



Image Driven Hydrological Components-based Fish Habitability Modeling in Riparian Wetlands Triggered by Damming

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Abstract

The main focus of the current study is on assessing the habitability of some selected fishes in the Indo-Bangladesh barind tract wetland in pursuance of damming using hydrological components such as hydro-period, water depth, and water presence consistency deriving from satellite images. For pre-dam and post-dam periods, a rule-based decision tree modeling approach was used to integrate the aforementioned hydrological factors to determine habitat suitability for the chosen fishes like carp fishes, shrimps, tilapia, and catfishes. Damming has hastened the pace of wetland hydrological transformation, enhancing water presence inconsistency, shortening hydro-duration, and shallowing water depth. Based on the model, a small part of the wetland was identified as good fish habitat (16.54–39.90%) prior to damming, but virtually all portions have become the least suited for fish after damming habitability. A field survey showed that fishing quantity and growth rate was higher before such hydrological alteration but steadily decreased over the post-dam period. Image-driven hydrological parameters to estimate fish habitability are novel techniques; however, essential elements such as food availability and water quality metrics could be included to improve the result.

Keywords Damming · Hydrological modification · Fishing habitat suitability · Rule based decision tree model and hydrological components

Introduction

Wetland, a natural capital, takes up 6% of the world's land area (Mitsch et al. 2013). It provides a variety of socio-ecologically important provisional, regulating, habitat, and cultural services (Wang et al. 2020). Wetland is a key source of income for developing countries such as India and Bangladesh, where much of the population relies on basic activities such as fishing, agriculture, dairy farming, and livestock ranching. Fishermen communities rely on fish since it is the most demanding provisioning service available in wetlands. However, rapid wetland conversion poses a threat to their livelihoods. Agricultural development in wetland regions

is a danger to wetland change (Saha and Pal 2019). Damming has a critical influence in changing the characteristics of wetland ecosystems (Dudgeon 2000). Water diversions through canals and over lifting of water for various reasons have reduced water depth and open water extent. A reduction in downstream flow causes the hydrological drought in rivers (Wen et al. 2011; de Araújo and Bronstert 2016). Gain and Giupponi (2014) calculated a 52% reduction inflow in the Ganga River because of the construction of the Farakka Barrage, Talukdar and Pal (2018) estimated a 41% reduction inflow in the Punarbhava River, and Uday Kumar and Jayakumar (2020) calculated a 30% reduction inflow in the Krishna River. Reduced flow results in the loss of tie channels for riparian wetlands, causing the water supply to be depleted (Pal and Sarda 2020). In certain wetlands of the Indo-Bangladesh Barind tract, eco-hydrological deficits are severe (Saha and Pal 2019; Talukdar and Pal 2020).

Fish survival requires a specific environmental gradient of various components. Each component has its distinct impact on fish survival, and fish can grow at varying degrees of comfort along this gradient. Water depth is one of the critical hydro-ecological factors that significantly

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impact fish survival (Hosen et al. 2019). A specific depth range is necessary for various fish species for economic growth; since this can control food availability and environmental compatibility (Baras and Lucas 2001; Mouton et al. 2007). Dey, 1997 and Hosen et al. (2019) have estimated some fishes' suitable depth of survival in a riparian flood plain environment. For instance, Hosen et al. (2019) has identified the depth of water between 1.2 and 2.8 m is suitable for carp fishes (*Labeo rohita*, *Gibelion catla*, *Cirrhinus mrigala*), 1 to 2 m for tilapia fish, 1 to 3 m for shrimp fish and over 2.14 m for catfishes. Hydrological alteration concerns a decrease in water depth and availability, affecting fish survival and fish habitat quality. Because of many people who rely on fishing for their livelihood, they become more economically vulnerable to such hydro-ecological changes. Consequently, this has becoming a thought-provoking issue. Therefore, this article aims to evaluate the impact of reduced flow on hydrological components and how changes in these components might affect fish habitat for some specific fish species in the investigated region.

Modeling the modification patterns of hydrological regimes for depth of water, water presence frequency, and hydro-duration in the concerned wetland is crucial for achieving the aims mentioned above. These characteristics are crucial for determining acceptable fish habitats. However, collecting field data from such a large wetland tract is difficult. Few earlier scholars used satellite imageries data to derive consistency of water presence in seasonal wetlands in the Barind tract (Debanishi and Pal 2020a, b; Khatun et al. 2021) reported that suitable water indices could obtain relative water depth from the wetland. Field data-based calibration of the water indices may convert relative water depth into absolute water depth. Irregularity in water flow in the downstream river has increased due to damming, and water depth has declined substantially in this kind of seasonal wetland mainly fed by the river and rainwater (Talukdar and Pal 2020). Besides these factors, hydro-period is an essential hydrological regulator of fish habitat since fish phenology is concerned with this damming which has a detrimental impact on hydro-duration, affecting fish species availability and production. Mapping hydro-period by a field study in such a vast region of the wetland is incredibly difficult. As a result, we used a novel technique to map hydro-period utilizing multi-date image data of each year. Fish habitat suitability may be determined by integrating all three hydrological factors.

Various researchers from across the world have used several techniques to model habitat compatibility. Among the several habitat suitability models, the physical habitat simulation model (Boove 1982) is the most used model for simulating fish habitat by employing water depth and flow velocity as parameters. The primary aim

of this model is to use bi-variate or multi-variate statistics to connect various physical characteristics of flow regimes to water richness. Mouton et al. (2007) used this model in the Belgian Zwalm River. The Habitat Suitability Index, which was developed in the early 1980 s, is another common technique. Such index was derived using various characteristics, such as food availability, natural fish activity, spawning, seasonal behavioral patterns, and flood inundation areas. Another index is derived in Ecuador's Abras de Mantiquilla wetland using HABITAT modeling in the MATLAB toolbox, taking water depth and flow velocity as parameters (Mieles 2019). With Jinsha River Basin, HSI was computed in the higher reaches of the Yangtze River (Zhang et al. 2018).

Besides these, the fuzzy logic-based habitat suitability index is a commonly used method. In the Zwalm River, Belgium (Mouton et al. 2007) used this by taking water depth, flow velocity, and dominating fluid substrate logic. Table 1 depicts the dominant literature on fish habitat exploration and related issues. However, it has been established from multiple pieces of literature that most fish habitat models are carried out on flowing water. Very few researches throughout the world on the measuring of fish habitat adequacy in wetlands have been recorded. The work's novelty stems from the fact that no previous work on wetlands has been done using just image-driven hydrological components, such as hydro-period, water presence frequency (WPF), and water depth. For wide-area mapping, this is very crucial. We performed individual parameter and combined parameter specific habitat suitability analyses in this study. However, using a rule-based decision tree approach incorporating image-driven hydrological parameters over the wider geographical area is extremely uncommon. We chose Punarbhaba River basin as a case since it has been witnessed substantial hydrological modification triggered by damming.

Materials and Methods

Study Area

In the Barind region of India-Bangladesh, the Punarbhaba River basin encompasses a 5265.93 km² area. This river had hydrological potential before neo-tectonic movement when the Teesta River flowed through it. After being severed from the Teesta, the river lost its primary water supply and became a hydrological tributary (Rashid and Sultan-Ul-Islam 2014). Because of this geo-hydrological event, the hydro-ecological setting of this river has changed dramatically, and it has transitioned from a perennial river to a rain-fed river. In 1992, the Komardanga dam was built in Birganj across the Dhepa River, a significant tributary of

Table 1 List of literatures on water habitat modeling and related issues

Literatures	Focusing aim	Methods applied for habitat modeling	Case region	Species dealt with
Valentin et al. 1996	Physical habitat modeling under hydro-peak condition	PHABSIM Module (Physical HABitat Simulation system) by considering hourly and daily water level monitoring	Oriege River and Anee du Nord River in Pyrenees, France	Brown Trout (<i>Salmo Trutta</i>)
Alvarez-Cavria et al. 2017	Modelling fish biotic indices	River Habitat Survey Model	Different river catchments in northern and southern Spain	Brown Trout and Atlantic Salmon
Kano et al. 2016	Assessment of effects of dams on fish biodiversity	MAXENT (Maximum Entropy Modeling Approach)	Indo-Burma Hotspot	Freshwater fishes
Yousefi et al. 2020	Conservation of endemic freshwater fishes under the impact of climate change	MaxEnt using Dismo package	Freshwater habitats in Iran	Endemic freshwater fishes
Stefan et al. 1995	Fish habitat modelling	Water Quality Model using Dissolved Oxygen and water temperature as sole parameters	Minnesota state of Central United States	Resident fish species of the lake
Kwon et al. 2015	Effects of climate change on phenology and distribution of fish species	Species Distribution Model	Han River, Nakdong River, Geum River, Youngsan River and Seomjin River in South Korea	145 fish species of 29 families
Mouton et al. 2007	Fish habitat modelling	Computer Aided Simulation Model for Instream Flow Requirements (CASiMIR) based on fuzzy logic approach	River Zwalm in northern Belgium	Bullhead Shark
Teal et al. 2018	Fish habitat suitability assessment	Physiological Models-i. Aerobic Scope Models, ii. Dynamic Energy Budget	Worldwide	Fish Species
Moore et al. 2013	Fish habitat suitability assessment	Empirical modeling of maximum weekly average	British Columbia, Canada	Resident fishes
Morris and Ball 2006	Fish habitat modelling	Multivariate approach	Port Philip Bay, Victoria, Australia	Snapper, Australian Salmon, Greenback Flounder, King George Whiting
Miele 2019	Fish habitat suitability assessment	Habitat Suitability Index	Abras de Mantequilla Wetland, Equador	Small littoral fish species
Li et al. 2015	Fish habitat suitability assessment for rare fish species	Habitat Suitability Model by applying Landscape Ecology Index and ecological hydrograph	Lijiang River, China	Indigenous fish <i>Spinibarbus hollandi</i>
Zhang et al. 2018	Fish habitat suitability assessment	Ecological Model using daily water level data	Jinsha River basin in upper catchment of Yangtze River	Fish biomass of the river

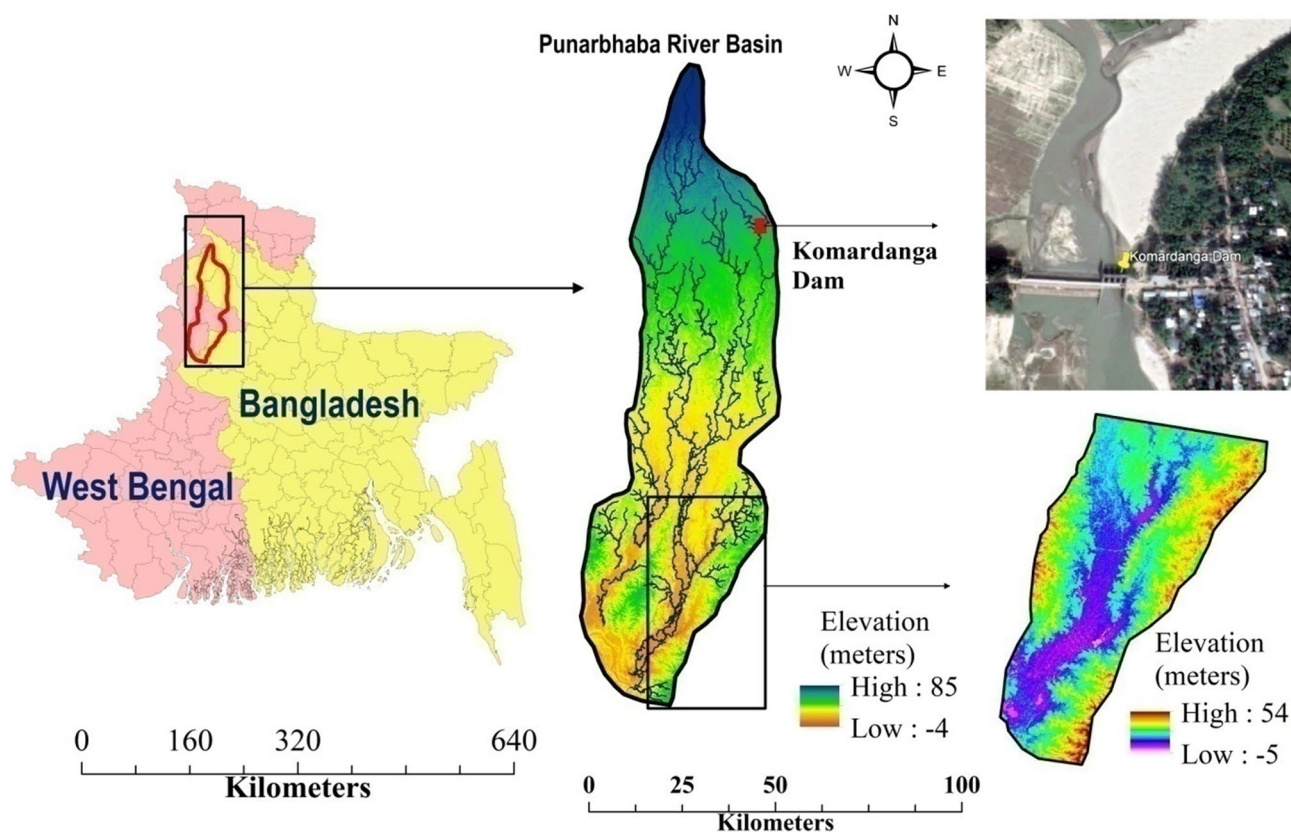


Fig. 1 Location of study area

the Punarbhaba River, causing hydrological flow changes (Fig. 1). Because wetland ecosystems rely entirely on river water and rainfall, hydrological change has a significant influence. This region has a humid subtropical climate with alternate rainy and dry periods. Monsoon rains account for roughly 80% to total rainfall, with an annual average of 1500 mm. In the summer, high temperatures ($>35^{\circ}\text{C}$) combined with high evapotranspiration cause perennial wetland to be squeezed (March to May). The region is heavily inhabited, and the most of its people rely on agriculture and fishing for a living. People in downstream catchment villages such

as Rohanpur, Gomastapur, Chowdala, and Mokrapur rely heavily on fishing for their livelihood. As a result, detecting changing faces of wetland hydrology particularly in reference to fish habitability is necessary.

Materials

USGS Earth Explorer is the most important source for analyzing land use time series and monitoring its dynamic changes (Nguyen et al. 2018). We provided a detail of the data source in Table 2.

Table 2 Database of the study

Data types	Available years	Description	Purpose	Sources
Landsat 4-5 TM	1991-2012	Path/Row: 139/43, Resolution 30 m, Band 7	Water consistency mapping, water depth mapping and hydro-duration mapping	United States Geological Society(USGS) Earth Explorer Website (https://earthexplorer.usgs.gov)
Landsat 8 OLI	2013-2020	Path/Row: 139/43, Resolution 30 m, Band 11	Water consistency mapping, water depth mapping and hydro-duration mapping	United States Geological Society(USGS) Earth Explorer Website (https://earthexplorer.usgs.gov)

Methods

Wetland Mapping

For extracting water bodies from satellite imageries, water indices such as the Normalized Difference Water Index (NDWI), Modified Normalized Difference Water Index (MNDWI), and Re-Modified Normalized Difference Water Index (RMNDWI) are available. These indices can map and monitor surface water bodies such as reservoirs, rivers, wetlands, and lakes. All indices are unsuitable for all regions; Das and Pal (2018) showed that NDWI is most suited for the Indo-Bangladesh barind tract. McFeeters (1996) first proposed NDWI, and it is calculated using Eq. 1. The NDWI value ranges from -1 to 1. A positive value shows a water body; a higher positive value implies more water depth and vice versa (Debanshi and Pal 2020a, b).

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

Where,

b_{green} is the green band (Band 2 for TM and Band 3 for OLI).

b_{NIR} is the near infrared band (Band 4 for TM and Band 5 for OLI).

The Kappa coefficient (K) measures how well-predefined producer ratings and user-assigned ratings coincide. According to Monserud and Leemans (1992), 'K' values of 0.4 imply poor or very bad classification, values from 0.4 to 0.55 represent fair, 0.55 to 0.7 represent good, 0.7 to 0.85 show very good conformity, and values higher than 0.85 represent the outstanding agreement between map and ground truth. In the works on wetland mapping and monitoring, several researchers employed the Kappa Coefficient (Lu et al. 2011; Du et al. 2014; Singh et al. 2015). The Kappa Coefficient (K) has been used to validate wetland maps in recent years (since 2016) (Eq. 2). 100-150 ground control points (GCPs) were collected for those years to confirm wetland maps.

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

Where, N refers to the total number of pixels; r refers to the number of rows in the matrix; x_{ii} is equal to the number of observations in row i; and column ii and x_{+i} , $x_i + i$ refer to as the marginal totals for row i and column i respectively.

Measuring Hydrological Modifications

Hydro-period Mapping The duration of water stagnation in a particular wetland pixel in a year is referred to as the hydro-period for that year. Wetlands are characterized as permanent, seasonal, or ephemeral, according to the length of the hydro-period. In order to construct hydro-period models for both pre-dam and post-dam, monthly NDWI images in a year were assigned binary values, i.e., 1 to the wetland and 0 to the non-wetland pixels. The monthly binary maps were added together to create a final hydro-duration map. Theoretically, this value ranges from 0 to 12, 0 means non-wetland, 12 means a wetland pixel retains water up to 12 months of a year and therefore perennial.

Wetland Water Depth Mapping Water depth mapping was obtained by calibrating NDWI following Debanshi and Pal (2020a, b; Khatun et al. (2021). The water depth of 2020 was used to calibrate NDWI images (1991 for pre-dam and 2020 for post-dam). For calibrating the NDWI to the depth map, water depth data of 36 ground measuring sites were taken. The obtained field depth data was regressed with NDWI values of the respective coordinates. The derived equation ($Y=0.475+14.05x$) was used for calibrating the NDWI images to make them into depth maps. After developing the layer, another 15 sites were taken for verification and accuracy check. 0.5-7% departure of depth between calibrated image and field depth were recorded.

Water Presence Consistency Mapping Water presence frequency (WPF) refers to the frequency of water appearance in a pixel in a period (Borro et al. 2014; Debanshi and Pal 2019). Each NDWI map was converted into a binary map assigning 0 to non-wetland and 1 to the wetland for computing WPF. This was done for pre and post-dam periods separately. These binary images were summed separately for pre-dam and post-dam periods and then divided by the number of years chosen (Eq. 3). It can be expressed as a decimal (0-1) or in percentage (0-100%), multiplying the decimal values with 100. Low WPF value (near to 0) signifies inconsistent water presence, and a value towards 100 signifies consistent water appearance in the wetland. For the convenience of work, WPF was classified into three categories like low WPF (<33%), moderate WPF (33-67%), and high WPF (>67%). High water presence is always good for reliable fishing activities.

$$WPF_p = \frac{\sum_{j=1}^n X_j}{n} \quad (3)$$

where WPF_p is the calculated water presence frequency for p pixel, X_j is the frequency of jth pixel in image X having water appearance, and n is the number of years taken.

Integration of Hydrological Components for Analyzing Habitat Suitability for Fishing Several variables determine fish habitat; however, critical hydrological parameters such as WPF, hydro-period, and water depth were considered to determine fish habitability in this study. Before integrating the parameters, it is necessary to determine the optimal depth for fish survival, the optimal range of hydro-duration, and the optimal WPF in a particular wetland of a specific geo-climatic environment. Several chosen economically viable and frequently catch fish species such as carps (*Labeo rohita*, *Cirrhinus mrigala*, *Gibelion catla*), catfish, shrimps, and tilapia fishes in floodplain wetlands, the ideal range of water depth for fish survival were determined using available literature. More extended growth periods or longer periods of water stagnation may benefit the growth of fish and its phenology (Freeman et al. 2001). Perennial wetland habitat is more potential than ephemeral or seasonal wetland habitat in this respect (Hosen et al. 2019). Therefore, a greater range of hydro-period was suitable for fish habitat. A wetland with a high WPF is a reliable fishing site than one with a low WPF. Natural fish planting causes a wetland that is regularly inundated. It is helpful for fishers to seed fish in permanent water bodies for long-term fishing and greater profitability. Given the facts, a fishing ground with a high WPF is the best option as chosen here as well. A rule-based decision tree (RBDT) model was developed by adding factors based on set logic to produce fish habitability. A good many researchers employed RBDT on wetland mapping and monitoring in the lower basin of Gallatin River watershed, USA (Baker et al. 2006); wetlands in Canada (Li and Chen 2005); freshwater lake wetlands of Hongze lake in China (Ruan and Ustin, 2012); Godagari of Rajshahi dist, Bangladesh (Hasan and Moniruzzaman, 2009); Kabansky Nature Reserve, Russia (Berhane et al. 2018). However, no RBDT model has been developed to generate the fish habitat suitability in the wetland. Declarative rules are used as input in RBDT to define a specific decision tree. The first stage is the attribute selection criteria, which determine how inputs are incorporated in the model. For this study, three hydrological characteristics, namely water depth, hydro-period, and water presence frequency, were considered for both the pre-dam and post-dam periods. The set rule for habitat suitability is hydro-period >9 months, WPF>67%, and the existence of optimum survival depth of particular fish. Obviously, perennial water bodies with high WPF would be much beneficial. However, hydro-period up to nine months and WPF up to 67% were considered here because of the dominance of seasonal wetland with high erratic nature of water appearance. Nine months of duration is a good time for the growth of fish of economic profitability.

Results

Wetland Scenario in Pre and Post-dam Periods

Because the quantity of rainfall in the current research area is seasonally variable, the wetland scenario in this region is highly dynamic in behaviour. There is a substantial variation in the average wetland area between pre and post-monsoon seasons and between the pre-dam and post-dam periods with the high hydrological alteration. The pre-dam wetland area was 149.26 km², and during the post-dam period, it is 59 km², showing a substantial drop of wetland area.

The NDWI index-based wetland mapping was validated using the Kappa coefficient. The calculated K values ranged from 0.77 to 0.86, suggesting a good agreement between map and ground reality. No images from the pre-dam period were validated because of a lack of reference data. However, it is apparent that if recent data validates NDWI images, then pre-dam data are likely to be validated as well.

Characters of Wetland Hydrological Attributes

In the pre-dam period, wetlands with a high hydro-period (>9 months) were 92.35 km² (61.57% total wetland area) which is reduced to 3.34 km² (5.66% of total wetland area) in post-dam period. On the contrary, the area under a low hydro-period increased in the post-dam period. With WPF, high WPF (>67%) was 70.85 km² (47.23% of the total wetland area) in the pre-dam period, and it has been reduced to 42.28 km² (71.66% of total wetland area) in the post-dam period. Contrarily, an area under low WPF (<33%) has deflated by 20% from pre-dam to post-dam periods. This is a serious issue to the existing ecosystem in general and fish ecology in particular. Analysis of water depth also signifies the same trend of deterioration. In the pre-dam period, 58.51 km² or (39.01%) area was there, where the water depth was >3.37 m. However, in the post-dam period, no wetland area has been found within this depth category. In the post-dam period entire wetland area has been converted into a low water depth category (<1.78 m) (Table 3). In a spatial context, the degradation in terms of water depth and hydro-duration is clearly observable in the upper part of the selected study area and fringe wetland away from the major rivers (Fig. 2). Relatively steeper slopes and better drainage in the upper catchment, intensive encroachment of agriculture, and built land in the upper parts are majorly responsible for this greater degradation rate.

In this way, a pre-dam and post-dam depth-area relationship was drawn. Figure 3 shows the area under

Fig. 2 Hydrological attributes for pre dam and post dam periods

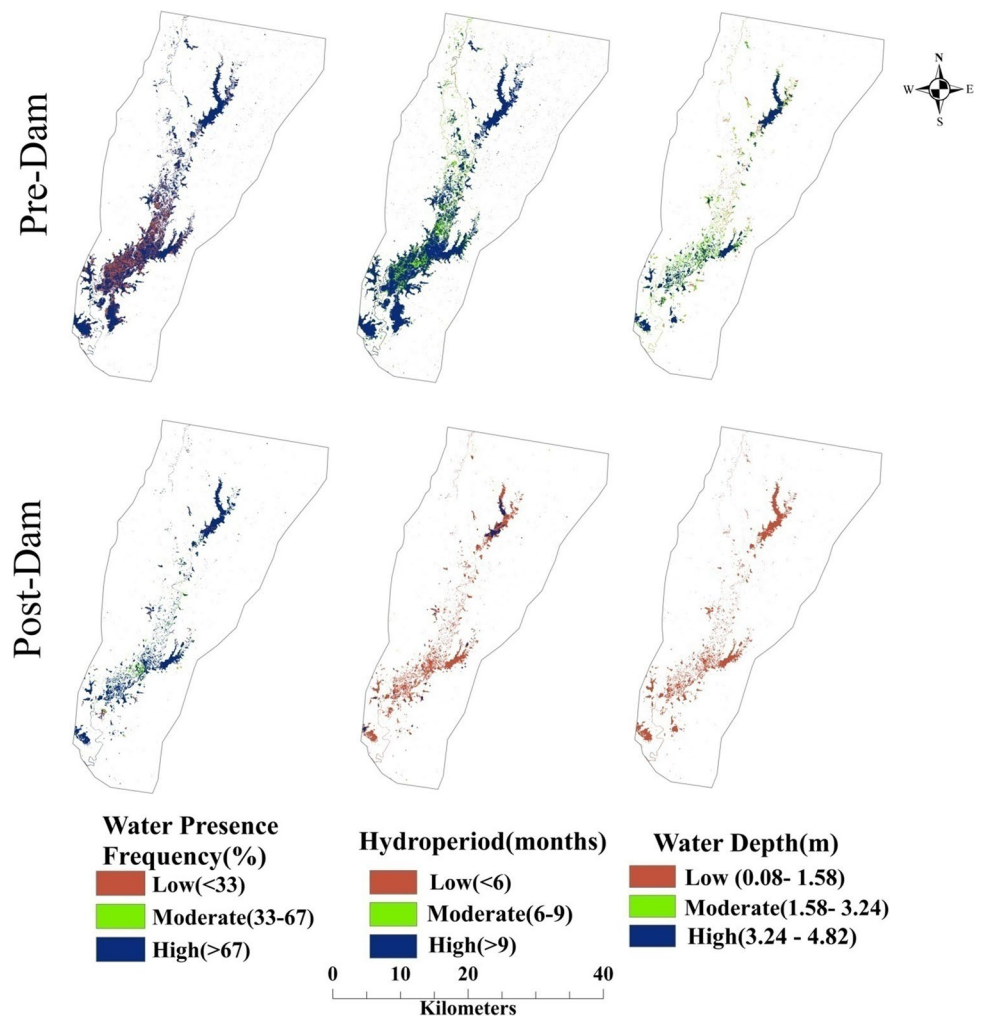


Table 3 Wetland area under different classes of the selected hydrological components

Parameters	Sub class	Pre-dam		Post-dam	
		Area in km ²	Area in %	Area in km ²	Area in %
WPF(%)	Low(<33)	49.36	32.91	7.78	13.19
	Moderate(33-67)	29.15	19.43	8.94	15.15
	High(>67)	70.85	47.23	42.28	71.66
Hydro-period (No of months)	Low <3	20.65	13.77	25.21	42.73
	Moderate 3-9	36.56	24.37	6.92	11.73
	High >9	92.35	61.57	3.34	5.66
Water Depth (m)	Low (0.19-1.78)	42.36	28.24	59	100
	Moderate (1.78-3.37)	48.39	32.26	0	0
	High (3.37-4.96)	58.51	39.01	0	0

different water depth zones of wetlands during pre-dam and post-dam periods using frequency curves. The curves show that the distribution pattern in the pre-dam and post-dam periods is positively and negatively skewed, respectively. It shows that a wider area with greater depth was found during the pre-dam period, but this has been reversed during the post-dam period.

Habitat Suitability in Reference to in Wetland Depth

Figure 4 portrays a habitat suitability map for some fishes like carp fishes (Labeo Rohita, Gibelion Catla, Cirrihinus Mrigala), shrimp fishes, catfishes, and tilapia fishes about water depth for the pre-dam and post-dam periods. We categorized each habitat suitability map into three classes, i.e.,

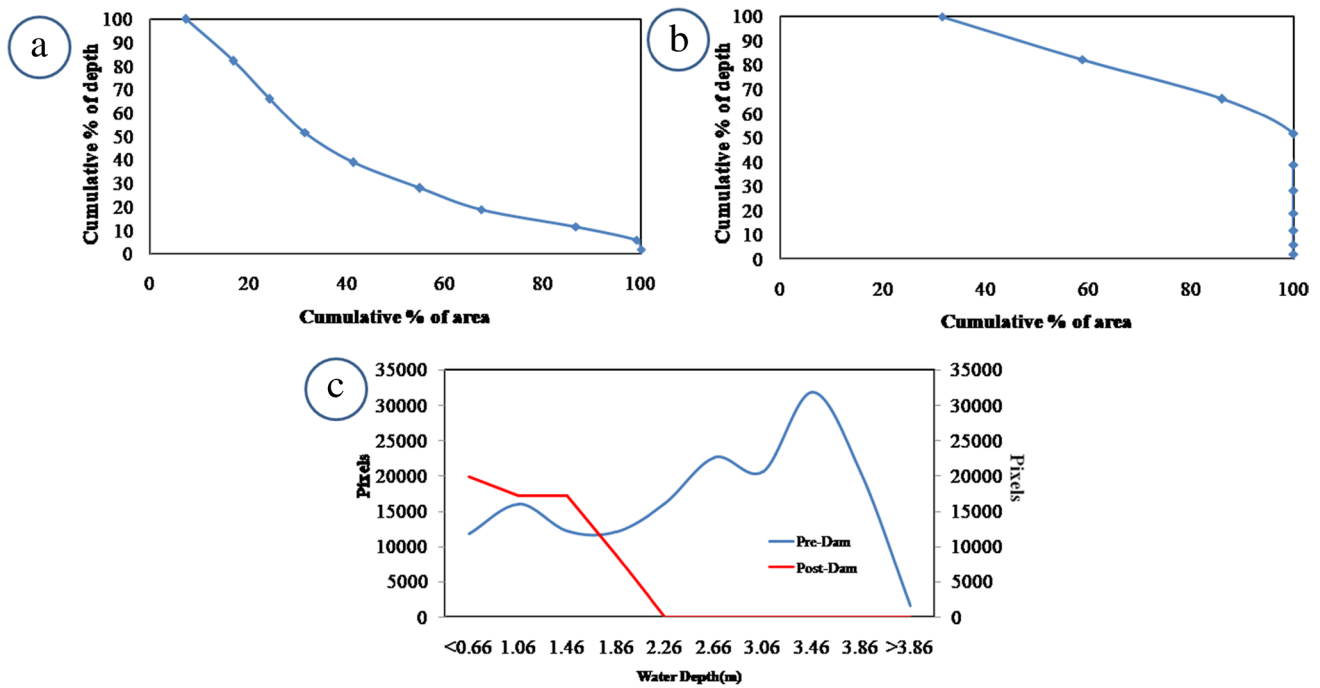
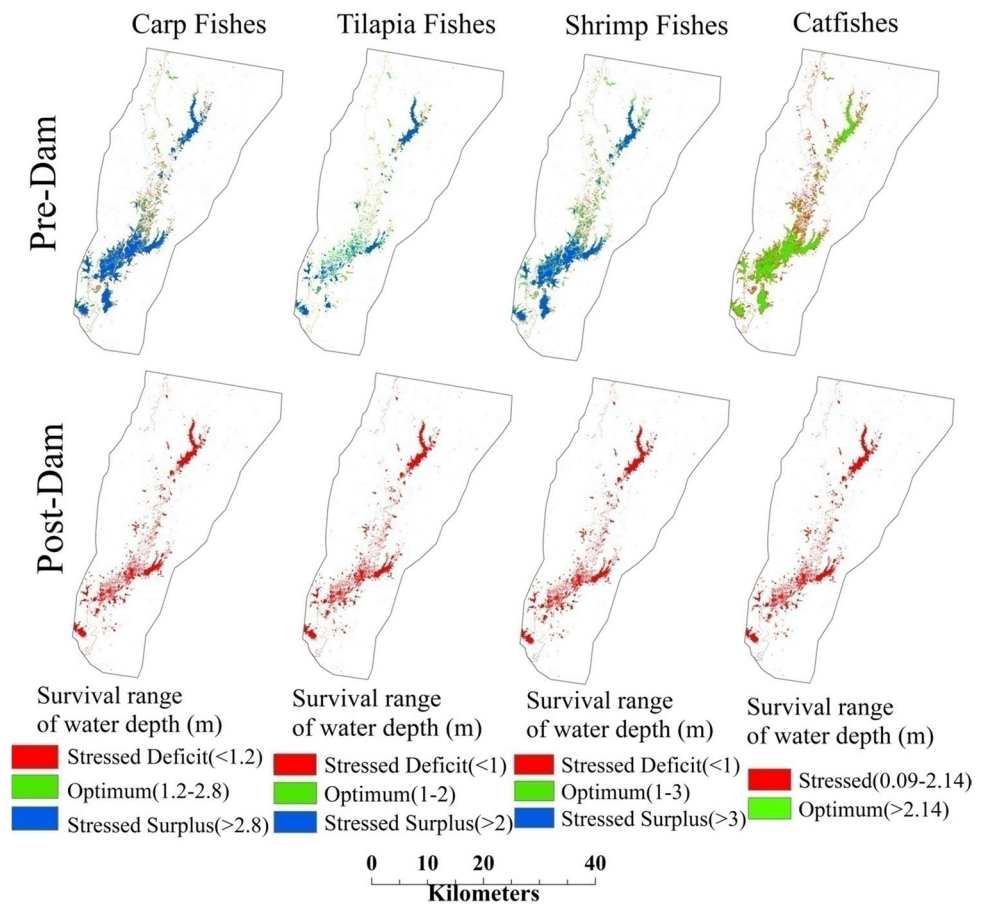


Fig. 3 Depth-Area relation in the wetland of pre and post-dam periods using (A) Cumulative % hypsometric curve for pre-dam period, (B) Cumulative % hypsometric curve for post-dam period, (C) Depth-Area frequency Curve

Fig. 4 Survival range of water depth for some selected fishes in pre and post-dam periods



stress-deficit, optimum, and stress-surplus conditions. The stress condition was divided into stress deficit and surplus state to segregate the water depth above and below the optimum range. The region with suitable and habitable water depth was identified as an optimum wetland area. In contrast, stress-deficit regions are areas with water depth below an optimum range of survival, and stress-surplus regions are areas with water depth above the optimum range. As it is already established that the water depth has been reduced substantially after the dam construction (Fig. 4), it is necessary to delineate optimum depth for each fish both for the pre-dam and post-dam periods. For instance, the area under optimum depth category for carp fishes, tilapia shrimp fishes, and catfishes were 30.04%, 37.60%, 35.36%, and 61.71% respectively of total wetland area during the pre-dam period, but it has become almost nil during post-dam (Table 4).

Fish Habitability Modeling

We performed fish habitability modeling using the above-mentioned hydrological parameters for each fish category both for the pre-dam and post-dam periods by applying RBDT (Fig. 5). The habitability of fishes has been categorized into suitable and less suitable conditions using the natural break method. From Fig. 5, suitable habitat area has been drastically reduced from pre-dam to post-dam period. Suitable habitat signifies wetland parts with high WPF, longer hydro-period, and optimum water depth. Less suitable habitat means those parts of wetland, where hydrological components are not optimum for fish habitability. With carp fishes, the suitable area was 16.54% in the pre-dam period, reduced by 7.35% in the post-dam period. The suitable habitable area was reduced from 15.97 to 5.19% for tilapia fishes, 37.22–6.28% for shrimp fishes, and 39.90–7.35% for catfishes. This reduction should not be judged not only in terms of the percentage gap. The absolute area should

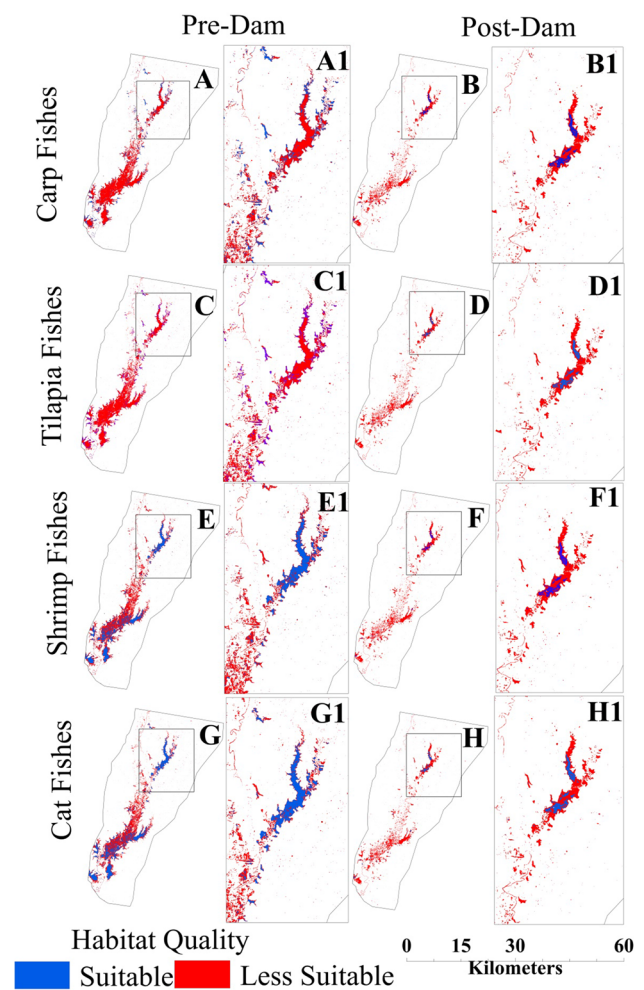


Fig. 5 Rule-based decision tree driven fish habitat quality models of some selected fishes during pre and post-dam periods

also be taken into consideration. The data gap points out the loss of enormous habitat between pre and post-dam periods (Table 4). Huge reduction of habitable area in case of shrimp

Table 4 Area under different survival range of water depth for some selected fishes in pre and post-dam periods

Fishes	Water Depth(m)	Pre-Dam		Post-Dam	
		Area in km ²	Area in %	Area in km ²	Area in %
Carp fishes	<1.2	38.39	25.64	59	100
	1.2-2.8	44.97	30.04	0	0
	>2.8	66.77	44.60	0	0
Tilapia fishes	<1	35.78	23.90	59	100
	1-2	56.28	37.60	0	0
	>2	58.02	38.76	0	0
Shrimp fishes	<1	34.68	23.17	59	100
	1-3	52.94	35.36	0	0
	>3	62.33	41.64	0	0
Catfish	0.09-2.14	57.47	38.39	59	100
	>2.14	92.38	61.71	0	0

and catfishes is the causes of deficit supply of such fishes in this catchment and rise of price (Table 5). The spatial pattern of suitable fish habitat analysis also exhibited that suitable habitat stretches have been fragmented. With shrimp and catfishes, we identified a relatively more extensive suitable stretch even after hydrological modification. However, poor habitat conditions in the post-dam period do not mean that such fishes will not be survived there. Physiologically, the fishes have to be compromised with hydrologically modified conditions, and it can hamper the growth of the fish. Field investigation also shows this cruel reality. The fishermen stated that water availability was very high before 25-30 years ago, large size fishes were very common, and the frequency of fish catches was very high per net. Their statement cross validates the computed hydrological components' centric fish habitat models.

Discussion

The analysis clearly shows that significant hydrological changes in hydro-period, water depth, and WPF have occurred during the post-dam scenario. Growing reversibility of fish habitat determinants like inconsistency WPF over a wider area, shallowing water depth, and shortening hydro-duration is the primary reason being squeezing the suitable habitat area of the chosen fishes in this study. About 65% of the wetland area has been turned to dry land, and existing wetlands suffer from water scarcity and unpredictable hydrological conditions. Such variability in hydrological regimes is not conducive to a healthy aquatic ecosystem or fish habitat (Khatun et al. 2021). Wetland fragmentation, reduced river flow owing to damming, human disturbance (built-up augmentation, agricultural encroachment, abrupt changes in land use, etc.) are all elements that contribute to the hydro-ecological alteration of affected wetlands (Wood et al. 1988; Fournier et al. 2018; Pal et al. 2020). Talukdar and Pal (2020) reported a 41% reduction in water flow in this river basin, remarkable attenuation of flood frequency and magnitude. Since most wetlands are rain and flood-fed,

reducing flow is caused for reducing water availability in the wetland. It is one of the primary reasons behind shallow water depth within wetlands (Pal and Sarda 2021; Khatun and Pal 2021). Erecting embankment alongside the river also has a restricted water supply from the river to the wetland. Huge water-lifting for irrigation from river and wetland and lack of groundwater support because of lowering the groundwater table are crucial determinants. Das and Pal (2018) reported 3-6 m. groundwater table lowering in last 30 years. This vertical disconnection is also responsible for lowering water availability in the wetland. Moreover, a good number of tie channels that connect rivers and wetlands have been defunct. It is also responsible for reducing water availability in the wetland (Talukdar and Pal 2018). Horizontal and vertical disconnections have curtailed the water supply and reduced the nutrient supply, the leading natural fishing food. Such food deficit is against quality fish habitat (Talukdar and Pal 2020; Larson et al. 2019). Regular inundation also washes out the pollutants of the wetland. Lateral disconnection has restricted this service. Regular Encroachment of built-up land and agricultural land are the significant determinants of wetland transformation in land use transformation and wetland fragmentation (Saha and Pal 2019). Such fragmentation handles the patchy fish habitat in this region. Many people rely on wetland fishing to support their livelihood. Damming has deteriorated fishing habitat and quality fish stores, forcing fishers to seek alternative employment. Before damming, a more significant portion of the wetland was suitable for fishing, but the situation has become much more adverse after hydrological modifications. The fishers who are still engaged with their parents' profession are suffering from the economic fish catch. Moreover, the quality of fish also degraded significantly as per their statement over time.

The severity of the hydrological drought increases in summer season owing to the lack of rainfall. The availability of water in perennial wetlands decreases as the rate of evaporation increases, and broader areas of the marsh have become dry (Pal and Talukdar 2018). Because of rainfall differences, seasonal variations have been seen in water depth,

Table 5 Area under habitat quality for some selected fishes in pre and post-dam

Fish category	Habitat Condition	Pre-dam		Post-dam	
		Area in km ²	Area in %	Area in km ²	Area in %
Carp fishes	Suitable	18.3	16.54	3.43	7.35
	Less suitable	92.64	83.73	43.24	92.65
Tilapia fishes	Suitable	17.67	15.97	2.42	5.19
	Less suitable	93.27	84.30	44.25	94.81
Shrimp fishes	Suitable	41.18	37.22	2.93	6.28
	Less suitable	69.77	63.06	43.74	93.72
Catfish	Suitable	44.14	39.90	3.43	7.35
	Less suitable	66.8	60.38	43.24	92.65

as wetlands are heavily reliant on rainwater. Because of the damming, huge water-lifting for irrigation, and other purposes, the hydro-period gets shorter in this situation (Khatun et al. 2021). The climate change issue is also crucial for shortening the hydro-period, but it has not been explored in this present work. As a result, both natural and manmade factors contribute to fish habitat degradation. We cannot change the natural rainfall cycle, but human involvement in the flow may be reconsidered.

It is unique to use the RBDT technique to find the ideal fishing habitat by combining image-driven hydrological data. It would be more challenging to use other extremely objective machine learning algorithms that provide robust results since all the specified parameters have no clear optimal range of survival. However, hydro-period and WPF have no clear quantitative optimal range of survival; this applied model is also suitable here because these were chosen based on the field experience and expertise of the fishers. This approach is helpful in incorporating logic into categorical data sets. Important factors such as water presence frequency and hydro-period have been overlooked in earlier studies. Despite the challenges of including such factors because of a lack of spatial data, the current work aims to construct such parameters using satellite imageries calibrated field data. Such an attempt is also suitable for removing the barrier of working with this issue over a wider geographical area. Since the study has figured out the suitable area for fish habitability, it could frame policy regarding this. Apart from the good aspects of this study, some limitations should also be mentioned for future exploration and upgradation. However, in the future, the calibration procedure might incorporate more ground truth data and other techniques linking water depth and water indices values. Only hydrological components were used in this study; however, some components, such as water quality, nutrient availability, and so on were not included because of a lack of spatial data. Including them might undoubtedly improve the model's accuracy.

Conclusions

The study shows that damming has harmed appropriate fish habitat in terms of water depth, water presence frequency, and hydro-duration. After hydrological modification, 60% wetland has been dried out, about 5–25% good habitat has been turned in to poor habitat for the chosen fishes. Some fishes may adapt to the new environment, while others will not be able to live comfortably. Catfish, for example, may adapt to the altered hydrological conditions. A novel technique, RBDT modeling incorporating image driven hydrological components, was used. Because of the model's effectiveness, this study suggests that it could be used for fish habitability mapping, particularly where training data is not

very prominent. There is still room to improve the model by including other key hydrological factors as mentioned earlier. Since hydrological alteration is a significant cause of habitat deterioration and squeezing for fish habitat, it is suggested to rethink about discharging policy from the dam and other forms of large scale water harvesting for restoring the wetland. Moreover, more research could be carried out regarding the suitable economic fish species in the altered condition for restoring the livelihood of the people and continuing such demanding provisioning service.

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Author Contribution Both the authors contributed to the study conception and design. Conceptualization; methodology designing; supervision; editing and reviewing were performed by Swades Pal. Data curation; investigation; formal analysis; validation; and writing of original draft were performed by Rumki Khatun. Both the authors read and approved the final manuscript.

Data Availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare that they have no competing interests.

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