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Integration of satellite image derived temperature and water depth for assessing fish habitability in dam controlled flood plain wetland

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Abstract

The present study attempted to investigate the changes in temperature conducive to fish habitability during the summer months in a hydrologically modified wetland following damming over a river. Satellite image-driven temperature and depth data calibrated with field data were used to analyse fish habitability and the presence of thermally optimum habitable zones in some fishes such as Labeo Rohita, Cirrhinus mrigala, Tilapia fish, Small shrimp, and Cat fishes. The study was conducted both at the water's surface and at the optimum depth of survival. It is very obvious from the analysis that a larger part of wetland has become an area that destroyed aquatic habitat during the post-dam period and existing wetlands have suffered significant shallowing of water depth. This has resulted in a shrinking of the thermally optimum area of fish survival in relation to surface water temperature (from 100.09 km² to 74.24 km² before the dam to 93.97 km² to 0 km² after the dam) and an improvement in the optimum habitable condition in the comfortable depth niche of survival. In the post-dam period, it increased from 75.49 % to 99.765%. Since the damming effect causes a 30.53 to 100% depletion of the optimum depth niche, improving the thermal environment has no effect on fish habitability. More water must be released from dams for restoration. Image-driven depth and temperature data calibrated with field information has been successfully applied in data sparse conditions, and it is further recommended in future work.

Keywords

Wetland; damming effect; Fish habitat; Depth niche; Thermal gradient; Consistency of thermally conducive habitat

1. Introduction

Water temperature is regarded as an important indicator of its physical habitability (Zhang et al. 2020; Gleeson et al. 2020; Quan et al. 2020). It directly and indirectly influences and controls a wide range of aquatic ecological processes (Zhang et al. 2020; Yang et al. 2020). Water temperature, for example, has a strong positive correlation with fish habitability. Higher water temperatures can aid in the rapid formation of algal blooms, which can have an impact on ecosystem functions and water quality (Sin & Lee 2020; Mahdiyan et al. 2021). Low dissolved oxygen in stream water is a result of high water temperature, which affects aquatic species and a variety of biogeochemical processes (Zhi, 2021), such as nitrification, denitrification, and respiration (Yang et al. 2021; Martinez-Espinosa et al. 2020). The relationship between top-down and bottom-up regulation of the food web is affected by water temperature, which affects biogeochemical cycle as well as growth of aquatic organism and abundance (Zimmerman et al. 2020). Changes in thermal conditions in aquatic species cause physiologic or behavioural responses, according to numerous reports (Alfonso et al. 2020; Ferreira et al. 2020; Boukal et al. 2019). Thermal stress, for example, can stifle aquatic organisms' development, affect their immune systems, or set off a chain of metabolic reactions that includes the production of heat shock proteins (Khan & Shahwar 2020; Tiwari et al. 2020). There are numerous rivers, streams, estuaries, backwaters, impoundments, mangroves, flood plain wetlands, man-made reservoirs, dams, tanks, and ponds throughout India. This country also has a diverse fish population with high genetic diversity (2,200 species) and ranks ninth in terms of freshwater mega biodiversity (Sarkar et al. 2008). Seasonal wet and dry spells of rainfall, as well as hot and cold spells of temperature, are very noticeable in this country dominated by a subtropical monsoon climate. During the summer season (March-May), the combination of low rainfall and high temperature frequently creates an unfavourable thermal environment for aquatic species in general, and fish species in particular. Temperature rise is a critical issue that contributes to the escalation of such problems as the thermal state of the aquatic habitat. Simultaneously, decreased water availability, particularly shallowing of water depth, often leads to an increase in thermal penetration, which increases hostility of aquatic species, particularly during the summer season.

In this country, wetlands are the most important natural resources. It provides a variety of socioeconomically important provisioning, regulating, habitat, and cultural services (Aulia et al. 2020). Among all the services provided by wetlands, the fishing industry is one of the most important sectors in the world for providing nutritious food and promoting livelihood (Aazami & Shanazi 2020). This industry is especially important for developing countries like India and Bangladesh, particularly for their rural populations (Uddin et al. 2021). Fish demand in India's domestic market is expected to reach about 16 million tonnes (MT) by 2025, up from 10.07 MT currently, with 65 percent coming from inland wetlands and 35 percent from marine fisheries (DAHDF, 2015). Inland open water fisheries account for approximately 21% of total inland fisheries production (1.3 MT) (FAO, 2016). Wetlands and fisheries are extremely important in countries such as India, where people depend heavily on primary activities such as agriculture, livestock farming, and fishing. However, because of the deterioration of wetlands around the world, inland fishing industries have been facing threats in recent decades. The productivity of a water body is well known to be influenced by its ecological conditions. Via continuous monitoring of water quality, productivity can be improved in order to achieve maximum sustainable fish yield while maintaining environmental and social stability. Temperature, hardness, pH, dissolved gases (O₂ and CO₂), salinity, and other water quality parameters must be controlled on a regular basis, either individually or in concert, in order to maintain a fish-friendly aquatic habitat (Souder & Giannico 2020). Water quality parameters have a major impact on the fish assemblages in lakes and reservoirs (Jiang et al. 2020). Water quality parameters have a major effect on lake and river fish assemblages (Jiang et al. 2020). However, over the last two decades, India's floodplain wetlands have suffered the most from environmental destruction (Sarkar et al. 2021). A huge number of people in India depend on fishing for a living, and the current crisis has disproportionately affected them. Anthropogenic environmental destruction, including urbanisation, dam construction, and water drainage for agriculture and power generation, as well as pollution, all contribute to this stress (Newton et al. 2020). Hydrological alteration of wetlands by damming is one of the main causes of the degraded state of wetlands and fisheries.

Several studies have shown the damming effect decreased downstream river flow by a large amount in different cases (Michie et al. 2020; Almeida et al. 2020; Ko et al. 2020). Unscientific usage of wetlands, massive amounts of water used for irrigation, and excessive water use for

domestic and industrial uses have all contributed to a substantial reduction of water supply and depth. [Gain and Giupponi \(2014\)](#) discovered a 52 percent reduction in flow due to the construction of the Farraka Barrage over the Ganges river; [Uday Kumar and Jayakumar \(2020\)](#) discovered a 30 percent reduction in flow in the Krishna river; [Talukdar and Pal \(2017\)](#) discovered a 41 percent reduction in flow rate in the Punarbhaba river due to damming. In the wetlands of India's Barind tract, there has been a strong reduction in water supply and an increasing eco-flow deficit as reported by [Saha and Pal \(2019\)](#) and [Pal and Sarda \(2020\)](#). These circumstances are inextricably linked to the wetland's ecology. Quality fishing grounds and fish production are inextricably related to hydrological changes. Some environmental factors are essential for the survival of fish. Each component has a survival gradient, which allows fish to survive and develop at various rates. As per [Ouma \(2020\)](#) depth is a hydro-ecological aspect whose variation is linked to the fish habitat's comfortability. Each fish has a preferred depth niche ([Rosinski et al. 2020](#)). It's largely due to food supply and environmental suitability ([Funk et al. 2020](#); [Hvas et al. 2021](#); [Abdul Azeez et al. 2021](#)). [Hosen et al \(2019\)](#) have determined the optimal depth of survival for certain fish species in the Indo-Bangladesh flood plain environment. [Hosen et al \(2019\)](#) found that 1 to 2 m for Tilapia fish, 1 to 3 m for Shrimp fish, more than 2.14 m for cat fish and 1.2 and 2.8 m for carp fishes (*Labeo Rohita*, *Gibelion Catla*, *Cirrhinus Mrigala*) are optimum depth of survival. Hydrological change is a direct cause of changing water depth and availability of water in wetlands, which is linked to fish habitat quality and storage. Since many people rely on fishing for a living, reducing fish storage in wetlands puts their livelihood in jeopardy. As a consequence, this is a critical matter that needs to be looked into. In the flood plains of India and Bangladesh, reduced river and riparian wetland flows have a significant effect on suitable fish habitat. Damming has the potential to reduce wetland depth as well as impact fish availability and total tonnage. Hydro-duration mapping over a larger stretch of wetland with the aid of physical field investigation is extremely difficult due to data scarcity. Simultaneously, a variety of studies have been undertaken to look at the threats to fish habitat and diversity ([Stoeckl et al. 2020](#); [Jahan et al., 2020](#); [Liu et al. 2020](#); [Giacomazzo et al. 2020](#)). A number of studies ([Ouellet et al. 2020](#); [Strm et al. 2020](#); [Budnik et al.2021](#)) have been linked to the thermal habitat state of stream or wetlands ecosystems.

Along with the phenomenon, the agricultural intensity has gradually increased in developing countries such as India and Bangladesh to meet the increasing demand for food crops. In India,

dam-induced hydrological alteration has modified the wetland scenario, in addition to wetland conversion due to agricultural expansion. Hydrological alteration has a huge effect on wetland hydrology in this area because the wetlands are primarily dependent on rainfall and river water for their water resources. The existing research region is subjected to a sub-humid monsoon climate with seasonal rainfall and a wide range of temperatures. The monsoon season (June to September) receives nearly 80% of total annual rainfall (1450 mm), while the summer season (March to May) has a very high evaporation rate due to high temperatures ($>35^{\circ}\text{C}$) and other positive conditions. At this time, a larger portion of the wetland naturally becomes dry or the water level goes extremely shallow. Such incidents in this area have been exacerbated by the damming impact (Pal et al. 2020). No such study has yet been conducted regarding the change of thermal condition of aquatic environment linking the effect of damming on it. But it is very vital for monitoring the good habitat state of the economically fished fishes. The present study, therefore, has tried to analyze the changing nature of the thermal gradient of fish habitability in consequence of damming.

2. Materials and methodology

2.1 Study area

Tangon is a major Mahananda tributary that flows through the Barind tract. The Tangon rises in the highlands of Bangladesh's northern piedmont and flows 267 km., passing through Bangladesh (125 km.) and India (142 km.). The basin is defined by latitudes of $26^{\circ}19'56''\text{N}$ to $24^{\circ}57'22''\text{N}$ and longitudes of $88^{\circ}29'29''\text{E}$ to $88^{\circ}14'14''\text{E}$, covering a region of 2388.88 km^2 . Bangladesh occupies 1234.68 km^2 , while India occupies 1154.20 km^2 . The climate in the area is monsoon, with significant seasonal variation in rainfall and temperature. The average annual rainfall is about 1450 mm. During the monsoon season, about 80% of this rain falls (June to September). The post-monsoon season (October-November) is marked by a retreating monsoon with little rain, while the pre-monsoon season (March-May) is marked by a lack of rain with high temperature and evapotranspiration. This tract has a population density of 1000 people per square kilometre, with more than 70% of the population employed in agriculture and fishing. A major dam across the Tangon River in Bangladesh was built in 1989 primarily to help irrigation, but it has resulted in hydro-ecological issues such as flow reduction, changes in flow variability, flood state, water scarcity for irrigation, water scarcity in riparian wetlands, and

reduced fish abundance in the dam downstream river segments and riparian corridor. Some villages in the river's downstream catchment, such as Chhatiangachi, Dubapara, Shivganj, Aiho, and Laxmipur, are heavily reliant on fishing, both directly and indirectly. Hydrological change, on the other hand, has forced a large number of people to change careers.

Figure 1 Study area showing location of Tangon river basin and wetland dominated lower part of the basin

2.2 Materials

Landsat images from the USGS Earth Explorer are the most useful source for time series analysis of land composition and tracking its dynamic change (Nguyen et al. 2018). Satellite images are also critical for calculating land surface temperature, as well as measuring land composition and monitoring its dynamic change (Balew & Korme 2020). Landsat imageries from various sensors are commonly used for wetland monitoring and measuring the surface temperature of wetlands. From 1988 to 2020, images driven by the Thematic Mapper (TM), Enhanced Thematic Mapper (ETM), and Operational Land Imager (OLI) with a resolution of 30 m were considered for study. The satellite images are as follows: 1988 (4 March), 1989 (23 March), 1990 (10 March), 1991 (13 March), 1993 (18 March), 1994 (21 March), 1996 (10

March), 1997 (30 April), 1998 (1 April), 1999 (4 April), 2000 (21 March), 2011 (20 March), 2017 (20 March), 2018 (24 April), 2020 (28 March).

2.3 Methods

2.3.1 Methods for wetland delineation and accuracy assessment

There are a variety of water indices available for mapping and tracking wetland transition, including the Normalized Difference Water Index (NDWI), Modified Normalized Difference Water Index (MNDWI), and Re-Modified Normalized Difference Water Index (RMNDWI). For each field, different indices were discovered to be suitable. Das and Pal (2018) propose the Normalized Difference Water Index (NDWI) for the Barind zone of India and Bangladesh. The Mcfeeters (1996) was the first to support the NDWI process. Equation 1 is used to calculate it.

$$NDWI = \frac{b_{green} - b_{NIR}}{b_{green} + b_{NIR}} \quad (\text{Eq. 1})$$

where,

The green band is indicated by the term bgreen (Band 2 for TM and Band 3 for OLI)

The near infrared band is denoted by the abbreviation bNIR (Band 4 for TM and Band 5 for OLI)

From -1 to 1, the NDWI value arrays. Water pixels have a positive value, whereas non-water pixels have a negative value (Chen et al. 2020). A higher positive value means that the water is thicker (Yue et al. 2020).

NDWI images have been validated using 105 to 231 reference sites gathered from Google earth images of the relevant years. For those years, the Kappa coefficient (K) has been calculated using equation 2.

$$K = \frac{N \sum_{i=1}^r X_{ii} - \sum_{i=1}^r (x_i + *x_i + i)}{N^2 - \sum_{i=1}^r (x_i + *x_i + i)} \quad (\text{Eq. 2})$$

Where, N denotes the total number of pixels, r denotes the number of rows in the matrix, X_{ii} denotes the number of observations in row i and ii , x_{i+} and x_{+i} denotes the marginal sums for row i and column i respectively.

2.3.2 Methods for wetland water temperature extraction and validation

Method for Emissivity and Fractional Vegetation Cover (FVC)

Emissivity and Fractional Vegetation Cover are calculated using this method (FVC). Each of the earth's materials is made up of molecules with atoms bound together within by molecular bonds. The atoms at the end of a bond vibrate when the infrared spectrum reaches the molecule. In other words, the molecule reemits light of the same wavelength. Every molecule has its own vibration frequency, and the composition of a natural surface that emits infrared light is determined by the surface composition. Soil chemistry, soil structure, soil composition, organic matter, moisture content, and vegetation cover characteristics all influence the emissivity of the land surface (Bindajam et al. 2020). NDVI values are used to estimate land surface emissivity using various methods. In this section, the NDVI thresholding process- NDVITHM has been used, which was first proposed by Sobrino and Raissouni (2000). In different instances, the approach introduced for extracting emissivity values from the NDVI. For example, the pixels are supposed to be bare soil when the NDVI is lower than 0.2, and emissivity in the red field is measured with reflectivity values. (ii) the pixels are called completely vegetated with NDVIs of more than 0.5, with emissive values assumed to be consistent, typically at 0.99. (iii) the pixel value for NDVI is assumed to be greater than 0.5; the pixel consists of the mixture of bare soil with plants, with the emissivity being calculated using the equation (3):

$$\varepsilon = \varepsilon_v P_v + \varepsilon_s (1 - P_v) + d\varepsilon \quad (\text{Eq. 3})$$

Where ε_v is the emissiveness of vegetation and ε_s is the emissivity of soil, P_v is the proportion of vegetation measured with Carlson & Ripley's (1997) (Eq. 8).

Equation 4 presents the final phrase for LSE. The emissivity of the land surface (ε) is between 0.97 and 0.99.

$$\text{Land surface emissivity } (\varepsilon) = 0.004 * P_v + 0.986 \quad (\text{Eq. 4})$$

FVC is a quantitative measurement of vegetation coverage status which compares vertically projected vegetation area with total land area (Liu et al. 2021). FVC is used as a critical indicator for many applications in the atmosphere and climate modelling, such as hydrological models, earth surface model, soil erosion and weather models (Wong et al. 2019). FVC is derived mainly from remotely sensed information (Gao et al. 2020; Yan et al. 2019). This is usually between 0 and 1; 1 indicates increased density and integrity of vegetation and 0 or nearly 0 indicates the bare ground.

Extraction of LST from a Thermal band of Landsat Image

As the temperature of an object increases beyond absolute zero, it emits electromagnetic thermal energy (K). This theory is used to calculate the LST of a wetland. A core of LST derivation consists of conversion to Spectral Radiance (L) of the digital number (DN) and conversion of Spectral Radiance (L) to At-satellite brightness Temperatures (TB), Land Surface Temperature (LST), and conversion of LST from Kelvin to degree Celsius. This is well illustrated by the Landsat Project Science Office (2002). Many papers have gone through this phase in great depth (Zhang et al. 2018; Dutta et al. 2018; Isioye et al. 2020; Pal et al. 2020) (For more detailed steps of LST derivation, see supplementary section).

LST Validation Methodology

Water temperature at surface and deeper part of the wetland has been monitored at 58 sites in 2019 and 2020 using piper aquarium digital water temperature thermometer. Root mean square error (RMSE) has been computed based on image driven temperature and observed aquatic temperature of the measuring sites. The RMSE is measured using the formula of Kuang et al. (2014).

$$RMSE = \sqrt{\frac{\sum_{i=1}^N (Q - Obs)^2}{N}} \quad (\text{Eq. 5})$$

Where, Q is the value retrieved from remote sensing data, Obs is the value retrieved from ground observations, and N is the number of samples (here 58). The $RMSE < 1$ is considered accepted (Duan et al. 2019).

2.3.3 Satellite image based wetland depth mapping and validation

NDWI has a good interaction with water depth, according to many studies (Chai et al. 2020; Pal & Sarda 2020). In order to acquire depth data at each pixel, water depth data from 58 sampling locations in 2019-20 was used to calibrate NDWI images. To extract the calibration equation, a regression between field water depth data and image derived water indices was performed. As a result, a coefficient has been achieved from the equation, which has been used to calibrate the images. For depth calibration, average NDWI images from both before and after the dam were used.

$$Y = 0.475 + 8.953x \quad (\text{Eq. 6})$$

2.3.4 Calibration of temperature at optimum depth of fish habitability

Water surface temperature has been measured from satellite image derived LST. To measure the temperature data at optimum depth, water temperature of that depth has been measured at 58 sites using piper aquarium digital water temperature thermometer. The temperature gap between surface and at the optimum depth has been computed. It has been regressed with the NDWI values of the respective coordinates. Applying the coefficient on NDWI image, temperature at the optimum depth has been calibrated in order to obtain the temperature surface at a specific depth.

2.3.5 Identifying thermal gradient of fish habitability (based on surface water temperature and temperature at comfortable water depth)

We estimated the LST of the wetlands using the above-mentioned LST measurement procedure (Equations 3–11), and then calibrated the temperature at the optimal depth of fish habitability to assess the thermal gradient of fish habitability. Hosen et al. (2019) assessed the optimum depth of survival for certain fish species and found that 1 to 2 m for Tilapia fish, 1 to 3 m for Shrimp fish, more than 2.14 m for cat fish, and a depth of water between 1.2 and 2.8 m for carp fishes are the optimal temperatures for fish habitability (Labeo Rohita, Gibelion Catla, Cirrhinus Mrigala). Using Equation 7, we divided the surface temperature of the pre-dam and post-dam periods into three zones: stress (below), optimum, and stress (above) in terms of thermal habitat comfortability. The temperature status of the safe habitable depths of the respective fishes is often monitored in the same way.

$$TG = \frac{\sum (X_1 + X_2 + X_3 + \dots + X_n)}{N} \quad (\text{Eq. 7})$$

Where TG stands for thermal gradient, X signifies the temperature of individual year, and N for the number of years taken for consideration.

2.3.6 Identifying consistent fish habitat zone (based on surface water temperature and temperature at comfortable water depth)

To compute the consistency of thermally comfortable fish habitat regions, annual temperature images were converted into binary images that described 0 as non-comfortable and 1 as the optimum thermal zone, and added them separately for pre and post-dam periods (Equation 8). The optimal temperature presence frequency (OTPFp) varies from 0 to 100%. 0 indicates the absence of optimal temperature conditions in the considered years, while 100 percent indicates the existence of optimal temperature conditions in all years.

$$OTPF_p = \frac{\sum_{n=1}^i X_j}{N} \quad (\text{Eq. 8})$$

where OTPFp is the frequency of optimum temperature presence for a pixel, Xj is the frequency of the jth pixel having optimum temperature presence in the used images, and N is the number of years taken.

OTPF maps for respective fishes have been created independently, taking into account both surface water temperature and temperature at a safe water depth.

3. Results

3.1 Modeling of wetland surface water area and depth during pre and post-dam periods with validation

Pre-dam and post-dam depth maps have been created to show the wetland distribution and depth state in the lower Tangon river basin. The total identified wetland area in the pre-dam and post-dam phases is 51.756 km² (1988) and 13.658 km² (2020). Geographically, wetland area is primarily concentrated alongside the main river within a 4-kilometer buffer zone, and density is highest near the stream's confluence segment. There is a substantial difference in average wetland area between the pre-dam and post-dam periods. In the wetland fringe region, this

transformation rate is much higher than core area. Some core wetland area has also been fragmented disrupting the wetland's continuity (Fig. 2). Along with shrinkage of wetland area, depth of wetland has also been reduced significantly in post-dam period (Fig. 2). There was a 23.648 km² (45.692 percent) area in the pre-dam phase where the water depth was >3.255 m, but no wetland area was found in this depth range in the post-dam period. During the post-dam phase, the entire wetland area was converted to a low water depth category (less than 1.57 m.) (Table1). The computed Kappa coefficient of the post-dam wetland map (2020) is 0.87, indicating that the ground reality and image-driven wetland area are in with excellent agreement.

Table 1 Area of wetland under different water depth zones in pre and post-dam periods

Pre-Dam			Post-Dam		
Depth (m)	Area (km ²)	Area (%)	Depth (m.)	Area (km ²)	Area (%)
0.188 - 1.777	13.5819	26.242	0.085 - 0.504	6.4629	47.3181339
1.777 - 3.255	14.526	28.066	0.504 - 0.981	4.7943	35.101476
3.255 - 4.844	23.6484	45.692	0.981 - 1.568	2.4012	17.5803901
Total	51.7563			13.6584

Figure 2 Wetland area and depth of water in pre and post-dam periods

3.2 Water surface temperature characteristics in wetland and validation

Water surface temperature fluctuates in nature over time, according to calculations. When comparing pre-dam and post-dam temperatures, it was found that the later phase's temperature was 30.33°C, which was higher than the former. The average, maximum, and minimum temperatures during the pre-dam period were 26.79°C, 39.84°C, and 20.66°C, respectively, and 30.33°C, 44.72°C, and 21.98°C during the post-dam period. This change may be the result of a shifting water landscape in the wetland, particularly shallowing in the wetland's broader areas, rather than just an increase in sunlight intensity.

3.3 Change in thermal gradient of fish habitability

3.3.1 Thermal gradient of fish habitability based on surface water temperature

Figure 3 depicts a thermal habitat status map of the water surface for the chosen fishes (Labeo Rohita, Cirrihinus Mrigala, tilapia, tiny shrimp, and catfishes) both before and after the dam. Every species' thermal gradient has been divided into three categories: optimum, stress (below), and stress (above). The ideal wetland region is described as those areas where the water temperature is suitable and habitable for fish. The stress (below) and stress (above) regions are described by water temperatures that are below and above the optimum range of survival. Pal et al. (2019) and Talukdar and Pal (2017) reported that below-optimal stress is more vulnerable to ecosystems than above-optimal stress. As the temperature of the water during the post-dam period is higher, the area must be measured for each fish at an optimal surface temperature. The areas under optimum surface temperature for Labeo Rohita, Cirrihinus Mrigala, tilapia, small shrimp and catfish were 94, 312%, 97, 511%, 94,312% and 94 416%, respectively during pre-dam periods (Table 2), which was 25% less in post-dam periods. However, for Cirrihinus Mrigala fish, the ideal area remains approximately 94 percent of the entire wetland area in the post-dam phase (Table 2), although for Tilapia fish the surface water temperature does not provide optimal habitat conditions (Table 2). It means that the whole wetland region has been turned into a Tilapia fish stress zone.

Figure 3 Wetland areas under different thermal gradients of habitability of some selected fishes in reference to water surface temperature both during pre and post-dam periods

Table 2 Area under different thermal comfortability zones (based on surface water temperature) of the selected fishes during pre and post-dam periods

Name of the Fishes	Zones	Pre-Dam		Post-Dam	
		Area in km ²	Area in %	Area in km ²	Area in %
Labeo Rohita	Stress (below)	0.106	0.103	0.000	0.000
	Optimum	96.805	94.312	3.671	24.507
	Stress (above)	5.732	5.584	11.309	75.493
Cirrhinus mrigala	Stress (below)	0.000	0.000	0.000	0.000
	Optimum	100.088	97.511	14.076	93.968
	Stress (above)	2.555	2.489	0.904	6.032
Tilapia fish	Stress (below)	0.106	0.103	0.000	0.000
	Optimum	74.239	72.327	0.000	0.000
	Stress (above)	28.298	27.569	14.980	100.000
Small shrimp	Stress (below)	0.106	0.103	0.000	0.000
	Optimum	96.805	94.312	3.671	24.507

	Stress (above)	5.732	5.584	11.309	75.493
Cat fishes	Stress (below)	0.000	0.000	0.000	0.000
	Optimum	96.911	94.416	3.671	24.507
	Stress (above)	5.732	5.584	11.309	75.493

3.3.2 Thermal gradient of fish habitability based on water temperature at comfortable depth

Like thermal gradient of surface water temperature in reference to fish habitability, the same analysis has been done considering the temperature of the comfortable depth of survival for the selected fishes. The overall area under the optimum range of thermal comfortability has decreased significantly in both the pre-dam and post-dam periods. The area under optimum temperature in their respective comfortable depth zones for Labeo Rohita, Cirrihinus Mrigala, tilapia, small shrimp, and catfishes was found to be within 1 to 14% of the total wetland area of the pre-dam period. More than 85% of the area was in a stress zone below the optimal temperature level for survival. However, in post-dam period, all parts of the wetland have become thermally comfortable for fish survival. Although the area with comfortable depth has become less convenient, there is no good effect in enhancing thermal convenience.

Figure 4 Wetland areas under different thermal gradients of habitability of some selected fishes in reference to temperature at optimum depth zone both during pre and post-dam periods

Table 3 Area under different thermal comfortability zones (based on water temperature at optimum depth zone) of the selected fishes during pre and post-dam periods

Name of the Fishes	Zones	Pre-Dam		Post-Dam	
		Area in km ²	Area in %	Area in km ²	Area in %
Labeo Rohita	Stress (below)	12.632	94.107	0.000	0.000
	Optimum	0.791	5.893	1.270	100.000
	Stress (above)	0.000	0.000	0.000	0.000
Cirrhinus mrigala	Stress (below)	11.612	86.399	0.000	0.000
	Optimum	1.828	13.601	1.270	100.000
	Stress (above)	0.000	0.000	0.000	0.000
Tilapia fish	Stress (below)	7.519	91.241	0.000	0.000
	Optimum	0.626	7.591	2.297	99.765
	Stress (above)	0.096	1.169	0.005	0.235
Small shrimp	Stress (below)	16.725	94.249	0.000	0.000

Cat fishes	Optimum	1.021	5.751	2.302	100.000
	Stress (above)	0.000	0.000	0.000	0.000
	Stress (below)	31.901	98.120	0.000	0.000
	Optimum	0.611	1.880	0.000	0.000
	Stress (above)	0.000	0.000	0.000	0.000

3.4 Consistency in fish habitable zone

3.4.1 Consistency in fish habitable zone based on surface water temperature

Figure 5 depicts the consistency of optimum temperature appearance in different years in pre and post-dam periods. In every year, since the thermal optimum zone is not found in same geographical position, it is very vital to recognize the areas which consistently found thermally optimum. Such region would be very reliable for good fish habitat. In this context, OTPF map for each fish has been classified into three consistency gradients like high (>67%), moderate (33-67%) and low (<33%) consistency. High consistency means the areas have experienced OTPF >67% years to total chosen period of time.

According to the findings, the areas under high consistent zone in terms of fish habitability for the Labeo Rohita, Cirrihinus Mrigala, tilapia, small shrimp, and cat fishes, respectively were 21.879 km² (21.84%), 69.742 km²(69.49%), 0.002 km²(0.003%), 21.875 km²(21.84%), and 64.808 km²(64.58%) in the pre-dam period (Table 4). In post-dam period, major parts of the high frequency optimum thermal condition has shifted to moderate and low OTPF zones signifying qualitatively degradation of fish habitat. In case of all the fishes, 73% to 92% area is found under moderate OTPF zones.

Figure 5 OUTF maps of some fishes in pre and post-dam periods signifying consistency gradient of thermal optimality in reference to surface water temperature.

Table 4 Areas under different OUTF gradients for some selected fishes in pre and post-dam periods

Name of the Fishes	Frequency Zones (%)	Pre-Dam		Post-Dam	
		Area in km ²	Area in %	Area in km ²	Area in %
Labeo Rohita	< 33	8.430	8.415	0.208	1.402
	33 - 67	69.875	69.746	13.585	91.579
	> 67	21.879	21.839	1.041	7.020
Cirrhinus mrigala	< 33	3.422	3.409	0.008	0.054
	33 - 67	27.206	27.106	11.275	75.270
	> 67	69.742	69.485	3.696	24.676
Tilapia fish	< 33	58.370	94.527	3.553	24.841
	33 - 67	3.378	5.470	10.440	72.988
	> 67	0.002	0.003	0.311	2.171
Small shrimp	< 33	8.430	8.415	0.208	1.402

	33 - 67	69.875	69.746	13.585	91.579
	> 67	21.879	21.839	1.041	7.020
Cat fishes	< 33	5.549	5.530	0.091	0.607
	33 - 67	30.002	29.894	11.846	79.080
	> 67	64.808	64.576	3.043	20.314

3.4.2 Consistency in fish habitable zone based on water temperature at comfortable depth

OTPF analysis was also performed using the thermal conditions at the optimum depth of the respective fishes' survival zones. Figure 6 depicts the OTPF maps of various fishes for the pre and post-dam periods. The maps clearly show that the proportion of area with optimum depth of survival was less in the pre-dam period and has also been less in the post-dam period. But for *Cirrhinus mrigala*, computed area under various optimum thermal consistency gradients was 4% of total wetland area in pre-dam times for all fishes (57.808 percent). In the post-dam period, this proportion has dropped to a very low level (2.1 percent) (Table 5). This means that there is thermal stress in the fishes.

Figure 6 OTPF maps of some fishes in pre and post-dam periods signifying consistency gradient of thermal optimality in reference to water temperature at optimum depth zone.

Table 5 Areas under different OTPF gradients (based on temperature at optimum depth) for some selected fishes in pre and post-dam periods

Name of the Fishes	Frequency Zones (%)	Pre-Dam		Post-Dam	
		Area in km ²	Area in %	Area in km ²	Area in %
Labeo Rohita	< 33	10.384	77.260	0.000	0.000
	33 - 67	2.522	18.763	1.280	100.000
	> 67	0.535	3.978	0.000	0.000
Cirrhinus mrigala	< 33	5.707	42.192	0.000	0.000
	33 - 67	0.000	0.000	1.271	99.297
	> 67	7.819	57.808	0.009	0.703
Tilapia fish	< 33	6.371	80.115	0.000	0.000
	33 - 67	1.543	19.398	2.260	97.857
	> 67	0.039	0.487	0.050	2.143
Small shrimp	< 33	13.830	77.926	0.094	4.067
	33 - 67	3.257	18.352	2.206	95.855
	> 67	0.661	3.722	0.002	0.078
Cat fishes	< 33	22.166	68.177	0.000	0.000
	33 - 67	9.751	29.990	0.000	0.000
	> 67	0.596	1.833	0.000	0.000

4. Discussion

The results of this work clearly have demonstrated that thermally comfortable habitat stretch is found declining in trend from pre to post-dam periods. Consistency of OTPF has also found degraded in post-dam period. Damming effect has reduced the water supply to the downstream river reaches and cognitive flood plain wetlands. It causes drying out wider part of the wetland and existing wetlands have faced lowering of water depth. Such lowering of water depth has destroyed habitable water depth niche at a larger scale and facilitated sunshine to penetrate greater depth and heated up the water temperature. These have posed adverse condition on aquatic habitability. More than 70% of wetland area has been converted to land, and existing

wetlands have undergone into hydrological inconsistency, diminishing water depth, unpredictable water supply, and rising temperatures and all of these are detrimental to the aquatic environment in general and fish habitat in particular (Whitney et al. 2020; Pandey et al. 2021; Thaman 2021). Wetland loss and hydro-ecological alteration in existing wetland are caused by land use change, agricultural encroachment, built-up extension, fragmentation of wetland, loss of tie channels, and river flow reduction due to damming (Talukdar & Pal 2020; Islam, et al. 2021; Pal & Paul 2020). Wetland is an excellent fishing spot, and a large number of people depend on it for their livelihood (Gosling et al. 2017; Aazami & Shanazi 2020). Fishermen have been forced to change careers due to changes in fishing grounds and reduced fish storage. Prior to the damming, a larger portion of the wetland was not appropriate for carp but was suitable for catfish. However, dam-induced hydrological alteration has harmed the habitat quality of some fish species studied in this research. Most fishes have lost their optimal temperature range and depth of survival due to damming, which has reduced flow. In this basin, the extent and frequency of flooding has decreased, resulting in a lateral disconnection between the wetland and the river (Pal & Talukdar 2018; Pal & Talukdar 2019; Talukdar et al. 2020). It is responsible not only for decreasing water availability, but also for nutrient supply, fish seed supply, and other factors (Pal and Talukdar, 2019). According to the findings, a larger portion of the wetland with lower temperatures has turned into a high-temperature region in terms of both surface and below-water temperatures. It has an effect on the phenology and growth of fish (Pichaud et al. 2020; Castro et al. 2020; Ashaf-Ud-Doulah et al. 2020). Due to the lack of rain in the sub-humid monsoon region, this issue of elevated water temperature and reduced depth is naturally found to be more extreme during the summer season. Strong evaporation from the wetland during this season decreases the amount of water available in the perennial wetland, causing larger wetland parts to dry out as the temperature rises (Debanshi & Pal 2020). Since wetlands rely primarily on rainwater for their water supply, seasonal rainfall disparities result in seasonal changes in water depth and temperature. Because of this, there is less consistency in surface temperature and temperature below water in the pre-dam period, but it has become less consistent as a result of the damming impact on river flow (Pal & Sarda 2021). This indicates that both natural and anthropogenic factors are to be condemned for the poor fishing habitability. We can't alter the natural rainfall pattern or the seasonal temperature intensity, but through increasing flow thermal intensity could be minimized to some extent.

During summer season shallowing water depth in wetland and high temperature create immense problem in fish habitability. Flow curtailing through damming has imparted additional problem in this regard. Since each fish has its own optimum survival condition, analyzing the thermal gradient and the optimum thermal consistent zone has provided a reliable result for their habitat condition. The findings of this study may be useful to the policy makers in this consonance. Rising temperature coupling with damming effect on aquatic lives, particularly fish habitat zone is not studied so far and therefore, this is a new and effective approach for identifying changing extent of fish habitability. Consistency analysis of optimum temperature using OTPF analysis is a novel approach in this regard and really it is very fruitful for analyzing long term assessment of suitable fish habitat. Since there is a wide gap of spatial water temperature data across a wetland, such analysis has not been done so far but this work has alternatively tried to develop spatial temperature data set from satellite images calibrating with field data. The present study has also computed thermocline of the wetlands in order to calibrate the temperature character in the optimum depth of survival for different fishes. The lags of water depth data at spatial level has been replaced with the help of satellite image driven water indices calibrating with field data. All these are very useful and alternative means of data harvesting in the data sparse region and such approach could be applied in such similar environment.

5. Conclusion

The analysis clearly shows that the damming effect has converted larger areas of wetland into land and existing wetland into shallower wetland. As a result of this temperature situation, the thermally habitable area for certain chosen fishes has shrunk in wetland. Because of the reduction in water depth, loss of suitable depth niche for fishes, and temperature rises at both the water surface and suitable depth niche, suitable fish habitat area has been significantly reduced in the post-dam period. According to the study, damming has specifically harmed optimum fish habitat in terms of the consistency of optimum temperature for fish in wetland and water depth. The fish in this study include Labeo Rohita, Cirrihinus Mrigala, tilapia, small shrimp, and catfishes, all of which have been forced to survive in a squeezed habitat niche. While the altered surface water temperature has provided more prospects for Cirrihinus Mrigala fish, the shrinking of the optimal temperate zone at an optimum depth niche is not conducive to fishing survival.

This information could be helpful in the planning process. The use of image-based calibrated depth and temperature for determining suitable fish habitat and consistency of suitable habitat produced positive results. As a result, prospective studies should take a similar approach. Even before the dam, the fish habitat condition for the mentioned species was poor in terms of temperature at a comfortable depth, but hydrological alteration has exacerbated the problem. If this condition is to be resolved, sufficient flow should be released from the dam, and the tie channels linking the river and the wetland should be re-excavated.

Declarations

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