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Geo-informatics Approach for Sustainable Aquaculture Expansion: A Case Study on Mapping the Availability of Water Spread Area and Fish Production Potential in Manar Reservoir, Maharashtra

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***Abstract*:** To utilize the Indian reservoir's untapped fish production potential, managers require precise information about the water body. The current study employed Normalized Difference Water Index (NDWI) to generate reservoir's Water Spread Area (WSA), Water Presence Frequency (WPF) and the Digital Elevation Model for bathymetry analysis. The reservoir has a total area of 2490.86 ha and retained approximately 90 percent and 69 percent of its maximum WSA in February and May, respectively. According to the estimated WSA, stocking ~10 lakh fish fingerlings can yield around 200 mt of fish production. The reservoir has a large area with high WPF (63.70% in pre-monsoon and 87.79% in post-monsoon season) and around 32 percent of the reservoir retains water throughout the year. The majority of the reservoir area falls in the range of 4 to 10-meter depth still the reservoir failed to meet the minimum depth criteria for the cage culture set by the National Fisheries Development Board. Therefore, it has been determined that cage culture cannot be practiced in this reservoir, however, fish production can be increased by stocking pen-reared fingerlings in potential reservoir sites by erecting pens.

***Keywords*:** Reservoir, Normalized difference water index, Water presence frequency, Water spread area, Bathymetry mapping, Geo-informatics

Fisheries and aquaculture play an important role in the food supply, food security, and income generation. They account for ~20 percent of per capita animal protein intake for more than 1.5 billion people and provide employment to ~200 million people (Cochrane et al 2009). Indian fishery is changing its dominance from marine to inland with a 76% contribution from the latter to the total fish production. Within inland fisheries, a shift from capture to culture- based fisheries has paved the way for a sustained blue economy. (DoF 2020, 2022). Despite the significant growth of inland fisheries, the potential is yet to be realized, therefore, more emphasis is being placed on the existing underutilized natural waterbodies like reservoirs, lakes, tanks, etc. to maximize their productivity potential than that on farm-based aquaculture (Anand et al 2020, Yadav et al 2021). Because of its tremendous scope of fish production, reservoirs are named as 'Sleeping Giants'. PMMSY is targeting to harness the underutilized potential of the reservoirs and the department is committed to installing 20,000 cages in the reservoirs and water bodies which in turn would produce an additional 60,000 mt of fish by 2025 (DoF, 2022).

Maharashtra ranks 7th with ~5 percent share in the country's fish production and is yet to explore its untapped potential (Bhendarkar et al 2020). It is having the second highest number of medium and large reservoirs (No. 81) followed by Gujarat (No. 88) (DoF 2022). The total water area of reservoir and lake under the DoF Maharashtra is 2.82 lakh ha with an anticipated fish production of 1.28 Lakh MT (DoF 2021). Manar is one of the medium reservoirs of Maharashtra and has a significant share in the fish production of the state. Although the reservoir has been stocked with fingerlings, there is still a yield gap. The resultant gap in the expected and the actual production can be due to the higher mortality rate which can be lowered by stocking bigger sized fingerlings. Water resource structures require careful planning to ensure that water management objectives are met (Dumka and Kumar 2021). The present study assesses the seasonal water dynamics and depth of the Manar reservoir with the help of retrieved Water Spread Area and bathymetry estimation using Remote Sensing (RS) and Geographical Information System (GIS) techniques. The study also attempts to identify the potential site for enclosure culture fisheries.

MATERIAL AND METHODS

Study area: Manar is a medium reservoir (18°50'N to 18°51'N latitudes, 77°19' to 77°09'E longitude) located at village Warwant, Maharashtra (India). Manar Dam project has been completed in 1968 with the primary services of irrigation and small-scale fisheries. The reservoir contract has been given to the Jalkranti Fishermen Cooperative Society Limited, Bahadarpura for the years 2019 to 2023. This reservoir was chosen for the study because of its large Water Spread Area (WSA) and good water holding capacity throughout the year. Given the availability of water and current fish production, it has been hypothesized that enclosure culture can increase fish production. Spatio-temporal change in WSA, Water Presence Frequency (WPF) of the Manar reservoir were monitored for the period 2019 to 2022. Availability of water extent was considered based on irrigation in nearby area. February (Rabi season) was considered for water availability for at least 8 months and May was considered for water availability for at least 11 months. It was assumed to be the minimum water extent throughout the year.

Satellite data acquisition: For the present study, Sentinel-2 Multispectral Instrument (MSI) satellite data from 2019 to 2022 was obtained from the open access Copernicus Hub. In image analysis, band-3 (green band) and band-8 (near infrared band) were used with the spatial resolution of 10 m. For estimating reservoir water spread dynamics, a total of 16 images were processed, i.e., 2 images each for February and May over the four-year study period. WPF estimation was performed using 64 images, implying that a total of 8 months were studied (June, July, August and September excluded due to high cloud cover in satellite images). Figure 1 shows diagrammatic representation of the methodological framework adopted for WSA and WPF assessment.

Waterbody boundary formation: The reservoir outer boundary shapefile was created in Quantum GIS (QGIS). Sentinel 2 MSI image from November 13, 2019, was used for this purpose. The farthest water mark of a waterbody visible as tonal discontinuity of wet areas from the bordering dry area was used to define the outer boundary of a waterbody (Anand et al 2020).

Water body extraction: Water indices such as Normalized Difference Water Index (NDWI) (McFeeters 1996) differentiates between the water, soil and terrestrial features. NDWI is basically used to delineate and monitor changes in surface water and can be calculated using the green band and near infrared (Eq. 1).

$$NDWI = \frac{G - NIR}{G + NIR} \qquad \text{(Eq. 1)}$$

where, G is green and NIR is near infrared channel named as band-3 and band-8, respectively in the sentinel 2 dataset. In QGIS, NDWI was calculated using the raster calculator tool and clipped with the reservoir outer boundary vector shape file to extract only reservoir information. NDWI value ranges between -1 to +1 where the values between -1 to 0 represents the soil and terrestrial feature (non-water area) and 0 to +1 represents the water feature. These values of the pixels were threshold manually by comparing with the true colour composite image with the NDWI product and the NDWI product's values of water (1) and non-water (0) pixel.

Assessing the water spread dynamics: Considering the annual rainfall fluctuation and changing pattern of water usage, WSA of four subsequent years (2019-2022) were studied for the true representation of water spread dynamics of the reservoir. Classified image of WSA derived from NDWI for February (8 months) for four succeeding years were aggregated into a single February composite map. Similarly, single water availability layer was prepared for May (11 month). Area of both the maps were calculated using the attribute table.

Composite seasonal WSA map: Aggregate maps of February and May were integrated and one final composite map was generated for WSA. The two aggregate bit map images were first converted into vector shape files and then merged in QGIS using the union tool. The polygon in the

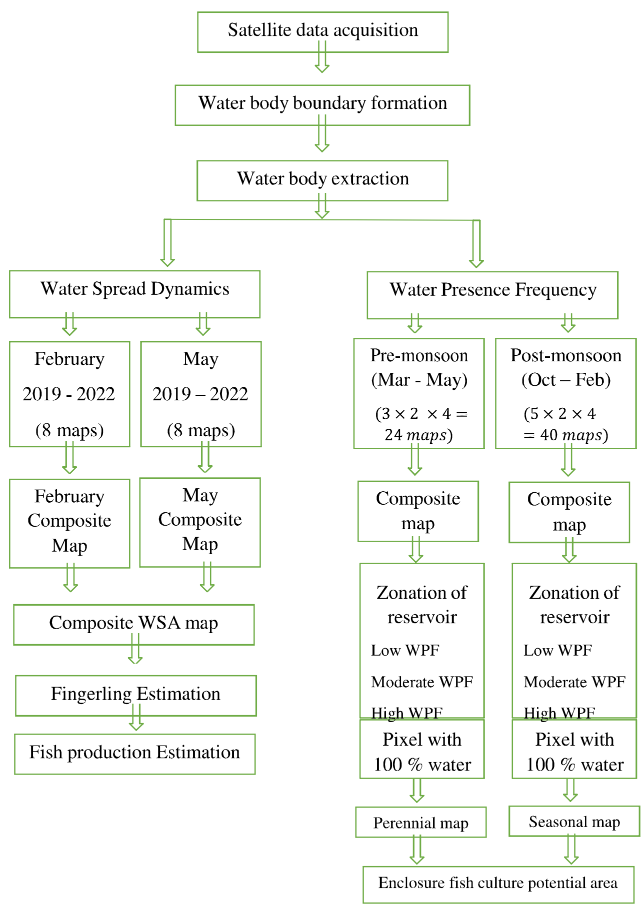

Fig. 1. Diagram of the methodological framework used in this study

composite layer was divided into three zones (Anand et al 2020):

1. Dry bed zone/zone with less than 8 months of water availability
2. 8-month water availability zone from June/July to February/March
3. 11-month zone that retains water from June/July through May

Estimating fingerlings requirement and minimum fish yield potential from seasonal WSA: Number of fingerlings required for stocking in water availability zone was calculated using the following Eq. 2.

$$F = a \times SD \quad \text{(Eq. 2)}$$

where, F, the average minimum fingerling required per year; *a*, the average WSA, SD, the minimum stocking density suggested by the Government.

The average WSA means average of February (8 months) and May (11 months). i.e., here, average WSA of February and May was considered to eliminate the risk of overstocking (if area for February was considered) or understocking (if the area of only May was considered).

Minimum fish yield production potential was calculated using the following Eq. 3.

$$Y = F \times AW \times SR \quad \text{(Eq. 3)}$$

where, Y, potential fish yield from the reservoir; F, estimated number of fish fingerlings to be stocked; AW, average body weight of individual fish; SR, survival rate

Assessment of seasonal WPF: WPF was estimated using the following Eq. 4 (Anand et al 2020). The reclassified NDWI images were integrated in pre-monsoon and post-monsoon bit maps.

$$WPFj = \frac{\Sigma^{n}_{i=1} I_j}{n} \times 100 \qquad \text{(Eq. 4)}$$

where WPFj, WPF of jth pixels in a time period; Ij, jth pixel having water in the selected NDWI images; n, number of images.

The values of WPF ranges between 0 to 100%, as these values approaches to 100% the frequency of the water presence in the pixels increases, lower values indicate less frequent water appearance in the pixel. Based on these values of the WPF, the map was classified in three classes as low (WPF, 0-33%), moderate (WPF, 33 – 66%) and high (WPF, 66 -100%), pixels with 0% WPF were classified as no water area (dry beds).

Potential area estimation for enclosure culture: The WSA of the reservoir was divided into two parts namely, seasonal and perennial area.

Perennial area: The perennial area is the area of the reservoir where the WPF was 100% in the pre-monsoon season, i.e. this is the area where the water will be present almost year-round (11 months). Pixels with 100% WPF in the pre-monsoon composite map were recorded to generate a perennial area map.

Seasonal area: Pixels with 100% WPF in the post-monsoon composite map were recorded to generate the seasonal WSA map.

Reservoir bathymetry assessment: For the establishment of the enclosure culture in the reservoir, one more important criterion should be considered is the depth of the reservoir. In the present study, depth of the reservoir was estimated using DEM through these steps:

Generation of path map: Using Latitude and Longitude Path map of the reservoir prepared in Google Earth Pro

Generation of elevation map: Elevation data has been generated on the open access GPS Visualizer website using the path map

Interpolation: Interpolation is a statistical method by which related known values are used to estimate an unknown value or set of values. There are various methods of interpolation from which Kriging was used for the study because of its superiority over other methods (Khattab et al 2017)

Clipping the reservoir area: Water area of the reservoir has been clipped using the shape file of the full reservoir (maximum water availability zone)

Classification: Based on the elevation of the given sample points, reservoir depth was classified at 2 m depth interval

Water column measurement for the seasonal and perennial water area: Using the coastal boundaries water column range were estimated for the seasonal and perennial waters.

RESULTS AND DISCUSSION

Seasonal water availability in the reservoir: Using NDWI, the available WSA of the reservoir was studied for February and May (Table 1). The maximum WSA of the Manar reservoir was 2490.86 ha, average WSA in February and May (2019-2022) was 2250.41 ha and 1740.9 ha, respectively (Fig. 2). This shows that the reservoir is holding a huge amount of water throughout the year i.e., around 90 percent till February and 69 percent till May.

Estimation of fingerlings requirement: In case of small and medium reservoirs, auto- stocking is not possible. For better utilization of the waterbody, regular stocking of the hatchery-reared fish seeds is required. The National

Table 1. Seasonal WSA of the reservoir

WSA	Post-monsoon	February	May
In hectares (ha.)	2490.86	2250.41	1740.19
In percentage (%)	100%	90.34%	69.86%

Fisheries Development Board (NFDB) proposes reservoir stocking at a standard stocking rate of 1000 fingerlings but implementing agencies can alter the stocking rate based on size of the reservoir, water retention capacity, prevalence of predators and productive water area. The medium and large reservoirs should be stocked with a minimum of 500 fingerlings per hectare (NFDB, 2014). Considering the minimum stocking density suggested by the NFDB, estimated minimum number of fingerlings needed for effective waterbody utilization is around 10 lakhs (Table 2).

Estimation of fish production potential: Fish production depends on several limnological, hydrobiological ad climatic features of the waterbody (Pal & Yadav 2022). This governing feature differs in every water body and that affects production potential of the water body. For the calculation of potential fish production, a 10% survival rate is considered with average weight of fish as 2kg (Anand et al 2020). Estimated fish production potential is around 200 mt (Table 3).

Seasonal WPF: WSA and the water storage capacity of the waterbody can be correlated with sediment deposition and the natural sedimentation process is changing due to several human activities (Kummu et al 2010, Pandey et al 2016) therefore, it is necessary to estimate WPF of the reservoir

Table 2. Estimated fingerling requirement for the reservoir

Month	Area of water availability zone (ha)	Stocking density (SD) (nos./ha)	No. of fingerlings required (F)
Feb	2250.41	500	1,125,205
May	1740.19	500	870,095
Average	1995.3	500	997,650

Table 3. Estimated fish production potential

Month	Fingerlings required	Potential yield (mt)
Feb	1,125,205	225.041
May	870,095	174.02
Average	997,650	199.53

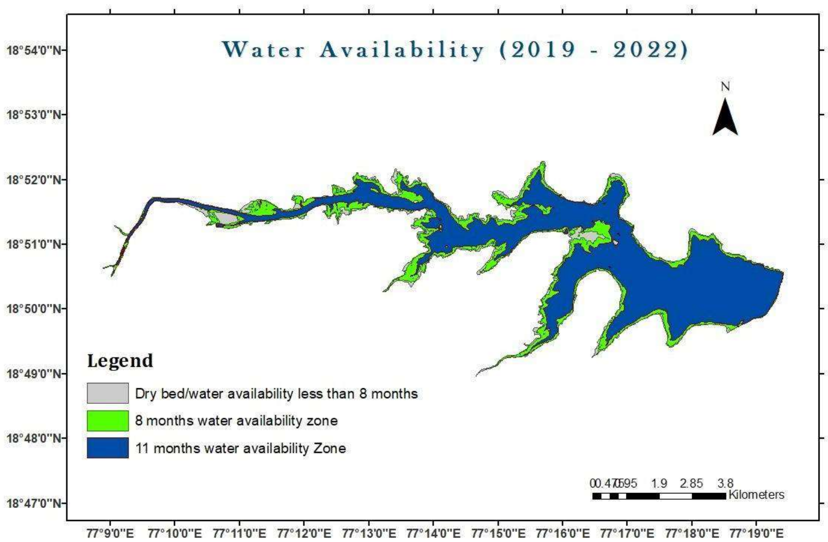

Fig. 2. Seasonal WSA of the reservoir

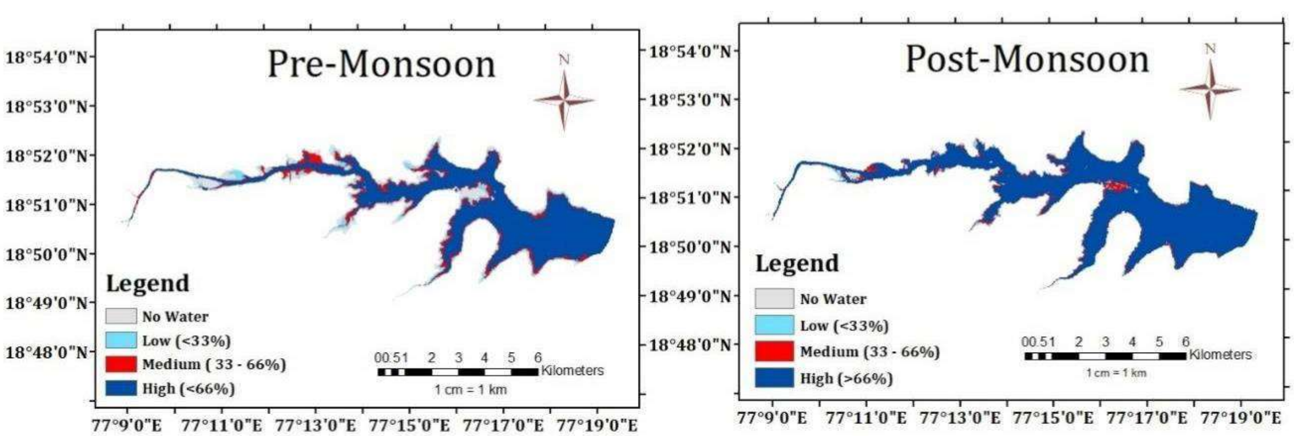

Fig. 3. Seasonal and perennial WPF map

Table 4. Seasonal and perennial WPF map

WPF	Post-Monsoon (October-February)		Pre-Monsoon (March-May)	
	Area (ha)	% of total	Area (ha)	% of total
No Water Zone	34.8405	1.39%	316.714	12.55%
<33%	102.258	4.10%	280.12	11.24%
33-66%	165.312	6.63%	305.95	12.24%
>66%	2186.72	87.79%	1586.89	63.70%
TOTAL	2490.86	100%	2490.86	100%

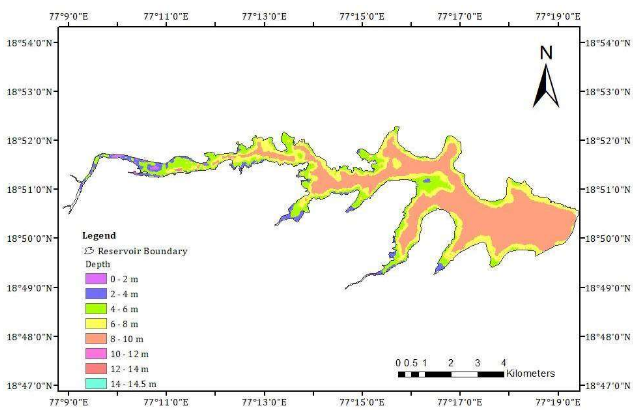

Fig. 4. Post-monsoon bathymetry map of the reservoir

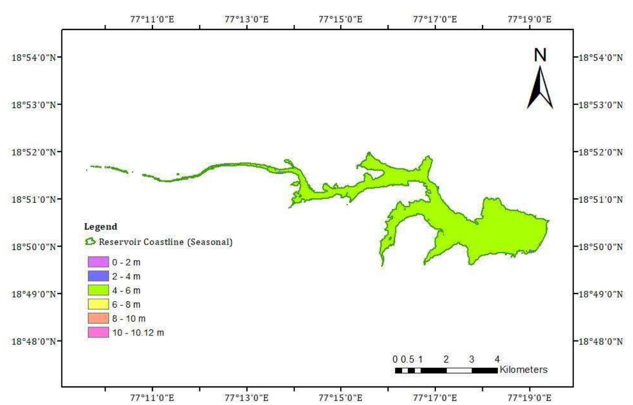

Fig. 5. Seasonal area bathymetry map of the reservoir

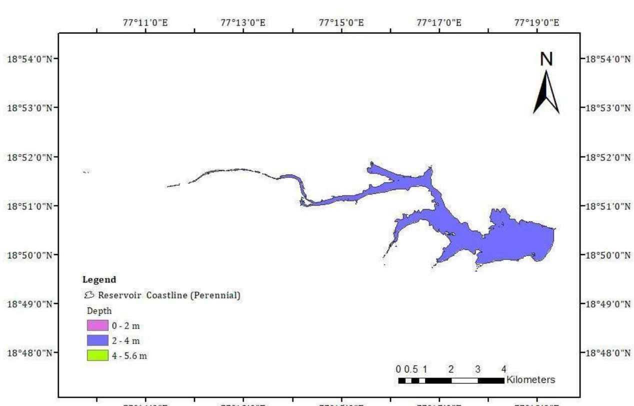

Fig. 6. Perennial area Bathymetry map of the reservoir

Table 5. Seasonal and perennial WSA

Reservoir	Category	Area (ha)	%
Manar Reservoir (2490.86 Ha)	Seasonal area	1192.55	47.87%
	Perennial area	820.789	32.95%

before setting up any fish culture activity in the reservoir (Table 4 , 5). Approximately 87.8 and 63.7% of the reservoir area is showing high water presence in the post-monsoon and pre-monsoon seasons respectively. The study reveals that the reservoir is retaining a good amount of water (32%) throughout the year. WPF map of the reservoir during pre-monsoon and post-monsoon shows the area of the reservoir having potential for the enclosure culture based on the WPF (Fig. 3).

Reservoir bathymetry assessment: From the bathymetry analysis, in the post-monsoon season, the deepest point of the reservoir is having a depth of 14.5 m, but majority of the reservoir area is falling in the range of 4-10 m depth (Fig. 4). The seasonal and perennial WSAs have the majority water depth in the range of 4-6 m and 2-4 m, respectively (Figs. 5, 6). Permanent cage culture cannot be established in Manar reservoir as the requirement of at least 10 m water depth (as per NFDB) has not been met. Fish production of the reservoir can be enhanced by stocking bigger sized fingerlings, study has depicted a 12.6% increase in fish yield by raising smaller fingerlings in pens and releasing them into a beel (Debnath et al 2021). For fingerling rearing, pens can be constructed in the potential reservoir area which retains a good amount of water.

CONCLUSION

The study was conducted to measure the WSA of the reservoir throughout the year and to suggest the required stocking material of seed so that its potential can be adequately utilized. The reservoir is currently being stocked with the minimum stocking density, but the actual production from 2019-2021 is similar to the estimated production. In order to achieve the maximum potential production, stocking can be increased. Cage culture cannot be practiced in the

Manar reservoir because of low depth. However, the production can be increased by increasing stocking density of bigger sized fingerlings to 1000 numbers/ha/year in pen culture. Various studies have accounted for the threats of sedimentation on water storage capacity and sustainability of the reservoir and is proposed to assess reservoir sedimentation in order to determine its impact on the WSA and reservoir depth.

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