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Assessing land suitability for sustainable aquaculture development in Muzaffarpur, Bihar using integrated approach of multi-criteria decision analysis and GIS

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Abstract

The study aimed to assess land suitability for sustainable aquaculture development in Muzaffarpur, Bihar, India, utilising a multi-criteria decision analysis (MCDA) and GIS-based approach. In India, issues such as water and soil degradation, insufficient infrastructure and inadequate maintenance pose significant challenges to aquaculture growth. The research employed 15 base layers, including water quality, soil characteristics, engineering parameters and high-resolution satellite imagery, analysed through the Analytical hierarchy process (AHP) and GIS-based multi-criteria evaluation. Results revealed 9.85% highly suitable and 35.09% unsuitable areas for fish farming, achieving an 80% overall accuracy through validation with satellite images and field visits. The study provides valuable insights for policy makers, farmers, and resource managers in selecting suitable sites for sustainable aquaculture, enhancing resource management in the region.

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Introduction

Aquaculture is an important subdivision of food production in India which provides nutritional security, besides livelihood support and profitable employment to more than 14 million fishers and fish farmers. With the vivid and diverse resources ranging from marine capture fisheries across 8129 km^2 of shoreline and continental shelf area to inland water bodies such as reservoirs, rivers, ponds and cold-water lakes, derelict water areas (Wije nayake *et al.,* 2016; USUP *et al.,* 2021). Indian subcontinent is the habitat to biodiversity hotspots, water heritage sites and several endemic fish species which contributes more than 10% of the worldwide biodiversity (DoF, 2020; NFDB, 2020). Since its independence, the country has seen a steady and consistent growth in both fish farming and fishing from both fresh and saltwater. There has been a notable increase in the production of fish from both fresh and marine sources. This has been achieved through the implementation of various initiatives such as aquaculture, resource management and conservation efforts which have improved the sustainability of the fishing industry. The government has also invested in infrastructure, technology and training for fishermen, which has helped to enhance their productivity and efficiency in the industry. As a result of these efforts, the country has seen an increase in fish production, which has had a positive impact on the economy (Zhang *et al.,* 2015; Yu *et al.,* 2016).

According to assessments from the National Fisheries Development Board (NFDB) and Department of Fisheries, the global fish production in 2017-18 was estimated at 12.60 million t. Of this, approximately 65% originated from the inland sector and 50% from aquaculture fisheries. This constitutes 6.3% of the global fish production (DoF, 2020; NFDB, 2020).

Owing to greater awareness on health among the youth and due to Its highly nutritive value in terms of PUFAs, vitamins and minerals, it is one of the most consumable and demandable food items globally and domestically (Thompson *et al.,* 2016; Subramani *et al.,* 2017; Teixeira *et al.,* 2018). India is the largest exporter of fish and fish products in agricultural export sector. Seventy-five countries around the world's major countries such as United States of America, South East Asia and European Union import more than 50 different types of fish and shellfish products which attributes a quantity of 13.77 lakh t valued at ₹45,106.89 crore (Ngasotter *et al.,* 2020; Rajeev and Bhandarkar, 2022). According to research by Hamilton *et al.* (2020), Hossain *et al*. (2009) and Hossain and Das (2010), exports account for approximately 10% of the entire exports and nearly 20% of the agricultural exports, contributing 0.91% to the GDP and 5.23% to the Agricultural GDP of the country.

In order to meet the demand for scrumptious fish produce, dependency on capture fisheries will not only overburden the resource but also have deleterious impact on the environment (Falconer *et al.,* 2016; Gimpel *et al.,* 2018; Gameiro *et al.,* 2022). Inland fisheries and aquaculture are growing tremendously in the last two decades due to the diverse nature of fisheries resources (Aura *et al.,* 2018, 2019, 2020). Once sighted as subsistence activity, today farmers, businessmen and entrepreneurs are attracted towards fish culture as it is a profitable agribusiness generating sustainable profits under sound techniques and technologies (Silva *et al.,* 2011, 2012; Richard and Ogba, 2016; Prasad *et al.,* 2019; Shunmugapriya *et al.,* 2021; Phu *et al.,* 2022). Many of the landlocked states such as Haryana, Uttar Pradesh and Bihar are producing a substantial share in inland fish production though culture of shrimp in inland saline soils, carp and pangas farming in ponds, fish cum shingara (water chestnut) and makhana cultivation in flood plain wetlands respectively after deeply understanding the future benefits of these non-conventional resources as another source for sustained income for the farming community (Ongore *et al.,* 2018).

Bihar is a landlocked state consecrated with 2800 km stretch of rivers; 2,00,000 ha of tal area and floodplain wetlands; 9,000 ha of oxbow lakes 25,000 ha of reservoirs and 90,000 ha of ponds and tanks (Lal *et al.,* 2020; Chand and Prasad 2021). Fish is a highly sought-after food item, particularly during certain periods among Hindus, while other communities across the country consume it extensively. With some significant taboos, carps are the most cultured fish species along with other species such as pangas and catfishes that have recently gained prominence due to their faster growth and high market demand (Assefa and Abebe 2018; Anand *et al.*, 2020; Aura *et al.,* 2018, 2019, 2020; Boitt and Aete, 2021). With a fish production of 5.9 lakh t in 2017-18 (Singh *et al.,* 2020), a deficit of 0.5 lakh t persists in the state of Bihar, that is met by imports from other states like Andhra Pradesh. Unfortunately, cases of formalin contaminated fishes having reported (Kundu *et al.,* 2017; Mehmood *et al.,* 2017; Kumar *et al.,* 2018; Iversen *et al.,* 2020; Mohsin *et al.,* 2022), posing a threat to public health. Availability of quality seed is the major constraint faced by several farmers in the state and further, lack of proper knowledge and skill among farmers contribute to the low production from the available resources in the district.

Considering the fisheries scenario in the state, there is need to understand the potential of the inherent water resources through proper management measures that span various aspects, including meticulous site selection for aquaculture based on water availability and soil conditions. A key factor to enhance the state's fisheries sector involves strategic development of hatcheries. This ensures a continuous and reliable supply of good quality fish seed to farmers. To further boost aquaculture production, there is a need to diversify aquaculture practices in terms of species diversification, management practices and introduction of new technologies such as ornamental fish rearing as well as establishment of markets in close proximity to aquaculture sites, ensuring freshness of the product and fair prices to the fish farmer. Fish, being a highly perishable commodity, needs a streamlined supply chain to minimise post-harvest losses (Ngoc *et al.,* 2016; Nayak *et al.,* 2018; Mwamburi *et al.,* 2020). A comprehensive approach that encompasses proper site selection, robust hatchery development, diversification of aquaculture practices and strategic market placement is essential for aquaculture development in the state. This paves the way for application of remote sensing and GIS techniques in fisheries and aquaculture for righteous decision and precision management (Anand *et al.*, 2020).

Muzaffarpur District of Bihar is endowed with rich water resources such as rivers, ponds and tanks and flood plain wetlands that are locally known as Chaurs and Mauns. This provides an ample scope for aquaculture owing to the high demand among the locals and in the nearby districts. Fish being a cheap source of protein and rich in essential amino acids and fatty acids, forms source of proteinaceous food as well as livelihood for poor fishing communities in the region. But unpredictable monsoon and prolonged periods of drought has enhanced the uncertainty of successful fish production. The problem is further aggravated due to improper site selection such as digging of ponds in soils with heavy seepage and relying permanently on groundwater, that can have serious impediments in near future as groundwater levels are declining day by day. Further, availability of quality seed, feed and aqua medicines are another limitation, faced by fish farmers in the region. Thus, proper site selection and availability of proper infrastructure and ancillary support can boom fish production in the district.

Materials and methods

Study area

Muzaffarpur District located in north Bihar between latitudes 25°53'52.475"N to 26°15'33.053"N and longitudes 85°43'15.814"E to 84°52'6.792"E covering an area of 3,175.9 square km (Fig. 1). Muzaffarpur District has sixteen blocks with four rivers, *i.e.* rivers Gandak, Budhi Gandak, Bagmati and Lakhandei. Study area falls in the highly potential area from agricultural point of view (Gangetic plain) and mostly the area cover sandy and sandy loam soil. Topography in the study area is found between 1 to 5% slope. Muzaffarpur District comes under sub–humid climatic zone which receives an average annual rainfall of 119 cm, more than 85% from monsoon in the period of June to October and posing more than 50 days as rainy days. Muzaffarpur has humid subtropical climate as illustrated by Koppen climate classification. West part of the study area is affected by waterlogging. This study utilises satellite image LANDSAT 8 ETM with spatial resolution of 15 m for identifying waterlogged area with the help of time series satellite data. The

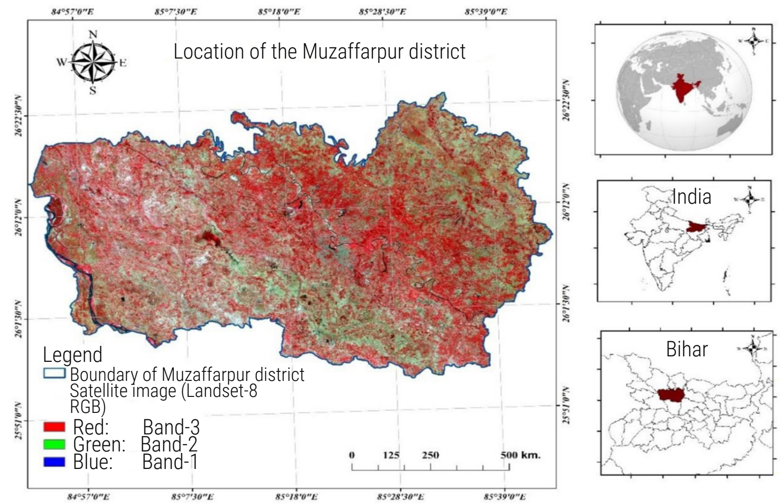

Fig. 1. Geographical location map of the study area

maximum and minimum temperature and relative humidity of this region is 44.5^{0}C and 20.3^{0}C and 71% respectively. The most part of the area comes under the banks of the perennial Budhi Gandak River and connected with Ganga basin, having reservoirs, rivers, lakes, ponds and other waterbodies. Clay, silt and sandy loam soil are mostly found in the study area. In Muzaffarpur District fisheries plays an important role in income generation for fishers and also serves as a source of protein diet for villagers.

Data and methods

The methodology adopted to identify site suitability for fish farming during the present study is shown in Fig. 2. Different data sets were prepared such as water quality (Electrical conductivity, pH, Nitrogen, Phosphorus, Organic Carbon); soil quality (pH, Total dissolved solids, Nitrate, Electrical conductivity, Calcium) and engineering parameters (Topography, Drainage, Distance from the water source, Soil texture) using Remote Sensing and GIS techniques. The data were analysed and processed using GIS software *viz.*, ArcGIS and QGIS for identifying the water resources and water bodies like rivers, streams, canals, ponds and tanks. The drainage and slope map were prepared using Digital Elevation Model (DEM) of 30 m higher resolution SRTM remote sensing data (Nayak *et al.,* 2018; Ghobadi *et al.,* 2021; Tarunamulia and Sammut, 2023). The primary data (soil and water parameter) were collected from different departments as per Table 1. Data analysis was done in GIS environment and different thematic maps for soil parameters (Soil texture, pH, Organic carbon, Nitrogen, P_20_5, EC) and water parameters (pH, TDS, NO_3, EC, Ca) were prepared. Meteorological data were collected from Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar, India. Secondary data was generated with a high resolution of 30 m Landsat-8 ETM satellite image data *i.e.,* Blue (band-2), Green (band-3), Red (band-4) and Near Infrared Band (band-8) from Earth Explorer (https://earthexplorer.usgs.gov/) and was used for Normalised Difference Vegetation Index (NDVI) and Normalised Difference Water Index (NDWI). Ground verification data were collected from study areas with ground points using Global Positioning System (GPS) and digital photographic camera and accuracy of prepared thematic data were improved.

Soil texture and soil quality parameters play key roles for water holding and fish cultivation. The five soil quality parameters *viz.*, pH, organic carbon, nitrogen, P_2O_5 and EC were estimated. Effort was made towards estimation of five water quality parameters in water bodies (pH, TDS, NO_3, EC and Ca) (Nayak *et al.,* 2018). Some of the existing waterbodies exhibit complex features such as turbidity, eutrophication and pollution.

Soil quality parameters

The general requirements for positioning an aquaculture venture are related to the tolerance of the species and the engineering systems (Ghobadi *et. al.,* 2021). Soil quality data were interpolated with IDW tool in GIS software and spatial map was prepared (Fig. 3.)

The main soil parameters considered in this study were pH, organic carbon, nitrogen, P_2O_5 and EC (Table 1), which were estimated following standard methods (Rongoei *et al.,* 2016), analysed and thematic layers were prepared.

Table 1. List of data set and source

Data used	Parameters	Source
Soil data	Soil texture, pH , Organic carbon, Nitrogen, P_20_5, EC	Soil Science Department, Govt. of Bihar
Water data	pH, TDS, NO_3, EC, Ca	Central Ground Water Board (CGWB)
Meteorological parameters	Annual rainfall, Temperature, Relative humidity, Evaporation, Wind speed	DRPCAU, Pusa, Bihar
Satellite data (Landsat 8)	Land use and land cover, Monthly waterlogged area	Earth explorer (https://earthexplorer.usgs.gov)
Topography/Elevation data	DEM, slope	Earth explorer: (SRTM DEM 1 Arc second)

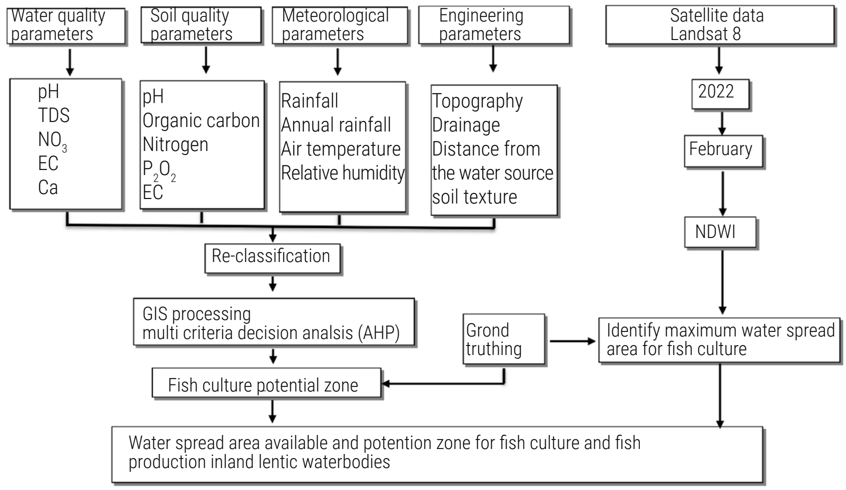

Fig. 2. Flow chart elaborating the methodology for site suitability for fish farming

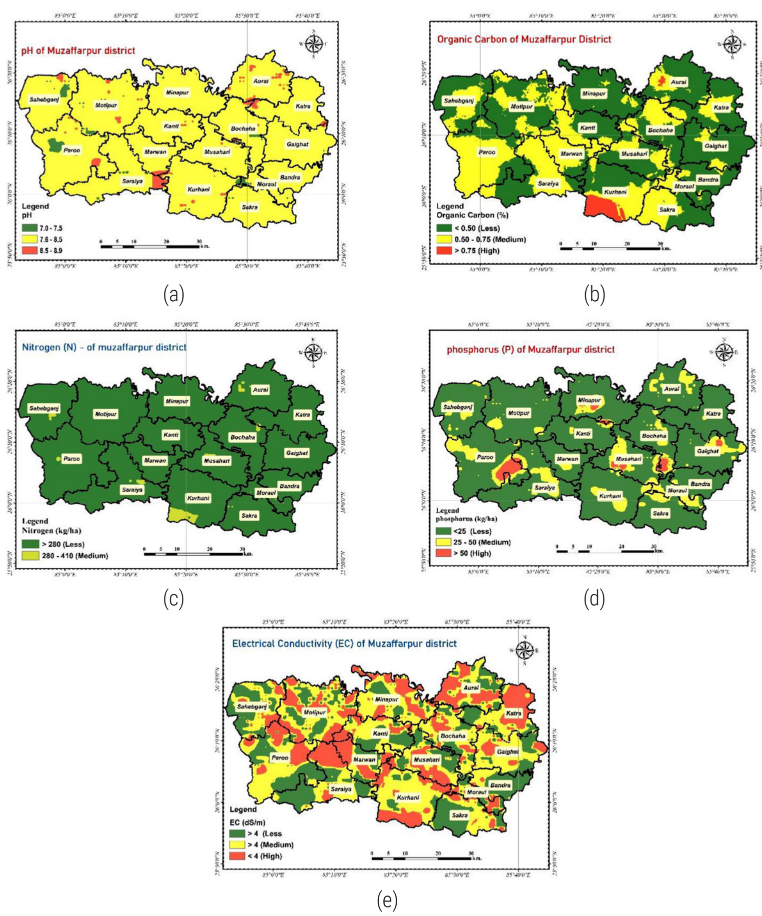

Fig. 3. Water quality parameters (a). pH, (b). Organic carbon, (c). Nitrogen, (d). Phosphorus and (e). Organic carbon

Water quality parameters

The water quality parameters generally monitored in aquaculture are pH, TDS, NO_3, EC and Ca (Table 1). The water quality data of operational freshwater fish farms were collected from Central Ground Water Board (CGWB) Report 2017 . The data were analysed in GIS and spatial map was prepared (Fig. 4) (More *et al.,* 2019; Singh *et al.,* 2020).

Meteorological parameters such as rainfall, maximum temperature, minimum temperature, evaporation are very important for fish farming (Fig. 5). Water sources for inland fisheries and aquaculture are developed from amount of rainfall and its annual distribution received in the study area which plays an important role (Anand *et al.,* 2020; Mohsin *et al.,* 2022).

Coldwater fish species will not tolerate temperatures above 20 to 27°C. Rise in temperature beyond the optimum temperature affects growth of fish

Engineering parameters

Engineering parameters such as slope, drainage, water bodies and soil texture (Fig. 6) play important roles in assessing potential areas suitable for fish farming. Slope and drainage map were prepared with the help of SRTM DEM of 30 m resolution in GIS environment to estimate surface water storage.

The water bodies and wetlands maps were prepared with NDWI using satellite imagery and verified with observed ground data (Nayak *et al*., 2018).

GIS-AHP-MCDA model framework

Fish farming suitability map developed with the help of AHP technique (Saaty,1980), is a multi-criteria decision-making approach

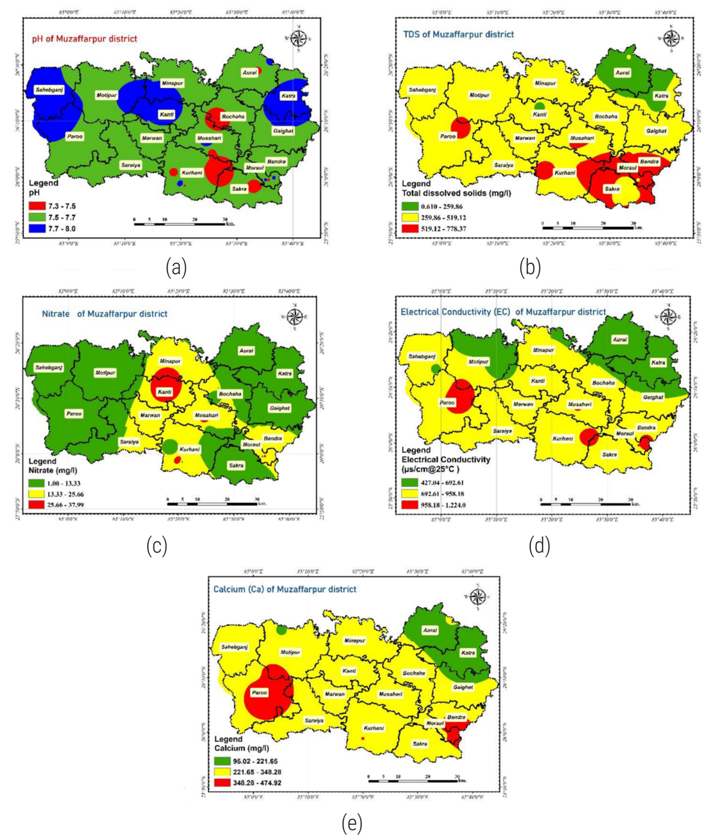

Fig. 4. Water quality parameters (a). pH, (b). Total dissolved solids, (c). Nitrate, (d). Electrical conductivity and (e). Calcium

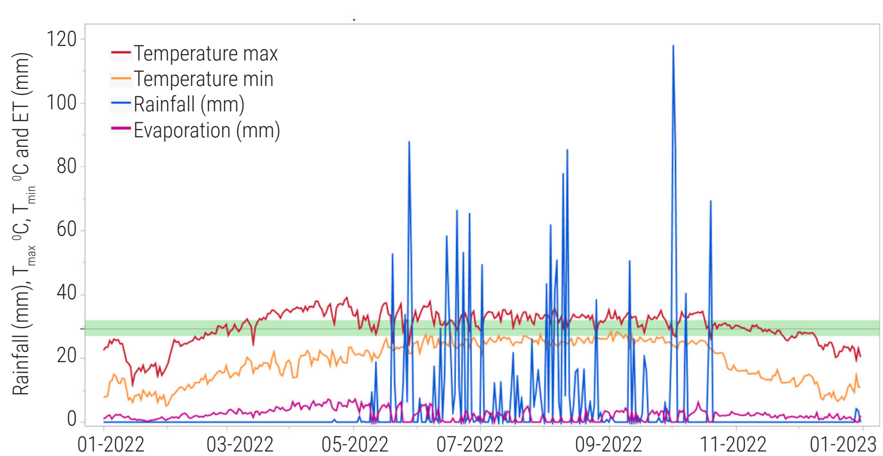

Fig. 5. Effect of temperature on fish growth

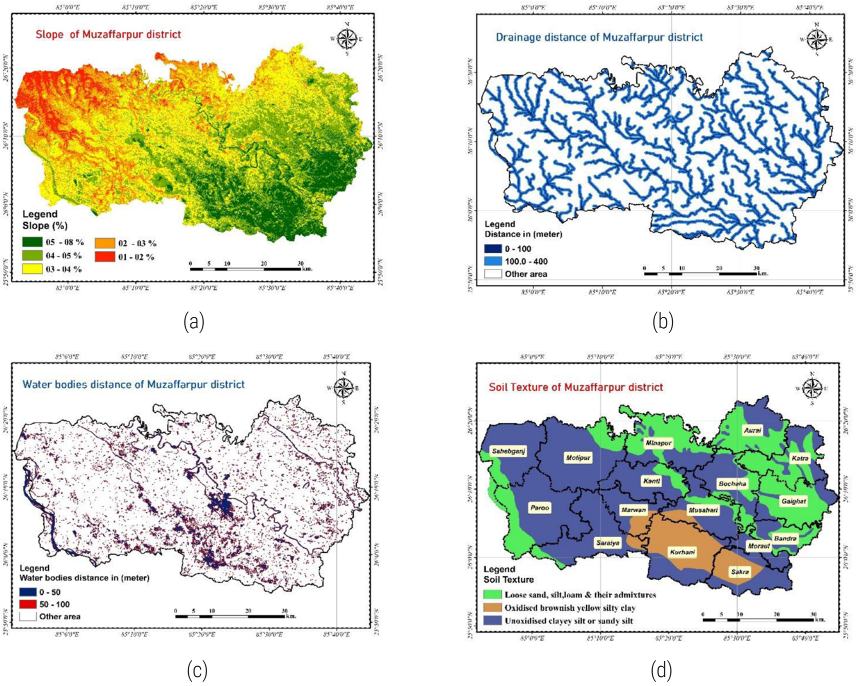

Fig. 6. Engineering parameters (a). Topography, (b). Drainage distance, (c). Drainage distance from the water source and (d). Soil texture

(MCDA) where criteria are arranged in hierarchical structure. It is a mathematical approach to solve the complex problems using multiple criteria.

The Analytical hierarchy process (AHP) is a widely used decision-making tool (Kumar *et al.*, 2014; Kumar and Jhariya, 2015, Nayak *et al.,* 2018). The process begins by decomposing a decision problem into a hierarchical structure of sub-problems. To evaluate the relative importance of each element, decision-makers use pairwise comparisons to assign numerical values (weights or priorities). These values are then used to calculate a score for each alternative (Saaty, 1977, 1980, 1991). Additionally, a consistency index is used to measure the consistency of the decision-maker's responses. One potential limitation of the AHP is the phenomenon of 'Rank Reversal'. This occurs when the relative ranking of alternatives changes due to the addition or removal of new alternatives to the model (Saaty, 1977, 1980, 1991). Table 2 provides a scale with values running from 1 to 9 that was employed in this technique.

If the pair-wise comparisons are fully consistent, matrix will have rank 1 and the maximum value will be equal to the number of elements of the relevant pair-wise comparison. In this scenario, the weights can be calculated by standardising any of the rows or columns. Saaty (1980) presented a rating scale for the AHP method, which is depicted in Table 2 and 3. The standard solution outlined by Saaty (1980, 2003) was used to evaluate the consistency of the AHP decision matrices. If the maximum value (λ max) is equal to the number of elements of the relevant pair-wise comparison, it means that a consistent matrix is available. Otherwise, if λ max is greater than the number of elements of the relevant pair-wise comparison, the matrix is deemed inconsistent.

$$CI = \frac{(\lambda max - n)}{n-1} \quad \text{......(1)}$$

$$CR = \frac{CI}{RI} \quad \text{......(2)}$$

whereas the pairwise comparison matrix provides essential information about the importance of one criterion on a scale of 1→9.

The importance of a certain criterion on a scale of 1 to 9 can be measured by two indicators: the Consistency Index (CI) and the Consistency Ratio (CR) (Eq. 1). The ratio of CI to Random Index (RI) is CR (Eq. 2). According to Saaty (1980), CR should not surpass 0.1. If this proportion is exceeded, the entire decision process should be reexamined. The CR of the study area in this case is 0.075, which is less than 1. Subsequently, the inconsistent pair-wise comparison matrices were modified by decreasing or increasing the value that

Table 3 Saaty's ratio index for different values of N

N	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.89	1.12	1.24	1.32	1.41	1.45

Table 2. Saaty's 1–9 scale of relative importance

Scale	1	2	3	4	5	6	7	8	9
Importance	Equal Importance	Weak	Moderate Importance	Moderate Plus	Strong importance	Strong Plus	Very Strong Importance	Very Very Strong	Extreme Importance

was the most disparate until the necessary CR level of 0.1, was attained.

Researchers have found that AHP is an effective tool for analysing decision making in situations where quantitative ratings are not available and human judgment is of great importance in determining the importance of one criterion over another. Saaty (1980, 2003) proposed a reliable method for converting pair-wise comparisons into numerical values that represent the relative priority of each of the criteria shown in Tables 4, 5, 6 and 7. The AHP starts by dividing the decision-making problem into a number of sub-problems, and then evaluates the relative importance of its various elements through pair-wise comparisons. The results of these evaluations are then converted into numerical values (weights or priorities), which are used to calculate a score for each alternative (Saaty 1980, 1990). This weighting and rating of each criterion and sub-criterion allows for their evaluation and helps to understand their significance in achieving the objective of the AHP method, which is used in the MCDM process as shown in Table 8.

Multicriteria investigation based on GIS may be convenient for land assessment in bigger areas for aquaculture development. This will minimise the loss incurred due to ignorance of many environmental and social aspects during pre-establishment of aquaculture farm.

Table 4 Pair-wise comparison matrix of five criterion (soil parameter - AHP)

Suitability criterion	EC	pH	N	P_2O_5	OC	Weight
EC	1.000	0.125	0.143	0.167	0.200	0.037
pH	8.000	1.000	3.000	2.000	1.000	0.335
N	7.000	0.333	1.000	0.333	0.455	0.135
P_2O_5	6.000	0.500	3.000	1.000	1.000	0.242
OC	5.000	1.000	2.200	1.000	1.000	0.251
Total	27.000	2.958	9.343	4.500	3.655	1

CI= 0.047, RI = 1.12, C. Ratio = 0.085, EC = Electrical conductivity, N - Nitrogen=N, $P2O_5$ Phosphorus =, OC = Organic carbon

Table 5. Pair wise comparison matrix of five criteria (water parameter - AHP)

Suitability criterion	Ca	pH	TDS	No3	EC	Weight
Ca	1.000	0.143	0.167	0.200	0.250	0.042
pH	7.000	1.000	3.000	2.020	2.400	0.394
TDS	6.000	0.333	1.000	0.500	1.000	0.161
No3	5.000	0.495	2.000	1.000	2.400	0.257
EC	4.000	0.417	1.000	0.417	1.000	0.146
Total	23.000	2.388	7.167	4.137	7.050	

CI = 0.047, RI = 1.12, C Ratio = 0.032, TDS = Total dissolved solids, = NO_3= Nitrate-N, EC −= Electrical conductivity X, = Ca

Table 6. Pair-wise comparison matrix and relative criteria weightage of five criterion (Climatic suitability parameter - AHP)

Suitability criterion	AR	AT	RH	E	WS	Weight
AR	1.000	0.143	0.167	0.200	1.000	0.073
AT	7.000	1.000	3.000	2.000	1.600	0.367
RH	6.000	0.333	1.000	0.435	0.500	0.148
E	5.000	0.500	2.300	1.000	1.000	0.225
WS	1.000	0.625	2.000	1.000	1.000	0.188
Total	20.000	2.601	8.467	4.635	5.100	1

CI= 0.047, RI = 1.12, C.ratio = 0.057, AR = Annual rainfall, AT = Air temperature, RH = Relative humidity, E = Evaporation, WS = Wind speed

Present study helps in optimum utilisation of fisheries resources of Muzaffarpur region as well as the model can be replicated in similar kind of geographical areas (Kumar *et al.,* 2014; Jhariya, *et al.,* 2016; Jhariya, *et al.,* 2019; Jhariya, *et al.,* 2020; Agnihotri, *et al.,* 2021).

Selection of fish farming sites was done through Multi-Criteria Decision Analysis (MCDA) using Analytical Hierarchy Process (Saaty, 1980). MCDA method empowers a set of criteria for decision making given (Kumar *et al.,* 2014; Jhariya, *et al.,* 2016; Jhariya, *et al.,* 2019; Jhariya *et al.,* 2020; Agnihotri *et al.,* 2021). A set of relative weights for each sub criteria using AHP technique was developed by pairwise comparison matrix given in Table 4, 5, 6 and 7.

Estimation of fish potential area using GIS-AHP technique

The potential areas for fish farming were identified with the help of GIS-AHP technique using three sub criteria such as soil, water and engineering parameters. GIS technology was utilised to measure the relative levels of various categories within individual layers when engaging in multi-criteria assessment. This process helps to identify the rate of each class in the layer. The delineation of fish farming zones for the Muzaffarpur District was found through different weights and by overlaying of thematic layers in ArcGIS. (Kumar *et al.,* 2014; Jhariya, *et al.,* 2016; Jhariya, *et al.,* 2019; Jhariya, *et al.,* 2020; Agnihotri, *et al.,* 2021). The criteria for assigning normalised weights to each thematic layer can be found in Tables 4 to 7. The total normalised weights for the integrated layer were used to calculate the prioritisation of potential fish areas as proposed by Jhariya *et al.* (2020) and Agnihotri *et al*. (2021).

Using the information from Tables 4-8, AHP weights were added to each parameter for soil, water and infrastructure facilities which was created by adding the criteria together using a mathematical equation. The map was used to evaluate various factors and determine the best possible outcome: ($grid_i$*$weight_i$) presented in equation 3, 4, 5.

$Soil_{grid} = Grid_N * 0.135 + Grid_{pH} * 0.335 + Grid_{OC} * 0.251 + Grid_{P2\,O5} * 0.242 + Grid_{EC} * 0.037$ Eq-3

$Water_{grid} = Grid_{pH} * 0.394 + Grid_{NO3} * 0.257 + Grid_{TDS} * 0.161 + Grid_{EC} * 0.146 + Grid_{Ca} * 0.042$ ....Eq 4

$Engineering_{grid} = Grid_{ST} * 0.533 + Grid_{DWS} * 0.269 + Grid_D * 0.147 + Grid_T * 0.052$ ....Eq 5

where, water parameters comprises pH, NO_3 = Nitrate, TDS = Total dissolved solids, EC = Electrical conductivity, Ca = Calcium.

Table 7. Pair-wise comparison matrix and relative criteria weightage of four criterion (Engineering Parameter- AHP)

Suitability criterion	T	D	DWS	ST	Weight
T	1.000	0.125	0.200	0.250	0.052
D	8.000	1.000	4.000	2.000	0.533
DWS	5.000	0.250	1.000	0.250	0.147
ST	4.000	0.333	4.000	1.000	0.269
Total	18.000	1.708	9.200	4.500	1

CI= 0.047, RI = 0.89, C ratio = 0.042, T = Topography, D = Drainage, DWS = Distance from the water source, ST = Soil texture

Table 8. Soil, water, climatic and engineering parameters for suitability of aquaculture farming in Muzaffarpur District, Bihar (Source: Anand *et al.,* 2021, Esmaeilpour *et al.,* 2019, Hossain *et al.,* 2009 Mohanty *et al.,* 2017, Nayak *et al.,* 2018 and Ghobadi *et al.,* 2021).

Parameter	Unit	Suitability range of parameter		
		Highly suitable	Moderately suitable	Not suitable
Water quality parameter				
pH	-	6.5 to 8.5	6 to 9	<5 or >9.2
TDS	mg l^{-1}	<400	400-600	<600
NO_3	mg l^{-1}	0.02 to .05	0.05 to 0.4	0.4 to 2.5
EC	mg l^{-1}	< 400	400-600	>600
Ca/Alkalinity	mg l^{-1}	75-300	300	
Soil quality parameter				
pH	-	6.5-7.5	5.5-6.5	<5.5
Organic carbon	%	>1.5	0.5-1.5	<.0.5
Nitrogen	(mg100 g $soil^{-1}$)	>50	25-50	<25
Phosphorus	(mg100 g $soil^{-1}$)	>6	3-6	<3
EC	mg l^{-1}	<4	<4	>4
Climatic suitability parameters				
Annual rainfall	Mm	>1200	1200-600	>600
Temperature	°C	25–32	12–25	<12, >32
Relative humidity	(%)	30 - 50%	50-70%	<30 and >50
Evaporation	mm day^{-1}	<2	2-4	>6
Engineering parameters				
Topography	%	0–5	5–15	>15
Drainage distance	m	<500	500-1000	>1000
Distance from the water source	m	<500	500-1000	>1000
Soil texture	Texture	Clay loam	Sandy clay	Loam, sand

Soil parameters include N = Nitrogen, pH, OC = Organic carbon, P_2O_5 = Phosphorus, EC = Electrical conductivity

Engineering parameters include Soil texture, DWS = Distance from the water source, D = Drainage, T = Topography

Extraction of satellite Imagery of water bodies

The delineation of water bodies from satellite images is a great challenging task. The high-resolution map used for identification of ponds, lakes, canals and rivers and for estimation of water availability and water spread area (Ke *et al.,* 2015, Ashok *et al.,* 2021). Surface water maps are essential for many environmental applications. Normalised Difference Water Index (NDWI) (McFeeters, 1996) was used for generating a water surface area map (Eq. 6):

$$NDMI = \frac{X_{Green} - X_{NIR}}{X_{Green} + X_{NIR}} \quad \text{.........}(6)$$

Results

The suitability of land for fish farming in Muzaffarpur District was evaluated using AHP weighted overlay technique. This technique involved analysing multiple parameters, such as water parameters comprising pH, nitrate, total dissolved solids and electrical conductivity; soil parameters such as nitrogen, pH, organic carbon, phosphorus and electrical conductivity as well as engineering parameters such as soil texture, drainage, distance from the water source, drainage and topography in a Geographic Information System (GIS) environment. Using these criteria, potential zones suitable for fish production were identified by assigning appropriate AHP weights to different thematic layers. Suitable zones for fish farming in the Muzaffarpur District identified based on the results of this analysis are shown in Fig. 7, 8, and 9.

In this research, a suitable land for fish culture was determined by utilising the AHP, GIS and Remote Sensing techniques. Eighteen factors, including soil, water, meteorological and engineering, were selected to calculate the weights of each factor based on the data from Table 4, 5, 6 and 7. According to the AHP model, pH has the most suitable weight (39%) followed by Nitrate (25%) among the water quality parameters. IAmong the soil quality parameters, the most suitable weights were found for soil pH (33%) and organic carbon (25%). Among the Agro-meteorological parameters, temperature (36.7%) and evaporation (22.5%) had the most suitable weights. Among the engineering parameters, the most suitable parameters were soil texture (53.3%) and slope (26.9%). Water quality played a key role of 54%, compared to soil quality of 24% and infrastructure facilities of 22%, for fish farming in the region.

Soil quality has been found with the help of 5 input criteria such as pH, organic carbon, nitrogen, P_2O_5 and EC. Calculated AHP weights (Table 6) were applied in GIS software and found suitability of soil zone for fish farming. The soil zone area based on AHP method has been classified into three categories such as low (31.43 %), moderate (46.58 %) and highly (21.99 %) suitable (Fig. 8.)

The suitability of land for fish farming according to water quality parameters such as pH, TDS, NO_3, EC and Ca have been utilised for site selection. AHP weights (Table 8) were applied in each input

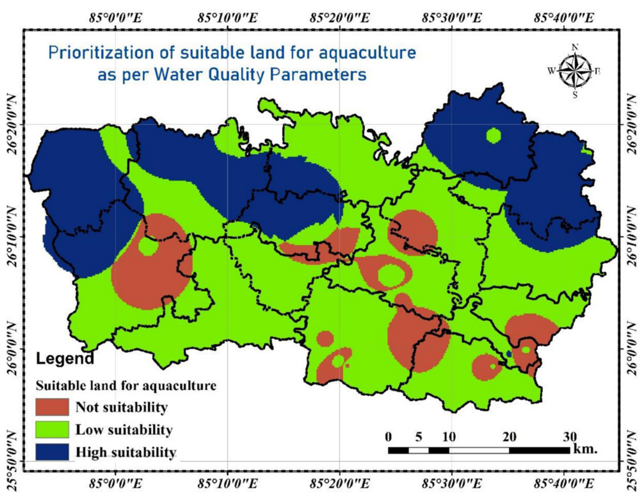

Fig. 7. Suitability of land for fish farming as per soil quality

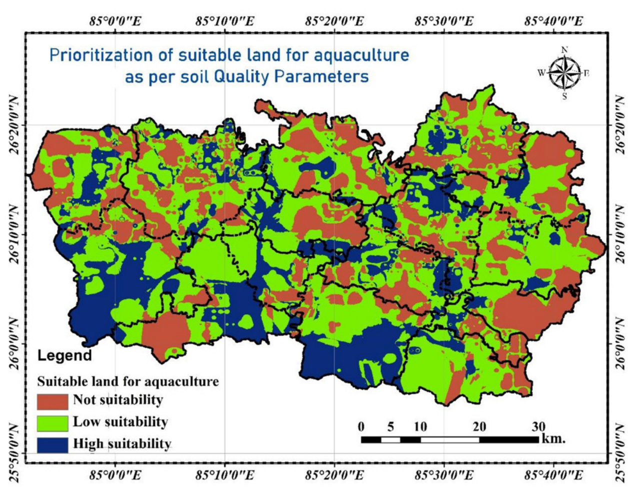

Fig. 8. Suitability of land for fish farming as per water quality

layer in GIS environment. Site suitability of water zone has been classified into three categories such as low (13.21 %), moderate (55.72 %) and highly (31.07 %) suitable (Fig. 9.)

Land suitability was identified for fish farming as per engineering parameters such as slope, drainage, water bodies, and soil texture (Fig. 5). The soil texture is a very important parameter for water holding on land surface. Among the calculated AHP weightages (Table 8), more weightage was observed for soil texture and drainage. Engineering parameters suitability was categorised in to three such as low (24.90%), moderate (55.06 %) and high (09.85%) (Fig. 9.)

Overall suitability

In this study, analysis of water parameters (pH, TDS, NO_3, EC, Ca), soil parameters (N, pH, OC, P_2O_5, EC), engineering parameters (ST, DWS, D, T) and meteorological data applied GIS technique. AHP technique and weightage overlay incorporated to integrate all the criteria and factors in Table 4 to Table 8 and subsequently land suitability map identified for fish farming given in Fig. 10. Geographically, block Sahebganj, Paroo, Saraiya, Aurai and Kurhani had high suitability to another block of the Muzaffarpur District. It can be observed from Fig. 9 that 1114.32 sq. km., 1748.67 sq. km and 312.91 sq. km. of the study area falls under the "Low", "Moderate" and "High" respectively for fish farming as shown in Table 9, Fig. 10 and Fig. 11.

GIS is a powerful tool for determination of the extent of suitable land for fish farming. The most suitable village for fish farming was identified based on water, soil, engineering parameters and satellite imagery with respect to suitability index map. Fish farming suitability of areas in the village, shows that 374 villages falls in the high suitability category, whereas 831 villages fall under low suitability and 665 villages were found not suitable for fish farming. In the present study, it is found that not suitable class and minimum area covered by high suitability (Fig. 12), cover the maximum area.

Validation with satellite image and field visit

The obtained suitability index map for fish farming using various techniques such as RS, GIS and MCDA were verified with the help of 15 points from satellite imagery LANDSAT 8 ETM with a 15 m spatial resolution, along with field visits (ground truthing) in the study area, as illustrated in Fig. 12 and detailed in Table 8. Analysis

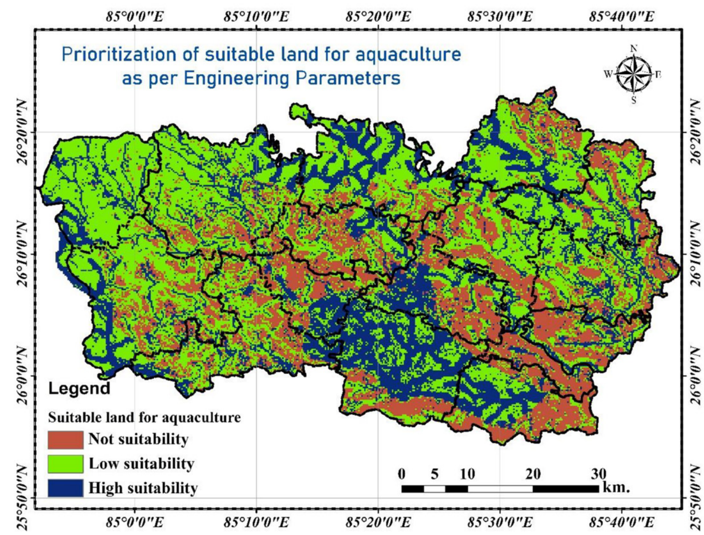

Fig. 9. Suitability of land for fish farming as per engineering parameters

Table 9. Area and percentage of aquaculture suitable sites

Suitability class	Water		Soil		Engineering		Over all	
	Area	%	Area	%	Area	%	Area	%
Low suitable	419.55	13.21	998.17	31.43	790.90	24.90	1114.32	35.09
Moderate suitable	1769.56	55.72	1479.40	46.58	1511.67	47.60	1748.67	55.06
High suitable	986.79	31.07	698.33	21.99	873.33	27.50	312.91	9.85
Total	3175.90	100.00	3175.90	100.00	3175.90	100.00	3175.90	100.00

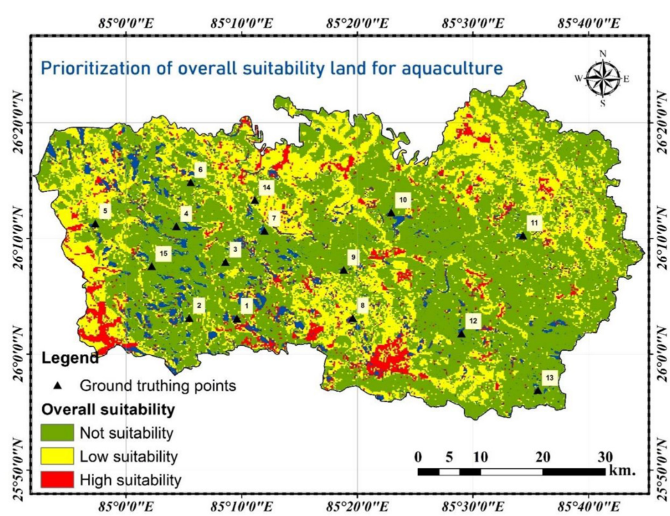

Fig. 10. Suitability index map for fish farming on the basis of water, soil engineering parameters and satellite imagery

of satellite image and ground truthing (field visit) (Fig. 13) was done and data revealed that 12 locations agree and 3 locations disagree. The overall accuracy calculated for suitability index of fish farming was 80% (Table 10).

Discussion

Aquaculture growth provides significant socio-economic benefits, ensuring nutritional security, enhancing lifestyles and giving income and opportunities for employment. However, the success and sustainability of such increases rest on careful site selection, influencing both operating efficiency and land use rationality (Hadipour *et al.,* 2015). Geographic Information Systems (GIS) plays a significant part in varied worldwide aquaculture operations, from clam culture in Florida to shrimp farming in Australia and crab farming in Bangladesh. Despite their efficiency, the persistent issue comes in identifying ideal aquaculture locations, limited by poor baseline knowledge on physicochemical and topographic

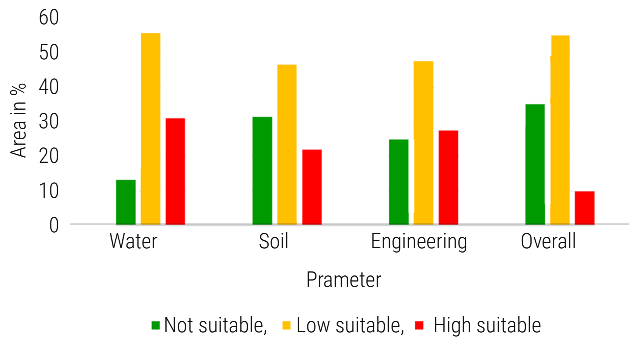

Fig. 11. Area cover in percentage with respect to fish farming sites as per water, soil and engineering parameter

characteristics and current land use patterns. This information gap offers a risk of harmful ecological and environmental repercussions (Vafaie *et al.,* 2015).

The current study applied GIS to find possible aquaculture growth sites in the Nainital District of Uttarakhand. It combined water quality, soil traits and infrastructure factors to measure suitability. Failure to consider these factors in land use planning can result in natural resource misuse, environmental damage and social problems.

Analysis of soil conditions showed 21.99% of the area as most suited for fish growth, with an extra 46.58% being fairly suitable. A similar trend was found in water quality parameters, where 31% of total water bodies were found most suitable, 55.72% fairly suitable and the remaining area deemed low suitable. Regarding engineering parameters, only 27.50% of the space was most suitable, with 47.60% being fairly suitable.

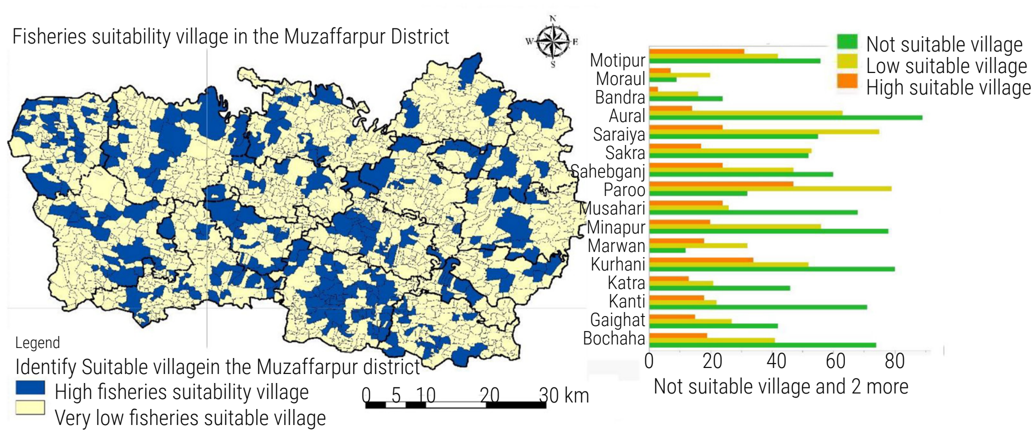

Fig. 12. Block-wise, suitable villages for fish farming based on potential map

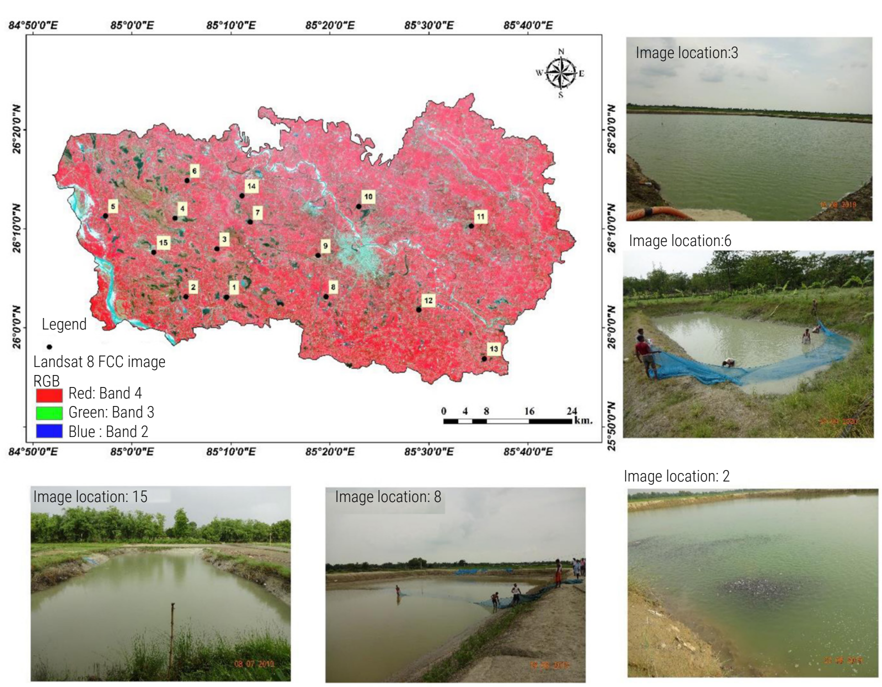

Fig. 13. Location of ground truthing (field verify) data on satellite image

Table 10. Accuracy assessment and comparison of field data against the suitability model

Location ID	Latitude	Longitude	Field observation	Satellite image	Land suitability model
1	85.15986112910	26.05168134010	Fish farming pond	Water bodies	High suitability
2	85.09121248110	26.05234142320	Fish farming pond	Water bodies	High suitability
3	85.14335905020	26.13287156800	Fish farming pond	Water bodies	High suitability
4	85.07273015280	26.18435805400	Fish farming pond	Water bodies	High suitability
5	84.95589543450	26.18831855290	Fish farming pond	Water bodies	High suitability
6	85.09319273050	26.24772603670	Fish farming pond	Water bodies	High suitability
7	85.19946611830	26.17775722240	Fish farming pond	Water bodies	Low suitability
8	85.32686216700	26.05234142320	Fish farming pond	Water bodies	High suitability
9	85.31366050390	26.12165015440	Water Logged area	Wet land	High suitability
10	85.38230915190	26.20416054860	Fish farming pond	Water bodies	High suitability
11	85.57175301700	26.17115639090	Fish farming pond	Water bodies	High suitability
12	85.48330187440	26.02989859600	Agricultural activity	Agricultural land	Not suitability
13	85.59353576110	25.94804828490	Fish farming pond	Water bodies	High suitability
14	85.18560437210	26.22198279370	Agricultural activity	Fallow land	Low suitability
15	85.03708566250	26.12693081960	Fish farming pond	Water bodies	High suitability

The 80% overall accuracy in fish farming suitability mapping, confirmed using RS, GIS and MCDA with satellite images and ground truthing, is encouraging. However, the 20% disparity (3 out of 15 sites) was observed. Analysing these disparities is vital for refining approaches and boosting accuracy. The study's holistic methodology, combining water, soil, engineering and climatic elements, created a full suitability map. Despite finding high appropriateness in particular blocks, resolving the 20% disparity is crucial for nuanced interpretation and driving future enhancements in fish farming assessments.

The study stresses that a productive aquaculture system relies on a site's suitability in terms of soil, water, and technical factors. To support informed decision-making, the study suggests zoning the land into different categories *viz.,* most suitable, moderately suitable and low suitable zones. This zoning method helps potential farmers and investors in finding zones matched with their goals, safeguarding aquaculture from environmental deterioration and adverse social interactions.

Recognising the value of local information, the study fits with the idea that "farmers are the real scientists." The land suitability review found the most favourable places, confirmed by the current placement of fish farms in the study area. The GIS-based multi-criteria analysis, presented in this study, proves instrumental in complete land evaluation, minimising losses caused due to oversight of social and environmental aspects (Gameiro *et al.,* 2022; Mohsin *et al.,* 2022). While the area displays suitability for aquaculture concerning soil and water traits, it falls short in terms of infrastructure services. The study not only adds to safe fishing practices but also leads the best usage of fisheries resources for the socio-economic growth of rural communities in the area.

The present study in Muzaffarpur District, Bihar, found that the district has a serious issue of waterlogging due to its low land area and inadequate drainage. The results of this research demonstrate that aquaculture expansion brings with it a range of socio-economic benefits, such as nutritional security, improved lifestyle, income generation, and employment opportunities. However, proper site selection is essential to ensure the success and sustainability of the aquaculture project, as well as to make efficient use of the land. The framework used to map out the potential zone for aquaculture includes soil, water, engineering parameters, high-resolution satellite imagery, GIS and AHP technique. AHP technique is more effective than other methods in determining the weights of multiple factors in a systematic and logical way and its consistency can be controlled in the presence of conflicting criteria. GIS is a powerful tool to delimit the study area, manipulate geographic data, produce maps, and represent results. The combination of AHP and GIS provides an exact and powerful approach for land suitability analysis. This model emphasises the importance of floodplain areas suitable for freshwater aquaculture, which can have a huge impact on fish production and the income of fishers and fish farmers in the region. The region's rich biodiversity of fish fauna provides many possibilities for fisheries, such as seed production, fry and fingerling rearing and composite fish production based on the water holding capacity and receding time as per the season.

Analysis of results on the soil quality conditions of the region for fish culture revealed that 21.99% of the area is most suitable for such activities, while the remaining 46.58% is moderately suitable. This indicates that the region is, overall, suitable for fish culture in terms of its soil and water features. Similarly, the water quality parameters of the region showed that 31.07% of the total water bodies were most suitable, while the remaining area was 46.58% moderately suitable. However, in terms of Engineering parameters, only 27.50% of the region was found to be most suitable, while 47.60% was categorised as moderately suitable. The combination of remote sensing, GIS and MCDA can be used to identify suitable locations for fish farming in the study area. The accuracy of the suitability index map was found to be 80%, indicating that the developed method is reliable for identifying suitable sites for fish farming. Further research is needed to improve the accuracy of the suitability index map and to better understand the underlying factors that influence the suitability of sites for fish farming.

Using a GIS-based multi-criteria analysis could be a beneficial approach to land evaluation in larger areas, as it can reduce the losses associated with aquaculture development that stem from a lack of consideration of various social and environmental factors. Results from this study determined that the region is suitable for aquaculture in terms of soil and water characteristics, but is less suitable with regards to infrastructure. Additionally, this study can assist in the optimal use of fisheries resources for the socio-economic development of rural people in the region. The results suggest effective ways to enhance land use efficiency and better management of aquaculture in Muzaffarpur District, Bihar.

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