Site Suitability Analysis for Aquaculture and Management using Multi Criteria Decision Analysis (MCDA) and Analytic Hierarchy Process (AHP)

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Abstract

Water logging is a most important environmental issues as well as socio-economic problem which directly associated with the agricultural command areas. The prime objectives of this investigation are to identify waterlogged areas associated with suitable site analysis for sustainable development of aquaculture using Multi Criteria Decision Analysis (MCDA) and Analytic Hierarchy Process (AHP) through GIS model in the Moyna basin, West Bengal, India. The Landsat 9 OLI, SRTM DEM, Google Earth data has been taken to delineate water logged area. Band Rationing of multispectral Landsat imagery for NDVI (Normalized Difference Vegetation Index) and NDWI (Normalized Difference Water Index) is applied to identify the water content pixel in study area. Terrain variation, drainage density and the soil type map are also generated for hazard zoning of water-logged areas. On the other hand, to detect the suitable site for aquaculture land, different factors like water-logged hazard zone, land use/land cover, water quality, soil quality, road network, distance from markets and drainage map have been prepared. This spatial model approach is conversion of the entire thematic layer attributes into a normalized weighted raster as per as water holding capacity and the decision maker's preferences. Thereafter, construct an overall priority through GIS based weighted overlay operation to map water-logged hazard zone as well as site suitability for fish farming. The result depicts the water logging hazard viz. high, moderate and low and site suitability for aquaculture in terms of most suitable, moderately suitable and unsuitable areas. It is found that about 32% (50.53 km^2) area is most suitable for aquaculture land where the people once were worried about the water logging environment. In the present-day context, local people are taking this adverse environmental situation as an opportunity to utilize the valuable land through fishing activity towards sustainable development of aquaculture and socio-economic development.

Keywords Aquaculture, Water logging zone, Site suitability, MCDA, Weighted overlay, Analytic hierarchy process.

Introduction

The term aquaculture broadly refers to the cultivation of aquatic organisms such as fish. Aquaculture involves cultivating freshwater and saltwater populations under control conditions and contrasted with commercial fishing. It is a very well-regulated industry and this regulation may well keep fish farming. It involves raising fish commercially in fish tanks and ponds usually for food. The highest rates of population growth occur in some developing countries, where the standard of living for many people is inadequate. A major challenge is not only to adequately feed the world's burgeoning population but also to improve the quality of life for those living in poverty. Meeting those challenges requires improvements in food security in the economic status of many developing countries. One major food productive and profit-oriented sector in India, after rice and wheat is aquaculture. The fish production needs to be enhanced not for only the food security but also for necessary nutritional demands of our society (Acharyya et al., 2021). The importance of the fisheries sector in India is demonstrated by the fact that it employs more than five million people, which contributes to food and nutritional security and employment that increases the socio-economic status of poor fishing communities, particularly in the developing countries (FAO,2012).

The rural areas of India are highly affected by natural and quasi-natural environmental hazards like water-logging activity (Sar et al,.2015). Fishing and aquaculture are significant primary economic activities in India. To change the socioeconomic situation of the rural population, aquaculture in the lowland paddy field in Moyna block of Purba Medinipur district is now of national significance (Barman et al.,2023). The assessment of waterlogging as well as flood vulnerability using spatial multi-criteria evaluation (MCE) techniques on the GIS platform was reported by several papers (e.g. Pandey et al. 2010; Suriya and Mudgal 2012). CD block of Moyna is situated along the Kansai, Keleghai, and Chandia River basins which is a topographically low-lying, bowl-shaped territory and haplaquepts soil type, therefore, the major problem occurs mainly during the monsoon season and is waterlogged. It is a prime need to highlight the water-logged zone that can support and provide a suitable site for aquaculture development rather than agriculture. It is the best way to manage natural calamities like this water-logged trough conversion of unproductive agricultural land to productive aquaculture land for better management. Site selection is the process by which various factors are considered to enable one to decide on the right site for aquaculture, and to decide on a culture system suiting the site available being a profit-yielding business fish farming has provided direct and indirect benefits to the population which is being realized in terms of generating thousands of employment opportunities, relatively low environmental impact (Michaels.,2014).

The land degradation process and the surface/subsurface soil erosion are highly affected by the waterlogging activity directly related to the socio-economic and land resources in basin areas (Sahu.,2014). The result depicts the water logging hazard viz. low, moderate, and high site suitability for aquaculture in most suitable, moderately suitable, and unsuitable areas. Water bodies like rivers, channels, impounded ponds, tanks, wetlands and waterlogged areas, and lakes are the main source of sufficient amount of fish fauna therefore there living environment needs to be evaluated (Acharyya et al., 2022). Besides, the proper analysis of the total system relating to aquaculture may proceed to have the quality estimation of Water Parameters in the prime necessary for aquaculture zone formation. Hence, it is desirable to monitor the trends in aquaculture, so that effective measures can be taken to check the spread of aquaculture into productive agricultural lands (Acharyya et al.,2015). The Analytic Hierarchy Process (AHP) is a structured and transparent way of making decisions analysis. This decision-making method compares multiple alternatives, each with several criteria to help select the best option. The GIS-AHP model is used for analysing the multiple thematic layers assigned with weights and ratings based on the degree of magnitude of groundwater potential. The aim of this research work is to select a suitable site for aquaculture management through an analytical hierarchy process based on integrated Remote Sensing and GIS-based spatial modelling in the study area. The overall objectives of the study are to

- Assess surface water bodies from Landsat 9 OLI data through different band rationing techniques viz. NDVI (Normalized Difference Vegetation Index), and NDWI (Normalized Difference Water Index).
- Analysis of the Site Suitability zone for aquaculture.
- To detect the low land waterlogged areas from SRTM DEM.
- To measure Drainage density of the study area.

About the Study Area: Moyna is one of flood prone Community Development (CD) block of Purba Medinipur, West Bengal in India. This block is located between 22°09´37´´N to 22°18´58´´N latitude and 87°42´17´´E to 87°49´53´´E longitude (Fig. 1). Moyna is situated in a river basin area, bounded by the river of Kasai, Chandia, and Keleghai on the eastern, western, and southern sides respectively. The total geographical area of Moyna block is about 145.88 sq. km

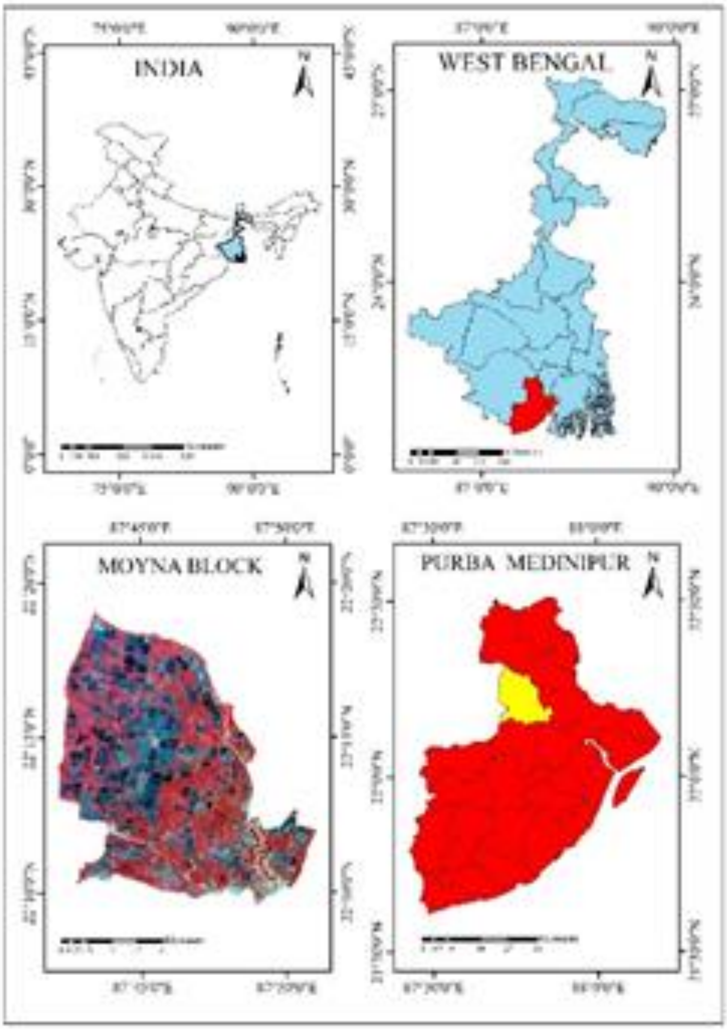

Fig. 1 Location map of the study area.

Materials and Methods

The use of Remote Sensing and GIS technique is identifying the extent of aquaculture land has been very well established over the past decade. This paper deals with how Remote Sensing & and GIS can analyse the site suitability and management for aquaculture. The site suitability analysis involves evaluating assets of the site for development on the basis of thematic layers and requires assessing the relative importance among multiple criteria this can be done by the pairwise comparison method, developed by Saaty (1980) to produce a relative weight of this thematic layers this approach is referred to as spatial AHP (Banai-Kashani 1989). The final step is to aggregate the relative weights of the hierarchy, this is done by means of a sequence of multiplications of the matrices with relative's weights at each level of hierarchy (Malczewski, 2000).

At first Landsat 9 OLI satellite image was downloaded from Earth Explorer, USGS website. Then the Band composition and clip according to the study area has been done. After that NDVI, NDWI map was prepared from Landsat 9 OLI image in ArcGIS 10.8 platform. The Digital Elevation Model, Slope map was created from SRTM DEM data which is downloaded from USGS website. The Land Use and Land Cover map is prepared by supervised classification technique from Landsat 9 OLI image in ERDAS Imagine software. Road network and market places were digitized from Google Earth Pro. The distribution map of the geospatial data (primary and secondary) such as water quality (temperature, pH, dissolved oxygen, total hardness, total alkalinity), and soil quality (PH, texture) is also prepared with the help of spatial interpolation operation.

Table 1 Data use and source.

Map	Data	Source	Year
Digital Elevation Model	SRTM Data	(Earth explorer), USGS.gov	2014
Slope Map	SRTM Data	(Earth explorer), USGS.gov	2014
Drainage Density Map	SRTM Data	https://earthexplorer.usgs.gov/	2014
Soil Map	WB Soil Map	https://nbsslup.icar.gov.in/	2022
Geology Map	Geology_250k	BHUVAN	2022
Geomorphology Map	Geomorphology_250k	Geological Survey of India	2022
MSS Image	Landsat 9 OLI	https://earthexplorer.usgs.gov/	2022
Water Quality & Soil Parameter Map	Water Quality & Soil quality Parameter	Field Survey	2022
Others Data	Rainfall, Temperature	Agriculture Office	2022

A pairwise comparison between the criteria of the aquaculture is estimated for analysing site suitability of the study area. Finally, all the criteria for suitability analysis are reclassified with equal interval and assigned different weights according to their importance for produce Site Suitability Map of the Aquaculture

Results

Normalized Difference Vegetation Index (NDVI): The Normalized Difference Vegetation Index (NDVI) is a measure of the amount of vegetation on the land surface. ArcGIS10.8 software is used to calculate NDVI value, the formula for calculating the NDVI of the Landsat 9 OLI data is as follows-NDVI= (Near Infrared [Band 5] – Red [Band 4]) / (Near Infrared [Band 5] + Red [Band 4]). This method is used to measure the vegetation cover as well as water bodies (Tucker, 1979). The NDVI value ranges from -1 to +1 where the positive value indicates the vegetation canopy pixel and the negative value represents the water content pixel. In the study area NDVI (Fig. 3) value ranges from –0.15 to + 0.43, whereas the water content pixel ranges from -0.01 to -0.15 in the study area (Fig. 3).

Normalized Difference Water Index (NDWI): McFeeters, 1996 modified the normalized difference water index (NDWI) that can enhance open water features. The formula for NDWI based on Landsat 9 OLI using the model is NDWI= (Green [Band 3] – Near Infrared [Band 5]) / (Green [Band 3] + Near Infrared [Band 5]) NDWI values range from -1 to +1 and it shows the opposite result of NDVI. A positive value indicates the presence of deep-water bodies and 0 is for soil moisture (Chowdary et all., 2008). In Moyna NDWI (Fig. 4) value ranges from - 0. 37 to + 0.19. In this study area NDWI value range + 0.01 to + 0.19 is considered as a value to demarcate water content pixels. Due to the bowl-shaped territory most probable, all waterlogged area is observed within this middle portion of the study area.

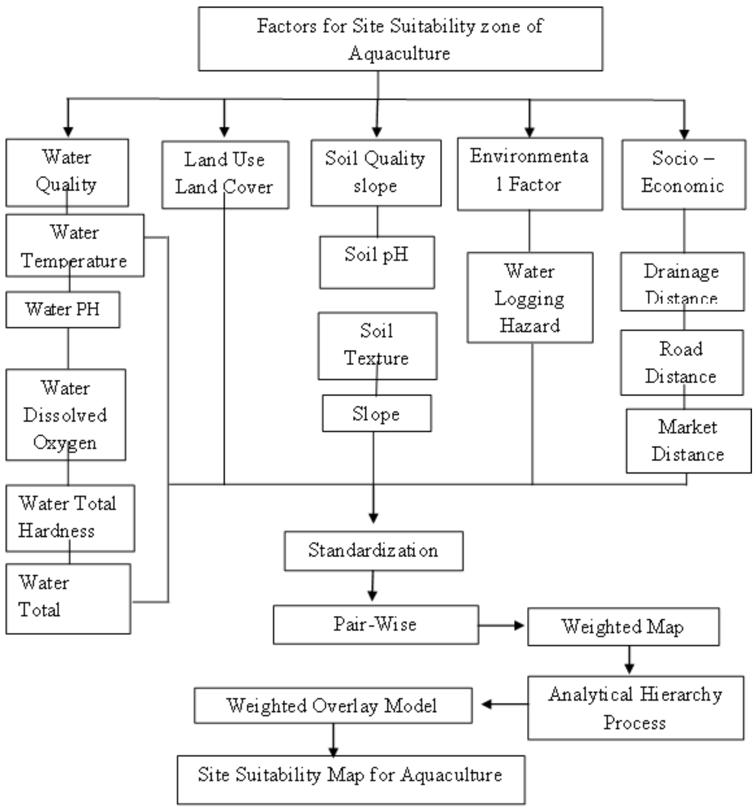

Fig. 2 Research flow chart.

GIS-based spatial modelling using Analytic Hierarchy Process for site suitability analysis: This paper presents different physical (Land use land cover, Water quality, Soil Quality, Drainage buffer distance) and different socio-economic (Transport network, Nearness to market) parameters have been used for the spatial modelling. At first, all the thematic layers have been converted into a single reference system i.e., UTM 45 N zone projected coordinate system. All the thematic layer's attributes have been ranked based on water holding capacity (for Water Logging Hazard Index) where the importance of the attribute is high, therefore the rank is also high. Thereafter all the thematic attributes are converted into an integer value using the reclassification tool (reclassify values to a common scale) in ArcGIS 10.8 because all input raster must be an integer before it can be used in the weighted overlay.

Compare the decision elements on pairwise base: Pair-wise comparisons are the basic measurement mode employed in the spatial AHP procedure; it involves three steps: a) development of a comparison matrix at each level of the hierarchy; b) computation of the weights for each element and c) estimation of the consistency ratio. It should be emphasized that this three–step process follows the procedure for estimating weights of relative importance for evaluation criterion (Jacek Malczewski,2000),

Construct an overall priority rating using a 'weighted overlay' analysis: The final step is to aggregate the relative weights of the pairwise comparison matrix through the weighted overlay tool in ArcGIS (Table. 2). Each value class in a reclassified attribute table is assigned a new value based on an evaluation scale.

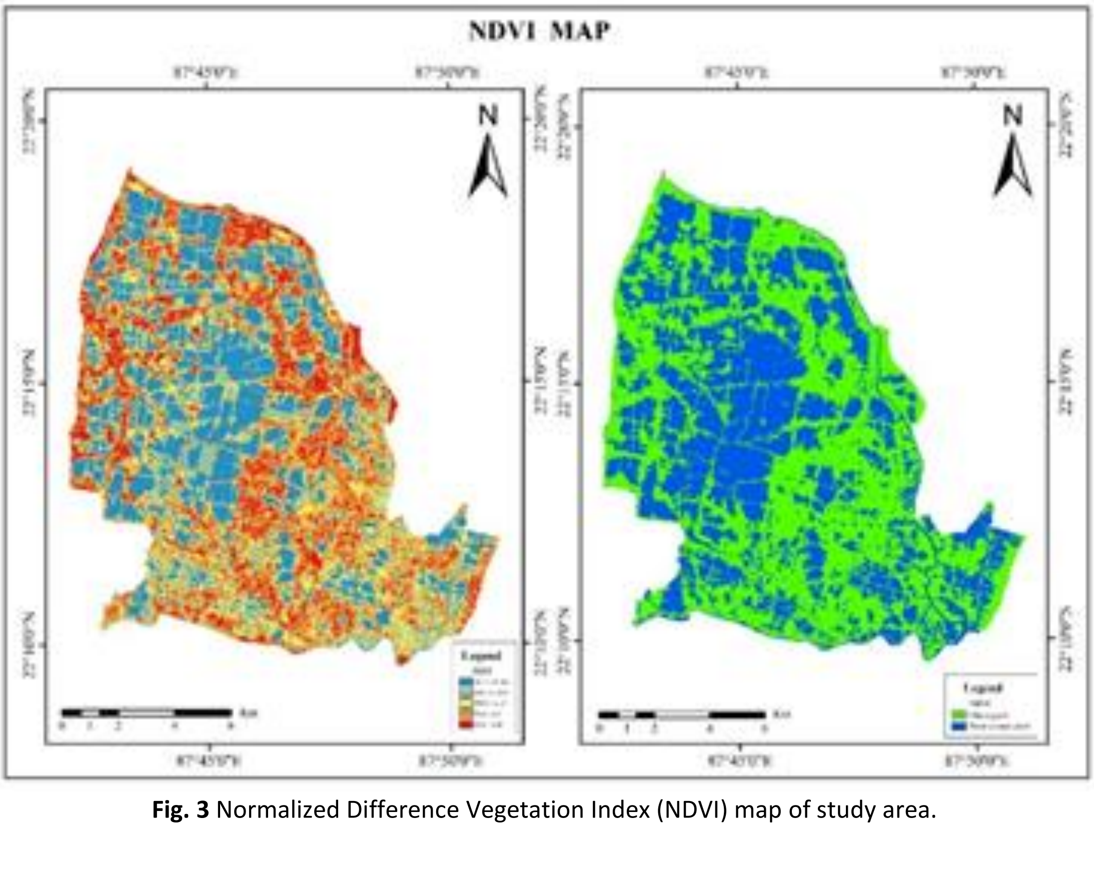

Fig. 3 Normalized Difference Vegetation Index (NDVI) map of study area.

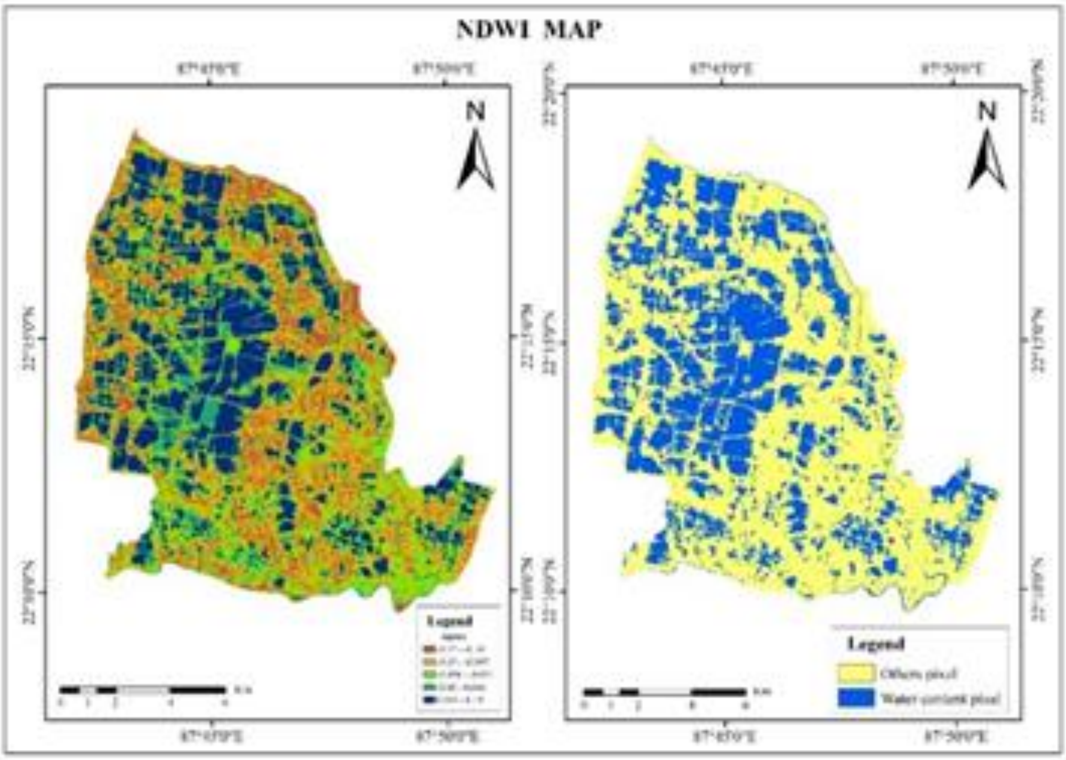

Fig. 4 Normalized Difference Water Index (NDWI) map of study area.

Table 2 Pair wise comparison matrix for site suitability analysis.

Criteria	WLZ	WQ	SS	LULC	S
WLZ	1	2	1.3	1.5	1.1
WQ	0.9	1	1.5	0.5	2.5
SS	1.1	0.9	1	1.1	1.25
LULC	1.5	0.75	0.65	1	0.85
S	0.25	0.45	0.65	1.2	1
	4.75	5.1	5.1	5.3	6.7

WLZ - Water logged zone, WQ – Water Quality, SS – Soil Slop, LULC – Land Use / Land Cover, and S - Socioeconomic

Criteria	WLZ	WQ	SS	LULC	S
WLZ	0.21	0.39	0.25	0.28	0.16
WQ	0.19	0.20	0.29	0.09	0.37
SS	0.23	0.18	0.20	0.21	0.19
LULC	0.32	0.15	0.13	0.19	0.13
S	0.05	0.09	0.13	0.23	0.15
	1	1	1	1	1

WLZ - Water logged zone, WQ – Water Quality, SS – Soil Slop, LULC – Land Use / Land Cover, and S - Socioeconomic

Criteria		Weightage	Weight
WLZ	(0.21+0.39+0.25+0.28+0.16) / 5	0.26	26
WQ	(0.19+0.20+0.29+0.09+0.37) / 5	0.23	23
SS	(0.23+0.18+0.20+0.21+0.19) / 5	0.20	20
LULC	(0.32+0.15+0.13+0.19+0.13) / 5	0.18	18
S	(0.05+0.09+0.13+0.23+0.15) / 5	0.13	13
		1	100

WLZ - Water logged zone, WQ – Water Quality, SS – Soil Slop, LULC – Land Use / Land Cover, and S - Socioeconomic

Criteria	Step - 1		Step - 2	
WLZ	(0.26*1) +(0.23*1.3) +(0.20*1.5) +(0.18*2) +(0.13*1.1)	1.39	1.39 / 0.26	5.34
WQ	(0.26*0.75) +(0.23*1) +(0.20*1.5) +(0.18*0.5) +(0.13*2.5)	1.18	1.18 / 0.23	5.13
SS	(0.26*1.1) +(0.23*0.9) +(0.20*1) +(0.18*1.1) +(0.13*1.25)	1.05	1.05 / 0.20	5.28
LULC	(0.26*1.5) +(0.23*0.75) +(0.20*0.65) +(0.18*1) +(0.13*0.85)	0.98	0.98 / 0.18	5.43
S	(0.26*0.25) +(0.23*0.45) +(0.20*0.65) +(0.18*1.2) +(0.13*1)	0.64	0.64 / 0.13	5.00
				26.18

WLZ - Water logged zone, WQ – Water Quality, SS – Soil Slop, LULC – Land Use / Land Cover, and S - Socioeconomic

λ= (5.34 + 5.13 + 5.28 + 5.43 + 5.00) / 5	5.24
CI=λ-n/n-1 = 5.24 - 5 / 5 - 1	0.059
CR = CI / RI = 0.059 / 1.12	0.05

Discussion

Site Suitability for Aquaculture Land: The site suitability analysis for aquacultural development of Moyna using Multicriteria Decision Analysis (MCDA) for better management of degraded land, which is most time affected by water-logged situation. In Moyna basin every year water logged situation initiated during the time of monsoonal season the period of late July to August and it is continued up to December and January. In the study area most of the water-logged areas (low lying areas) was productive agricultural land. These low-lying areas in water- logged environments, shifted into aquacultural land. The suitability map (suitable, moderately suitable, and unsuitable) of aquaculture site is prepared according to their suitability class (Fig. 5).

Most Suitable: This class is highly suitable region (Fig. 6) represented by green colour located more in the central portion, eastern portion, and some southern portion of the study area. This area can support aquaculture development because it is located within low lying area with adequate condition such as nearness to water supply, settlement, accessible transport that will provide business opportunities to the fishing community. The areas covered a total land area of 50.53 km² that represents 32% (Fig. 9) of the total area.

Moderately Suitable: The moderately suitable areas (Fig. 7) for fish farming located most of the part of around most suitable areas and also the northern, north western, and southern side that is dried or fallow for maintained the aquaculture land. The total moderately suitable area covers 94.16 km², this represents 60% (Fig. 9) of total land of Moyna basin.

Unsuitable: The 13.07 km² of the available land is not suitable for aquaculture (Fig. 8) development due to existing settlement and pond (built up areas and fresh water pond is a mixture is an organic matter that is not suitable for fish culture). This is because the built-up area with vegetated and natural pond is restricted in the analysis based on the fact that aquaculture cannot be sited in these land as they provide the basic need of the people. It is the smallest area with an area of 8% (Fig. 9) of total Moyna basin. It is observed that in some northern, north- eastern, north – western and some part of southern portion is not suitable.

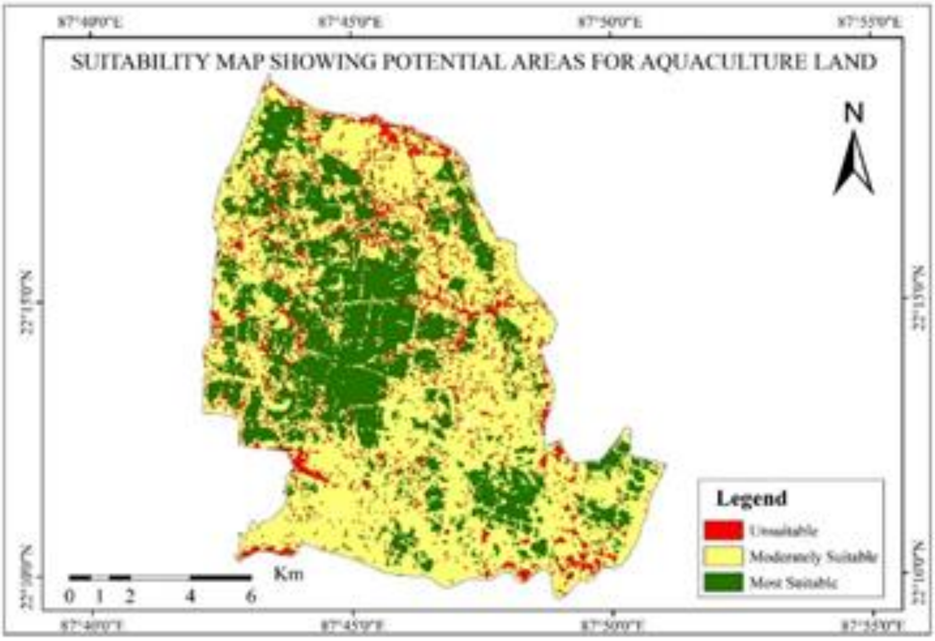

Fig. 5 Aquaculture Suitability Map of Moyna block, Purba Medinipur.

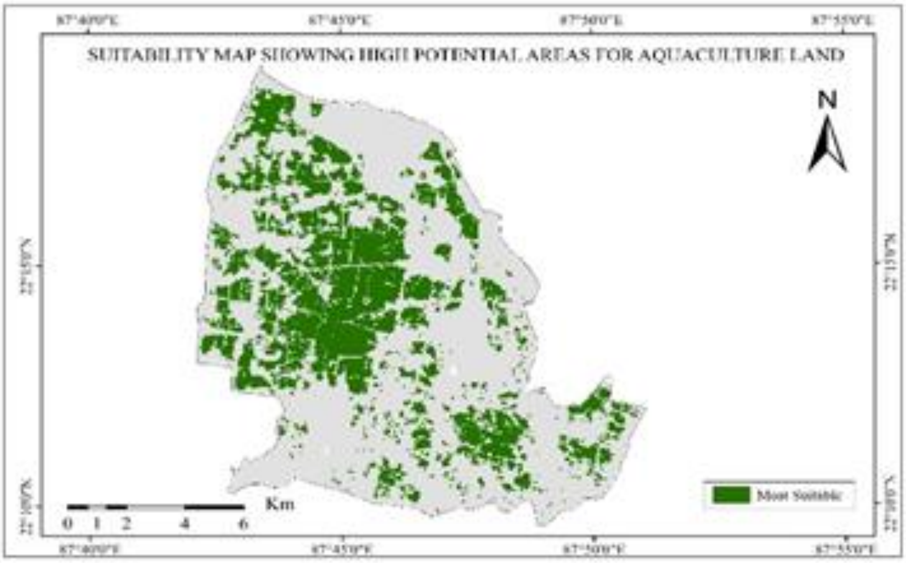

Fig. 6 High Potential Aquaculture area of Study area.

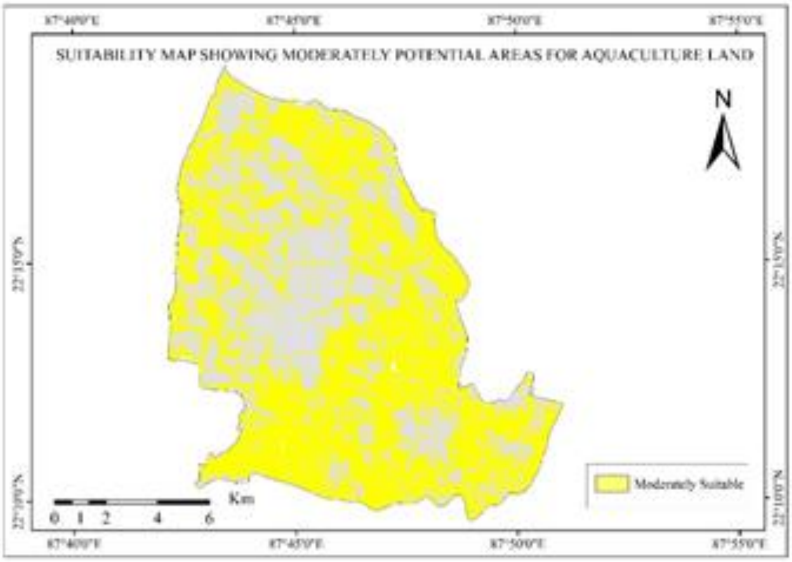

Fig. 7 Moderate Potential Map of study area.

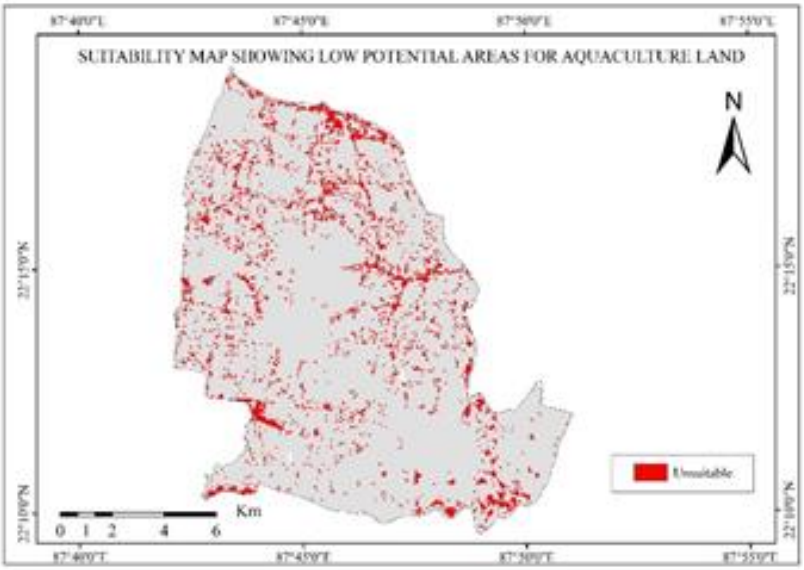

Fig. 8 Low Potential Map of study area.

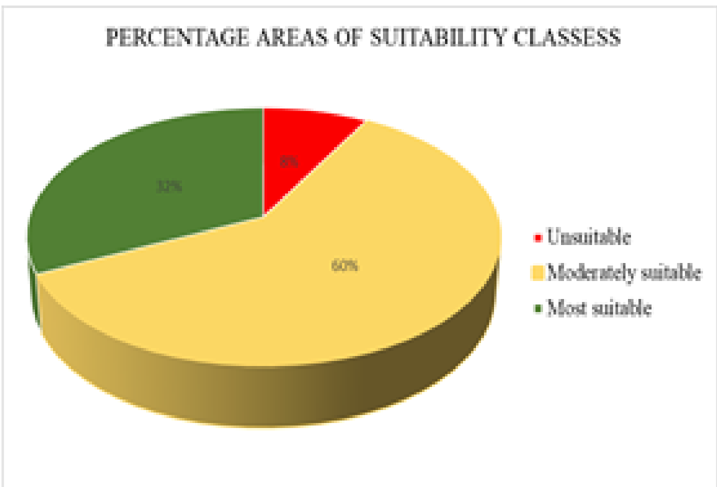

Fig. 9 Pie Chart showing the percentage areas of different aquaculture land suitability classes.

Conclusions

The Geospatial techniques can be efficiently used for spatial planning that delineates the water-logged hazard zone as well as the best site for aquaculture development and sustainable management of degraded land and water resources that influence socio-economic activity of Moyna Block. Water logging situation is the resultant function of relationships between favourable soil type with water holding capacity also topographical variation, drainage density, and there are many conditions like excessive rainfall, groundwater table and so many factors. Different Environmental as well as socio economic parameter are suitable for aquaculture development in Moyna low laying block. It is well recognized that within our society while something is hazardous to someone it is beneficial to another. Economically backward areas like water-logged zones are degraded land that is not occupied for the purpose of inhabitation and economic activity. Aiming to change traditional land use patterns, people will transform the water-logged problem into economically beneficial fishing activity.

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