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Geospatial Analysis for Sustainable Aquaculture Expansion: A Case Study on Water Spread Area Mapping and Fish Production Potential in Dimbhe

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Abstract: Indian reservoirs with an area of 3.91 million hectares, possess immense potential for fisheries that offer economic and social security. Planning fisheries and aquaculture activities in a reservoir require knowledge of water spread dynamics and potential fish culture areas. Geospatial technologies in inland water resource management and decision-making have been widely used worldwide. The current study assessed the water spread dynamics and map potential areas for enclosed fish culture in Dimbhe reservoir, Maharashtra, India using Sentinel-2 Multi Spectral Instrument (MSI) images during the period 2019-22. Mapping of the spatial extent of the Water Spread Area (WSA) for identifying the potential sites and area for scientific ranching and fish culture using Normalized Difference Water Index (NDWI) and Water Presence Frequency (WPF) along with bathymetry was performed. The results showed that the WSA declines from Rabi season to summer season, with 70.44 percent (1445.39 ha) of the area covered with water for at least 8 months and 39.60 percent (812.45 ha) retaining water for at least 11 months, respectively. The calculated average number of fingerlings required to utilize the available water area in Dimbhe reservoir is 0.56 million with a production potential of 112.88 metric tonnes. The perennial WSA available in the Dimbhe reservoir is 551.22 ha which is most suitable for permanent cage culture practices. The study shall help in planning out scientific ranching and the improvement of enclosed fish culture locations with other water resource applications and to plan appropriate interventions for reducing the fish yield gap.

Keywords: Normalized difference water index, Water spread dynamics, Water presence frequency, Bathymetry, Fish culture, Reservoir

Indian reservoirs with 3.91 million hectares (ha) area offer immense potential for fisheries and provide economic and social security, especially in rural areas (DoF 2022, Sarkar et al 2015). Fish yield from reservoirs is low to the tune of 49.9 kg $ha^{-1}yr^{-1}$ in small, 12.3 kg $ha^{-1}yr^{-1}$ in medium, and 11.4 kg $ha^{-1}yr^{-1}$ in large reservoirs despite their high production potential (Sarkar et al 2018). Inland fisheries provided 12.5 million tonnes (70%) of India's total fish production in 2017–18 (Yadav et al 2021) among which reservoir fish cage culture accounts for only about 3.81 percent (DoF 2022). The Department of Fisheries (DoF), India intends to increase current cage culture fish production from 2.44 lakh metric tonnes to 6.29 lakh metric tonnes by 2024-25 (DoF 2022). It is revealed that climate change is a major factor influencing global production of fisheries (Yadav et al 2022), whereas poor stocking and lack of insight into periodic water availability for aquaculture systems are reasons for low productivity in Indian reservoirs (Sugunan 2015, Kumar 2018). Regular stocking or annual stocking is recommended if auto stocking is not achievable for medium and large reservoirs until a mass breeding population is developed to provide stock replenishment throughout the reservoir's water-spread region (Mane et al 2014, Kiran et al 2015, NFDB 2016). The use of geospatial technologies in the management of inland water resources and decision-making for fish culture purposes have been well recognized as they can monitor large areas easily (Ingole et al 2015). Satellite-based Remote Sensing (RS) imagery provides applications for assessing and monitoring aquaculture sites and leverages sustainable development (Ottinger 2018). Mapping of waterbodies, their dynamics, periodicity, and their management by using high-resolution panchromatic and multispectral satellite data has been widely accepted (Ottinger et al 2018, Kumar et al 2021) also; the water resource use in different seasons can demonstrate the actual situation of the annual water availability in reservoir. Comprehensive databases of waterbody resources and their dynamics are required for planning fish culture practices. Based on satellite data, developing of spatiotemporal resource inventory for reservoirs can be used for sustainable fisheries management and optimizing fish productivity (Anand et al 2019). Adoption of enclosed fish culture methods in reservoirs have the high potential to increase the present fish production in Indian reservoirs (Sarkar et al 2018). Increasing trend in cage farming in reservoirs demand a very precise understanding of the dynamic water spread of reservoirs in order to develop and perform an economically viable enclosure fish culture activity (Kumar et al 2018, Anand et al 2019). Bathymetric information is also crucial for understanding reservoir environment and planning aquaculture activities (Hollister 2011, NFDB 2016).

In this context, this study has been taken up in Dimbhe reservoir, Maharashtra to analyze the water dynamics, assess effective Water Spread Area (WSA), stocking density, production potential and to map the potential areas for enclosed fish culture. This reservoir plays a major role in livelihood security of 19 villages and has a great potential for fisheries and aquaculture (Iyer 2014, Khanolkar et al 2018). As the yield potential and optimum stocking capacity of the reservoir is unknown, estimation of WSA and Water Presence Frequency (WPF) at different depths at different locations can aid in determination of the same. The information will be beneficial in identifying viable fish culture areas, and ultimately lead to the sustainable utilization of large-scale resources (Ghatge et al 2008). The water spread dynamics and potential fish culture area identification in inland water bodies is crucial for intensive aquaculture practices and water uses.

MATERIAL AND METHODS

Study area: The study was conducted in Dimbhe reservoir, which lies between 19° 05′ 52.82″ N, and 73° 43′ 19.56″ E on Ghod river basin near Ambegaon Taluka, Maharashtra (India). The basin is situated at an elevation of 717- 719 m surrounded by tropical forest, grassland and agricultural land. The reservoir is associated with Ghod river and water inflow is from the rainfall in Sahyadri hills, Western Ghat. It is the part of Kukadi project, a gravity dam made in 1992-1993 by the Government of Maharashtra, for irrigation in 19 villages (covering 34000 ha area) (Sehgal et al 2013, Theurkar et al 2015). The reservoir plays a major role as the water and power supply sources for the surrounding villages.

Study period and data set: The present study used satellite data of Sentinel-2 MSI cloud-free imageries were obtained from the Sci-Hub Copernicus open access website (https://scihub.copernicus.eu/dhus/#/home) with spatial resolution of 10 m for the visible bands, i.e. Blue (Band 2), Green (Band 3), Red (Band 4), and Near InfraRed (Band 8). Individually, a total of 64 images were downloaded and processed through Quantum GIS (QGIS) Software. Four years of seasonal water variation from the years 2019 to 2022 were featured in the study. Two satellite images were taken in 1st and 2nd quarter of each month to get the average water surface area value for a month. Based on seasonal water availability, time period was divided into two phases. The amount of water accessible in February (Rabi season) was deemed to represent the minimum amount required for fish culture, which is water available for at least 8 months (FAO 1992, NFDB 2016). Similarly, May (Zaid/summer season) represents the minimal amount of water that is present in a water body for at least 11 months, when all the irrigation demand has been fulfilled (FAO 1992, NFDB 2016, Anand et al 2019). For WPF analysis, 100% water pixel value areas were considered as consistent water availability zone suitable for enclosed fish culture. Outer boundary layer of reservoir is taken as the farthest waterbody mark area during the monsoon season where water is filled at full reservoir level (Sarda and Das 2018, Anand et al 2019).

Extraction of WSA for fish culture: An overview of the methodological framework used in the current for estimating the WSA (Fig. 2). NDWI was used for discriminating and mapping water pixels of the sites under the study (Borro et al 2014, Khattab et al 2014)

$$NDWI = \frac{DN_{Green} - DN_{NIR}}{DN_{Green} + DN_{NIR}} \qquad [-1 \text{ to } +1]$$

Water features are indicated by positive values while the vegetation and soil features have values between – 1 and 0. DN_{Green} and DN_{NIR} are the digital number value of green and near-infra-red (NIR) bands of the satellite imageries.

A composite seasonal WSA map was generated by integrating the two annual aggregate maps. As a single-year image does not justify the exact value of water presence area in water bodies, particularly in areas where annual and seasonal water level fluctuation is higher due to heavy water uses for irrigation, hydroelectric power generation and asymmetric rainfall pattern. Thus, NDWI for the month of Feb (Rabi season) and May (summer season) from 2019-2022

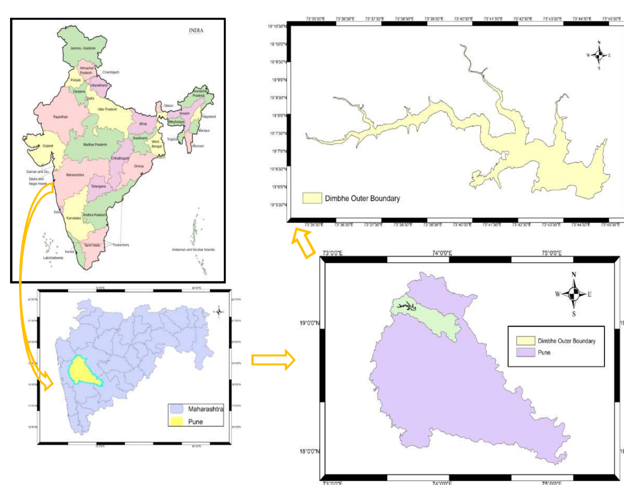

Fig. 1. Map of the study area

has been aggregated into a final composite image. From two annual aggregate maps, the WSA was estimated by geo-referencing.

Fingerlings requirement estimation: The fingerlings requirement and yield potential has been calculated (NFDB 2016, Anand et al 2019). Areas under the two water availability zones (8 or 11 months) were determined for calculating the total number of fingerlings required for stocking using the following Eq.

$$F = A * SD$$

F = Total number of fingerlings required for stocking in reservoir

A = Area of water availability zone (ha)

SD = Stocking density of particular water availability zone (numbers/ha) as per topography of the reservoir and guidelines for stocking in medium-large reservoir.

$$AF = \frac{\Sigma_n F_R + \Sigma_n F_z}{n}$$

A_F = Average number of fingerlings required for a waterbody

F_R = Fingerlings required for 8 month water availability zone

F_Z = Fingerlings required for 11month water availability zone

n = Number of years taken for preparation of a composite map

$$Y = F * AW * SR$$

Y = Potential fish yield in reservoir (kg/year)

F = Total number of fingerlings required for stocking in reservoir

AW = Average weight of individual fish at harvesting (kg)

SR = Survival rate of fish (%)

The total minimum potential fish yield of a specific waterbody can then be calculated (kg/ha/year)

Fish culture yield potential estimation:

A_Y = Average yield required for a waterbody

Y_R = Average yield in 8-month water availability zone

Y_Z = Average yield in 11-month water availability zone

n = Number of years taken for preparation of a WSA composite map

$$AY = \frac{\Sigma_n Y_R + \Sigma_n Y_z}{n}$$

Assessment of seasonal WPF: Reclassified NDWI images were merged seasonally using the WPF approach to determine the seasonal WPF for pre-monsoon (March to May, 24 Sentinel-2 MSI images) and Post-monsoon (October to February, 40 Sentinel -2 MSI Images). To investigate the phase-wise pre-monsoon and post-monsoon spatiotemporal fluctuations in the WPF of Dimbhe reservoir, images from 2019 and 2022 were individually combined into a vector image. WPF method was adopted (Sarda and Das 2018) to create the seasonal composite image of water presence as demonstrated in Figure 3 using the following Eq.

$$WPF_j = \frac{\Sigma_{i=1}^{n} I_j}{n} \times 100$$

WPF_j = WPF of jth pixels in a time period; I_j = jth pixel having water in the selected NDWI images; n = number of images.

The value of WPF image pixels ranges from 0 to 100%. A

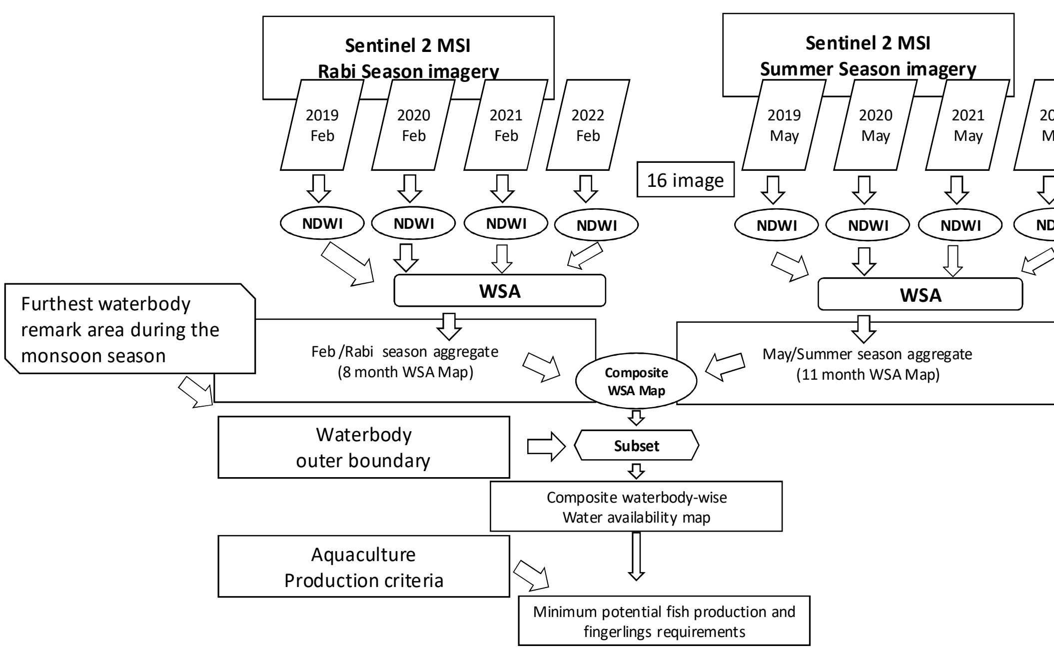

Fig. 2. Methodological framework for assessing WSA and fisheries potential area

higher WPF value indicates the frequent or regular appearance of water in the pixel, lower value or tending to zero indicates irregularity in the water presence. 100% indicates the presence of water in all the years. Based on the WPF value, the composite map was reclassified into three classes viz. Low WPF (<33%); Moderate WPF (33 -66%) and High WPF (>66%), pixels with zero value are classified as "No water". Pre and post-monsoon season WPF composite maps of 2019-2022 were used. Pixels with 100% frequency values in these composite maps were considered for identifying areas suitable for enclosure-based fish culture.

WSA in Dimbhe reservoir is divided into two section viz. perennial and seasonal based on the following criteria:

Seasonal WSA: 100% frequency pixels of post-monsoon season composite maps were first recorded to generate seasonal WSA maps that could only hold water from monsoon to post-monsoon.

Perennial WSA: Pixels with 100% frequency WPF composite maps generated from both pre and post-monsoon of 2019-22 represented parts that retained water year-round in the reservoir. Permanent enclosed fish culture installations require the availability of perennial water area.

Bathymetry Mapping of Dimbhe Reservoir: The selected site for cage installation and composite fish culture in the reservoir should have a minimum depth of 10 m and 1 m, respectively throughout the year (NFDB 2016). Integrating depth profile data with water availability area will help in meeting more accurate cage site selection and area requirements during installation (Anand et al 2019). Hence, a bathymetric model of the reservoir was generated using satellite dataset with a resolution of 10 m (Fig. 4).

The model was validated and corrected using field data surveys and topographic maps. The detailed methodological framework for bathymetric model was given in Figure 4. Path maps for perennial and seasonal water bodies were extracted from shape files prepared for estimating the WSA in

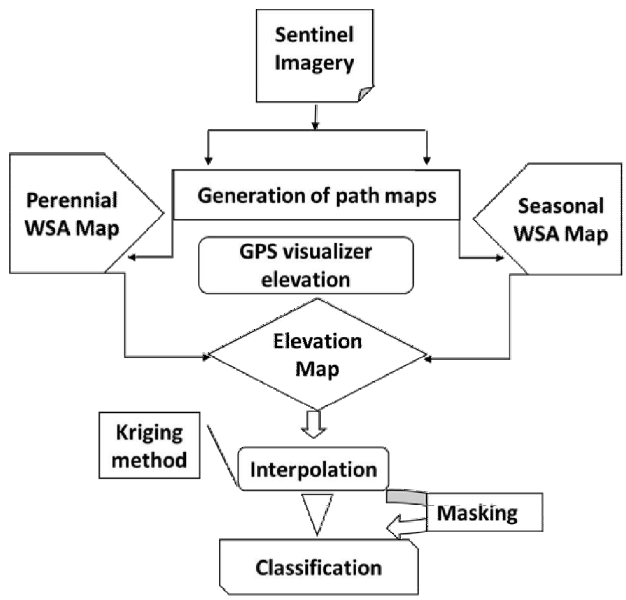

Fig. 4. Methodology framework for bathymetric mapping

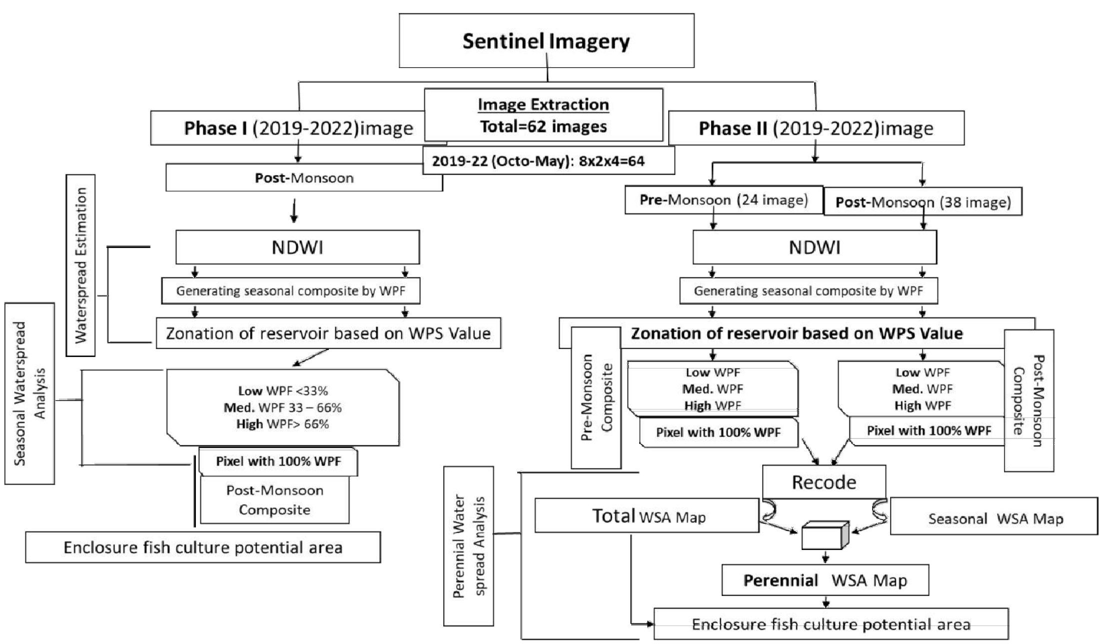

Fig. 3. Flowchart of methodological framework used for assessing water presence area mapping and potential area for enclosed culture

Google Earth Pro. Using an open-access GPS visualizer elevation (https://www.gpsvisualizer.com/elevation), an elevation GPX file was created and converted into to features class. Elevation data of precise position were obtained by adding the location (Latitude-Longitude) to the attribute table with field observation. The interpolation tool was used to get the unknown values in geographic coordinates for elevation using Kriging method which is a sophisticated geo-statistical tool that generates an estimated surface from scattering of z-valued points. Extracted Kriging file, based on the minimum and maximum depth, is classified into 10 m intervals and the plotted minimum value was chosen as surface values against the elevation map observed points (Khattab et al 2017). The estimated values of selected bathymetric models were compared with observed field survey data to ensure accuracy and to monitor the development of lake bottom throughout reservoir operation. The estimated perennial water availability zone with >10 m depth profile area was found to be suitable for cage culture (NFDB 2016). Ground truthing was performed to comprehend the dynamics of the waterbodies and usage patterns. Information on fish culture system, species cultured, duration of culture, stocking density, survival rate (%), yield per unit area, and types of culture systems were collected from Dimbhe Cooperative Society members. Water quality parameters such as dissolved oxygen (DO), chlorophyll content, turbidity, and depth were measured in different locations of the reservoir.

RESULTS AND DISCUSSION

Reservoir seasonal WSA estimation and mapping: WSA in Dimbhe reservoir shrinks dynamically from the end of monsoon to the end of summer season. The total WSA in Dimbhe reservoir was found to be 2051.48 ha, which is in par with the recorded result of 2202 ha at FRL (Waghmare et al 2022). Figure 5 depicts the dynamics of the average spatial watershed distribution for 8 months and 11 months in the Dimbhe reservoir. 70.44 percent (1445.39 ha) of the reservoir area remains covered by water for at least 8 months (Feb month composite WSA) and 39.60 percent (812.45 ha) retains water for at least 11 months (May month composite WSA), respectively (Table 1). Availability of water in the reservoir between February (8^{th} month) and May (11^{th} month) is very significant in terms of extending the fish culture period to the 11^{th} month, thereby increasing the fish yields.

NDWI was used in this study and the outcomes were consistent with the findings of Sarda and Das (2018) where Massanjore dam presence area dropped from 44.13 to 23.54 km^2 in pre-monsoon and from 63.37 to 37.57 km^2 in post-monsoon. Anand et al (2020) observed that estimation of seasonal water availability in terms of seasonal changes in WSA to be necessary for assessment of fish production potential from available water resources.

Estimation of fingerling requirement and enclosed fish culture potential: As per "Guidelines for Fisheries Development in Reservoirs" by NFDB, stocking rate for medium and large reservoirs should not be <500 fingerlings per hectare with a survival rate of 10 percent and average harvest size of 2 Kg. An average of 0.56 million fingerlings were estimated to utilize the available water of Dimbhe reservoir. Total annual average fish production potential conservatively estimated from the available WSA for the reservoir were 112.88 tonnes (Table 2).

Production in Dimbhe was between 27 to 32 tonnes in the last few years, which is much less than the estimated production potential of 112.88 tonnes. Dimbhe reservoir, with 70 % water availability in 8 months, can provide further opportunities for greater intensive aquaculture adoption. For enclosed fish culture purposes, estimated perennial WSA was 551.22 ha in and seasonal WSA was 1199 ha (Fig. 6).

Available perennial area in Dimbhe reservoirs is 551.22 ha that comprised 26.9% of their maximum WSA suitable for permanent cages (Fig. 7). Identification of enclosed fish culture regions based on reservoir perennial and seasonal WSA aids in the effective facility installation by preventing

Table 1. Seasonal WSA in Dimbhe Reservoir

Year	February (ha)	%	May (ha)	%
2019	1122.21	54.69	377.10	18.38
2020	1536.17	74.87	982.88	47.90
2021	1555.91	75.83	1161.66	56.62
2022	1452.28	70.78	816.17	39.78
Average	1445.39	70.44	812.45	39.60

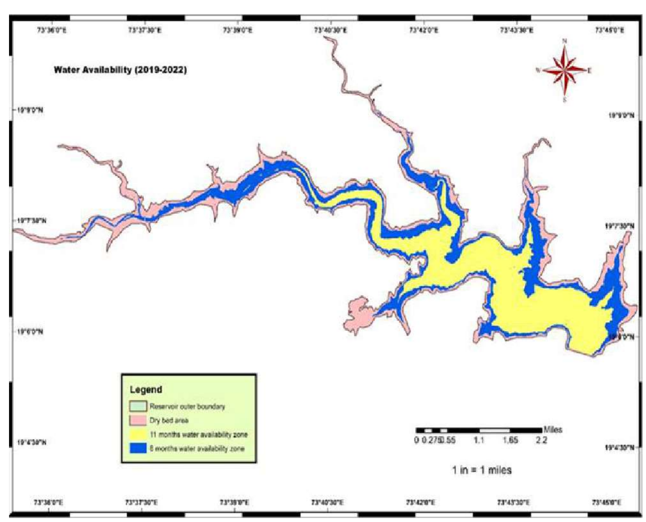

Fig. 5. Water spread dynamics in the Dimbhe reservoir

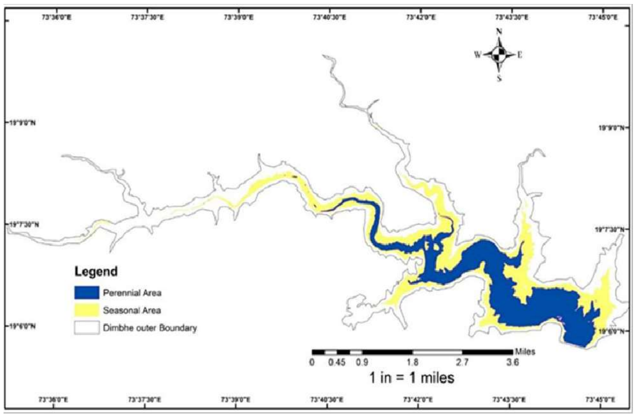

Fig. 6. Seasonal and perennial water area of Dimbhe reservoir

overcrowding and maximizing the use of water resources, thereby, facilitating effective fisheries management. Furthermore, WPF estimate was related to the findings of Deoli et al (2021) for WSA dynamics at Sattal Lake where a decreasing trend was observed during post-monsoon to February and also in summer season.

Bathymetry assessment: The highest water depth point of the reservoir in seasonal area is 69.7 m and its average depth is around 36 meters, i.e., 4 m deeper than that of the perennial area (Fig. 6). There is >66% water availability in the seasonal area and 20-36 m depth is concluded to be appropriate for cage culture. In India, the source of water for the reservoirs is usually precipitation.

Table 2. Standardized culture parameters used to estimate the expected fish production from the reservoir (Sugunan and Katiha 2004, NFDB 2016)

11 months (February)			8 months (May)			Average	
Area available (ha)	Stocking density (million fry)	Potential fish production (Tonnes)	Area available (ha)	Stocking density (million fry)	Potential fish production (Tonnes)	Stocking density (million fry)	Potential fish production (Tonnes)
1445.39	0.72	144.53	812.45	0.41	81.24	0.56	112.88

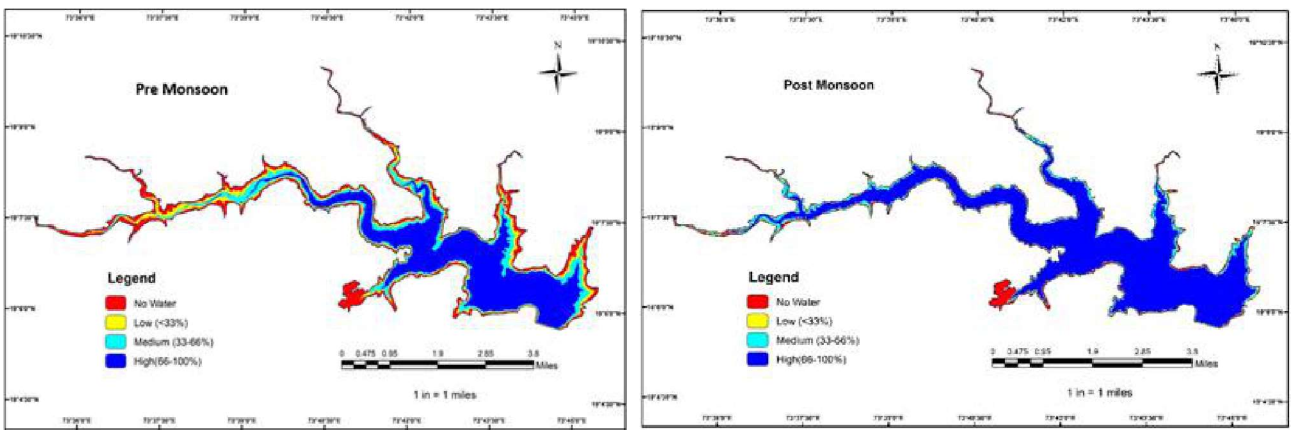

Fig. 7. Comparison between post-monsoon and pre-monsoon WPF dynamics

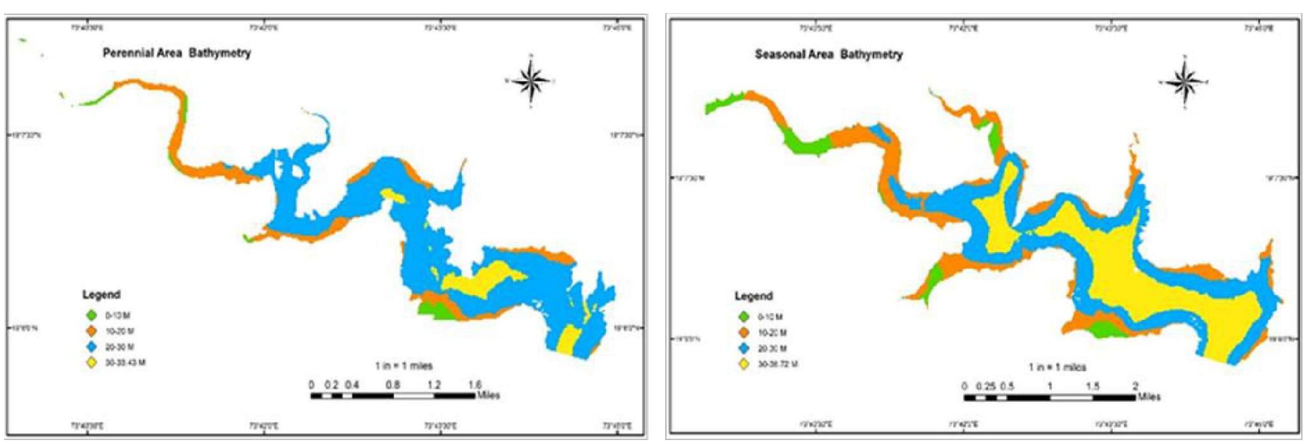

Fig. 8. Bathymetry map of seasonal and perennial area

After addressing the requirements for irrigation, hydroelectric projects and other activities; the retained water available year-round with a depth of >10 m is ideal for intensive fish culture practices. Incorporation of bathymetric analysis is effective for cage culture practice (NFDB 2016).

Based on the spatiotemporal water distribution and depth profile, a proposed model adopted from Anand et al (2019) for selecting an appropriate cage and pen fish culture method and candidate species in the Dimbhe reservoir (Fig. 9). The water pH varied seasonally from 6.7 to 7.6 and water surface temperature fluctuated between 20°-27° C. Species diversity in Dimbhe reservoir was high which included *Catla, Labeo rohita, Puntius ticto, Puntius sophore, Salmostoma bacaila, Garra mullya, Cyprinus carpio, Ompok bimaculatus, Chanda nama, Oreochromis mossambica*. These indigenous species are suitable for ranching and cage culture. For grow-out fish culture, pens and permanent cages can be utilized to locate perennial water regions with low depth (1-3 m) and high depth (10 m) respectively (NFDB, 2016). Indian Major and Minor Carp and ornamental breeding can be farmed in pens located on the reservoir's rim comprising at least 10 m of water. Because of high evaporation and low rainfall, usage of reservoir water for irrigation, water treatment plans, hydroelectric generation and other uses led to a decrease the water column depth and WSA from February (Rabi season) to May, which correlates the findings of Waghmare et al (2022). This study has been supported by the results of Anand et al (2019) who found WSA of the Nizamsagar reservoir in pre-monsoon season decline from 108.11 to

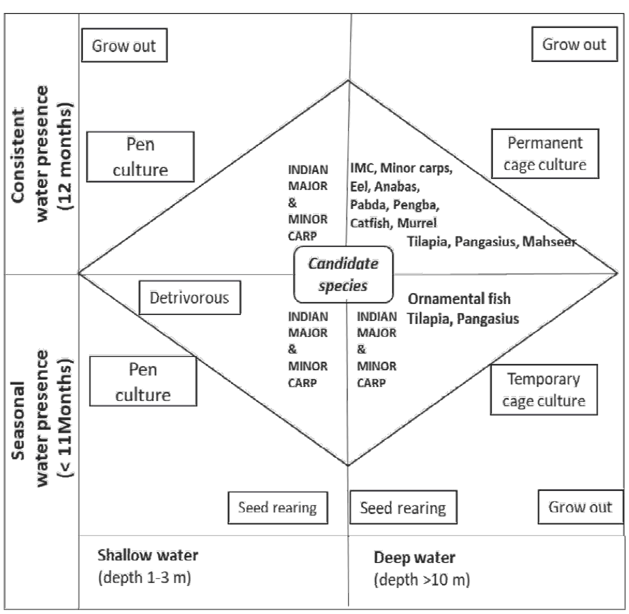

Fig. 9. Appropriate enclosing fish culture technique and potential species in a reservoir based on the depths and spatial water spread area (Das et al 2014)

99.34 km^2 by using NDWI and WPF. Remote sensing generated results were verified through in-situ survey multiple times which further strengthened this study. Therefore NDWI, WSA, WPF and all the parameters used are beneficial in sustainable reservoir fisheries management.

CONCLUSION

WSA and WPF suggest an appropriate place for enclosed intensive culture at seasonal WSA (54.46% of the total reservoir) and perennial WSA (26.9%). Majority of the perennial and seasonal WSA have respective depths of 20-27 m and 20-30 m which are highly suitable for cage culture as per the NFDB (NFDB, 2016). Bathymetry analysis of perennial and seasonal WSA is performed to identify the precise depth of locations for fish culture activities. Estimation of water spread dynamics and bathymetry analysis is essential for fishery managers, policymakers to build and execute knowledge-based management methods for sustainable development. Enclosure culture facilities, considering the seasonal water availability (pre-monsoon and post-monsoon) trends, will help to achieve economic sustainability of the production system as it involves huge initial investment. This study will be helpful in planning out scientific ranching and enclosed fish culture practices for reducing the fish yield gap.

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