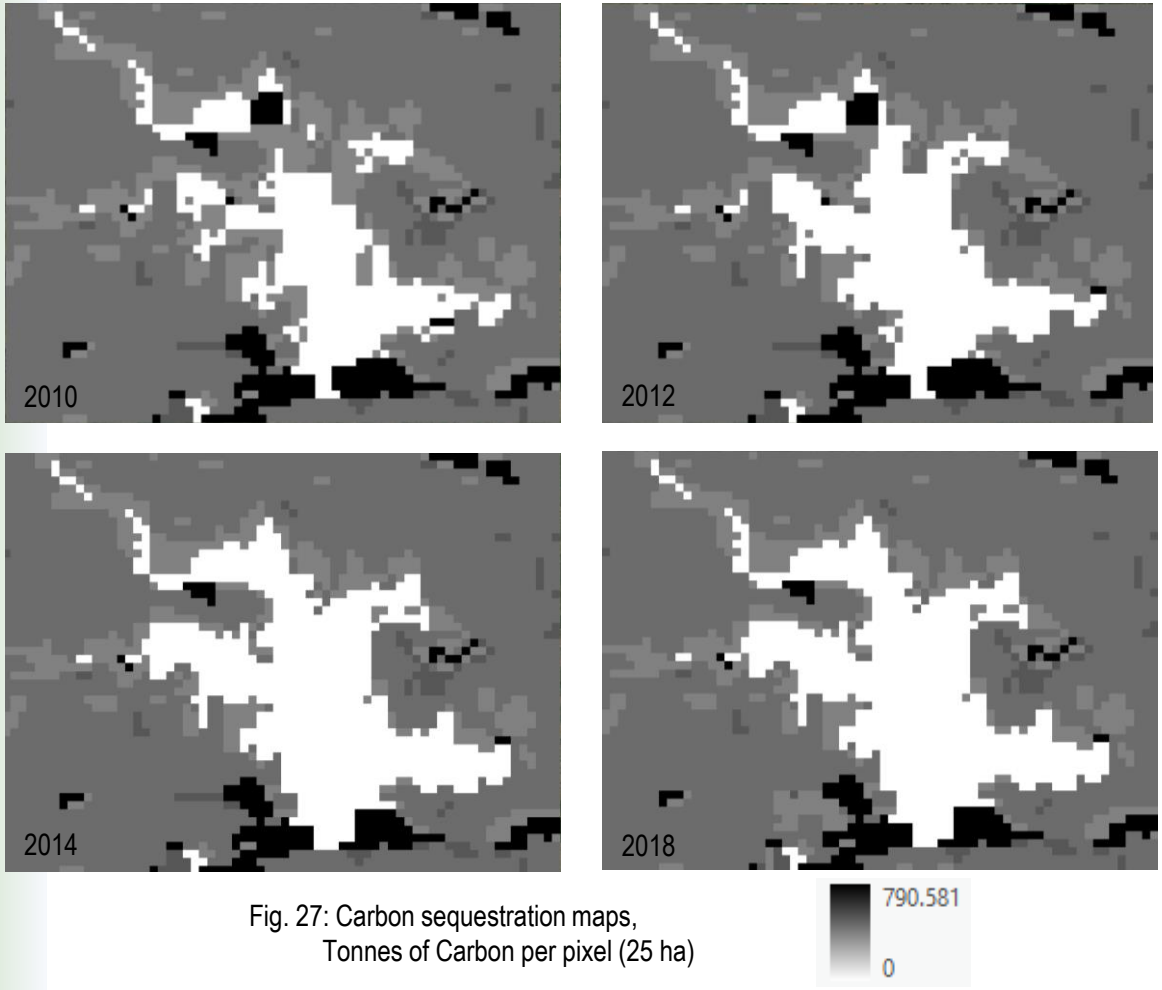

Fig. 27: Carbon sequestration maps,
Tonnes of Carbon per pixel (25 ha)

Flood Risk Mitigation

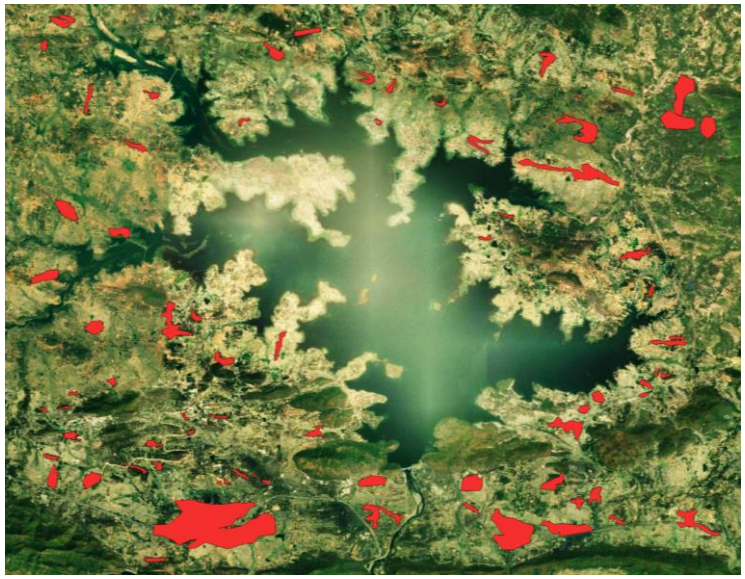

Fig. 28: Human settlements and built up area (marked in red) around the Chandil reservoir

For a design storm with depth of rainfall 80mm spread over two days, modelling the Phailin Cyclone of 2013, it was found that the economic losses due to flooding came to nearly **16.55 million**.

Table 17 takes into account soil carbon, but the carbon maps only account for carbon above ground, considering edge effects.

Water Yield

2010	2012	2014	2016	2018
78.17	290.27	217.16	389.46	376.52

Table 18: Combined water yield in associated watersheds (billion litres)

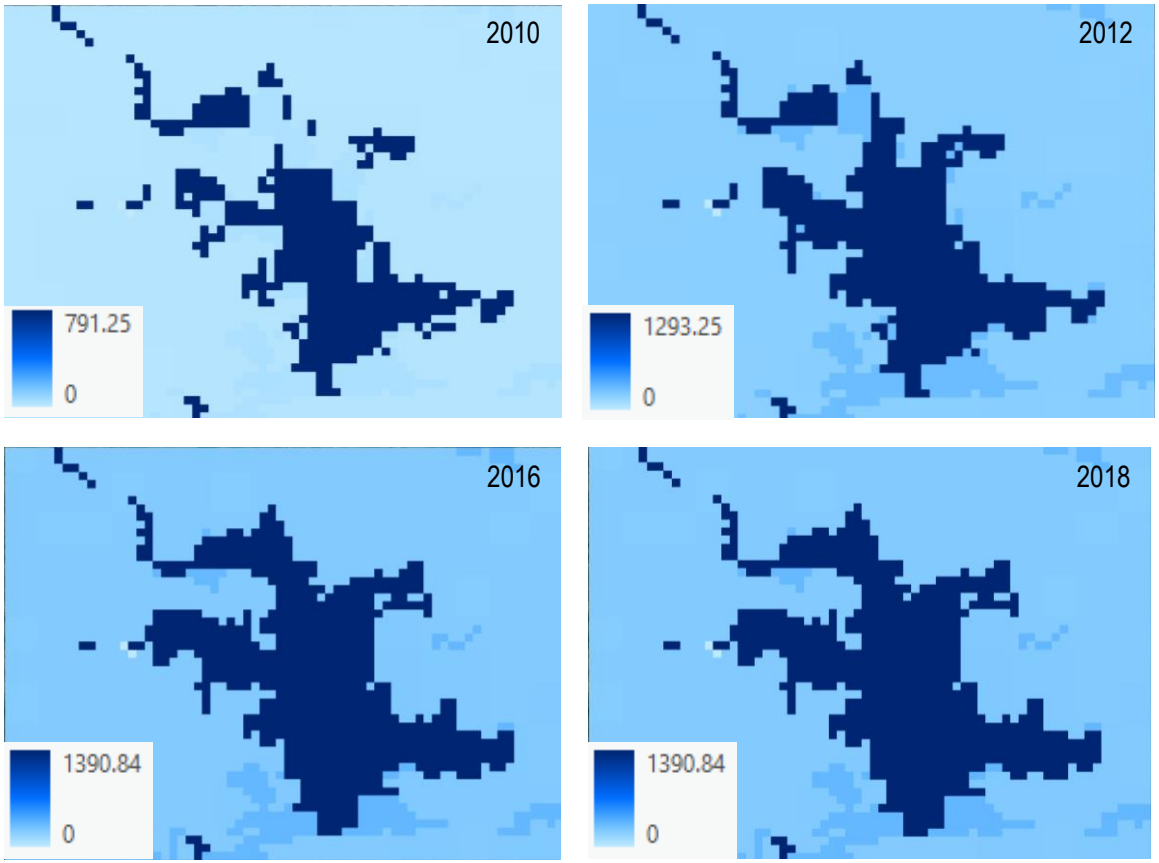

Fig. 29: Annual Water Yield Maps

Soil Sedimentation/Erosion

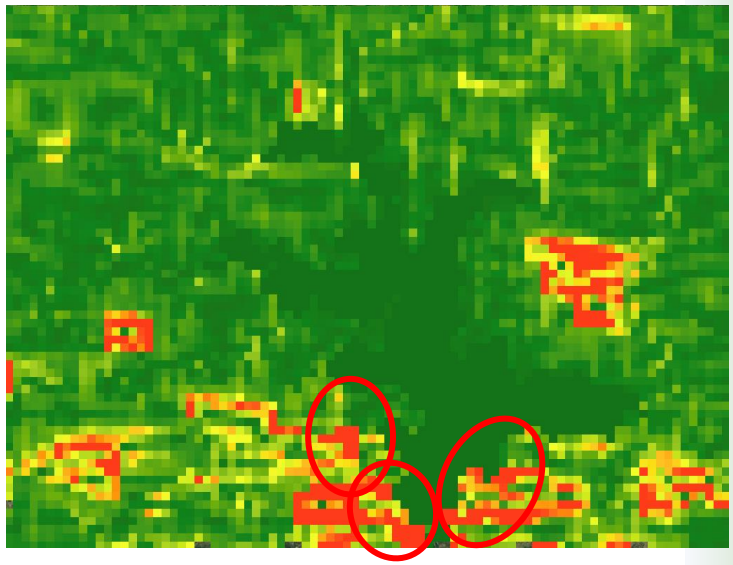

Fig. 30: Predicted soil erosion vulnerability maps. The red circles mark areas recommended for embankment to reduce soil erosion and loss of soil as a resource.

Regression Analysis

There is a weak positive correlation between the carbon stock and the area of the lake which signifies that the lake is an important sequestration zone for Carbon. There is a negative correlation between recreational index and Carbon storage and similarly between recreational quality and lake area which signifies that as human visitation to the lake has increased, it has been detrimental to the area of the lake and Carbon storage as well. The Water Yield is positively correlated with Carbon sequestration that doubly signifies the importance of carbon sequestration in the lake.

x	Carbon	Lake Area	Water Yield	Recreation
Carbon	x	0.23	0.87	- 0.50
Lake Area	0.23	X	- 0.36	- 0.91
Water Yield	0.87	- 0.36	X	0.46
Recreation	- 0.50	- 0.91	0.46	X

Table 19: Correlation coefficient between the different ecosystem services.

Current Valuations

a) Water Storage: The amount of water stored in the reservoir approx. = 1963 Hm^3
Taking the annual price of water storage as 1 USD = 74 INR/m^3
The annual value of water stored in the reservoir = **145.26 billion INR**

b) Carbon Sequestration: The amount of Carbon sequestered in the wetland approx. = 5.25 MT
The social cost of Carbon in India is 86 USD = 6400 INR/T*
The value of Carbon sequestered in the wetland = **33.6 billion INR**

c) Science and Education: Project estimate of Strategy 1.4 (by inflation, 2020) approx. 13.7 billion INR **
The total area of wetlands in India = 153000 km^2

* https://www.downtoearth.org.in/dte-infographics/social_cost_corbon/index.html#:~:text=India's%20country%2Dlevel%20social%20cost,per%20tonne%20of%20CO2%20emission.

** http://nwm.gov.in/?q=strategy-14

Approx. investment in science and education of wetlands = 90,000 INR/km^2
The area of concerned wetland = 64.08 km^2
Value of scientific investment in reservoir = **5.77 million INR**

d) Sediment Retention: The total amount of soil retained in watersheds (by InVEST) = 1030524.5 T
The average concentration of N and P in soil = 0.027%
The average quantity of retained nutrients = 278.24 T
The price of NPK approx. = 20,000 INR/ T
The value of sediment retention = **5.56 million INR**

e) Crop Production: Major annual crop production = Wheat (150 T), Maize (260 T), Paddy (13,156 T)
Min. Support Price = Wheat (19250 INR/T), Maize (18500 INR/T), Paddy (18680 INR/T)
Approx. major crop value: 2,887,500 + 4,810,000 + 245,754,080 = **253.45 million INR**

f) Hydel Power: Annual generation of electricity = 36.33 million kWh*
Average cost of electricity per unit in Jharkhand = 6 INR / kWh
Total value of electricity produced = **217.98 million INR**

* http://www.bshpcltd.com/pjhar.htm

Recreational Index

2010	2012	2014	2016	2018
1	0	4	20	39

Table 20: Annual no. of distinct photo user days – Chandil reservoir

The lake is highly impacted by human settlements in terms of scenic quality. The south eastern shore of the lake still retains scenic quality due to low build-up index. The wetland has high cultural and social value. The reservoir is highly developed for tourist activity with boating and nature walks set up. The annual no. of distinct photo user days, an output of the InVEST model is taken as the proxy for level of human activities near the lake

Interpretations and Recommendations

- The carbon sequestration increased from 2010 – 2020 but there was an overall decrease from 2000 to 2020. This is mainly because of the shrinkage in the size of the lake. ***It is advised to reduce human activity near the lake and to stop reclamation practices around the lake to reduce the negative impact and increase carbon storage value.***

Scenic Quality

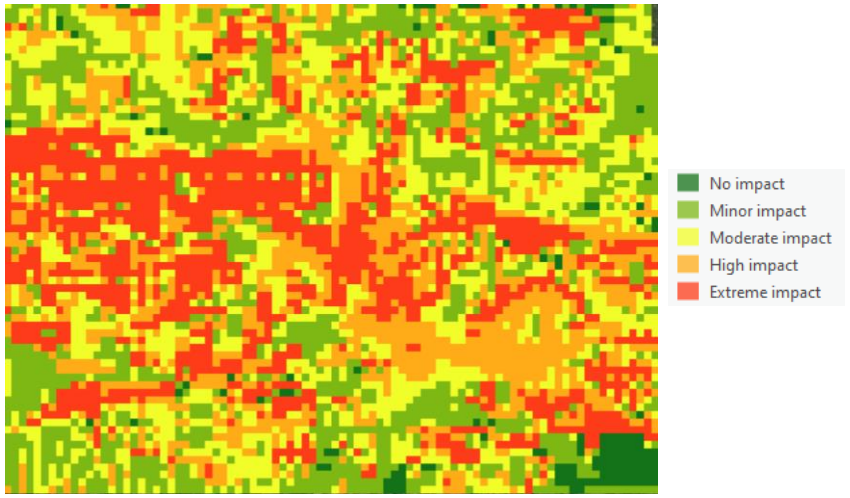

Fig. 31: Scenic Quality per pixel – Chandil Reservoir

- There is high probability of soil erosion on the southern edges of the lake. Soil erosion reduces the capacity of water storage of the lake, which is undesirable. ***Mitigation factors such as reforestation on those parts and building artificial banks can help reduce that.*** Soil is also an important non-renewable resource and it should be conserved at all costs.

- The scenic quality of the lake is highly impacted by man-made structures on the western and eastern coasts of the lake. ***Corrective steps need to be taken to raze these structures and reforest these parts with indigenous plant species.***

- Reduction in size of the lake negatively impacts scenic quality as well. Adequate steps should be taken in this direction. There is a trade-off between recreational quality and carbon sequestration. Recreation and human activities negatively impact the valuation of the lake***. Adequate balanced steps need to be taken to develop responsible modes of tourism which do not harm the lake's fragile ecosystem.***

2.4. Dimna Lake

2.4.1. Site Description

Dimna Lake is standing on the Subarnarekha River. It is situated in East Singhbhum district.

Fig. 32: Region of Interest – Dimna Lake

Watersheds / Catchment Area

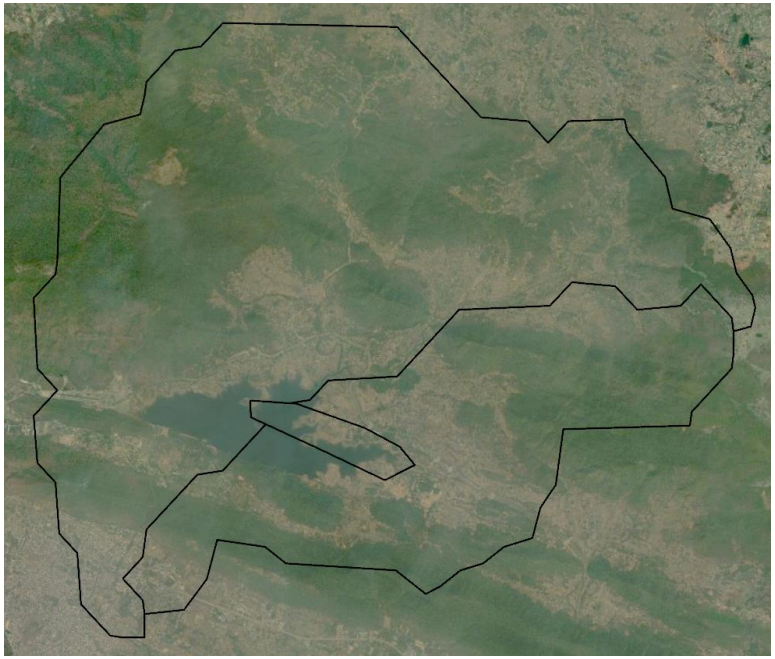

Fig. 33: Watershed regions associated with Dimna Lake marked with black boundaries

Latitude (N)	22°51'33.3"
Longitude (E)	86°15'42.65"
Area (km^2)	3.87
Maximum depth (m)	
Catchment area (km^2)	

Table 21: Geospatial details – Dimna Lake

2.4.2. Threats

Dimna Lake is being contaminated by increasing concentration of different ubiquitous pollutants, putting thousands of people residing on the nearby city/village into a tremendous health risk. Local population, especially population that is engaged in any fishing related operations are significantly are at higher risk (especially through Pb and Hg) through consumption of individual metal(loid) via fish intake. Research identifiy following sources of metal(loid) contamination in fish species: (a) industrial discharge from metal painting and pigment manufacturing industry, steel coating plant and power plants; (b) vehicular emission from light/heavy vehicle/sports boat; (c) agricultural run-off; and (d) geogenic source.

2.4.3. Values

✓ **Direct use value**

- Agriculture:
- Wetland products: Reservoir water is major sources of potable water for residents as well as Tata Steel works. It is also used for irrigation and fishing.
- Recreation (tourism): This lake is a tourist destination as it is near to the Dalma Wild life Sanctuary and is quite attractive having the facility for boating. It is famous for its picturesque aesthetics. The lake is surrounded by dense green forests and hill peaks.

✓ **Indirect-use value**

✓ **Non-use value**

- Cultural and heritage value:

2.4.4. Monitoring of wetland over time

The results show that there was increase in number of manmade structures (Fig 34), urban build-up (Fig. 35) and vegetation cover (Fig 36) around and in Dimna lake. There is reduction in the area cover of wetland from 2000 (4.12 km2) to 2020 (3.89 km2) and perimeter of wetland from 2000 (17.43 km) to 2020 (17.05 km). In Fig 35, Red colour shows urban build up areas. There is increase in urban build up in 2020. Red colour in Fig 36 shows water bodies and buildings, while the Green colour is vegetation cover. There is increase in vegetation cover in 2020

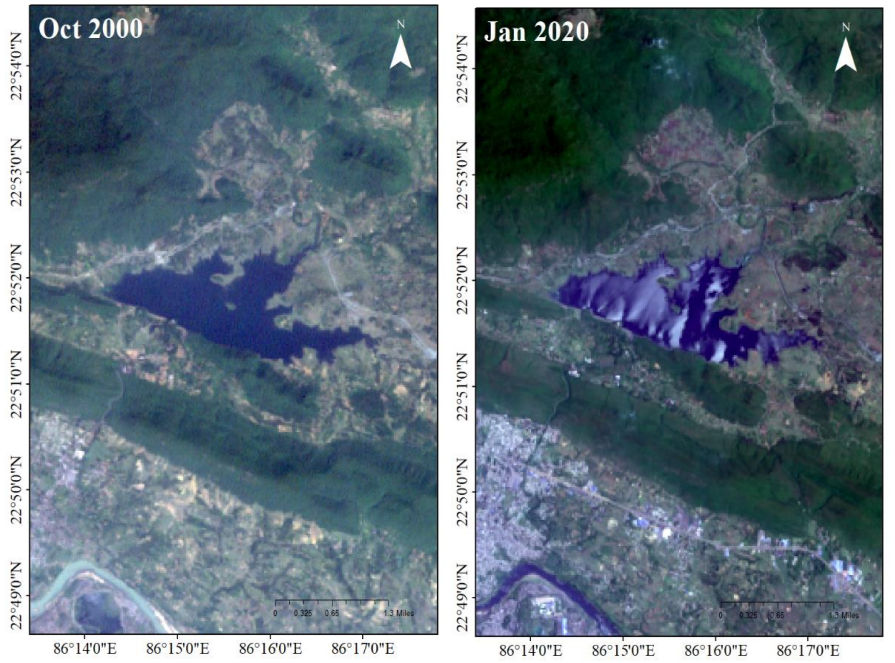

Fig. 34: Satellite data over time – Dimna Lake

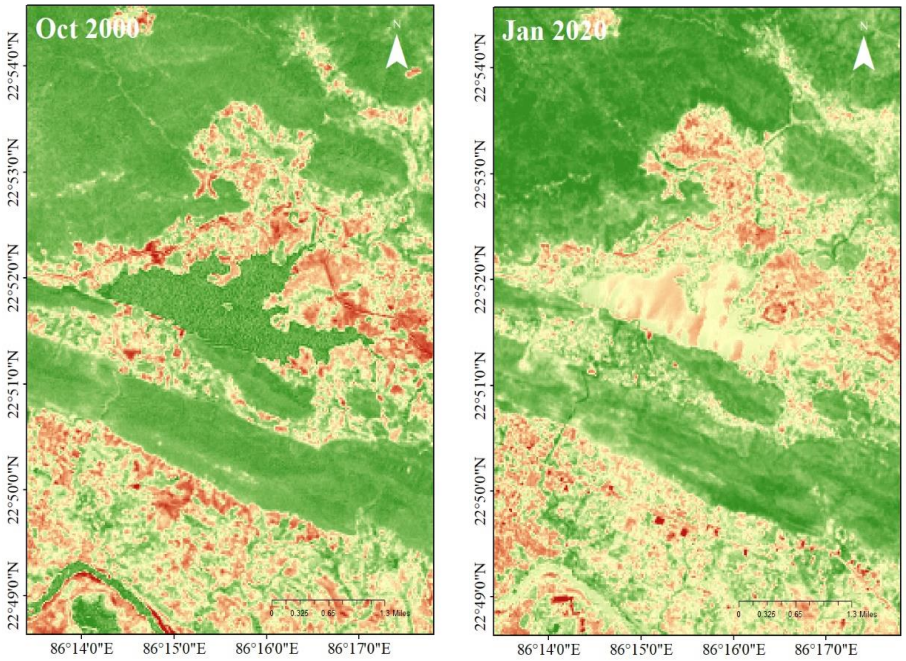

Fig. 35: Normalized Difference Build-up Index – Dimna Lake

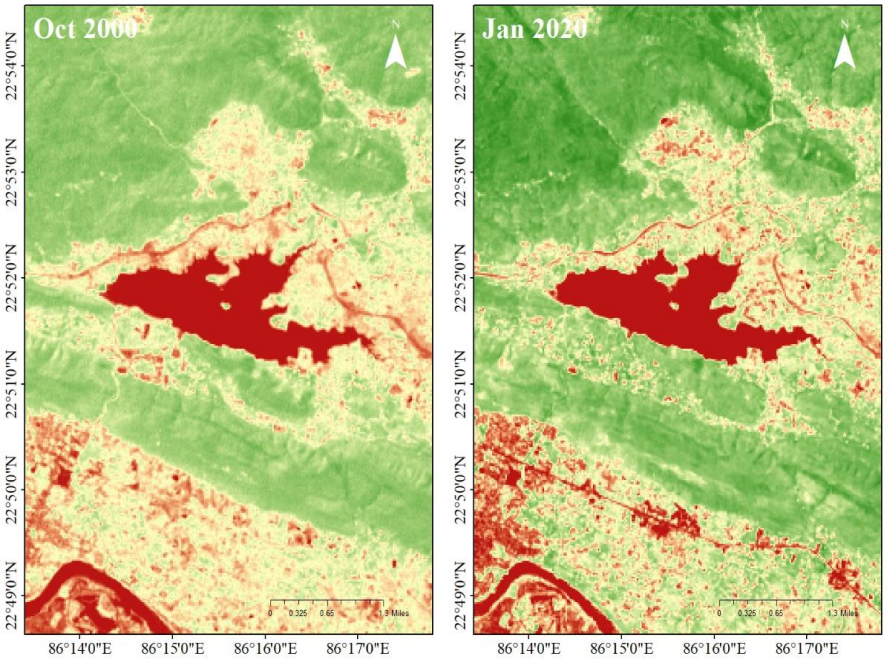

Fig. 36: Normalized Difference Vegetation Index – Dimna Lake

2.4.5. Biological Aspects

Results

- **Water quality:** Water quality was found "*Good (WQI score=79)".* The water was considered good in this wetland mainly due to low chemical parameter values contributing to lower composite effect on water quality.

Water temperature (°C)	18.0 - 38.5
pH	7.2-7.8
BOD	0.4-2.4
Total Dissolved Solids (mg l-1)	
DO (mg l-1)	3.3-8.1
Nitrate (mg l-1)	3.7-8.1
Phosphate (mg l-1)	
Gross Primary Production (mg C m2 d-1)	
Net Primary Production (mg C m2 d-1)	

Table 22: Water quality – Dimna lake

- The water parameter values are within the permissible limits given by Bureau of Indian standards guideline values for drinking water.

Interpretation

- ***Because of the good water quality (based on WQI score), it meets the expectation and is of least concern. This wetland is able to support a high diversity of aquatic life.***

- This reservoir is known to possess a diversity of edible fish species such as Labeo calbasu, Puntius ticto, Notopterus notopterus, Labeo rohita, Channa punctatus, and Aorichthys seenghala.

- ***The water is also suitable for drinking (human consumption) domestic, and irrigation*** purposes as water parameters are within the permissible limits given by Bureau of Indian standards guideline values for drinking water.

- ***In addition, the water would also be suitable for all forms of recreation, including those involving direct contact with the water.***

Recommendations

- ✓ Even though the overall water quality of wetland is good, there are some places it is being contaminated by increasing concentration of different ubiquitous pollutants from (a) industrial discharge from metal painting and pigment manufacturing industry, steel coating plant and power plants; (b) vehicular emission from light/heavy vehicle/sports boat; (c) agricultural run-off; and (d) geogenic source. Its recommended that at these places water treatment should be done by using the latest yet economically viable treatment method such as constructed wetland. The size of the constructed wetland will be based on the water flow rate and the quantity of water to be treated.

- ✓ Jharkhand State Pollution Control Board has a zero-tolerance policy toward pollution. If we identify the industry, which is causing pollution the agency can take action and if necessary, the plant can also be shut down to prevent further harm to the wetland.

2.4.6. Economic Aspects

Carbon Sequestration

2010	2012	2014	2016	2018
341.29	341.29	341.29	346.53	356.82

Table 23: Carbon sequestration over time, in thousands of Tonnes

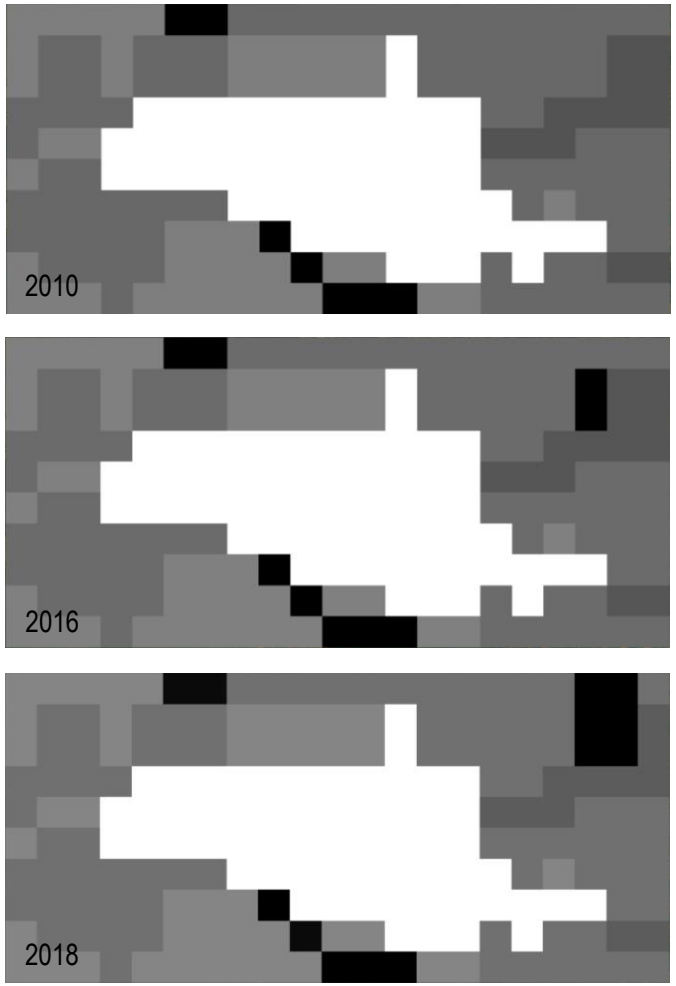

Fig. 37: Carbon sequestration maps, Tonnes of Carbon per pixel (25 ha)

Flood Risk Mitigation

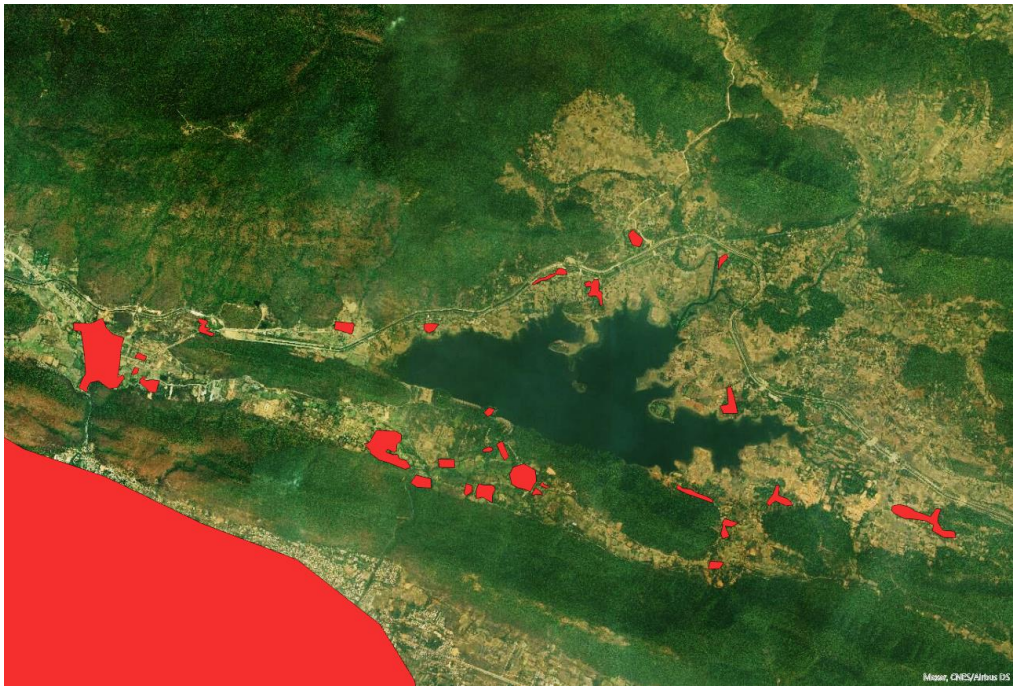

Fig. 38: Human settlements and built up area (marked in red) around the Dimna Lake

For a design storm with depth of rainfall 80mm spread over two days, modelling the Phailin Cyclone of 2013, it was found that the economic losses due to flooding came to nearly ***3.29 million***.

Table 23 takes into account soil carbon, but the carbon maps only account for carbon above ground, considering edge effects.

Table 24: Combined water yield in associated watersheds (billion litres)

2010	2012	2014	2016	2018
28.22	61.60	76.92	70.93	69.18

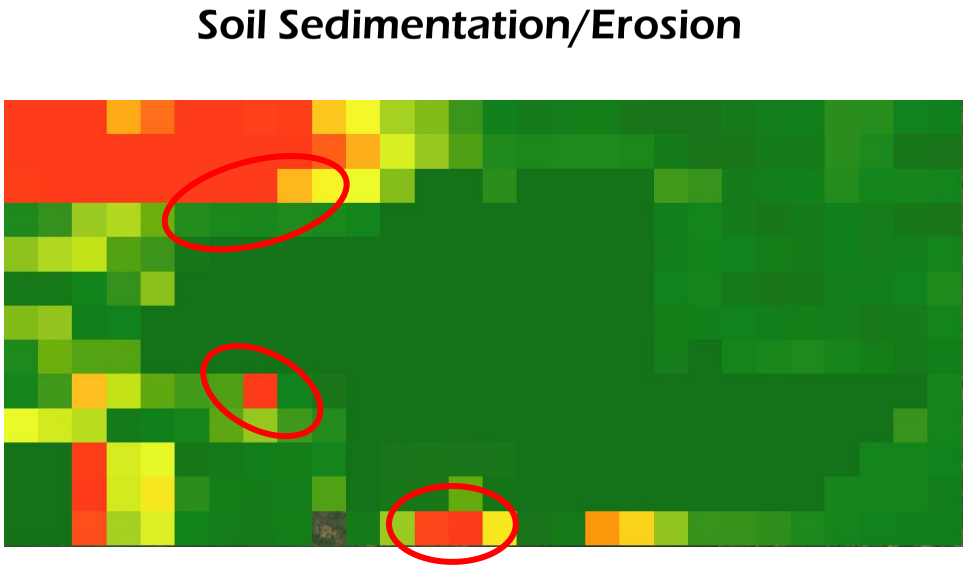

Fig. 40: Predicted soil erosion vulnerability maps. The red circles mark areas recommended for embankment to reduce soil erosion and loss of soil as a resource.

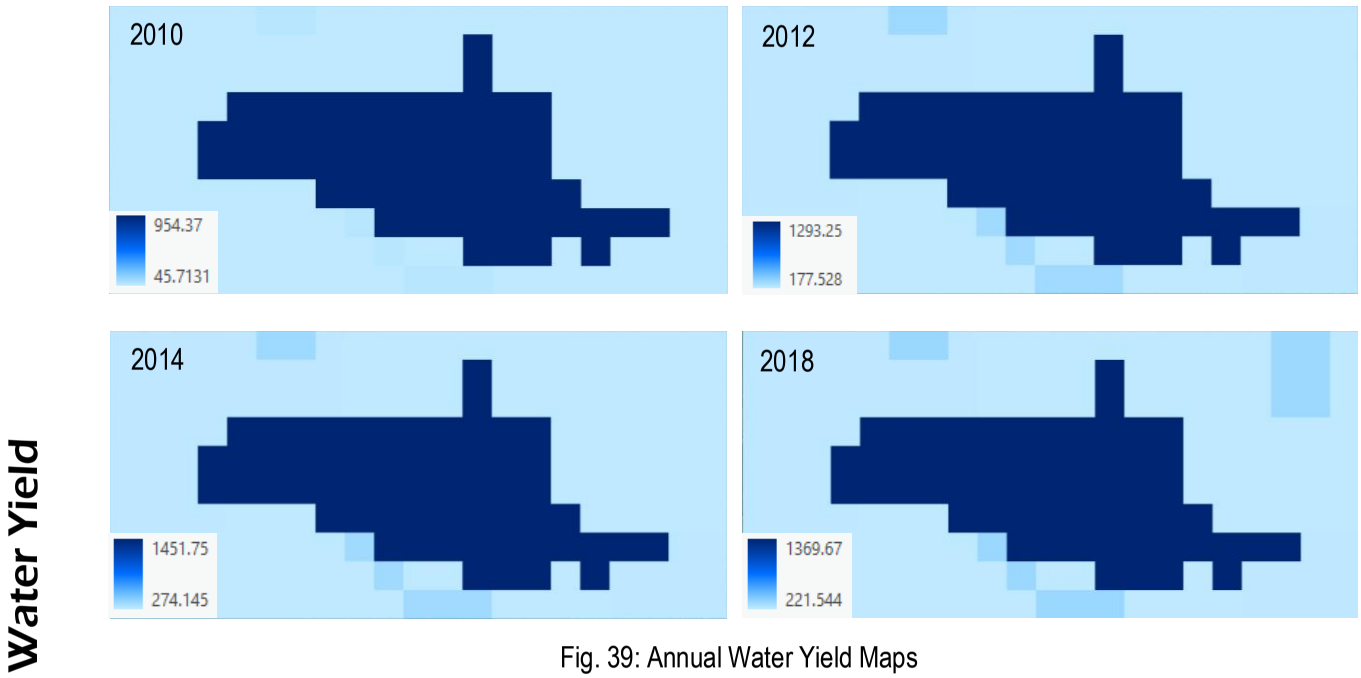

Fig. 39: Annual Water Yield Maps

Regression Analysis

There is a weak positive correlation between the carbon stock and the area of the lake which signifies that the lake is an important sequestration zone for Carbon. There is a negative correlation between recreational index and Carbon storage and similarly between recreational quality and lake area which signifies that as human visitation to the lake has increased, it has been detrimental to the area of the lake and Carbon storage as well. The Water Yield is positively correlated with Carbon sequestration that doubly signifies the importance of carbon sequestration in the lake.

x	Carbon	Lake Area	Water Yield	Recreation
Carbon	x	0.23	0.87	- 0.50
Lake Area	0.23	X	- 0.36	- 0.91
Water Yield	0.87	- 0.36	X	0.46
Recreation	- 0.50	- 0.91	0.46	X

Table 25: Correlation coefficient between the different ecosystem services.

Current Valuations

a) Water Storage: The amount of water stored in the reservoir approx. = 286556 m^3
Taking the annual price of water storage as 1 USD = 74 INR/m^3
The annual value of water stored in the reservoir = **21.21 million INR**

b) Carbon Sequestration: The amount of Carbon sequestered in the wetland approx. = 365.82 kT
The social cost of Carbon in India is 86 USD = 6400 INR/T*
The value of Carbon sequestered in the wetland = **2.34 billion INR**

c) Science and Education: Project estimate of Strategy 1.4 (by inflation, 2020) approx. 13.7 billion INR **
The total area of wetlands in India = 153000 km^2

* https://www.downtoearth.org.in/dte-infographics/social_cost_corbon/index.html#:~:text=India's%20country%2Dlevel%20social%20cost,per%20tonne%20of%20CO2%20emission.

** http://nwm.gov.in/?q=strategy-14

Approx. investment in science and education of wetlands = 90,000 INR/km^2
The area of concerned wetland = 3.87 km^2
Value of scientific investment in reservoir = **0.35 million INR**

d) Sediment Retention: The total amount of soil retained in watersheds (by InVEST) = 137504 T
The average concentration of N and P in soil = 0.027%
The average quantity of retained nutrients = 37.13 T
The price of NPK approx. = 20,000 INR/ T
The value of sediment retention = **0.74 million INR**

e) Crop Production: Major annual crop production = Wheat (21.8 T), Maize (30 T), Paddy (2610 T)
Min. Support Price = Wheat (19250 INR/T), Maize (18500 INR/T), Paddy (18680 INR/T)
Approx. major crop value: 419,650 + 555,000 + 48,754,800 = **49.73 million INR**

Recreational Index

2010	2012	2014	2016	2018
4	9	10	24	40

Table 26: Annual no. of distinct photo user days – Dimna Lake

The lake is not greatly impacted by human settlements in terms of scenic quality. The lake was built by the Tata Stell Corporation and hosts a bunch of tourist and recreational activities. The wetland has high cultural and social value. There is huge rush observed during Chhatt Pooja and New Year. The annual no. of distinct photo user days, an output of the InVEST model is taken as the proxy for level of human activities near the lake

Interpretations and Recommendations

Scenic Quality

- The carbon sequestration increased from 2010 – 2020 but it has remained fairly constant over the years due to small size of the lake compared to other wetlands. An overall decrease in carbon sequestration was observed from 2000 to 2020 due to shrinkage in size of the lake.

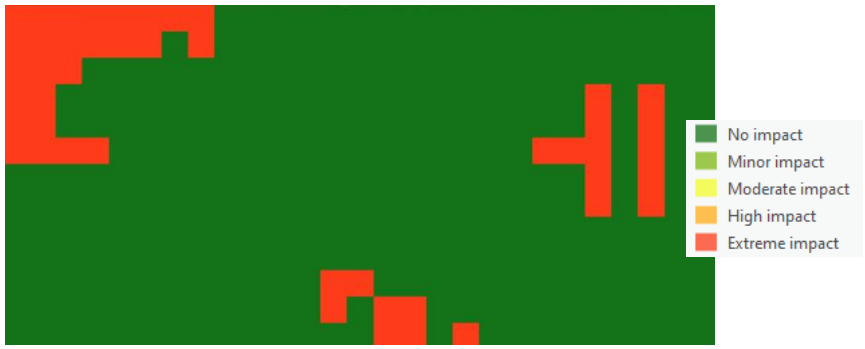

Fig.41: Scenic Quality per pixel – Dimna Lake

- There is high probability of soil erosion on the north-western edges of the lake. Soil erosion reduces the capacity of water storage of the lake, which is undesirable. ***Mitigation factors such as reforestation on those parts and building artificial banks can help reduce that.*** Soil is also an important non-renewable resource and it should be conserved at all costs.

- The scenic quality of the lake is mostly preserved and is affected negatively on the north-western and eastern shores due to man-made structures. ***Corrective steps need to be taken to raze these structures and reforest these parts with indigenous plant species.***

- Reduction in size of the lake negatively impacts scenic quality as well. Adequate steps should be taken in this direction. There is a trade-off between recreational quality and carbon sequestration. Recreation and human activities negatively impact the valuation of the lake. ***Adequate balanced steps need to be taken to develop responsible modes of tourism which do not harm the lake's fragile ecosystem.***

2.5. Konar Reservoir

2.5.1. Site Description

Konar reservoir is on the river Konar, another tributary of the Damodar. It is situated in 41 kilometres south-east o0.f Hazaribagh district.

Fig. 42: Region of Interest – Konar Reservoir

Watersheds / Catchment Area

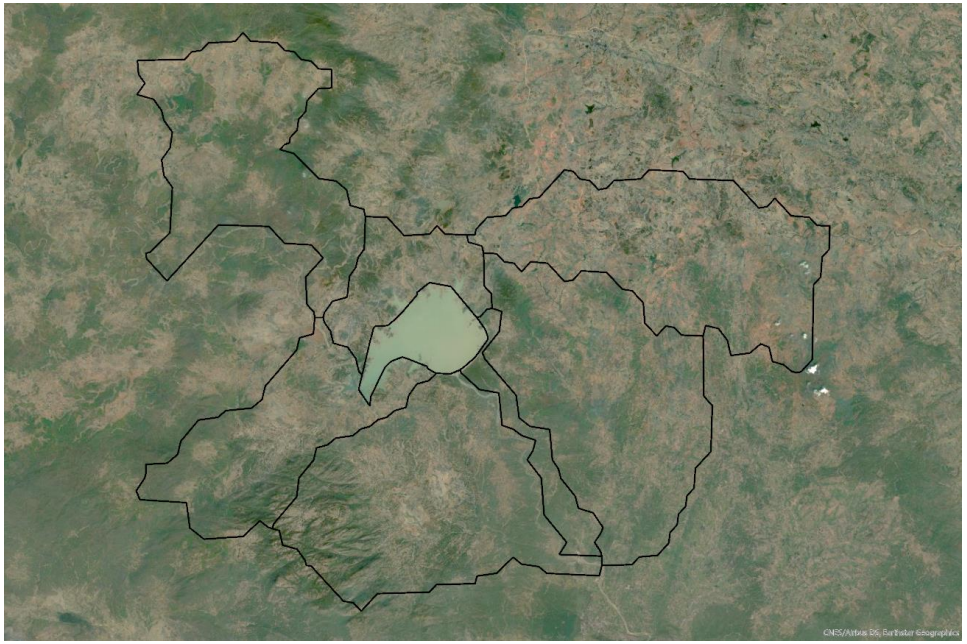

Fig. 43: Watershed regions associated with Konar Reservoir marked with black boundaries

Latitude (N)	23°55'50.85"
Longitude (E)	85°45'50.73"
Area (Km^2)	22.72
Mean depth (m)	12.97
Catchment area (km^2)	997
Rainfall (mm)	1198

Table 27: Geospatial details – Konar Reservoir

2.5.2. Threats

Decline in fish population due to overfishing. It receives huge industrial load from thermal power plants, ten coal washers, steel and fertilizer plants, and numerous other small industries. Thus, the fishes in this reservoir are under extreme stress.

2.5.3. Values

✓ **Direct use value**

- Agriculture:
- Wetland products: Reservoir water is major sources of power generation. It is also used for irrigation and fishing.
- Recreation (tourism):

✓ **Indirect-use value**

✓ **Non-use value**

2.5.4. Biological Aspects

Results

- **Water quality:** Water quality was found "*Good (WQI score=79)".* The water was considered good in this wetland mainly due to low chemical parameter values contributing to lower composite effect on water quality.

Water temperature (°C)	17.6–28.9
pH	5.4–5.9
BOD	
Total Dissolved Solids (mg l-1)	
DO (mg l-1)	
Nitrate (mg l-1)	0.10–0.60
Phosphate (mg l-1)	0-0.047
Organic carbon(%)	1.2–6.15
Gross Primary Production (mg C m2 d-1)	199–300
Net Primary Production (mg C m2 d-1)	

Table 28: Water quality – Konar Reservoir

- **Soil quality:**

Organic Carbon (%)	**0.3–0.9**
Available P (mg 100 g^{-1})	**1.2–8.0**
Available N (mg 100g^{-1})	

Table 29: Soil quality – Konar Reservoir

- The water parameter values are within the permissible limits given by Bureau of Indian standards guideline values for drinking water.

- Based on the water quality index *(WQI score=79)*, the wetland overall water quality was found "*Good".* The water was considered good in this wetland mainly due to low chemical parameter values contributing to lower composite effect on water quality. However, at some places It receives huge industrial load from thermal power plants, ten coal washers, steel and fertilizer plants, and numerous other small industries. Thus, the fishes in this reservoir are under extreme stress.

Interpretation

- ***Because of the good water quality (based on WQI score), it meets the expectation and is of least concern. This wetland is able to support a high diversity of aquatic life.***

Due to good water quality, wetland has high primary productivity. In wetland, The plankton in Konar is characterised by a poor species diversity and an overwhelming dominance of *Microcystis aeruginosa* and *Diaptomus* sp. among the phyto- and zooplankton respectively. Anabaena, Merismopedia, Botryoccocus, Spirogyra Oedogonium, Pleodorina, Ceratium and Peridinium are reported. Zooplankton comprises Difflugia, Arcella, Actinosphaerium, Keratella, Brachionus, Filinia, Polyarthra, Diaphanosoma, Ceriodaphnia, Cyclops and Diaptomus.

Different species of fish are Catla (Catla catla), Mirka (Cirrhinus mrigala), Labeo calbasu, Rohu (L. rohita), Bata (L. bata), L. dyocheilus, Puntius sarana, Cyprinus carpio, Notopterus notopterus and Ompok bimaculatus etc.

- ***The water is also suitable for drinking (human consumption) domestic, and irrigation*** purposes as water parameters are within the permissible limits given by Bureau of Indian standards guideline values for drinking water.

- ***In addition, the water would also be suitable for all forms of recreation, including those involving direct contact with the water.***

Recommendations

- ✓ Even though the overall water quality of wetland is good, there are some places where industrial effluents discharge occur. Its recommended that at these places water treatment should be done by using the latest yet economically viable treatment method such as constructed wetland. The size of the constructed wetland will be based on the water flow rate and the quantity of water to be treated.

- ✓ Jharkhand State Pollution Control Board has a zero-tolerance policy toward pollution. If we identify the industry, which is causing pollution the agency can take action and if necessary, the plant can also be shut down to prevent further harm to the wetland.

2.5.5. Economic Aspects

Carbon Sequestration

2010	2012	2014	2016	2018
1.614	1.614	1.614	1.614	1.619

Table 29: Carbon sequestration over time, in MegaTonnes

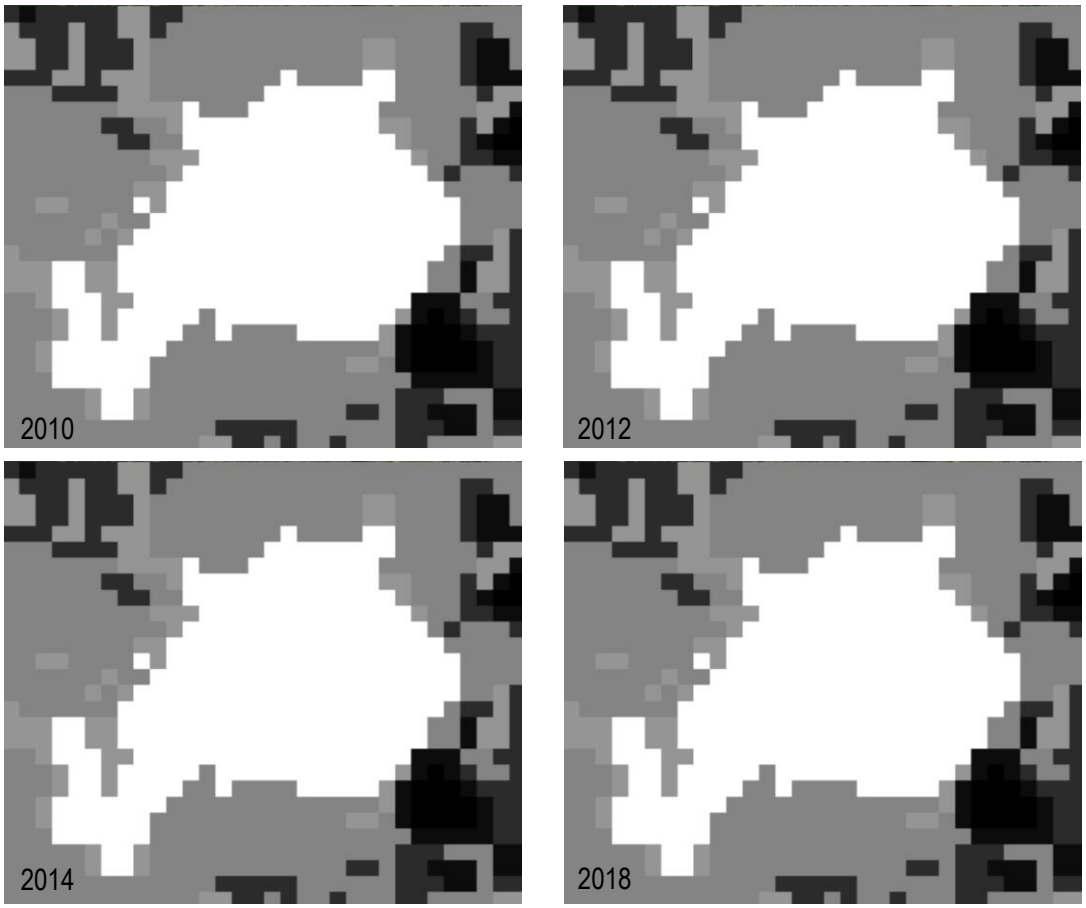

Fig. 44: Carbon sequestration maps, Tonnes of Carbon per pixel (25 ha)

Flood Risk Mitigation

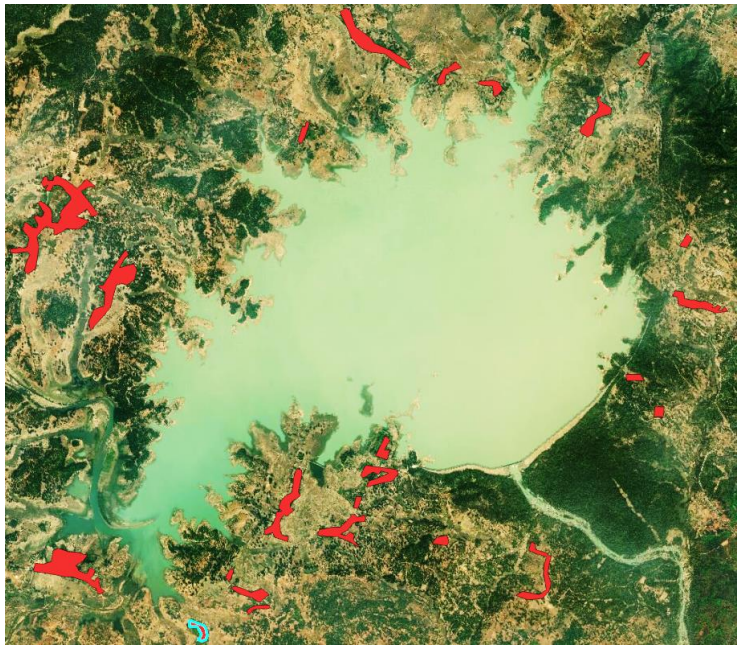

Fig. 45: Human settlements and built up area (marked in red) around the Konar reservoir

For a design storm with depth of rainfall 80mm spread over two days, modelling the Phailin Cyclone of 2013, it was found that the economic losses due to flooding came to nearly **1.68 million**.

Table 29 takes into account soil carbon, but the carbon maps only account for carbon above ground, considering edge effects.

Water Yield

2010	2012	2014	2016	2018
54.53	184.52	119.51	225.36	216.12

Table 30: Combined water yield in associated watersheds (billion litres)

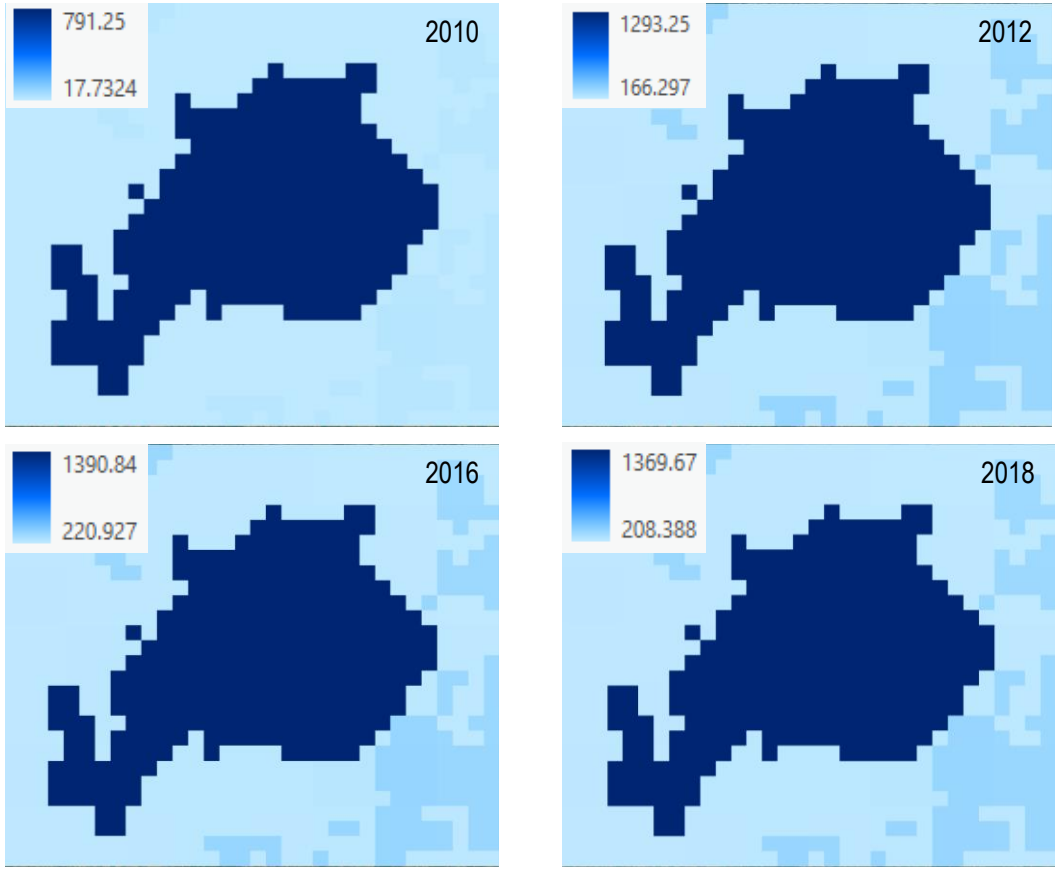

Fig. 46: Annual Water Yield Maps

Soil Sedimentation/Erosion

Fig. 47: Predicted soil erosion vulnerability maps. The red circles mark areas recommended for embankment to reduce soil erosion and loss of soil as a resource.

Regression Analysis

There is a weak positive correlation between the carbon stock and the area of the lake which signifies that the lake is an important sequestration zone for Carbon. There is a negative correlation between recreational index and Carbon storage and similarly between recreational quality and lake area which signifies that as human visitation to the lake has increased, it has been detrimental to the area of the lake and Carbon storage as well. The Water Yield is positively correlated with Carbon sequestration that doubly signifies the importance of carbon sequestration in the lake.

x	Carbon	Lake Area	Water Yield	Recreation
Carbon	x	0	0.44	0.94
Lake Area	0	X	0	0
Water Yield	0.44	0	X	0.58
Recreation	0.94	0	0.58	X

Table 31: Correlation coefficient between the different ecosystem services.

Current Valuations

a) Water Storage: The amount of water stored in the reservoir approx. = 294678400 m^3
Taking the annual price of water storage as 1 USD = 74 INR/m^3
The annual value of water stored in the reservoir = **21.81 billion INR**

b) Carbon Sequestration: The amount of Carbon sequestered in the wetland approx. = 1.62 MT
The social cost of Carbon in India is 86 USD = 6400 INR/T*
The value of Carbon sequestered in the wetland = **10.4 billion INR**

c) Science and Education: Project estimate of Strategy 1.4 (by inflation, 2020) approx. 13.7 billion INR **
The total area of wetlands in India = 153000 km^2

* https://www.downtoearth.org.in/dte-infographics/social_cost_corbon/index.html#:~:text=India's%20country%2Dlevel%20social%20cost,per%20tonne%20of%20CO2%20emission.

** http://nwm.gov.in/?q=strategy-14

Approx. investment in science and education of wetlands = 90,000 INR/km^2
The area of concerned wetland = 22.72 km^2
Value of scientific investment in reservoir = **2.04 million INR**

d) Sediment Retention: The total amount of soil retained in watersheds (by InVEST) = 110495 T
The average concentration of N and P in soil = 0.027%
The average quantity of retained nutrients = 29.83 T
The price of NPK approx. = 20,000 INR/ T
The value of sediment retention = **596.67 thousand INR**

e) Crop Production: Major annual crop production = Wheat (4342 T), Maize (232 T), Paddy (6785 T)
Min. Support Price = Wheat (19250 INR/T), Maize (18500 INR/T), Paddy (18680 INR/T)
Approx. major crop value: 83,583,500 + 4,292,000 + 126,743,800 = **214.62 million INR**

Recreational Index

2010	2012	2014	2016	2018
2	1	3	7	18

Table 32: Annual no. of distinct photo user days – Konar reservoir

The lake is highly impacted by human settlements in terms of scenic quality. The south eastern shore of the lake still retains scenic quality due to low build-up index. The wetland has high cultural and social value. The reservoir is highly developed for tourist activity with boating and nature walks set up. The annual no. of distinct photo user days, an output of the InVEST model is taken as the proxy for level of human activities near the lake

Interpretations and Recommendations

- The carbon sequestration increased from 2010 – 2020 but there was an overall decrease from 2000 to 2020. This is mainly because of the shrinkage in the size of the lake. ***It is advised to reduce human activity near the lake and to stop reclamation practices around the lake to reduce the negative impact and increase carbon storage value.***

Scenic Quality

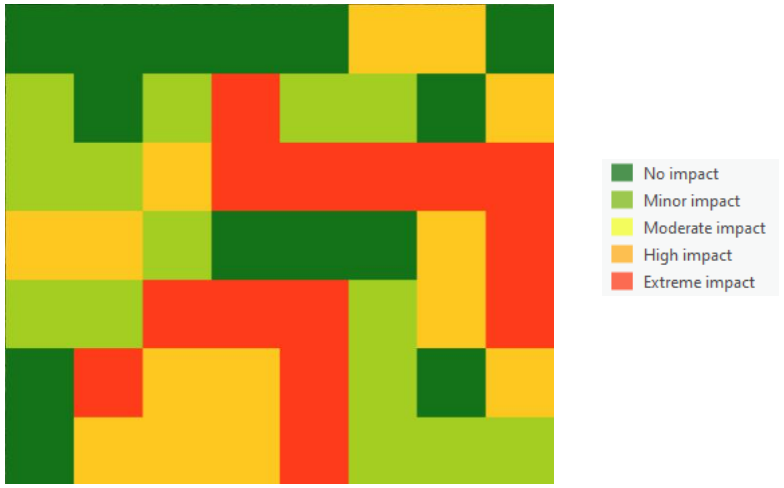

Fig. 48: Scenic Quality per pixel – Konar Reservoir

- There is high probability of soil erosion on the southern edges of the lake. Soil erosion reduces the capacity of water storage of the lake, which is undesirable. ***Mitigation factors such as reforestation on those parts and building artificial banks can help reduce that.*** Soil is also an important non-renewable resource and it should be conserved at all costs.

- The scenic quality of the lake is highly impacted by man-made structures on the western and eastern coasts of the lake. ***Corrective steps need to be taken to raze these structures and reforest these parts with indigenous plant species.***

- Reduction in size of the lake negatively impacts scenic quality as well. Adequate steps should be taken in this direction. There is a trade-off between recreational quality and carbon sequestration. Recreation and human activities negatively impact the valuation of the lake***. Adequate balanced steps need to be taken to develop responsible modes of tourism which do not harm the lake's fragile ecosystem.***

2.6. Massanjore Dam

2.6.1. Site Description

Massanjore reservoir was constructed on the river Mayurakshi and is situated in Dumka District of Jharkhand.

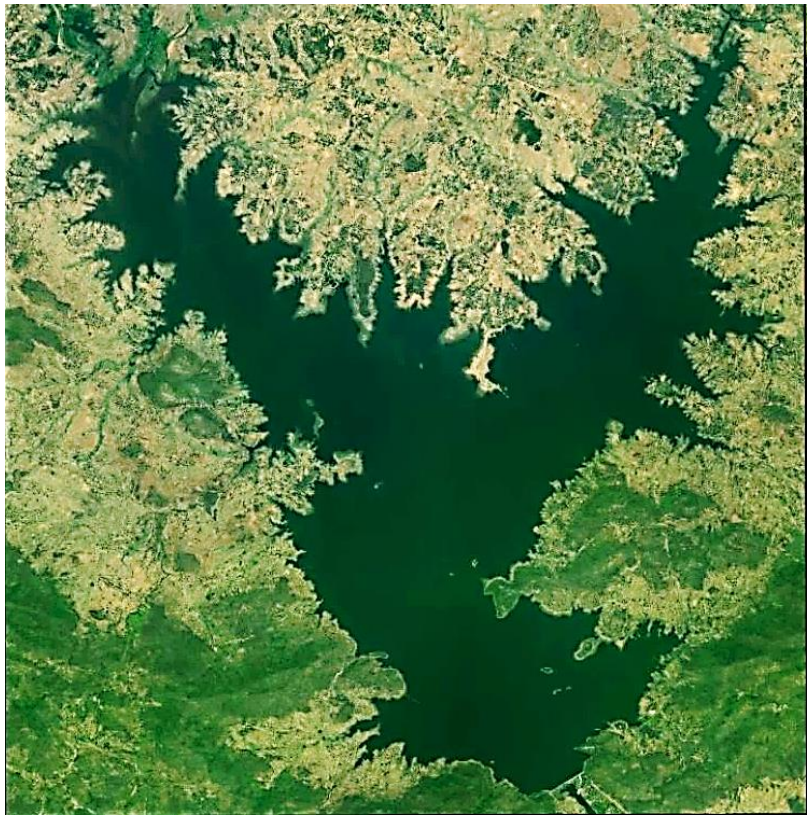

Fig. 49: Region of Interest – Massanjore Dam

Watersheds / Catchment Area

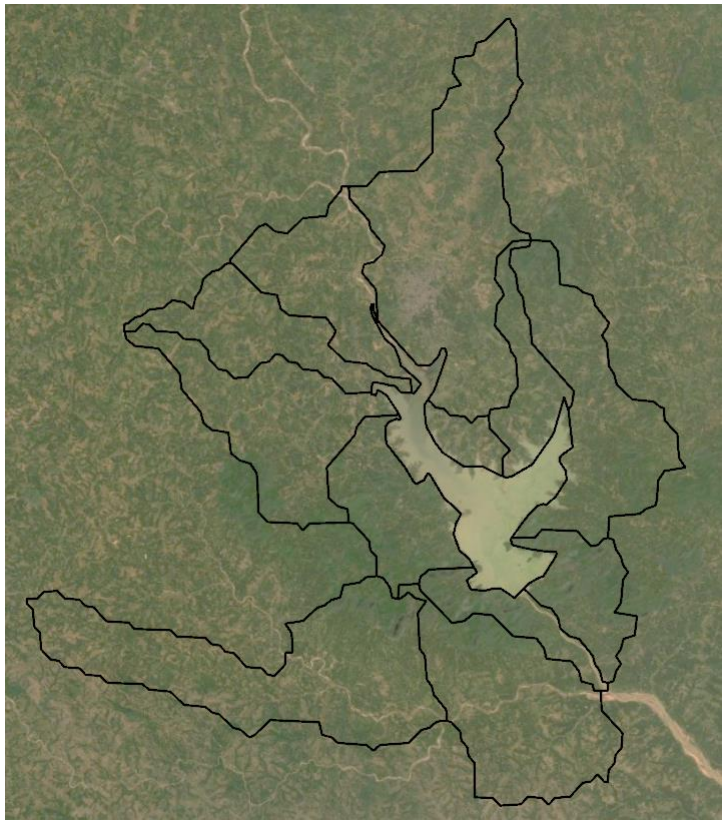

Fig. 50: Watershed regions associated with Massanjore Dam marked with black boundaries

Latitude (N)	24°6'29.9"
Longitude (E)	87°18'39.3"
Area (Km^2)	61.05
Mean depth (m)	
Catchment area (km^2)	1859
Rainfall (mm)	1447

Table 33: Geospatial details – Massanjore Dam

2.6.2. Threats

The pollution arising from the anthropogenic activities and other sources, such as increased application of agricultural chemicals.

2.6.3. Values

- ✓ **Direct use value**
- Agriculture:
- Wetland products: Reservoir water is major source of hydro-electricity and facilitate irrigation, drinking, and fisheries
- Recreation (tourism):

- ✓ **Indirect-use value**

- ✓ **Non-use value**

2.6.4. Biological Aspects

Results

- ***Water quality:*** Water quality was found "Medium or average water quality (WQI score=64)". The water quality is average due to high chemical parameter values (especially total solids) contributing to higher composite effect on water quality.

Water temperature (°C)	
pH	7.1 - 7.9
BOD	1.7 - 3.7
Total Dissolved Solids (mg l-1)	155.5 - 231.1
DO (mg l-1)	4.4 - 7.3
Nitrate (mg l-1)	32.8 - 36.6
Phosphate (mg l-1)	0.3 - 1.3
Gross Primary Production (mg C m2 d-1)	
Net Primary Production (mg C m2 d-1)	

Table 34: Water quality – Massanjore Dam

- The water parameter values are within the permissible limits given by Bureau of Indian standards guideline values for drinking water.

Interpretation

- **Because of the medium or average water quality (based on WQI score), this wetland has less diversity of aquatic aquatic life; and is of moderate concern.**

Due to Medium or average water quality, wetland has less diversity of aquatic organisms and frequently has increased algae growth.
Plankton species reported are *Agmenellum* sp., *Anabena* sp., *Ceratophyllum* sp., *Dentella* sp., *Diatomella* sp.
Flora species reported are *Ipomia aquatica*, Myriophyllum, Limnathemu, Potamogetan, Hydrilla and Ceratophyllum.
Major fish species present are W. attu, C. catla, N. chitala, H. fossilus, Papda, C. mirgala, L. rohita, M. aor etc.

- **The water is also suitable for drinking (human consumption) domestic, and irrigation** purposes as water parameters are within the permissible limits given by Bureau of Indian standards guideline values for drinking water.

Recommendations

- ✓ The overall water quality of wetland is medium or average, and is of moderate concern. In order to make the water quality good, we need to reduce the total solids in the wetland. Its recommended that water treatment should be done which removes the solids from the water.

- ✓ Jharkhand State Pollution Control Board has a zero-tolerance policy toward pollution. If we identify the industry, which is causing pollution the agency can take action and if necessary, the plant can also be shut down to prevent further harm to the wetland.

2.6.5. Economic Aspects

Carbon Sequestration

2010	2012	2014	2016	2018
3.646	3.646	3.646	3.646	3.646

Table 35: Carbon sequestration over time, in MegaTonnes

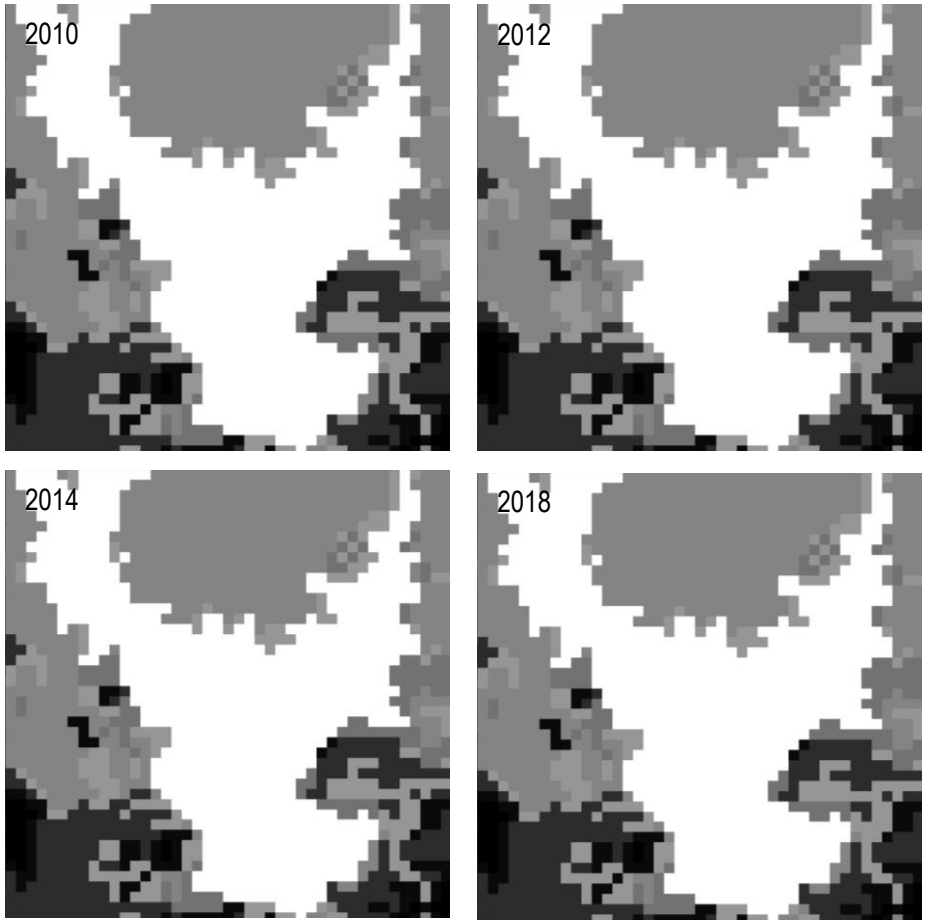

Fig. 51: Carbon sequestration maps, Tonnes of Carbon per pixel (25

Flood Risk Mitigation

Fig. 52: Human settlements and built up area (marked in red) around the Massanjore dam

For a design storm with depth of rainfall 80mm spread over two days, modelling the Phailin Cyclone of 2013, it was found that the economic losses due to flooding came to nearly **20.74 million**.

Table 35 takes into account soil carbon, but the carbon maps only account for carbon above ground, considering edge effects.

Water Yield

2010	2012	2014	2016	2018
131.9	274.1	316.8	345.4	298.5

Table 36: Combined water yield in associated watersheds (billion litres)

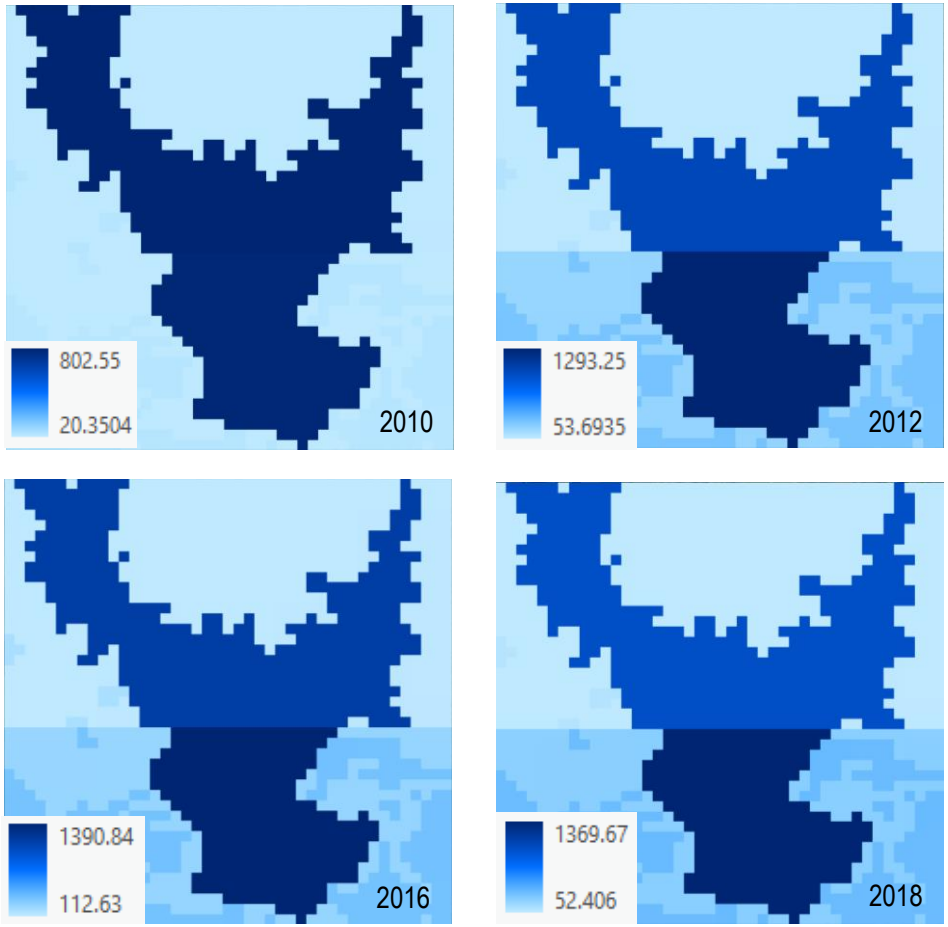

Fig. 53: Annual Water Yield Maps

Soil Sedimentation/Erosion

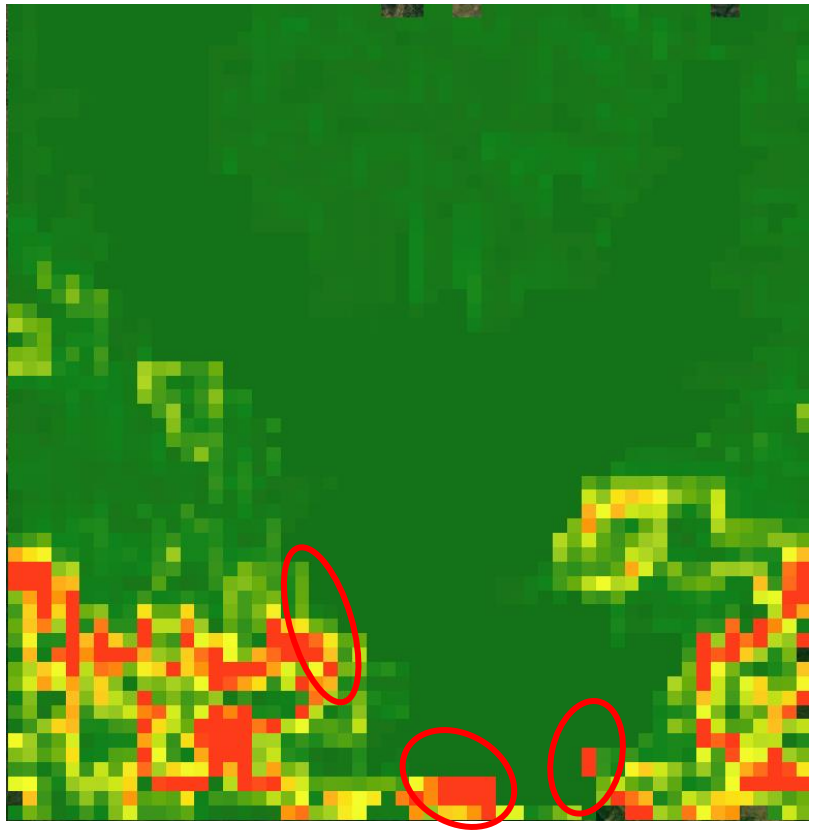

Fig. 54: Predicted soil erosion vulnerability maps. The red circles mark areas recommended for embankment to reduce soil erosion and loss of soil as a resource.

Regression Analysis

There is a weak positive correlation between the carbon stock and the area of the lake which signifies that the lake is an important sequestration zone for Carbon. There is a negative correlation between recreational index and Carbon storage and similarly between recreational quality and lake area which signifies that as human visitation to the lake has increased, it has been detrimental to the area of the lake and Carbon storage as well. The Water Yield is positively correlated with Carbon sequestration that doubly signifies the importance of carbon sequestration in the lake.

x	Carbon	Lake Area	Water Yield	Recreation
Carbon	x	0	0.17	0.89
Lake Area	0	X	0	0
Water Yield	0.17	0	X	0.51
Recreation	0.89	0	0.51	X

Table 37: Correlation coefficient between the different ecosystem services.

Current Valuations

a) Water Storage: The amount of water stored in the reservoir approx. = 620 million m^3
Taking the annual price of water storage as 1 USD = 74 INR/m^3
The annual value of water stored in the reservoir = **45.88 billion INR**

b) Carbon Sequestration: The amount of Carbon sequestered in the wetland approx. = 3.65 MT
The social cost of Carbon in India is 86 USD = 6400 INR/T*
The value of Carbon sequestered in the wetland = **23.36 billion INR**

c) Science and Education: Project estimate of Strategy 1.4 (by inflation, 2020) approx. 13.7 billion INR **
The total area of wetlands in India = 153000 km^2

* https://www.downtoearth.org.in/dte-infographics/social_cost_corbon/index.html#:~:text=India's%20country%2Dlevel%20social%20cost,per%20tonne%20of%20CO2%20emission.

** http://nwm.gov.in/?q=strategy-14

Approx. investment in science and education of wetlands = 90,000 INR/km^2
The area of concerned wetland = 61.05 km^2
Value of scientific investment in reservoir = **5.49 million INR**

d) Sediment Retention: The total amount of soil retained in watersheds (by InVEST) = 1.77 million T
The average concentration of N and P in soil = 0.027%
The average quantity of retained nutrients = 479.6 T
The price of NPK approx. = 20,000 INR/ T
The value of sediment retention = **9.59 million INR**

e) Crop Production: Major annual crop production = Wheat (1900 T), Maize (648 T), Paddy (6833 T)
Min. Support Price = Wheat (19250 INR/T), Maize (18500 INR/T), Paddy (18680 INR/T)
Approx. major crop value: 36,575,000 + 11,988,000 + 127,640,440 = **176.2 million INR**

f) Hydel Power: Annual generation of electricity = 11.87 million kWh*
Average cost of electricity per unit in Jharkhand = 6 INR / kWh
Total value of electricity produced = **71.22 million INR**

*WBSEDCL Annual Report 2017-18

2010	2012	2014	2016	2018
4	7	8	16	28

Table 38: Annual no. of distinct photo user days – Massanjore dam

Recreational Index

The lake is highly impacted by human settlements in terms of scenic quality. The south eastern shore of the lake still retains scenic quality due to low build-up index. The wetland has high cultural and social value. The reservoir is highly developed for tourist activity with boating and nature walks set up. The annual no. of distinct photo user days, an output of the InVEST model is taken as the proxy for level of human activities near the lake

Interpretations and Recommendations

- The carbon sequestration increased from 2010 – 2020 but there was an overall decrease from 2000 to 2020. This is mainly because of the shrinkage in the size of the lake. ***It is advised to reduce human activity near the lake and to stop reclamation practices around the lake to reduce the negative impact and increase carbon storage value.***

Scenic Quality

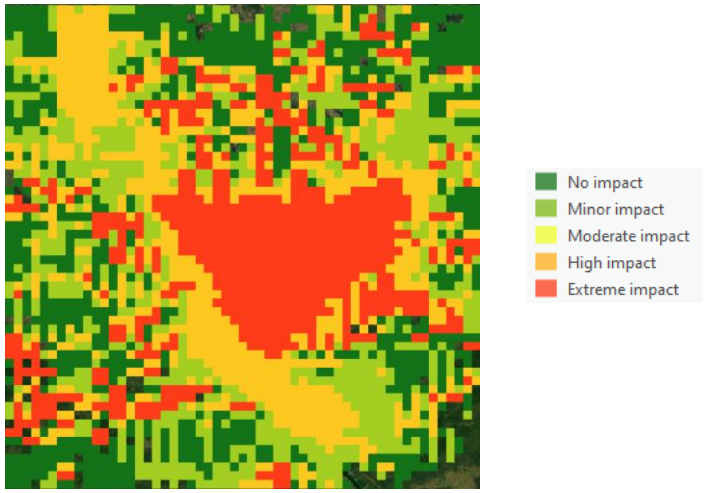

Fig. 55: Scenic Quality per pixel – Massanjore dam

- There is high probability of soil erosion on the southern edges of the lake. Soil erosion reduces the capacity of water storage of the lake, which is undesirable. ***Mitigation factors such as reforestation on those parts and building artificial banks can help reduce that.*** Soil is also an important non-renewable resource and it should be conserved at all costs.

- The scenic quality of the lake is highly impacted by man-made structures on the western and eastern coasts of the lake. ***Corrective steps need to be taken to raze these structures and reforest these parts with indigenous plant species.***

- Reduction in size of the lake negatively impacts scenic quality as well. Adequate steps should be taken in this direction. There is a trade-off between recreational quality and carbon sequestration. Recreation and human activities negatively impact the valuation of the lake. ***Adequate balanced steps need to be taken to develop responsible modes of tourism which do not harm the lake's fragile ecosystem.***

2.7. Panchet dam

2.7.1. Site Description

Panchet dam is built across the Damodar River in Dhanbad District's Panchet area in Jharkhand. It was the last of the four dams constructed in the first phase of the Damodar Valley Corporation.

Fig. 56: Region of Interest – Panchet dam

Watersheds / Catchment Area

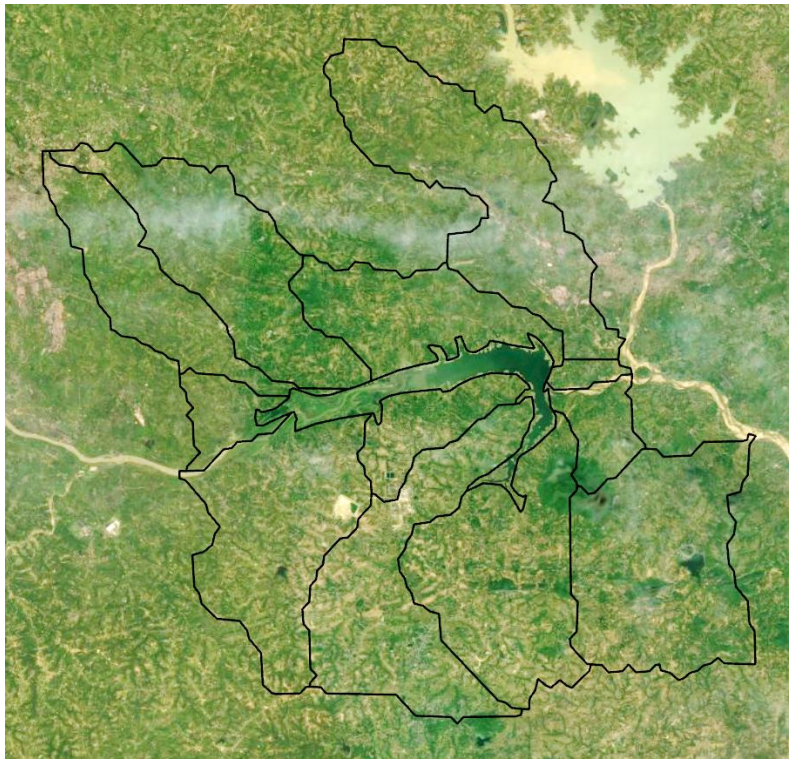

Fig. 57: Watershed regions associated with Panchet dam marked with black boundaries

Latitude (N)	23°40'41"
Longitude (E)	86°44'49"
Area (Km^2)	27.92
Mean depth (m)	5.2
Catchment area (km^2)	6120
Rainfall (mm)	1140

Table 39: Geospatial details – Panchet dam

2.7.2. Threats

A relatively recent report on Panchet reservoir depicts deterioration in the environment due to pollution. Apart from a heavy sediment input, the reservoir receives effluents from 31 different industrial establishments. The 21 coal industries alone add 0.9 million t of effluents per minute. bearing 4% fly ash. Four thermal power plants add huge quantities of effluents with pH above 10 and total solids above 5 000 mg 1-1. All the effluents, which include heavy metals, phenol and cyanide, exert stress on the ecosystem. Decline in fish population due to overfishing. It receives huge industrial load from

2.7.3. Values

✓ **Direct use value**

- Agriculture:
- Wetland products: Reservoir water is major sources of power generation. It is also used for irrigation and fishing.
- Recreation (tourism): The backdrop of the dam is the Panchet hill, which makes this place a great picnic spot for travellers, especially around the Christmas and New Year days.

✓ **Indirect-use value**

✓ **Non-use value**

2.7.4. Biological Aspects

Results

- **Water quality:** Water quality was found "*Fair (WQI score=44)".* The water was considered fair in this wetland mainly due to high chemical parameter values contributing to highrer composite effect on water quality.

Water temperature (°C)	24.9–40.2
pH	7.2–7.6
BOD	
Total Dissolved Solids (mg l-1)	
DO (mg l-1)	0.66–2.80
Nitrate (mg l-1)	
Phosphate (mg l-1)	
Organic carbon(%)	
Gross Primary Production (mg C m2 d-1)	
Net Primary Production (mg C m2 d-1)	

Table 40: Water quality – Panchet dam

The water parameter values are within the permissible limits given by Bureau of Indian standards guideline values for drinking water.

Interpretation

- **Because of the fair water quality (based on WQI score), this wetland only able to support a low diversity of aquatic life and are probably experiencing problems with pollution**

Due to fair water quality, wetland has less diversity of aquatic organisms and frequently has increased algae growth.

The occurrence of catla, rohu, mrigal and L. calbasu in the fishery, without stocking indicates that the carps now reproduce in the reservoir.

- **The water is also suitable for drinking (human consumption) domestic, and irrigation** purposes as water parameters are within the permissible limits given by Bureau of Indian standards guideline values for drinking water.

Recommendations

- ✓ The overall water quality of wetland is fair, and does not meet expectations so is of highest concern. In order to make the water quality good, we need to reduce the total solids in the wetland. Its recommended that water treatment should be done which removes the solids from the water.

- ✓ Jharkhand State Pollution Control Board has a zero-tolerance policy toward pollution. If we identify the industry, which is causing pollution the agency can take action and if necessary, the plant can also be shut down to prevent further harm to the wetland.

2.7.5. Economic Aspects

Carbon Sequestration

2010	2012	2014	2016	2018
4.715	4.732	4.846	4.843	4.831

Table 41: Carbon sequestration over time, in MegaTonnes

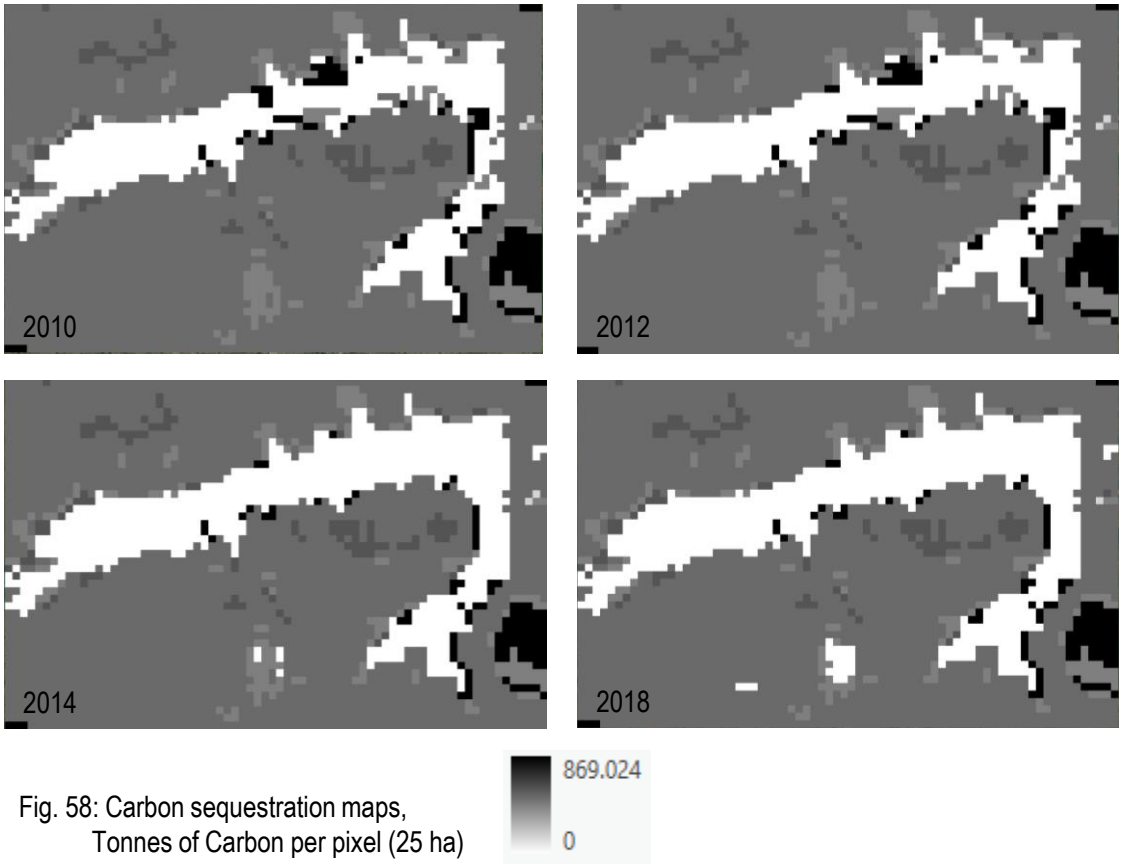

Fig. 58: Carbon sequestration maps, Tonnes of Carbon per pixel (25 ha)

Table 41 takes into account soil carbon, but the carbon maps only account for carbon above ground, considering edge effects.

Flood Risk Mitigation

Fig. 59: Human settlements and built up area (marked in red) around the Panchet dam

For a design storm with depth of rainfall 80mm spread over two days, modelling the Phailin Cyclone of 2013, it was found that the economic losses due to flooding came to nearly **11.11 million**.

Water Yield

2010	2012	2014	2016	2018
98.5	321.9	22.4	404.3	391.9

Table 42: Combined water yield in associated watersheds (billion litres)

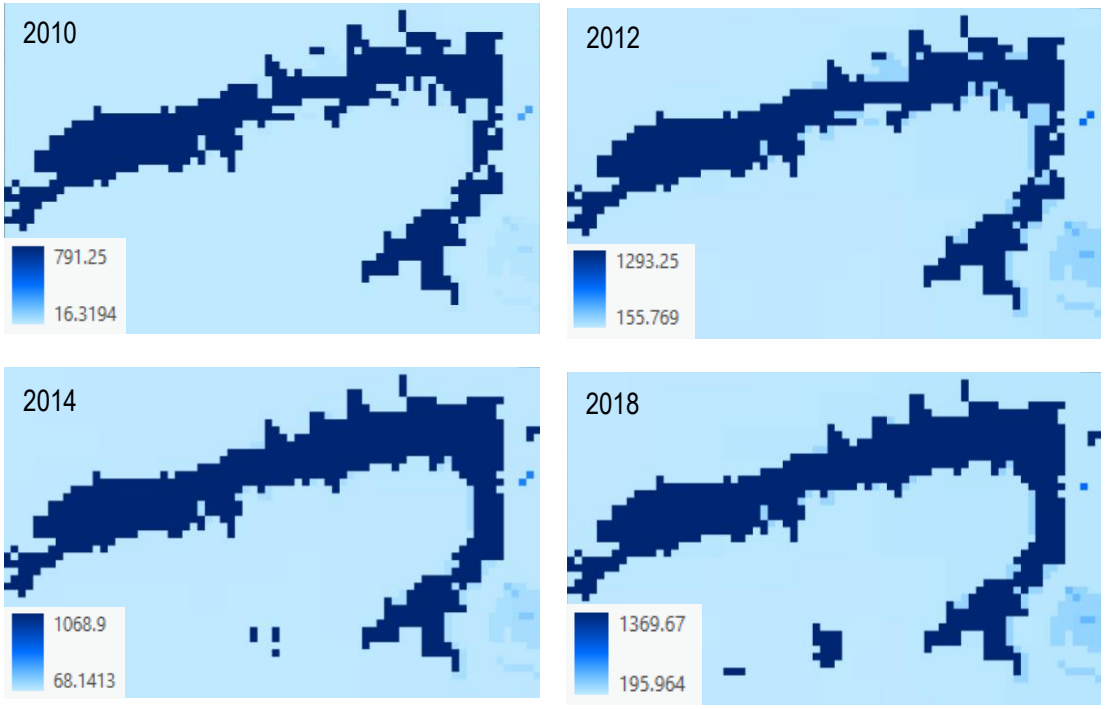

Fig. 60: Annual Water Yield Maps

Soil Sedimentation/Erosion

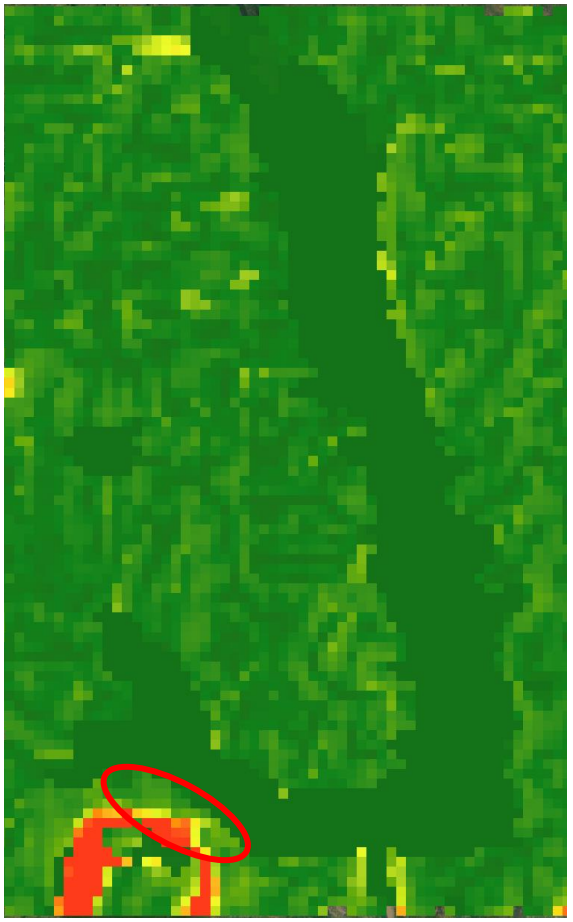

Fig. 61: Predicted soil erosion vulnerability maps. The red circles mark areas recommended for embankment to reduce soil erosion and loss of soil as a resource.

Regression Analysis

x	Carbon	Water Yield	Recreation
Carbon	x	0.19	0.59
Water Yield	0.19	X	0.75
Recreation	0.59	0.75	X

Table 43: Correlation coefficient between the different ecosystem services.

There is a strong positive correlation between the carbon stock and the water yield of the lake which signifies that the lake is an important sequestration zone for Carbon. There is a strongly positive correlation between recreational index and Carbon storage which signifies that human visitation to the lake has increased, as the Carbon storage has increased. Wetlands are an important natural sequestration zone for carbon, so tourism has increased as the lake has become a naturally better biome The Water Yield is positively correlated with Carbon sequestration that doubly signifies the importance of carbon sequestration in the lake.

Current Valuations

a) **Water Storage:** The amount of water stored in the reservoir approx. = 145.2 million m^3
Taking the annual price of water storage as 1 USD = 74 INR/m^3
The annual value of water stored in the reservoir = **10.74 billion INR**

b) **Carbon Sequestration:** The amount of Carbon sequestered in the wetland approx. = 4.83 MT
The social cost of Carbon in India is 86 USD = 6400 INR/T*
The value of Carbon sequestered in the wetland = **30.91 billion INR**

c) **Science and Education:** Project estimate of Strategy 1.4 (by inflation, 2020) approx. 13.7 billion INR **
The total area of wetlands in India = 153000 km^2

* https://www.downtoearth.org.in/dte-infographics/social_cost_corbon/index.html#:~:text=India's%20country%2Dlevel%20social%20cost,per%20tonne%20of%20CO2%20emission.

** http://nwm.gov.in/?q=strategy-14

Approx. investment in science and education of wetlands = 90,000 INR/km^2
The area of concerned wetland = 27.92 km^2
Value of scientific investment in reservoir = **2.51 million INR**

d) Sediment Retention: The total amount of soil retained in watersheds (by InVEST) = 1.29 million T
The average concentration of N and P in soil = 0.027%
The average quantity of retained nutrients = 348.3 T
The price of NPK approx. = 20,000 INR/ T
The value of sediment retention = **6.97 million INR**

e) Crop Production: Major annual crop production = Wheat (6861 T), Maize (4642 T), Paddy (11000 T)
Min. Support Price = Wheat (19250 INR/T), Maize (18500 INR/T), Paddy (18680 INR/T)
Approx. major crop value: 132,074,250 + 85,877,000 + 205,480,000 = **423 million INR**

f) Hydel Power: Annual generation of electricity = 223.13 million kWh* (in 2008)
Average cost of electricity per unit in Jharkhand = 6 INR / kWh
Total value of electricity produced = **71.22 million INR**

* http://globalenergyobservatory.org/geoid/4691

Recreational Index

2010	2012	2014	2016	2018
3	7	6	14	23

Table 44: Annual no. of distinct photo user days – Panchet dam

The lake is highly impacted by human settlements in terms of scenic quality. The southern, northern and eastern shore of the lake have very low scenic quality due to extremely high build-up index. The wetland has high cultural and social value. The reservoir is highly developed for tourist activity with boating and nature walks set up. The annual no. of distinct photo user days, an output of the InVEST model is taken as the proxy for level of human activities near the lake

Interpretations and Recommendations

Scenic Quality

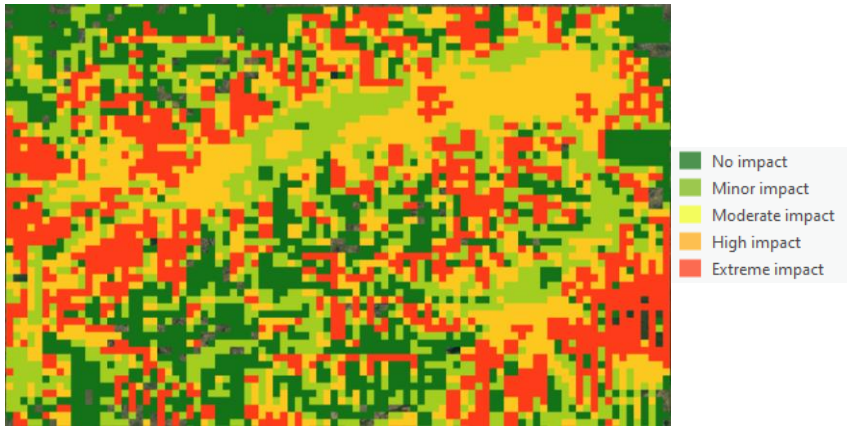

Fig. 62: Scenic Quality per pixel – Panchet dam

- The carbon sequestration increased from 2010 – 2020 but there was an overall decrease from 2000 to 2020. This is mainly because of the shrinkage in the size of the lake. ***It is advised to reduce human activity near the lake and to stop reclamation practices around the lake to reduce the negative impact and increase carbon storage value.***

- There is high probability of soil erosion on the south eastern edges of the lake. Soil erosion reduces the capacity of water storage of the lake, which is undesirable. ***Mitigation factors such as reforestation on those parts and building artificial banks can help reduce that.*** Soil is also an important non-renewable resource and it should be conserved at all costs.

- The scenic quality of the lake is highly impacted by man-made structures on the northern, western and eastern coasts of the lake. ***Corrective steps need to be taken to raze these structures and reforest these parts with indigenous plant species.***

- Reduction in size of the lake negatively impacts scenic quality as well. Adequate steps should be taken in this direction. There is a trade-off between recreational quality and carbon sequestration. Recreation and human activities negatively impact the valuation of the lake***. Adequate balanced steps need to be taken to develop responsible modes of tourism which do not harm the lake's fragile ecosystem.***

2.8. Tilaiya Dam

2.8.1. Site Description

Tilaiya Dam was the first of the four multi-purpose dams included in the first phase of the Damodar Valley Corporation. It was constructed across the Barakar River, at Tilaiya in Koderma district in Jharkhand.

Fig. 63: Region of Interest – Tilaiya Dam

Watersheds / Catchment Area

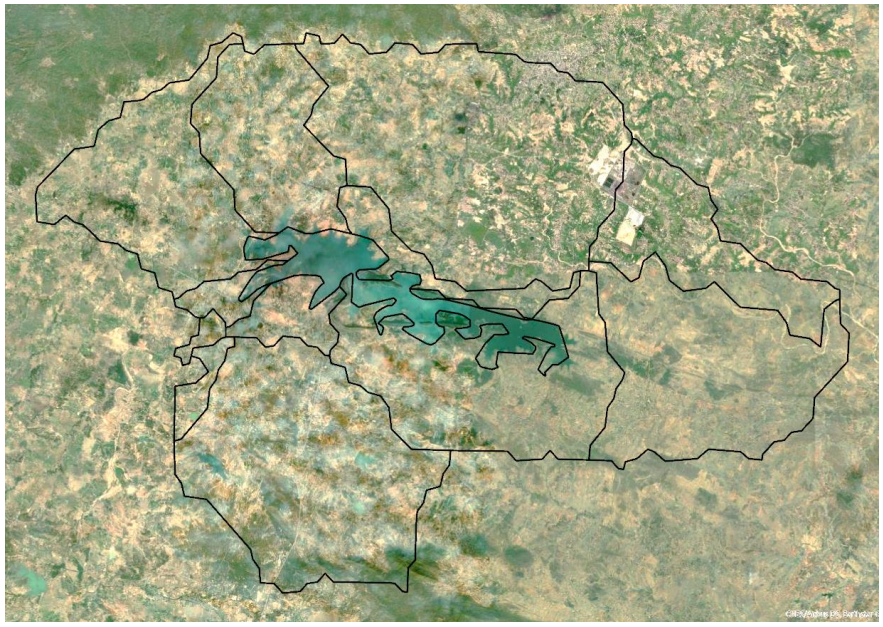

Fig. 64: Watershed regions associated with Tilaiya Dam marked with black boundaries

Latitude (N)	24°20'38.8"
Longitude (E)	85°25'56.20"
Area (Km²)	48.65
Mean depth (m)	6.65
Catchment area (km²)	984
Rainfall (mm)	1270

Table 45: Geospatial detail – Tilaiya Dam

2.8.2. Threats

The pollution arising from the anthropogenic activities and other sources, such as increased application of agricultural chemicals.

2.8.3. Values

- ✓ **Direct use value**
- Agriculture:
- Wetland products: Reservoir water is major source of hydro-electricity and facilitate irrigation, drinking, and fisheries
- Recreation (tourism):

- ✓ **Indirect-use value**

- ✓ **Non-use value**

2.8.4. Biological Aspects

Results

- ***Water quality:*** Water quality was found "Good (WQI score=90)". The water was considered good in this wetland mainly due to low chemical parameter values contributing to lower composite effect on water quality.

Water temperature (°C)	24.5-33.0
pH	6.7-7.0
BOD	
Total Dissolved Solids (mg l-1)	
DO (mg l-1)	4.7-8.3
Nitrate (mg l-1)	0.25
Phosphate (mg l-1)	0.03
Organic carbon(%)	
Gross Primary Production (mg C m2 d-1)	199-300
Net Primary Production (mg C m2 d-1)	

Table 46: Water quality – Tilaiya dam

- ***Soil quality:***

Organic Carbon (%)	0.31–0.50
Available P (mg 100 g^{-1})	3.0
pH	5.6-5.9

Table 48: Soil quality – Tilaiya dam

The water parameter values are within the permissible limits given by Bureau of Indian standards guideline values for drinking water.

Interpretation

- ***Because of the good water quality (based on WQI score), it meets the expectation and is of least concern. This wetland is able to support a high diversity of aquatic life.***

Due to good water quality, wetland has high primary productivity.

The major fish species were Catla (Catla catla), Mirka (Cirrhinus mrigala) Labeo calbasu, Rohu (L. rohita), Bata (L. bata), L. dyocheilus, Puntius sarana, Cyprinus carpio, Notopterus notopterus and Ompok bimaculatus etc.

- ***The water is also suitable for drinking (human consumption) domestic, and irrigation*** purposes as water parameters are within the permissible limits given by Bureau of Indian standards guideline values for drinking water.

- ***In addition, the water would also be suitable for all forms of recreation, including those involving direct contact with the water.***

Recommendations

- ✓ Even though the overall water quality of wetland is good, there are some places where industrial effluents discharge occur. Its recommended that at these places water treatment should be done by using the latest yet economically viable treatment method such as constructed wetland. The size of the constructed wetland will be based on the water flow rate and the quantity of water to be treated.

- ✓ Jharkhand State Pollution Control Board has a zero-tolerance policy toward pollution. If we identify the industry, which is causing pollution the agency can take action and if necessary, the plant can also be shut down to prevent further harm to the wetland.

2.8.5. Economic Aspects

Carbon Sequestration

2010	2012	2014	2016	2018
2.993	3.027	4.847	4.843	4.831

Table 47: Carbon sequestration over time, in MegaTonnes

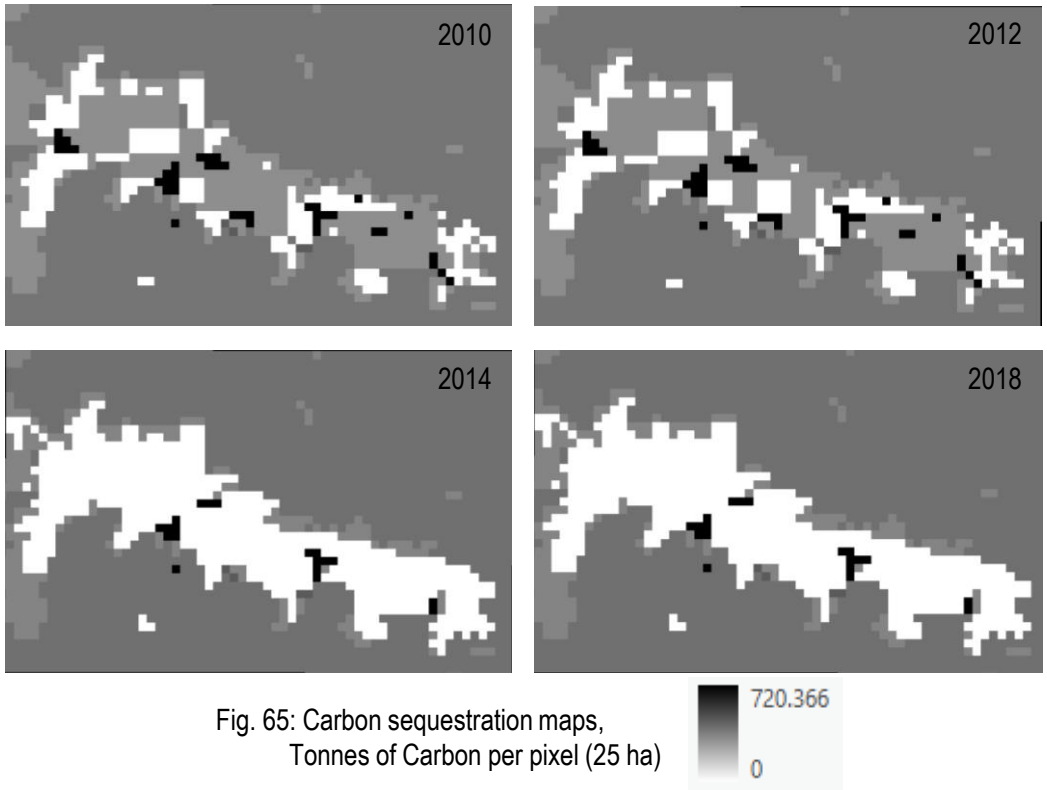

Fig. 65: Carbon sequestration maps, Tonnes of Carbon per pixel (25 ha)

Table 47 takes into account soil carbon, but the carbon maps only account for carbon above ground, considering edge effects.

Flood Risk Mitigation

Fig. 66: Human settlements and built up area (marked in red) around the reservoir

For a design storm with depth of rainfall 80mm spread over two days, modelling the Phailin Cyclone of 2013, it was found that the economic losses due to flooding came to nearly **11.83 million**.

Water Yield

2010	2012	2014	2016	2018
44.6	157.1	169.8	253.0	122.9

Table 48: Combined water yield in associated watersheds (billion litres)

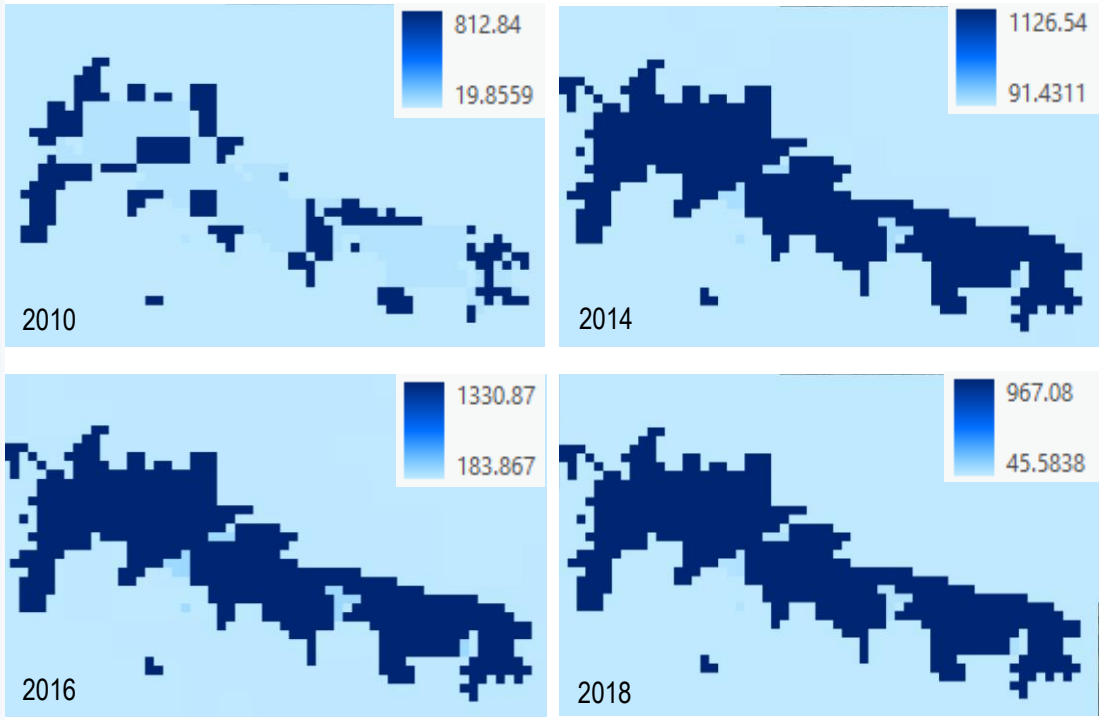

Fig. 67: Annual Water Yield Maps

Soil Sedimentation/Erosion

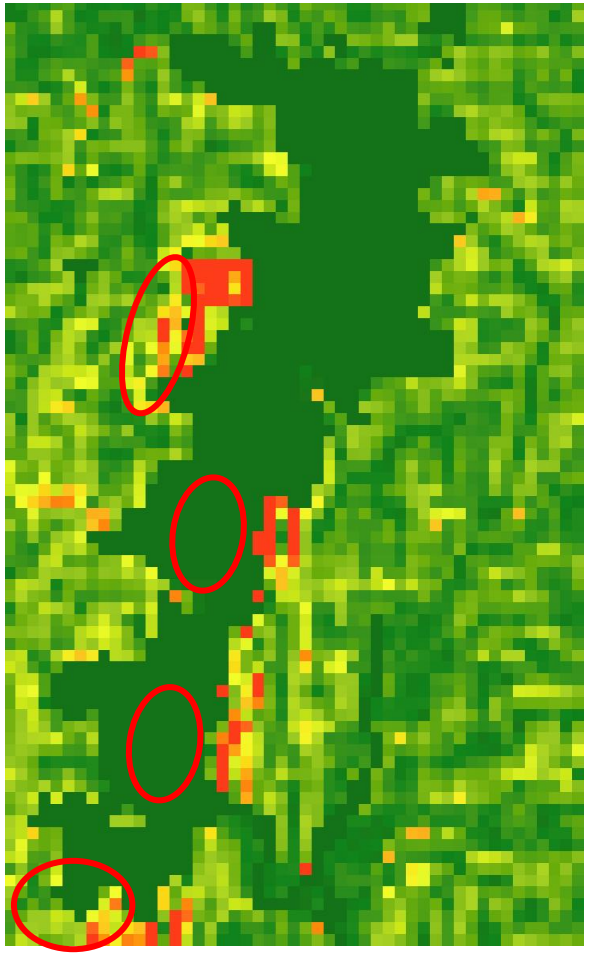

Fig. 68: Predicted soil erosion vulnerability maps. The red circles mark areas recommended for embankment to reduce soil erosion and loss of soil as a resource.

Regression Analysis

There is a strong positive correlation between the carbon stock and the water yield of the lake which signifies that the lake is an important sequestration zone for Carbon. There is a strongly positive correlation between recreational index and Carbon storage which signifies that human visitation to the lake has increased, as the Carbon storage has increased. Wetlands are an important natural sequestration zone for carbon, so tourism has increased as the lake has become a naturally better biome The Water Yield is positively correlated with Carbon sequestration that doubly signifies the importance of carbon sequestration in the lake.

x	Carbon	Water Yield	Recreation
Carbon	x	0.60	0.83
Water Yield	0.60	X	0.43
Recreation	0.83	0.43	X

Table 49: Correlation coefficient between the different ecosystem services.

Current Valuations

a) Water Storage: The amount of water stored in the reservoir approx. = 381 million m^3
Taking the annual price of water storage as 1 USD = 74 INR/m^3
The annual value of water stored in the reservoir = **28.19 billion INR**

b) Carbon Sequestration: The amount of Carbon sequestered in the wetland approx. = 4.83 MT
The social cost of Carbon in India is 86 USD = 6400 INR/T*
The value of Carbon sequestered in the wetland = **30.91 billion INR**

c) Science and Education: Project estimate of Strategy 1.4 (by inflation, 2020) approx. 13.7 billion INR **
The total area of wetlands in India = 153000 km^2

* https://www.downtoearth.org.in/dte-infographics/social_cost_corbon/index.html#:~:text=India's%20country%2Dlevel%20social%20cost,per%20tonne%20of%20CO2%20emission.

** http://nwm.gov.in/?q=strategy-14

Approx. investment in science and education of wetlands = 90,000 INR/km^2
The area of concerned wetland = 48.65 km^2
Value of scientific investment in reservoir = **4.38 million INR**

d) Sediment Retention: The total amount of soil retained in watersheds (by InVEST) = 0.33 million T
The average concentration of N and P in soil = 0.027%
The average quantity of retained nutrients = 89.1 T
The price of NPK approx. = 20,000 INR/ T
The value of sediment retention = **1.78 million INR**

e) Crop Production: Major annual crop production = Wheat (14957 T), Maize (11560 T), Paddy (16047 T)
Min. Support Price = Wheat (19250 INR/T), Maize (18500 INR/T), Paddy (18680 INR/T)
Approx. major crop value: 287,922,250 + 213,860,000 + 299,757,960 = **801 million INR**

f) Hydel Power: Annual generation of electricity = 10.85 million kWh* (in 2017)
Average cost of electricity per unit in Jharkhand = 6 INR / kWh
Total value of electricity produced = **65.1 million INR**

*https://www.dvc.gov.in/dvcwebsite_new1/downloads/annual-report/

Recreational Index

2010	2012	2014	2016	2018
3	2	6	12	14

Table 50: Annual no. of distinct photo user days – Tilaiya dam

The lake is highly impacted by human settlements in terms of scenic quality. The south eastern shore of the lake still retains scenic quality due to low build-up index. The northern part of the lake is highly built with a bridge intersecting the lake. The annual no. of distinct photo user days, an output of the InVEST model is taken as the proxy for level of human activities near the lake

Interpretations and Recommendations

Scenic Quality

- The carbon sequestration increased from 2010 – 2020 but there was an overall decrease from 2000 to 2020. This is mainly because of the shrinkage in the size of the lake. ***It is advised to reduce human activity near the lake and to stop reclamation practices around the lake to reduce the negative impact and increase carbon storage value.***

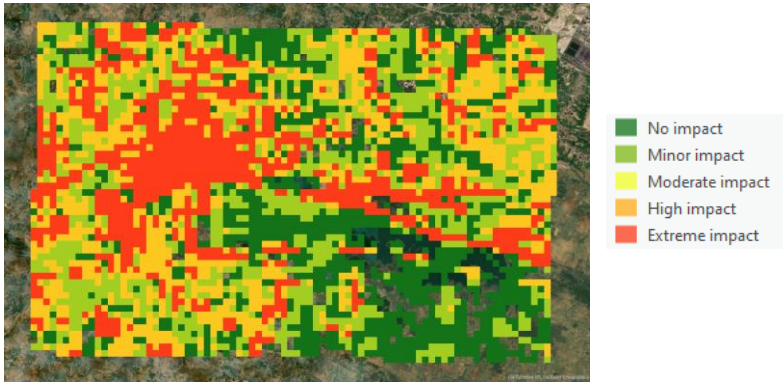

Fig. 69: Scenic Quality per pixel – Tilaiya dam

- There is high probability of soil erosion on the southern and eastern edges of the lake. Soil erosion reduces the capacity of water storage of the lake, which is undesirable. ***Mitigation factors such as reforestation on those parts and building artificial banks can help reduce that.*** Soil is also an important non-renewable resource and it should be conserved at all costs.

- The scenic quality of the lake is highly impacted by man-made structures on the western and northern coasts of the lake. ***Corrective steps need to be taken to raze these structures and reforest these parts with indigenous plant species.***

- Reduction in size of the lake negatively impacts scenic quality as well. Adequate steps should be taken in this direction. There is a trade-off between recreational quality and carbon sequestration. Recreation and human activities negatively impact the valuation of the lake. ***Adequate balanced steps need to be taken to develop responsible modes of tourism which do not harm the lake's fragile ecosystem.***

2.9. Patratu Dam

2.9.1. Site Description

The Nalkari, a tributary of the Damodar river that flows through the eastern states of Jharkhand and West Bengal, was dammed to supply water to the Patratu Thermal Power Station. There have been plans to turn it into a tourist attraction.

Fig. 70: Region of Interest – Patratu Dam

Watersheds / Catchment Area

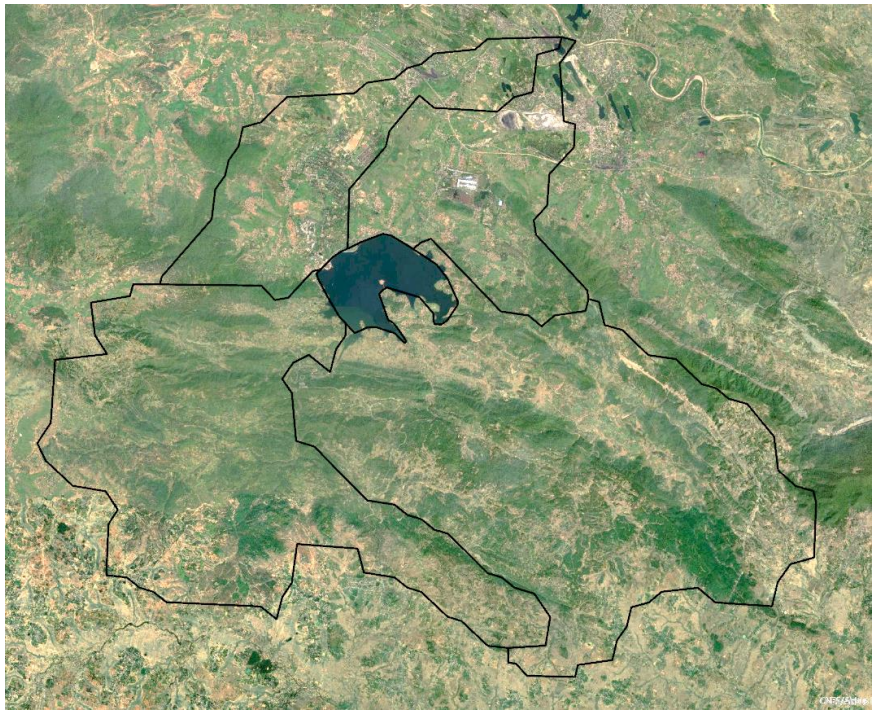

Fig. 71: Watershed regions associated with Patratu dam marked with black boundaries

Latitude (N)	**23°40'**
Longitude (E)	85°19'
Area (Km^2)	9.91
Mean depth (m)	
Catchment area (km^2)	
Rainfall (mm)	

Table 51: Geospatial details – Patratu Dam

2.9.2. Threats

The pollution arising from the anthropogenic activities and other sources, such as increased application of agricultural chemicals. The Nalkari carries huge quantities of oil and ash, discharged by the Patratu Thermal Power Station (PTPS)

2.9.3. Values

- ✓ **Direct use value**
- Agriculture:
- Wetland products: Reservoir water is major source of hydro-electricity and facilitate irrigation, drinking, and fisheries
- Recreation (tourism):

- ✓ **Indirect-use value**

- ✓ **Non-use value**

2.9.4. Biological Aspects

Results

- **Water quality:** Water quality was found "*Good (WQI score=78)".* The water was considered good in this wetland mainly due to low chemical parameter values contributing to lower composite effect on water quality.

Water temperature (°C)	22.0-31.0
pH	7.0-8.3
BOD	
Total Dissolved Solids (mg l-1)	0.9-7.6
DO (mg l-1)	
Nitrate (mg l-1)	0.07
Phosphate (mg l-1)	0-0.06
Organic carbon(%)	
Gross Primary Production (mg C m2 d-1)	

Table 52: Water quality – Patratu Dam

- **Soil quality:**

Organic Carbon (%)	0.26-0.67
Available P (mg 100 g^{-1})	10-16
Available N (mg 100g^{-1})	47.15
pH	5.4-6.2

Table 56: Soil quality – Patratu Dam

The water parameter values are within the permissible limits given by Bureau of Indian standards guideline values for drinking water.

Interpretation

- ***Because of the good water quality (based on WQI score), it meets the expectation and is of least concern. This wetland is able to support a high diversity of aquatic life.***

Due to good water quality, wetland has high primary productivity.

- ***The water is also suitable for drinking (human consumption) domestic, and irrigation*** purposes as water parameters are within the permissible limits given by Bureau of Indian standards guideline values for drinking water.

- ***In addition, the water would also be suitable for all forms of recreation, including those involving direct contact with the water.***

Recommendations

- ✓ Even though the overall water quality of wetland is good, there are some places where industrial effluents discharge occur. Its recommended that at these places water treatment should be done by using the latest yet economically viable treatment method such as constructed wetland. The size of the constructed wetland will be based on the water flow rate and the quantity of water to be treated.

- ✓ Jharkhand State Pollution Control Board has a zero-tolerance policy toward pollution. If we identify the industry, which is causing pollution the agency can take action and if necessary, the plant can also be shut down to prevent further harm to the wetland.

2.9.5. Economic Aspects

Carbon Sequestration

2010	2012	2014	2016	2018
0.582	0.582	0.582	0.593	0.598

Table 53: Carbon sequestration over time, in MegaTonnes

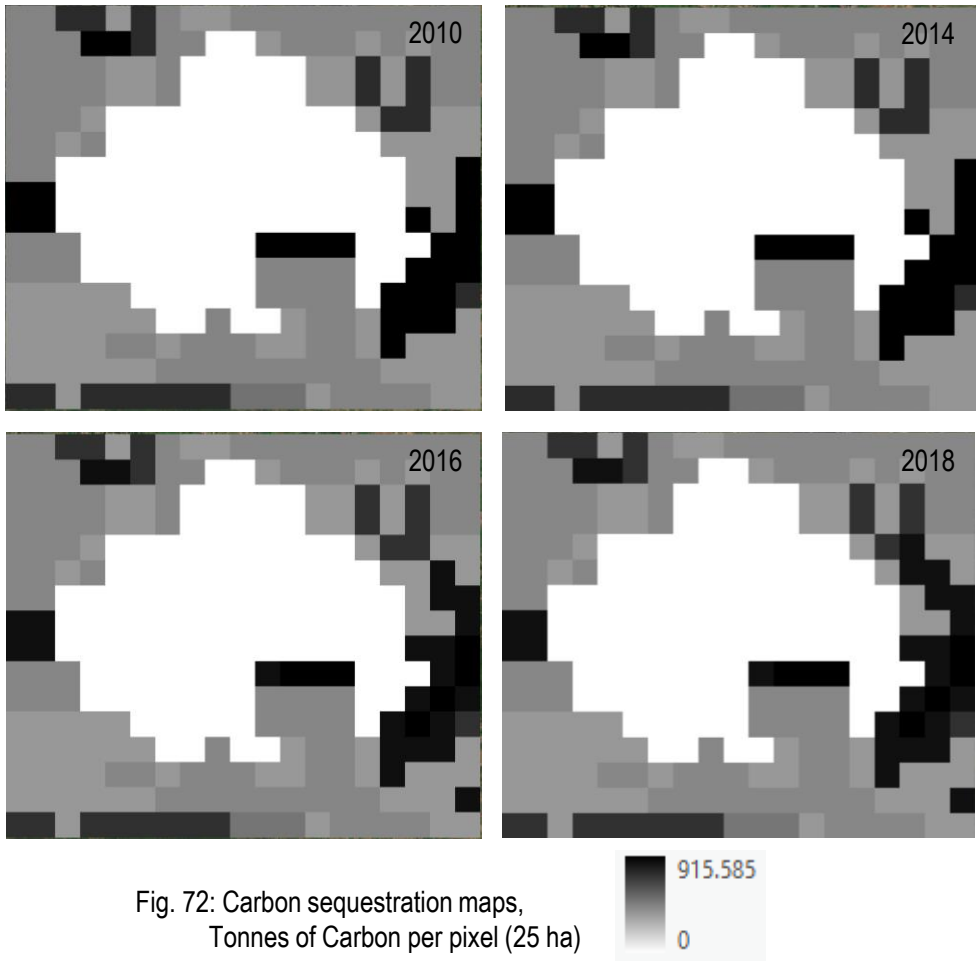

Fig. 72: Carbon sequestration maps, Tonnes of Carbon per pixel (25 ha)

Flood Risk Mitigation

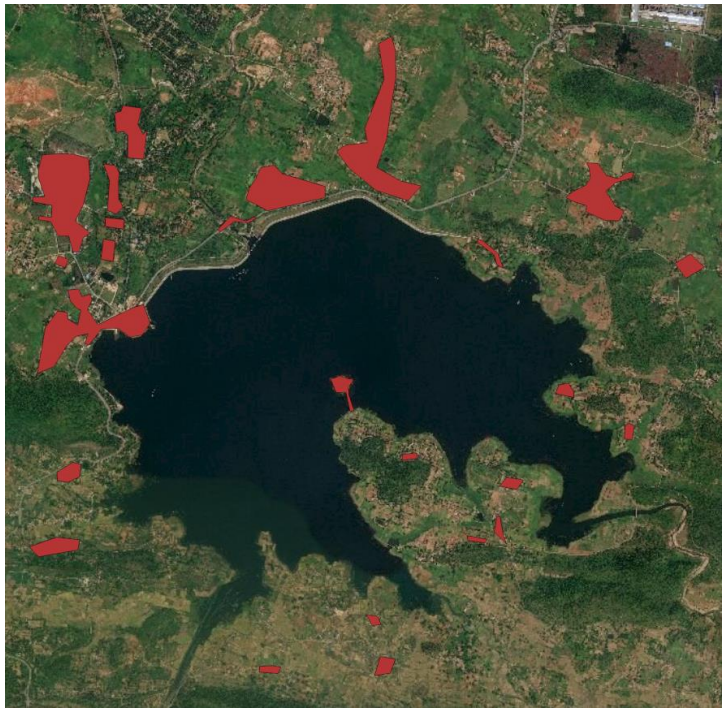

Fig. 73: Human settlements and built up area (marked in red) around the reservoir

[Soil hydrological data not available to calculate Urban Flood Risk Mitigation statistics]

Table 53 takes into account soil carbon, but the carbon maps only account for carbon above ground, considering edge effects.

Water Yield

2010	2012	2014	2016	2018
53.7	139.3	80.8	120.9	103.7

Table 54: Combined water yield in associated watersheds (billion litres)

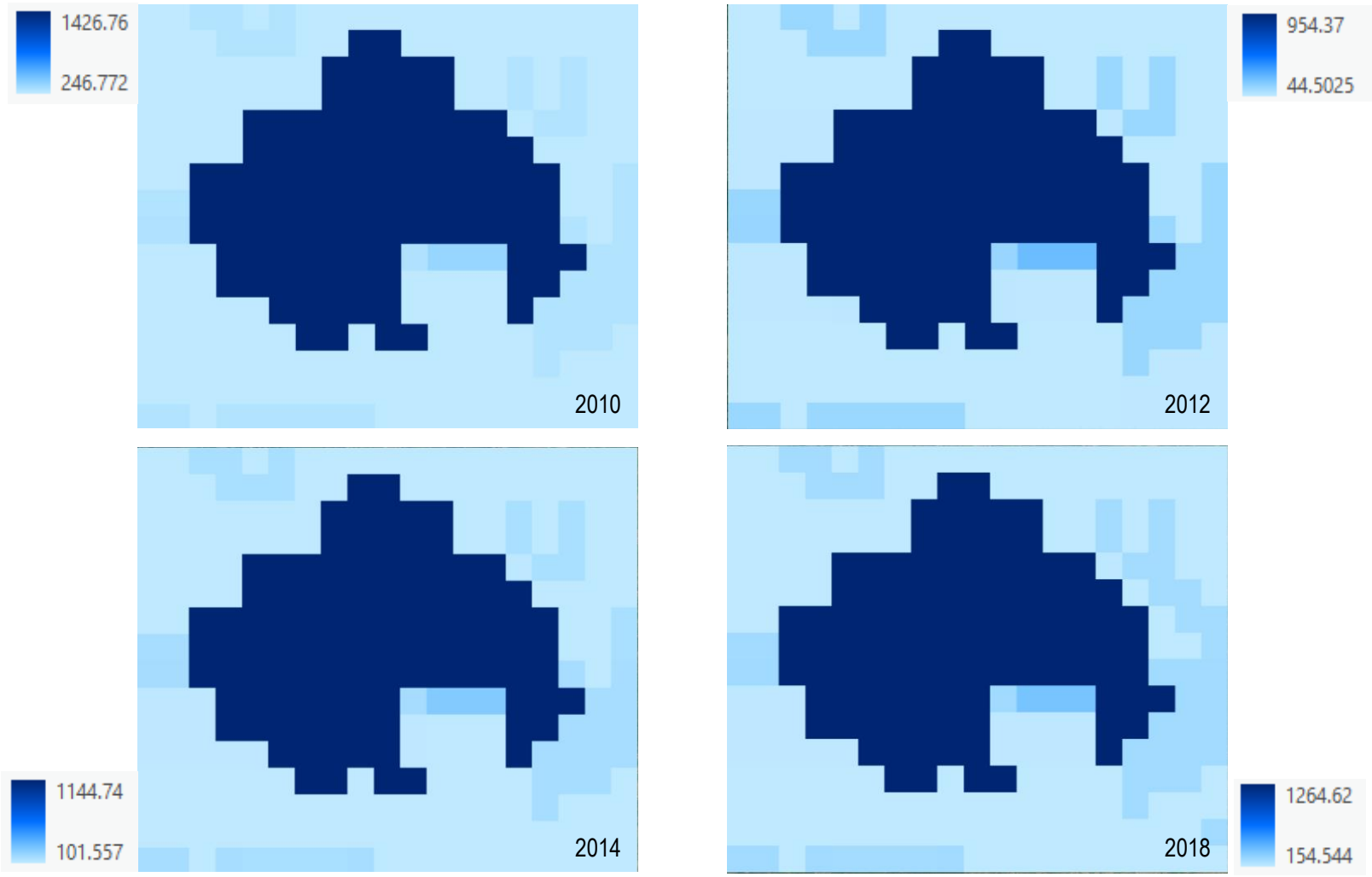

Fig. 74: Annual Water Yield Maps

Regression Analysis

x	Carbon	Water Yield	Recreation
Carbon	x	0.29	0.92
Water Yield	0.29	X	0.48
Recreation	0.92	0.48	X

Table 55: Correlation coefficient between the different ecosystem services.

There is a weak positive correlation between the carbon stock and the water yield of the lake which signifies that the lake is an important sequestration zone for Carbon. There is a strongly positive correlation between recreational index and Carbon storage which signifies that human visitation to the lake has increased, as the Carbon storage has increased. Wetlands are an important natural sequestration zone for carbon, so tourism has increased as the lake has become a naturally better biome The Water Yield is positively correlated with Carbon sequestration that doubly signifies the importance of carbon sequestration in the lake.

Current Valuations

a) Water Storage: The amount of water stored in the reservoir approx. = 2.62 million m^3 *
Taking the annual price of water storage as 1 USD = 74 INR/m^3
The annual value of water stored in the reservoir = **193.8 million INR**

b) Carbon Sequestration: The amount of Carbon sequestered in the wetland approx. = 0.60 MT
The social cost of Carbon in India is 86 USD = 6400 INR/T**
The value of Carbon sequestered in the wetland = **3.84 billion INR**

* https://www.prsindia.org/sites/default/files/bill_files/National%20Register%20of%20Large%20Dams%2C%202019.pdf

** https://www.downtoearth.org.in/dte-infographics/social_cost_corbon/index.html#:~:text=India's%20country%2Dlevel%20social%20cost,per%20tonne%20of%20CO2%20emission.

*** http://nwm.gov.in/?q=strategy-14

c) *Science and Education:* Project estimate of Strategy 1.4 (by inflation, 2020) approx. 13.7 billion INR ***
The total area of wetlands in India = 153000 km^2
Approx. investment in science and education of wetlands = 90,000 INR/km^2
The area of concerned wetland = 9.91 km^2
Value of scientific investment in reservoir = **0.89 million INR**

d) Crop Production: Major annual crop production = Wheat (7419 T), Maize (6576 T), Paddy (8924 T)
Min. Support Price = Wheat (19250 INR/T), Maize (18500 INR/T), Paddy (18680 INR/T)
Approx. major crop value: 142,815,750 + 121,656,000 + 166,700,320 = **431 million INR**

Recreational Index

2010	2012	2014	2016	2018
0	2	1	3	6

Table 56: Annual no. of distinct photo user days – Patratu Dam

The lake is highly impacted by human settlements in terms of scenic quality. The southern and north eastern shore of the lake have drastically reduced scenic quality due to high build-up index. The southern shore of the lake also includes a temple island which further reduces the scenic quality. The wetland has high cultural and social value. The reservoir is highly developed for tourist and religious activity with boating and nature walks set up. The annual no. of distinct photo user days, an output of the InVEST model is taken as the proxy for level of human activities near the lake

Interpretations and Recommendations

- The carbon sequestration increased from 2010 – 2020 but there was an overall decrease from 2000 to 2020. This is mainly because of the shrinkage in the size of the lake. ***It is advised to reduce human activity near the lake and to stop reclamation practices around the lake to reduce the negative impact and increase carbon storage value.***

Scenic Quality

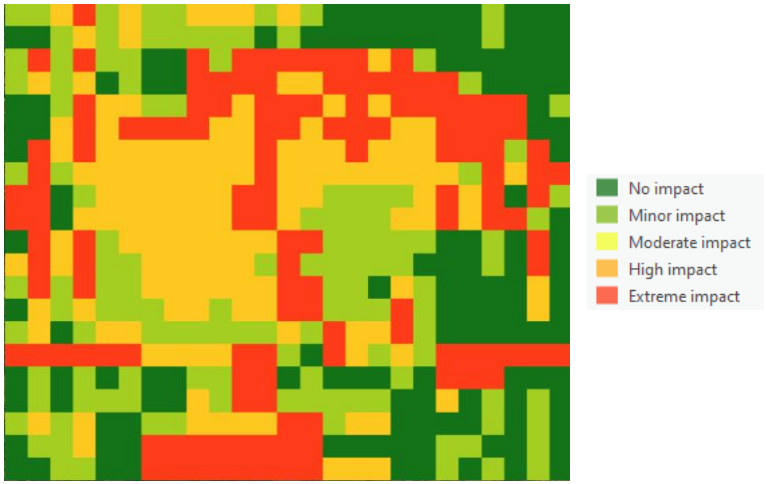

Fig. 75: Scenic Quality per pixel – Patratu Dam

- The scenic quality of the lake is highly impacted by man-made structures on the southern and north eastern coasts of the lake. ***Corrective steps need to be taken to raze these structures and reforest these parts with indigenous plant species.***

- Reduction in size of the lake negatively impacts scenic quality as well. Adequate steps should be taken in this direction. There is a trade-off between recreational quality and carbon sequestration. Recreation and human activities negatively impact the valuation of the lake. ***Adequate balanced steps need to be taken to develop responsible modes of tourism which do not harm the lake's fragile ecosystem.***

2.10. Udhwa Lake Bird Sanctuary

2.10.1. Site Description

Udhwa Bird Sanctuary is the only bird sanctuary of Jharkhand. It comprises of two backwater lakes over river Ganges, namely Patauda and Berhale. Migratory birds reach here from several parts of the world in winter.

Watersheds / Catchment Area

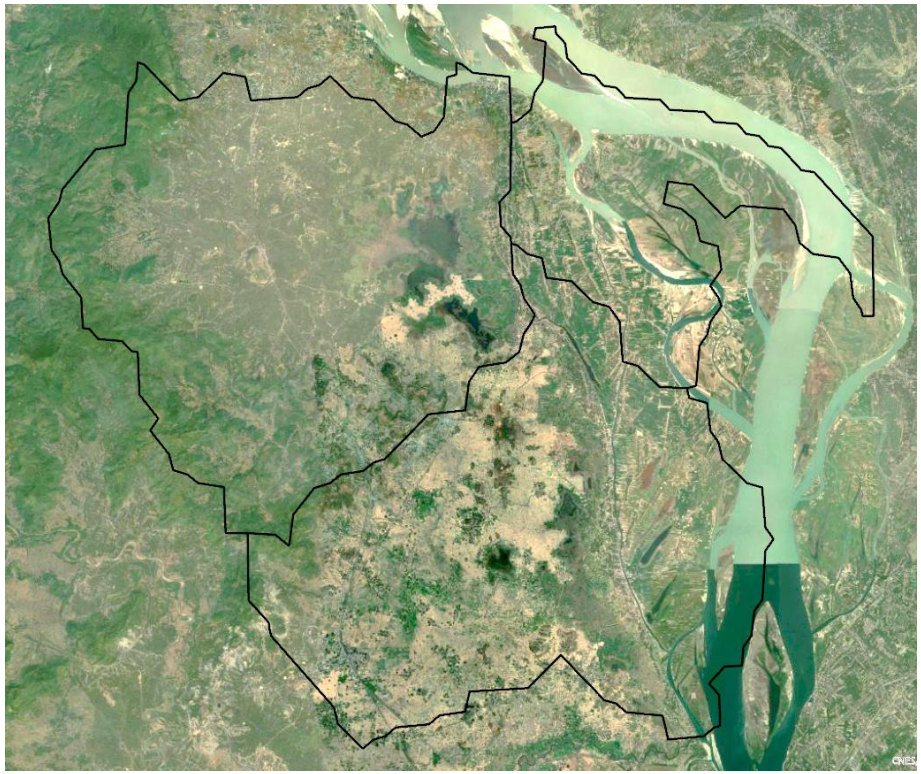

Fig. 77: Watershed regions associated with Udhwa Bird Sanctuary marked with black boundaries

Fig. 76: Region of Interest – Udhwa Bird Sanctuary

Latitude (N)	24°30’43”
Longitude (E)	87°38’3”
Area (Km^2)	5.65
Mean depth (m)	
Catchment area (km^2)	
Rainfall (mm)	

Table 57: Geospatial details – Nalkari Dam

2.10.2. Threats

Agriculture and illegal settlements; Illegal fishing and poaching; Tree felling in surrounding areas; Use of fertilizers and pesticides. Catching of birds and illegal fishing are the biggest challenges for the Forest Department ever since it was declared as a bird sanctuary under the Indian Wildlife (Protection) Act. There is decline in migratory birds, experts said. According to birdwatchers, the flocks have reduced to hundreds in the last few years. The surrounding hillocks suffer a severe threat due to heavy influx of suspected illegal Bangladeshi migrants who have settled beside the lake and have added to the demand on the surrounding natural resources.

2.10.3. Values

- ✓ **Direct use value**
  - Agriculture:
  - Wetland products: facilitate irrigation and fisheries
  - Recreation (tourism): It's a bird sanctuary.

- ✓ **Indirect-use value**

- ✓ **Non-use value**

2.8.5. Biological Aspects

Results

- ***Water quality:*** Water quality was found "*Good (WQI score=79)".* The water was considered good in this wetland mainly due to low chemical parameter values contributing to lower composite effect on water quality.

Water temperature (°C)	7.0-40.0
pH	7.0-8.3
BOD	
Total Dissolved Solids (mg l-1)	
DO (mg l-1)	4.7-8.0
Nitrate (mg l-1)	0.07
Phosphate (mg l-1)	0-0.03
Organic carbon(%)	
Gross Primary Production (mg C m2 d-1)	
Net Primary Production (mg C m2 d-1)	

Table 19: Water quality – Udhwa Lake Bird Sanctuaery

The water parameter values are within the permissible limits given by Bureau of Indian standards guideline values for drinking water.

Interpretation

- ***Because of the good water quality (based on WQI score), it meets the expectation and is of least concern. This wetland is able to support a high diversity of aquatic life.***

Due to good water quality, wetland has high primary productivity. The lake is infested with aquatic macrophytes comprising emergent, free floating and submerged forms eg. Eichhornia crassipes, Salvinia cuculata, Marsilea minuta etc. Water hyacinth was found to be the dominant form. Over all 50% of the lake surface was covered with aquatic weeds.
Not much work has been done on fauna of this Sanctuary, but Choudhary et al. (1992) have identified 83 species of birds, including many forest species. It includes migratory as well as indigenous birds.
Udhwa lake has about 22 fish species, most of them of commercial value (Choudhary et al. 1992). Some common fishes of the lake are Rohu (Labeo rohita), Catla (Catla catla), Tengra (Mystus cavasius), Bata (L. bata), reba (C. retra), Mirka (Cirrihinus mrigala) etc.

- ***The water is also suitable for drinking (human consumption) domestic, and irrigation*** purposes as water parameters are within the permissible limits given by Bureau of Indian standards guideline values for drinking water.

- ***In addition, the water would also be suitable for all forms of recreation, including those involving direct contact with the water.***

2.10.4. Economic Aspects

Carbon Sequestration

2010	2012	2014	2016	2018
0.710	0.710	0.710	0.710	0.723

Table 58: Carbon sequestration over time, in MegaTonnes

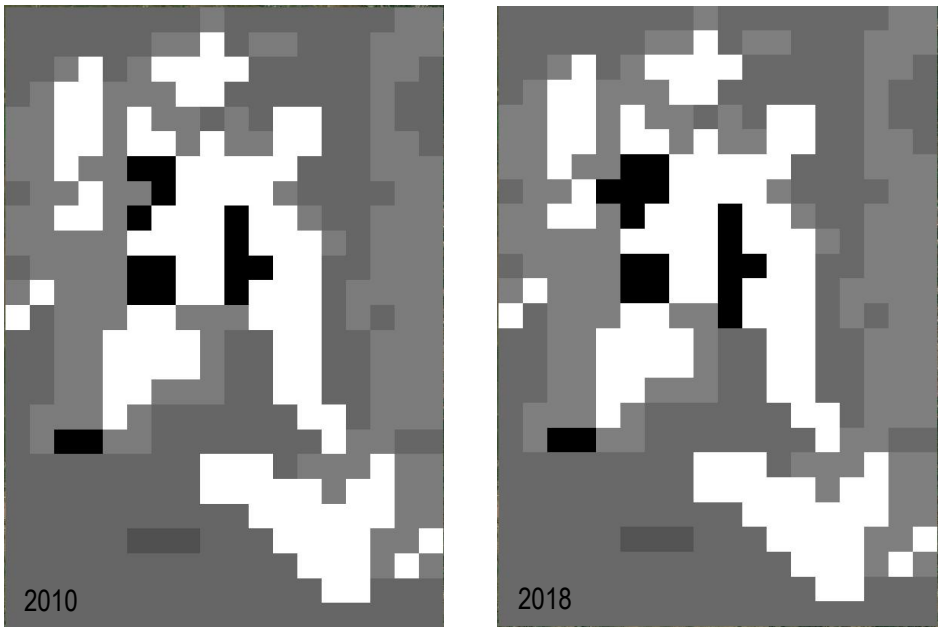

Fig. 78: Carbon sequestration maps, Tonnes of Carbon per pixel (25 ha)

Table 58 takes into account soil carbon, but the carbon maps only account for carbon above ground, considering edge effects.

Flood Risk Mitigation

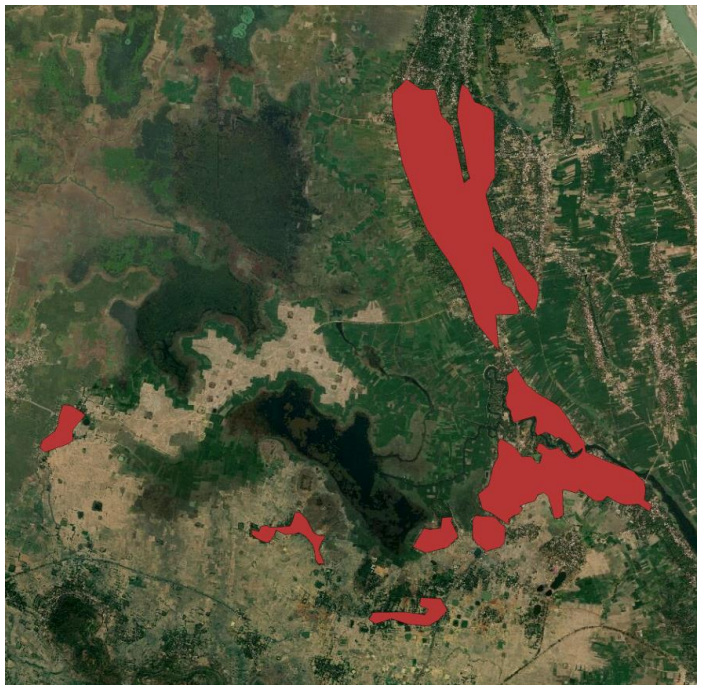

Fig. 79: Human settlements and built up area (marked in red) around the reservoir

For a design storm with depth of rainfall 80mm spread over two days, modelling the Phailin Cyclone of 2013, it was found that the economic losses due to flooding came to nearly **5.19 million**

Water Yield

2010	2012	2014	2016	2018
71.2	99.7	162.9	183.7	162.8

Table 59: Combined water yield in associated watersheds (billion litres)

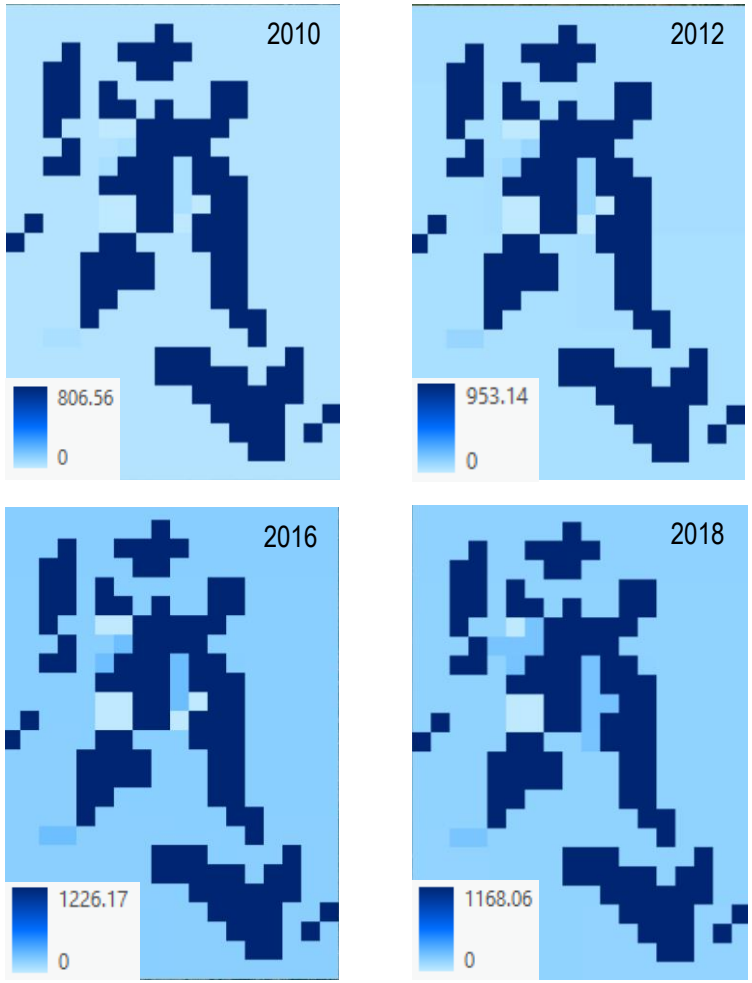

Fig. 80: Annual Water Yield Maps

Soil Sedimentation/Erosion

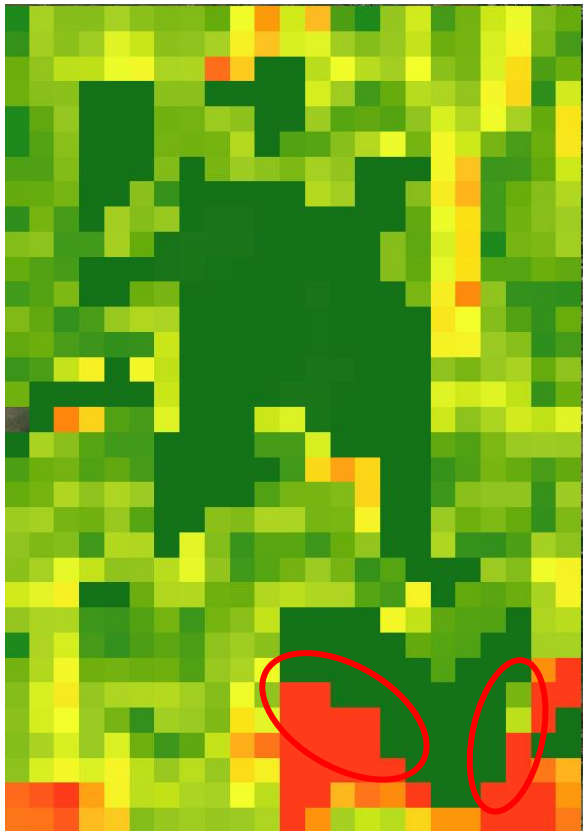

Fig. 81: Predicted soil erosion vulnerability maps. The red circles mark areas recommended for embankment to reduce soil erosion and loss of soil as a resource.

Regression Analysis

There is a weak positive correlation between the carbon stock and the area of the lake which signifies that the lake is an important sequestration zone for Carbon. There is a negative correlation between recreational index and Carbon storage and similarly between recreational quality and lake area which signifies that as human visitation to the lake has increased, it has been detrimental to the area of the lake and Carbon storage as well. The Water Yield is positively correlated with Carbon sequestration that doubly signifies the importance of carbon sequestration in the lake.

x	Carbon	Water Yield	Recreation
Carbon	x	0.31	0.13
Water Yield	0.31	X	0.53
Recreation	0.13	0.53	X

Table 60: Correlation coefficient between the different ecosystem services.

Current Valuations

a) Water Storage: The amount of water stored in the reservoir approx. = 6 million m^3
Taking the annual price of water storage as 1 USD = 74 INR/m^3
The annual value of water stored in the reservoir = **444 million INR**

b) Carbon Sequestration: The amount of Carbon sequestered in the wetland approx. = 0.723 MT
The social cost of Carbon in India is 86 USD = 6400 INR/T*
The value of Carbon sequestered in the wetland = **4.63 billion INR**

c) Science and Education: Project estimate of Strategy 1.4 (by inflation, 2020) approx. 13.7 billion INR **
The total area of wetlands in India = 153000 km^2

* https://www.downtoearth.org.in/dte-infographics/social_cost_corbon/index.html#:~:text=India's%20country%2Dlevel%20social%20cost,per%20tonne%20of%20CO2%20emission.

** http://nwm.gov.in/?q=strategy-14

Approx. investment in science and education of wetlands = 90,000 INR/km^2
The area of concerned wetland = 5.65 km^2
Value of scientific investment in reservoir = **510 thousand INR**

d) Sediment Retention: The total amount of soil retained in watersheds (by InVEST) = 22,400 T
The average concentration of N and P in soil = 0.027%
The average quantity of retained nutrients = 6.05 T
The price of NPK approx. = 20,000 INR/ T
The value of sediment retention = **121 thousand INR**

e) Crop Production: Major annual crop production = Wheat (687 T), Maize (696 T), Paddy (939 T)
Min. Support Price = Wheat (19250 INR/T), Maize (18500 INR/T), Paddy (18680 INR/T)
Approx. major crop value: 13,224,750 + 12,876,000 + 17,540,520 = **43.64 million INR**

Recreational Index

2010	2012	2014	2016	2018
1	2	1	3	2

Table 61: Annual no. of distinct photo user days – Udhwa Bird Sanctuary

The lake is highly impacted by human settlements in terms of scenic quality. The south eastern shore of the lake still retains scenic quality due to low build-up index. The wetland has high cultural and social value. The reservoir is highly developed for tourist activity with boating and nature walks set up. The annual no. of distinct photo user days, an output of the InVEST model is taken as the proxy for level of human activities near the lake

Interpretations and Recommendations

- The carbon sequestration increased from 2010 – 2020 but there was an overall decrease from 2000 to 2020. This is mainly because of the shrinkage in the size of the lake. ***It is advised to reduce human activity near the lake and to stop reclamation practices around the lake to reduce the negative impact and increase carbon storage value.***

Scenic Quality

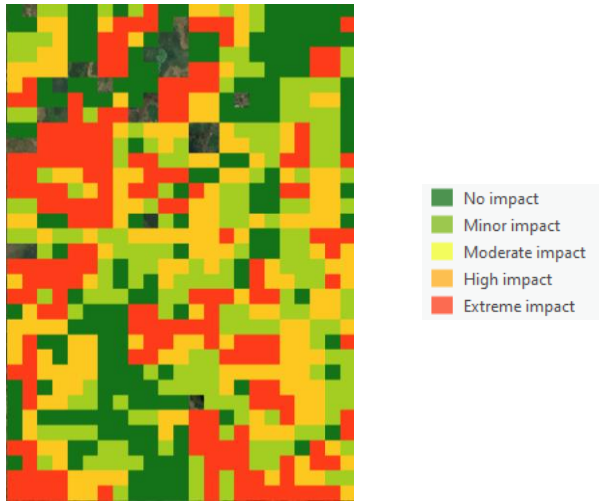

Fig. 82: Udhwa Bird Sanctuary

- There is high probability of soil erosion on the southern edges of the lake. Soil erosion reduces the capacity of water storage of the lake, which is undesirable. ***Mitigation factors such as reforestation on those parts and building artificial banks can help reduce that.*** Soil is also an important non-renewable resource and it should be conserved at all costs.

- The scenic quality of the lake is highly impacted by man-made structures on the western and coasts of the lake. ***Corrective steps need to be taken to raze these structures and reforest these parts with indigenous plant species.***

- Reduction in size of the lake negatively impacts scenic quality as well. Adequate steps should be taken in this direction. There is a trade-off between recreational quality and carbon sequestration. Recreation and human activities negatively impact the valuation of the lake. ***Adequate balanced steps need to be taken to develop responsible modes of tourism which do not harm the lake's fragile ecosystem.***

Appendix I: Data used for wetland monitoring

We used Landsat satellite data from 2000 to 2020 data in order to study the changes. This data was used to calculate different indices (NDVI, NDWI, NDBI) and area (sq. km) and perimeter (km) of the wetland. The satellite data was archived from https//earthexplorer.usgs.gov website. All the analysis and data processing were done using ArcGIS and QGIS software.

Appendix 2: Data used for InVEST modelling

Data	Source	Resolution	Link
Land Use Land Cover	European Space Agency Copernicus Land Cover Product	300 metres	https://cds.climate.copernicus.eu/cdsapp#!/home
Precipitation	Global Precipitation Climatology Centre, Monitoring 6	1 degree	https://opendata.dwd.de/climate_environment/GPCC/html/gpcc_monitoring_v6_doi_download.html
Hydrological Soil Groups	World HySOGs250m, ORNL DAAC, NASA	250 metres	https://daac.ornl.gov/SOILS/guides/Global_Hydrologic_Soil_Group.html
Ecosystem Rooting Depths	ISLCSP2, ORNL DAAC, NASA	1 degree	https://daac.ornl.gov/ISLSCP_II/guides/ecosystem_roots_1deg.html
Digital Elevation Model	GMTED2010, USGS EROS Archive	7.5 arc-sec	https://www.usgs.gov/centers/eros/science/usgs-eros-archive-digital-elevation-global-multi-resolution-terrain-elevation?qt-science_center_objects=0#qt-science_center_objects
Rainfall Erosivity, Soil Erodibility	GloSEM, EU ESDAC-JRC	25 km	https://esdac.jrc.ec.europa.eu/content/global-soil-erosion
Watersheds	HydroBASINS, HydroSHEDS, World Wildlife Fund	shapefile	https://hydrosheds.org/page/hydrobasins
Reference Evapotranspiration	Global-PET, CGIAR, Consortium for Spatial Information	30 arc-sec	https://cgiarcsi.community/2019/01/24/global-aridity-index-and-potential-evapotranspiration-climate-database-v2/
Points of Interest, Roadways, Airports, Bus Stations, etc	OpenStreetMap data	shapefile	https://download.geofabrik.de/asia/india.html
Plant Available Water Fraction	WISE30sec, ISRIC World Soil Information	30 arc-sec	https://data.isric.org/geonetwork/srv/eng/catalog.search#/metadata/dc7b283a-8f19-45e1-aaed-e9bd515119bc
Cropping Data, Fertilizer Rates	EarthStat 2000	5 arc-min	http://www.earthstat.org/

Appendix 3: InVEST Model Documentations

Model	Documentation Link
Carbon Model	http://releases.naturalcapitalproject.org/invest-userguide/latest/carbonstorage.html
Forest Carbon Edge Model	http://releases.naturalcapitalproject.org/invest-userguide/latest/carbon_edge.html
Annual Water Yield	http://releases.naturalcapitalproject.org/invest-userguide/latest/reservoirhydropowerproduction.html
Scenic Quality	http://releases.naturalcapitalproject.org/invest-userguide/latest/scenic_quality.html
Sediment Delivery Ratio	http://releases.naturalcapitalproject.org/invest-userguide/latest/sdr.html
Recreation	http://releases.naturalcapitalproject.org/invest-userguide/latest/recreation.html
Urban Flood Risk Mitigation	http://releases.naturalcapitalproject.org/invest-userguide/latest/urban_flood_mitigation.html

Applied & Environmental Biotechnology Laboratory,
Birla Institute of Technology and Science Pilani, KK Birla Goa Campus, Goa, India