

Chapter 36

Mapping of Aquaculture Potential Zones Using Geospatial Multi-Criteria Method for Sustainable Aquaculture Development-Thiruvallur District



R. Nishan Raja, P. Nila Rekha, Soumyabrata Sarkar, Albin Sunny, V. Chandrasekar, and C. P. Balasubramanian

Abstract Aquaculture sector has developed rapidly since the last decade and its development have been unregulated, which has caused many ecological problems. In this regard, this study has been undertaken to identify potential zone for sustainable aquaculture development. Thiruvallur district coastal sub-watershed boundary has been taken as the study area which has been delineated using SRTM DEM, toposheet, and also using watershed data collected from the agriculture department, Tamil Nadu. Water sources available in the study area are Pulicat Lake, Buckingham Canal, Arani River, and Kosathalaiyar River. Pulicat and Buckingham Canal are the major sources for aquaculture in the Thiruvallur district since Kosathalaiyar and Arani River are ephemeral in nature. A pair wise comparison matrix has been used to assign weightage to each criterion based on its relative importance. Various thematic maps were integrated into multi-criteria factors such as water quality, soil characteristics, infrastructure factors, and land use type to identify potential aquaculture zone using remote sensing and GIS. To ensure sustainable aquaculture development constrain, parameters have been framed according to coastal aquaculture authority

The original version of this chapter was revised with the table header changed in Table 36.2. The correction to this chapter can be found at https://doi.org/10.1007/978-3-030-95618-9_79

R. N. Raja (✉) · P. N. Rekha · S. Sarkar · A. Sunny · V. Chandrasekar · C. P. Balasubramanian
ICAR—Central Institute of Brackishwater Aquaculture, Chennai, Tamil Nadu 600028, India
e-mail: nishnwilliams@gmail.com

P. N. Rekha
e-mail: nila_71@yahoo.com

S. Sarkar
e-mail: sarkar.soumyabrata11@gmail.com

A. Sunny
e-mail: albinsunnykm@gmail.com

V. Chandrasekar
e-mail: vchandrasekar1989@gmail.com

C. P. Balasubramanian
e-mail: balu@ciba.res.in

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2022, corrected publication 2022

T. D. Lama et al. (eds.), *Transforming Coastal Zone for Sustainable Food and Income Security*, https://doi.org/10.1007/978-3-030-95618-9_36

regulations for mangroves, settlement, drinking water source and ecologically sensitive areas. The existing aquaculture farm in the study area has been mapped using Sentinel 2, it is about 660.65 hectares and the potential extend of the area available for aquaculture development estimated using AHP method is about 630 hectares.

Keywords Aquaculture · Analytical hierarchical process · GIS · Remote sensing · Sentinel 2

36.1 Introduction

Coastal aquaculture has been developing at a faster phase over the past decade, and worldwide aquaculture production has reached 82 million tons in 2018 with a value of 250 billion US dollars. It contributes 46% of total production and 52% of worldwide fish supply. (FAO 2020). Fish represents 16% of animal protein consumed globally; it has become more prominent that fish catch cannot cope up the demand for seafood consumption due to the increasing population. Sustainable supply of seafood without depletion and damage to the aquatic environment is a huge challenge; with increasing demand, aquaculture has shown prominent growth for fish and shrimp production for human consumption (De Silva 2001; Paez-Osuna 2001; Ottinger et al. 2016; Natale et al. 2012). Aquaculture provides a huge advantage in regards to offering a better lifestyle, healthy food, prosperity, employment, and export earnings (Belton and Thilsted 2014). Expansion of aquaculture has been rapid which has caused an unregulated expansion, resulting in many environmental issues such as changes in biodiversity conversion of ecologically important areas viz., mangroves and agricultural land conversion, agricultural land salinization (Perez et al. 2003; Primavera 2006; Richards and Friess 2016; Thomas et al. 2017). These issues would cause a serious problem if not addressed properly (Young et al. 2019). Hence, it is crucial to identify potential areas for further aquaculture expansion sustainable without affecting the environment, multi-user conflict, and to make effective use of brackishwater resources. The growth of remote sensing and GIS has provided a wide usage of practical application. Identification of aquaculture potential zones using remote sensing and GIS has been recognized as a potential tool by many researchers. Multi-criteria decision-support approach (MCDA) like analytical hierarchical process (AHP) has been widely used for aquaculture potential zone identification (Salam et al. 2003; Giap et al. 2005; Radiarta et al. 2008; Hadipour et al. 2015; Falconer et al. 2019), while these researchers have incorporated water, land, and soil characteristic, and environmental regulations, restrictions have not been considered. Hence, this study was undertaken to frame a suitable methodology for identifying potential aquaculture zones by incorporating water, land, and soil characteristic, environmental regulations, and restrictions in a sustainable manner.

36.2 Study Area

The southern part of Pulicat Lake, which is the second-largest brackishwater resource in India forms part of Thiruvallur district in Tamil Nadu. The coastal sub-watershed boundary of the Thiruvallur district has been delineated using SRTM DEM, toposheet, and sub-watershed data collected from the agriculture department. The study area comprises of Arani (4C2D8a, 4C2D8b), Gummidipoondi (4C2E1a), Kosathalayar (4C2D5d, 4C2D5f, 4C2D5t), and Pulicat (4C2E2a) sub-watershed located between 13.17°–13.57° N and 80.13°–80.35° E with a total area of about 61,841.5 hectares as shown in Fig. 36.1.

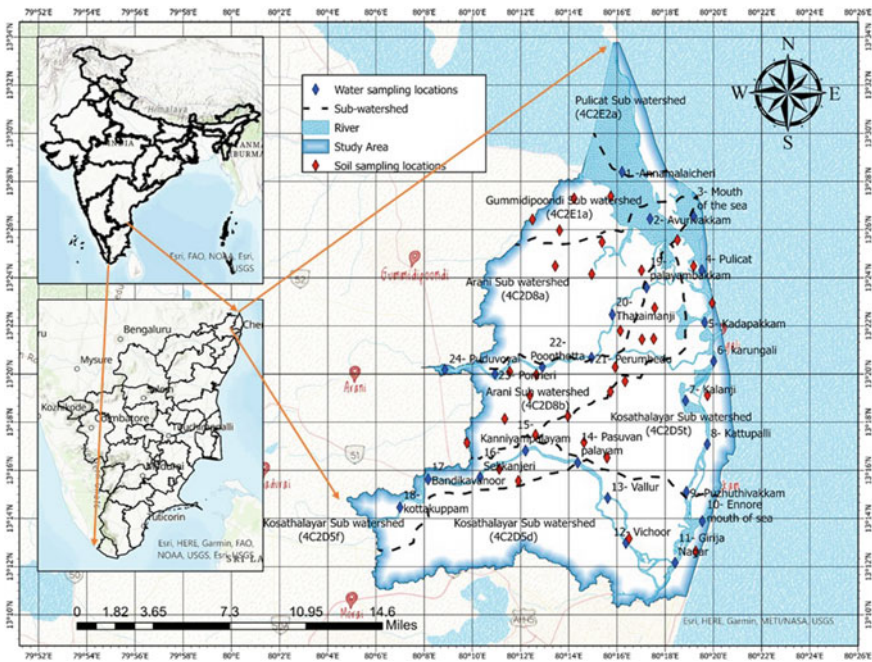


Fig. 36.1 Study area map

36.3 Materials and Method

36.3.1 Data Used

Aquaculture development mainly depends upon good soil quality, good water sources, and the coverage of land availability. Hence, their characteristic is an essential prerequisite for mapping potential area for aquaculture development. Sentinel 2 satellite image downloaded from (<https://scihub.copernicus.eu/dhus/>) was used to map the Land Use Land Cover (LULC) and SRTM DEM data from (<https://explorer.earthengine.google.com/#workspace>), the sub-watershed boundary of Thiruvallur district was collected from the agriculture department (<https://slusi.dacnet.nic.in/dmwai/TAMILNADU/District/Trivallur.html>) and was used to map and name the sub-watershed boundary. Soil texture data were collected from the National Bureau of Soil Survey and Land Use Planning Website (<https://esdac.jrc.ec.europa.eu>) and digitized in ArcGIS pro. The methodology used for identifying potential aquaculture zones is given in Fig. 36.2.

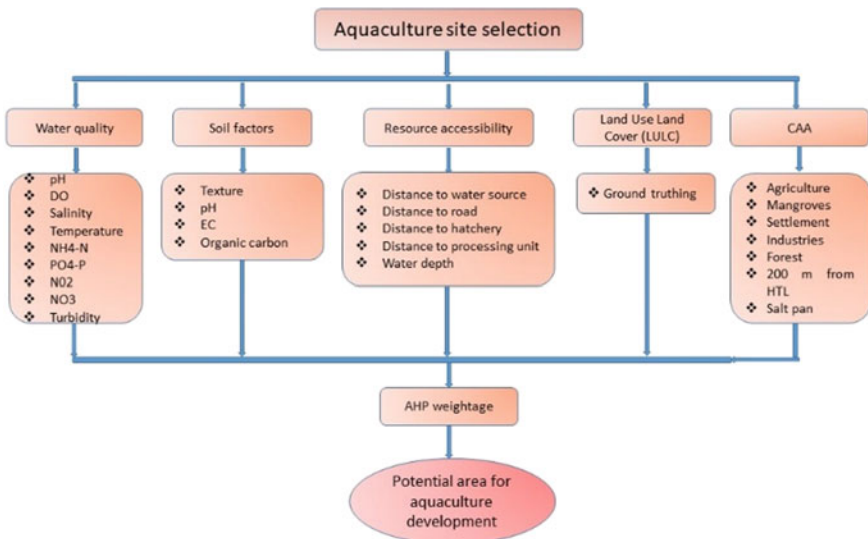


Fig. 36.2 Methodology flowchart

36.3.2 Land Use Land Cover (LULC) Classification

ArcGIS Pro 2.6 was used to preprocess Sentinel 2 satellite image, raster subset tool was used to clip the satellite image of the study area using the sub-watershed boundary of the study area before classification. Images were layer stacked at a band combination of Band 8 (NIR), Band 3 (Green), and Band 2 (Blue). A radiometric correction was carried out to enhance the image quality. 44 N Universal Transverse Mercator projection was applied to the satellite data. LULC map was classified using visual interpretation keys color, texture, tone, pattern, shape, size, and associated features (NRSA 1995; Lillesand and Kiefer 2000). Agriculture land was identified by mild red tone with continuous pattern medium to smooth texture. Mangrove was identified by dark red tone with smooth pattern and medium coarse texture located near creeks or estuaries. Aquaculture farms were identified by dark blue to light blue with rectangular or square shape, whereas salt pan was identified by gray/white color with smooth pattern and smaller in size compared to aquaculture farms. The dense vegetation was identified by light reddish-brown color with fine to medium texture. Scrublands were identified by yellow to light red tone with a medium to smooth texture. Mudflats were in gray with a smooth texture and continuous pattern, located near coastal areas. Abandoned aquaculture farms were identified using google earth, and the absence of water in the farm for more than 2 years was considered. Google earth images were used to verify the authentication of classification along with field verification. Kappa's coefficient (Campbell and Wynne 2011) was used to calculate the overall accuracy, and the area for each class is calculated using calculate geometry tool in ArcGIS pro.

36.3.3 Soil and Water Characteristic Assessment

Twenty-four surface water sampling locations have been identified at 4 km intervals, soil samples have been collected from 32 locations, and samples have been collected from September 2019–September 2020 at a monthly interval. It is observed that Kosathalaiyar and Arani River in the study area are ephemeral; hence, the flow of water is observed only during flood conditions. The southern part of Pulicat Lake is located in the northern part of the study area, which is interlinked with the Buckingham Canal and runs parallel to the coast in the study area. It is the main water source for shrimp farming. Water quality parameters such as water temperature and dissolved oxygen have been tested in field, pH, salinity, turbidity were analyzed using digital meter, while ammonia–nitrogen ($\text{NH}_4\text{-N}$) was analyzed using phenol hypochlorite method, phosphate phosphorus ($\text{PO}_4\text{-P}$) using phosphomolybdic acid-ascorbic acid method, and nitrite nitrogen ($\text{NO}_2\text{-N}$) using sulphanilamide NED method. Soil samples were assessed for organic carbon, pH, and electrical conductivity. All samples were analyzed within 2 days in the laboratory at Muttukadu

Experimental Station (ICAR-Central Institute of Brackishwater Aquaculture, Tamil Nadu, and India) (APHA 2005).

36.3.4 Mapping of Resource Accessibility

Factors such as distance to the water source, water depth, distance to road, distance to the seed source, and distance to processing unit come under this category. Water depth was measured in the field using a depth-measuring instrument. Water source and road networks were digitized from satellite images and topographic maps in ArcGIS pro. Buffer zones were created using a multi-ring buffer tool in ArcGIS pro. The hatchery and processing site source were collected from field surveying, google earth, and from the department of fisheries, Tamil Nadu. The buffer zones were created for 100 km for hatchery, 20 km, and 50 km for the processing unit.

36.3.5 Multi-Criteria Decision-Support Approach - AHP

The main criteria for aquaculture potential zone identification are classified into four parts water quality, soil quality, resource accessibility, and land use. Water, soil, resource accessibility characteristics have been classified as optimum based on literatures and experts' opinions as shown in Table 36.1 (Boyd 1995; Senarath and Visvanathan 2001; Saaty 2008; CAA 2014; Hadipour et al. 2015). Constraints have been framed as per CAA (2014). The weightage for each criteria is given as per the importance for shrimp farming based on works of literature and experts opinion (Eastman et al. 1993; Salam et al. 2003; Radiarta et al. 2008; Falconer et al. 2019), the weights are derived using (Saaty 2008) method. The consistency index and consistency ratio were calculated using the procedure adopted by various researchers (Saaty 1977; Hossain et al. 2009; Nayak et al. 2018). The relative weightage is given to each parameter as shown in Table 36.2.

pH, water temperature, Dissolved Oxygen (DO), salinity, total ammoniacal nitrogen, nitrate, and phosphate, turbidity were considered as influencing factors (Boyd and Tucker 1998) in deciding sites since they are crucial for the growth of the reared species, they were categorized into a subgroup "water quality."

By considering the optimum water quality parameters for vannamei shrimp (CAA 2014), the source water characteristics, prevailing tropical climate in the study area, source water bodies depth-related turbidity issues, the pH was considered as important with maximum weight (22.8%) followed by turbidity (21.4%). As DO and salinity in the water body reveal the health of the ecosystem and salinity of the water specifies the growth of species. DO was assigned 13.8% weightage, and salinity was assigned 15.8% weightage. The weightage of water temperature, nitrate, nitrite, ammonia and phosphate is 3.9%, they are assigned as per experts opinion. Soil quality, organic carbon, and texture are the most important criteria for which the

Table 36.1 Suitable range of resources for shrimp farming

Water quality	Highly potential	Moderately potential	Marginally potential	Not suitable
pH	6.5–8.0	8.1–8.5	6.1–6.4, 8.6–9	< 6, > 9
DO (mg L ⁻¹)	> 6.1	5–6	4–4.9	< 4
Salinity (ppt)	15–25	6–14, 26–35	1–5, 36–45	< 1, > 45
Water temperature (°C)	20–30	15–19, 31–35	10–14, 36–40	< 10, > 40
NO ₃ -N (mg L ⁻¹)	< 0.5	0.5–1.0	1.1–1.5	> 1.5
NO ₂ -N (mg L ⁻¹)	< 0.25	0.25–0.5	0.5–1	> 1
NH ₄ -N (mg L ⁻¹)	0–1	1–1.25	1.26–1.5	> 1.5
PO ₄ -P (mg L ⁻¹)	< 0.2	0.2–0.4	0.41–0.5	> 0.5
Turbidity (NTU)	25–35	10–24, 36–60	61–80	> 80
Soil factors				
Texture	Clay loam, sandy clay loam	Sandy clay	Sandy loam	Sand
pH	6.5–7.5	6–6.4, 7.6–8	8.1–9, 5.5–5.9	< 5.5, > 9
Organic carbon (%)	0.5–1.5	0.3–0.4, 1.6–2.0	0.1–0.2, 2.1–2.5	< 0.1, > 2.5
Electrical conductivity (dS m ⁻¹)	> 4	3–4	0.5–2.9	< 0.5
Accessibility factors				
Distance to road (m)	< 500	501–750	750–1000	> 1000
Distance to water source (km)	< 1	1.1–2	2.1–3	> 3
Distance to processing unit (km)	< 20	21–50	51–100	> 100
Distance to hatchery (km)	< 100	101–500	501–1000	> 1000
Water depth (m)	> 4	2.1–4	1–2	< 1
Land use	Abandoned farms, Abandoned salt pans	Mudflats	Scrublands	Agriculture land, mangroves, settlement, Saltpan, land upto 200 m from high tide line

Table 36.2 MCDM based AHP matrix for aquaculture potential zone mapping

Water quality	pH	DO	Salinity	WT	NO ₃ -N	NO ₂ -N	NH ₄ -N	PO ₄ -P	Turbidity	Weight
pH	1	4	1/2	3	6	6	6	6	1/2	22.8
DO	1/4	1	3	1	3	3	3	3	1/2	13.8
Salinity	2	1/3	1	2	3	4	4	4	1/2	15.8
WT	1/3	1	1/2	1	3	3	3	3	1/2	10.5
NO ₃ -N	1/6	1/3	1/3	1/3	1	1	1	1	1/5	3.9
NO ₂ -N	1/6	1/3	1/4	1/3	1	1	1	1	1/4	3.9
NH ₄ -N	1/6	1/3	1/4	1/3	1	1	1	1	1/4	3.9
PO ₄ -P	1/6	1/3	1/4	1/3	1	1	1	1	1/4	3.9
Turbidity	2	2	2	2	5	4	4	4	1	21.4
CR 0.06										
Soil quality	Organic carbon	EC	pH	Texture	Weight					
Organic carbon	1	2	2	1	32.9					
EC	1/2	1	2	1/2	20					
pH	1/2	1/2	1	1/2	14.2					
Texture	1	2	2	1	32.9					
CR 0.02										
Accessibility factors	Distance to water source	Distance to road	Distance to processing unit	Distance to hatchery	Water depth	Weight				
Distance to water source	1	3	8	8	1	38.8				
Distance to road	1/3	1	5	4	1/4	16				

(continued)

Table 36.2 (continued)

Distance to processing unit	1/8	1	1/5	1	1/5	5
Distance to hatchery	1/8	1	1/4	1	1/5	5.1
Water depth	1	4	5	5	1	35
CR 0.05						
Land use	Abandoned farm	Mudflats	Scrubland	Weight		
Abandoned farm	1	2	3	52.5		
Mudflats	1/2	1	3	33.4		
scrubland	1/3	1/3	1	14.2		
CR 0.05						
Overall factor	Resource accessibility	Soil quality	Land use	Water quality	Weight	
Resource accessibility	1	3	2	1	35.8	
Soil quality	1/3	1	1/3	1/2	10.7	
Land use	1/2	3	1	2	30.4	
Water quality	1	2	1/2	1	23.2	
CR 0.06						

weightage has been assigned 32.9% each. While EC and pH were assigned 20% and 14.2%, respectively. Accessibility factors were classified into five water depth and water source have been given highest weightage 35% and 38.8%, respectively. While distance to road, distance to processing unit and distance to hatchery was assigned a weightage of 16%, 5%, and 5.1%, respectively. Land use has been classified into three, and the highest weightage is given to abandoned farm 52.5%. While the mudflats and scrubland was assigned a weightage of 33.4% and 14.2%, respectively. The overall factors have been classified into four, and the highest weightage has been assigned to resource accessibility and land use factor 35.8% and 30.4%, respectively. While soil quality and water quality were assigned a weightage of 10.7% and 23.2%, respectively.

36.4 Results

36.4.1 Water and Soil Characteristics Suitability

Successful aquaculture operation depends upon good quality of water and soil. The water quality parameters have been mapped using IDW feature in ArcGIS pro, and the suitability extend has been calculated for each parameter. The spatial distribution of water quality is shown in Fig. 36.3a. Water salinity is a crucial parameter in the study area, it ranges from 2 to 39 ppt, the suitability of salinity in the region is about 38%, 19%, and 43% area is highly potential, moderately potential, and marginally potential, respectively. pH indicates 39.5%, 1.4%, and 6% area is highly potential, moderately potential, and marginally potential, respectively. Water temperature in the study area is favorable for aquaculture activity. DO indicates 21%, 17%, and 11% area is highly potential, moderately potential, and marginally potential, respectively. $\text{NH}_4\text{-N}$ shows that 98%, 0.5%, and 0.45 area is highly potential, moderately potential, and marginally potential, respectively. Nitrite and nitrate show that 95%, 70% highly potential area and 5%, 30% moderately potential area, respectively. Phosphate indicates 83%, 12%, and 4% area is highly potential, moderately potential, and marginally potential, respectively. Turbidity indicates 42%, 15%, and 7% area is highly potential, moderately potential, and marginally potential, respectively. The overall weightage grid for water quality is given in Eq. 36.1.

$$\begin{aligned} \text{Grid}_{\text{Water quality}} = & \text{Grid}_{\text{pH}} \times 0.228 + \text{Grid}_{\text{Turbidity}} \times 0.214 + \text{Grid}_{\text{salinity}} \\ & \times 0.158 + \text{Grid}_{\text{DO}} \times 0.138 + \text{Grid}_{\text{WT}} \times 0.105 \\ & + \text{Grid}_{\text{NO}_2\text{-N}} \times 0.039 + \text{Grid}_{\text{NH}_4\text{-N}} \times 0.039 \\ & + \text{Grid}_{\text{PH}_4\text{-P}} \times 0.039 + \text{Grid}_{\text{NO}_2\text{-N}} \times 0.039 \end{aligned} \quad (36.1)$$

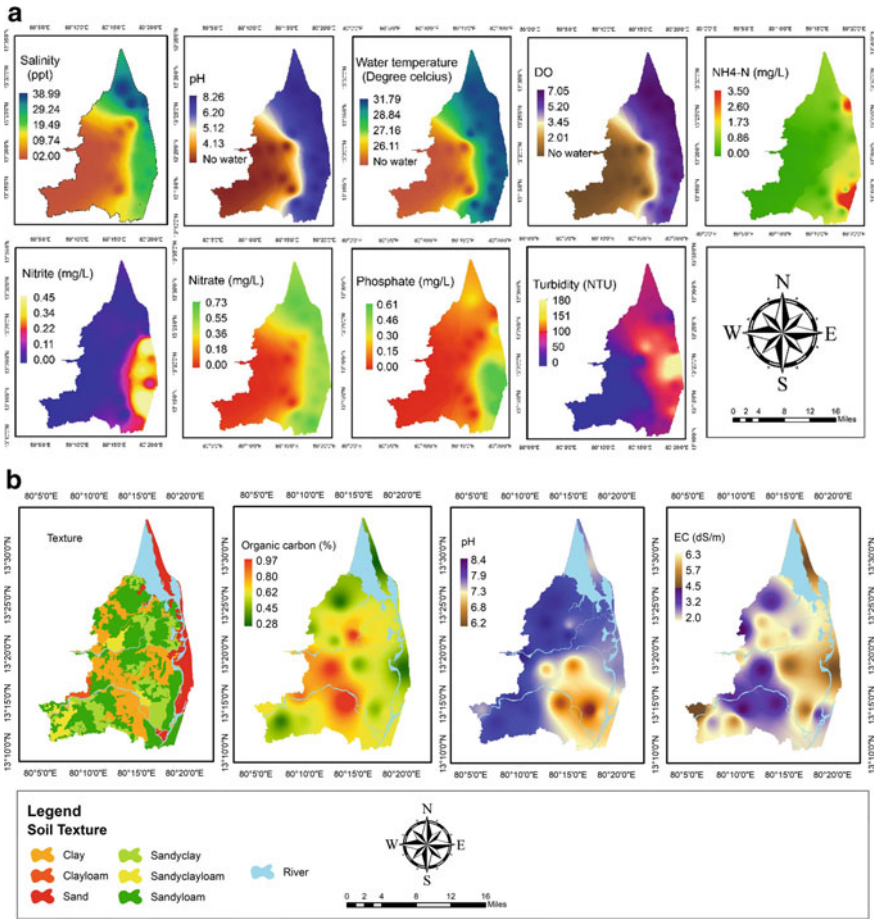


Fig. 36.3 a Spatial distribution of water quality. b Spatial distribution of soil quality

Soil parameters such as texture, organic carbon, pH, and EC in the study area are shown in the Fig. 36.3b. Soil texture is an important factor for aquaculture site selection as they play a crucial role in production. The clayey soils promote the growth of benthic blue algae and prevent seepage due to excellent water retention capacity; hence, it is considered best suited for farming. Sandy soils are permeable and porous; therefore, they are suitable for aquaculture (CAA 2014). The overall weightage grid for soil quality is given in Eq. 36.2.

$$\text{Grid}_{\text{soil quality}} = \text{Grid}_{\text{Organic carbon}} \times 0.329 + \text{Grid}_{\text{Texture}} \times 0.329 + \text{Grid}_{\text{EC}} \times 0.20 + \text{Grid}_{\text{pH}} \times 0.142 \quad (36.2)$$

36.4.2 Land Use Land Cover Map

Land Use Land Cover map was classified using Sentinel 2 image as shown in Fig. 36.4, result shows that vegetation/agriculture area is about 14,779 hectares, scrubland is about 15,000 hectares, settlement is about 7,212.57 hectares, water body in the study area is about 7,938.87 hectares, mudflat is about 130 hectares, and barren land is about 14,753.61 hectares. Existing aquaculture in the study area is about 660.65 hectares, abandoned aquaculture farm is about 330 hectares, salt pan land in the study area is about 878.82 hectares, and mangroves in the study area are about 157.33 hectares. The overall weightage grid for land use is given in Eq. 36.3.

$$\begin{aligned} \text{Grid}_{\text{land use}} = & \text{Grid}_{\text{Abandoned farm}} \times 0.525 + \text{Grid}_{\text{Mudflats}} \times 0.334 \\ & + \text{Grid}_{\text{scrubland}} \times 0.142. \end{aligned} \quad (36.3)$$

The Government of India has regulated certain restrictions for shrimp farming through CAA act, which prohibits conversion of agricultural land, mangroves, salt-pans, and other ecologically sensitive areas for aquaculture, but permits construction in marginally unfit lands with 50 m buffer distance from other productive lands.

36.4.3 Mapping of Resource Accessibility

Resource accessibility is a crucial factor for shrimp farming and the optimum suitability in terms of distance to road, distance to the water source, and the processing facility were 100, 80, and 100% of the lands, respectively. Most of the hatcheries supply the vannamei seed is present in the east coast states of the country, in particular, Tamil Nadu and Andhra Pradesh. The water depth in the water bodies is a major limiting factor in the study area, as such 40% of the land can be supported, and the rest 60% does not have enough water depth for shrimp farming. The spatial distribution of resource accessibility is given in Fig. 36.5. The overall weightage grid for accessibility is given in Eq. 36.4.

$$\begin{aligned} \text{Grid}_{\text{Accessibility}} = & \text{Grid}_{\text{water source}} \times 0.388 + \text{Grid}_{\text{hatchery}} \times 0.35 + \text{Grid}_{\text{Road}} \\ & \times 0.16 + \text{Grid}_{\text{Processing unit}} \times 0.05 \end{aligned} \quad (36.4)$$

36.4.4 Potential Area for Aquaculture

The water, soil, resource accessibility, and land use factors have been integrated, and then, the restricted classes were removed the final potential area map is shown in the figure. The finding shows that the already existing aquaculture area is about

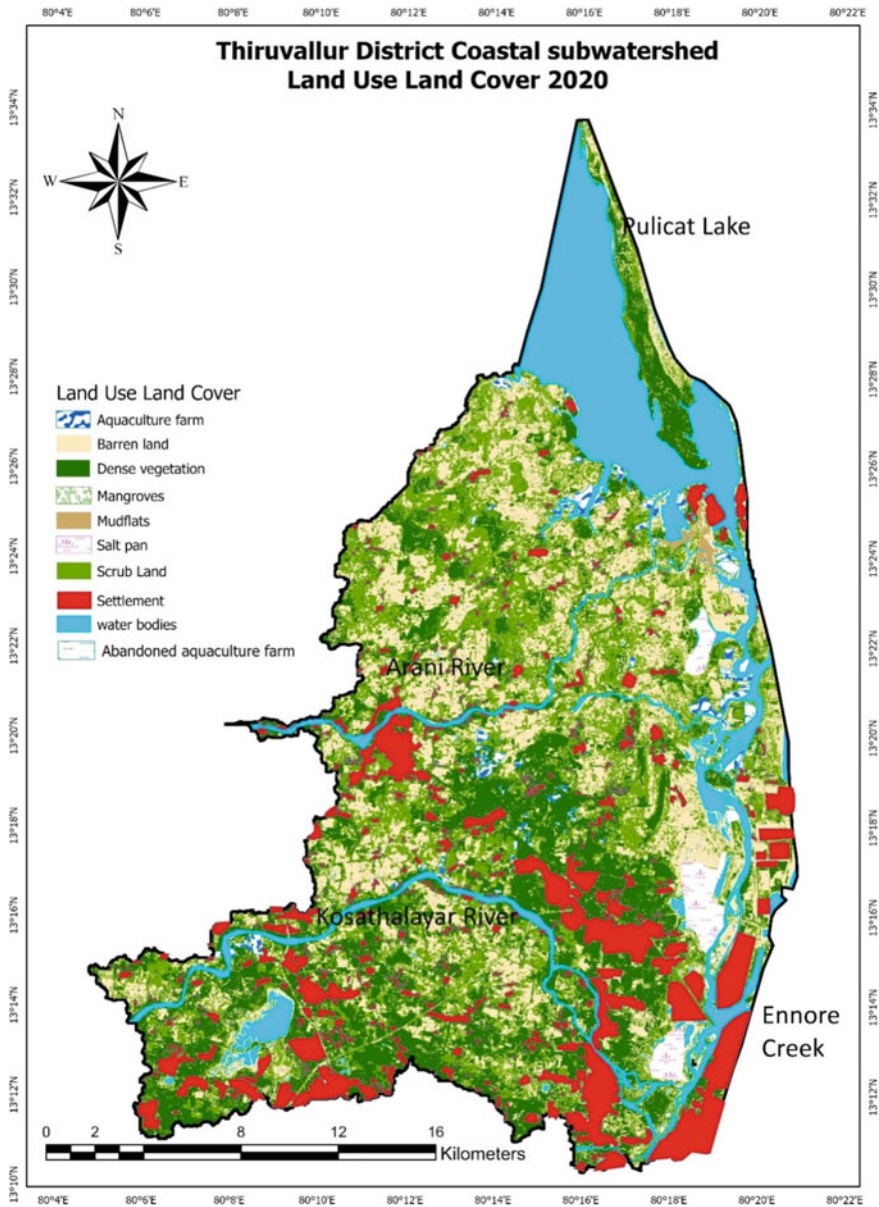


Fig. 36.4 Land use land cover map

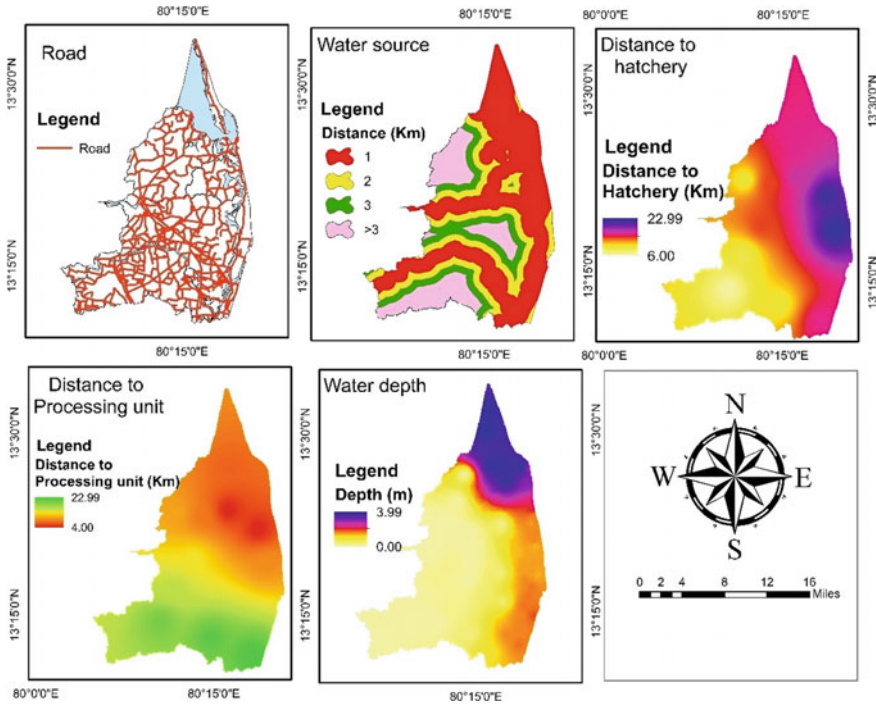


Fig. 36.5 Resource accessibility map

660.65 hectares, while the area available for further expansion is about 630 hectares as shown in Fig. 36.6. The sites were verified using field verification, and it was found the results estimated using the MCDM model were accurate. The overall weightage grid for potential area is given in Eq. 36.5.

$$\text{Grid}_{\text{Potential area}} = \text{Grid}_{\text{Accessibility}} \times 0.358 + \text{Grid}_{\text{land use}} \times 0.304 + \text{Grid}_{\text{water quality}} \times 0.232 + \text{Grid}_{\text{soil quality}} \times 0.107. \tag{36.5}$$

36.5 Discussion

The growth of aquaculture activity without any proper analysis would affect the environmental conditions, which would eventually affect the aquatic biodiversity (Vafaie et al. 2015). There are multiple factors, which need to be considered for site selection. Hence, GIS-based planning is essential for sustainable aquaculture expansion, which would provide a better management of resources. Many studies have been conducted using GIS for aquaculture site selection, while these studies have only

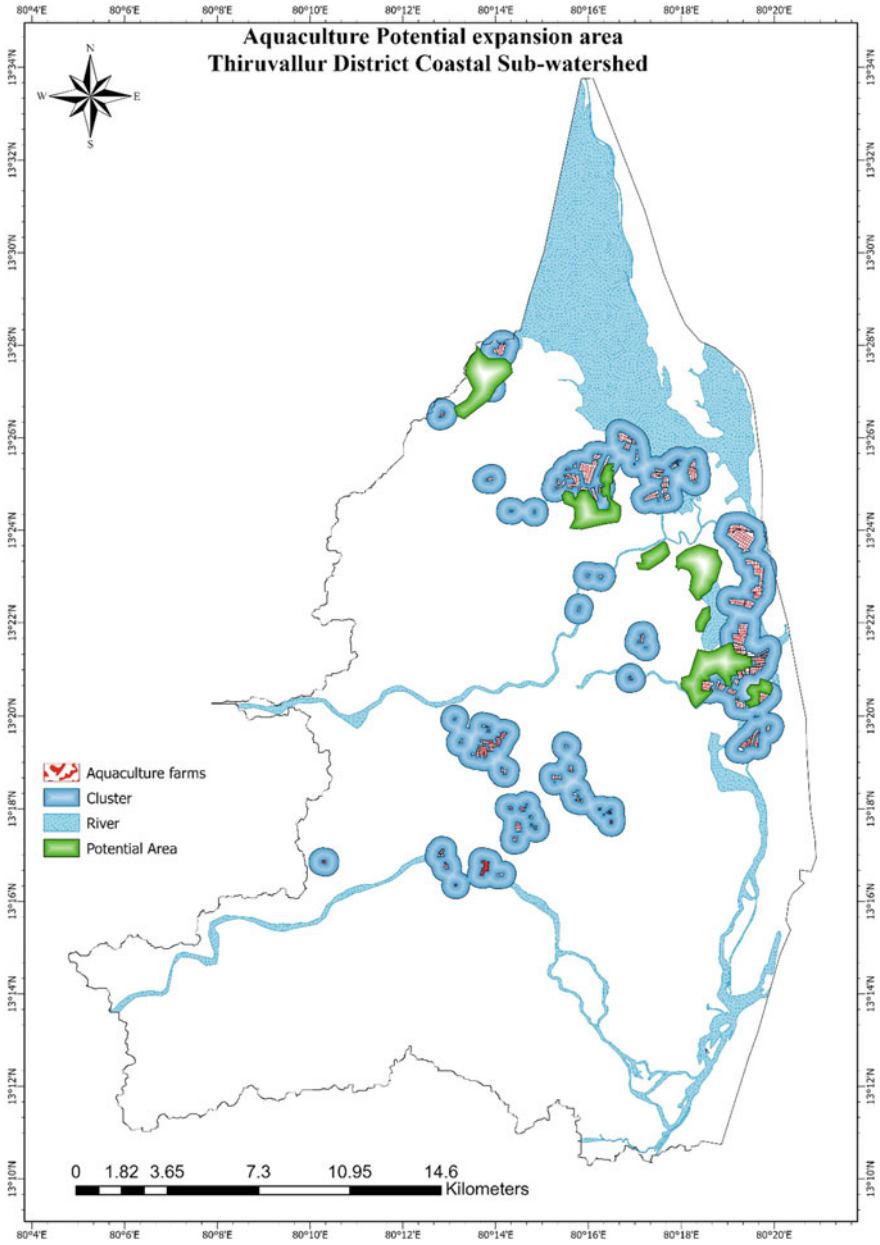


Fig. 36.6 Potential area for aquaculture expansion map

incorporated the resource characteristics such as water quality, soil quality, land use, and resource accessibility. The ecologically sensitive areas have not been excluded from the potential area in these studies (Giap et al. 2005; Hadipour et al. 2015), which would cause conversion of agricultural land, mangroves area and agricultural land salinization, etc. GIS-based mapping would increase the accuracy based on the inputs used, the higher the input factors greater the scale of accuracy. Coastal areas are mostly low lying, and aquaculture farms are mostly situated in these areas due to water accessibility (IPCC 2014). While flooding could not be completely avoided bund elevation could be raised and areas with very low elevation could be avoided to ensure flood damage. Climatic conditions are crucial for aquaculture activity hence incorporation of these factors in addition to the CAA regulations would improve the real-time model accuracy. A database could be created to make automatic delineation of the potential area using these factors which would greatly help the government and policy makers in providing license to the farmers and also improve the unproductive land for farmers livelihood. These management plans would greatly help in the raise of the economy and would decrease multi-user conflict. While many lands have been affected due to salinization if these lands are not used for agriculture for more than 5 years, they could be allowed for aquaculture process. Farmers livelihood depends on their land for survival; hence, government policies would make them to lead a better lifestyle. GIS-based shrimp farm database with farmers details provides great deal in planning (Nila Rekha et al. 2017). Hence, a database for potential aquaculture zone would greatly increase the planning and management efficiency. Water depth is the main limiting factor in many regions, deepest places are mostly creek and bar mouth, which makes it quite inconvenient for farming at a distance of more than 2 km. Water plays a crucial factor for shrimp farming, these resources would be utilized to the best by maintaining proper depth through dredging. Pollution in the coastal environment has been increasing at a rapid pace and proper policy for managing resource would increase the water quality for better farming practice. Hence, the environmental regulation CAA guideline is an important factor, which must be incorporated to obtain environmental sustainability.

Better planning and management would help to develop shrimp farm in a sustainable manner and further promote effective use of brackish water resources. This would help the government to make use of unproductive lands for improving the coastal community's livelihood and promote their status.

36.6 Conclusions

It can be concluded from the study that MCDM-based AHP technique is accurate in locating unproductive land for aquaculture operation. Integration of environmental regulations with the resource factors provides us a holistic approach, which will help to prevent multi-user conflict and promote sustainable farming. This method developed could be used as a tool by policy makers and stakeholders to make better planning for providing licenses to shrimp farmers. This methodology can be used as a base to estimate aquaculture potential areas in other places.

Acknowledgements We are grateful to NABARD for funding this work. We are also thankful to Director, ICAR-CIBA for the support and facility to carry out this work.

References

- APHA (2005) Standard methods for the examination of water & wastewater. In: Eaton AD, Clesceri LS, Franson MAH et al (eds) 21st ed. American Public Health Association, Washington, DC
- Belton B, Thilsted SH (2014) Fisheries in transition: food and nutrition security implications for the global South. *Glob Food Sec* 3(1):59–66. <https://doi.org/10.1016/j.gfs.2013.10.001>
- Boyd CE (1995) Bottom soils, sediments, and pond aquaculture. Chapman & Hall, New York
- Boyd CE, Tucker CS (1998) Pond aquaculture water quality management. Kluwer Academic Publishers, Norwell, MA
- Campbell JB and Wynne RH (2011) Introduction to remote sensing, vol 5. Guilford Press, New York, USA, pp 408–428. <https://doi.org/10.3390/rs5010282>
- Coastal Aquaculture Authority (CAA) (2014) Compendium of acts, rules, regulations and other notifications, p 236. <http://www.caa.gov.in/uploaded/doc/COMPUPD2014.pdf>. Accessed 11 May 2019
- De Silva SS (2001) A global perspective of aquaculture in the new millennium. In: Subasinghe RP, Bueno P, Phillips MJ et al (eds) Aquaculture in the third millennium. NACA, Bangkok, pp 431–459
- Eastman JR, Kyem PAK, Toledano J et al (1993) GIS and decision making. In: Explorations in geographic information systems technology, vol 4. United Nations Institute for Training and Research, Geneva.
- Falconer L, Middelboe AL, Kaas H et al (2019) Use of geographic information systems for aquaculture and recommendations for the development of spatial tools. *Rev Aquacult* 1–14. <https://doi.org/10.1111/raq.12345>
- FAO (2020) The state of world fisheries and aquaculture 2020. Sustainability in action, Food and Agriculture Organization, Rome. <https://doi.org/10.4060/ca9229en>
- Giap DH, Yi Y, Kwei Lin C (2005) Effects of different fertilization and feeding regimes on the production of integrated farming of rice and prawn *Macrobrachium rosenbergii* (De Man). *Aquacult Res* 36(3):292–299. <https://doi.org/10.1111/j.1365-2109.2005.01244.x>
- Hadipour A, Vafaie F, Hadipour V (2015) Land suitability evaluation for brackish water aquaculture development in coastal area of Hormozgan, Iran. *Aquacult Int* 23:329–343. <https://doi.org/10.1007/s10499-014-9818-y>
- Hossain MS, Chowdhury SR, Das NG et al (2009) Integration of GIS and multi-criteria decision analysis for urban aquaculture development in Bangladesh. *Landsc Urban Plann* 90(3–4):119–133. <https://doi.org/10.1016/j.landurbplan.2008.10.020>

- IPCC (2014) Geneva. In: Pachauri RK, Meyer LA (eds) Climate change 2014: synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change, vol. 151. http://www.ipcc.ch/pdf/assessmentreport/ar5/syr/SYR_AR5_FINAL_full_wcover.pdf.
- Lillesand TM, Kiefer RW (2000) Remote sensing and image interpretation, 4th edn. Wiley, New York
- Natale F, Hofherr J, Fiore G et al (2012) Interactions between aquaculture and fisheries. *Mar Pol* 38:205e213. <https://doi.org/10.1016/j.marpol.2012.05.037>
- Nayak AK, Kumar P, Pant D et al (2018) Land suitability modelling for enhancing fishery resource development in Central Himalayas (India) using GIS and multi-criteria evaluation approach. *Aquacult Eng* 83:20–129. <https://doi.org/10.1016/j.aquaeng.2018.10.003>
- Nila Rekha P, Gangadharan R, Dharshini S et al (2017) Digital database on shrimp farming in coastal watershed of Cuddalore District, Tamil Nadu. *Indian J Fish* 64(SI):39–45
- NRSA (1995) Integrated mission for sustainable development (IMSD)—technical guidelines. National Remote Sensing Agency, Hyderabad, India
- Ottinger M, Clauss K, Kuenzer C (2016) Aquaculture: relevance, distribution, impacts and spatial assessments—a review. *Ocean Coast Manag* 119:244–266. <https://doi.org/10.1016/j.ocecoaman.2015.10.015>
- Paez-Osuna F (2001) The environmental impact of shrimp aquaculture: causes, effects, and mitigating alternatives. *Environ Manag* 28(1):131–140. <https://doi.org/10.1007/s002670010212>
- Perez OM, Telfer TC, Ross LG (2003) Use of GIS-based models for integrating and developing marine fish cages within the tourism industry in Tenerife (Canary Islands). *Coast Manag* 31(4):355–366. <https://doi.org/10.1080/08920750390232992>
- Primavera JH (2006) Overcoming the impacts of aquaculture on the coastal zone. *Ocean Coast Manag* 49(9–10):531–545. <https://doi.org/10.1016/j.ocecoaman.2006.06.018>
- Radiarta IN, Saitoh SI, Miyazono A (2008) GIS-based multi-criteria evaluation models for identifying suitable sites for Japanese scallop (*Mizuhopecten yessoensis*) aquaculture in Funka Bay, southwestern Hokkaido, Japan. *Aquaculture* 284(1–4):127–135. <https://doi.org/10.1016/j.aquaculture.2008.07.048>
- Richards DR, Friess DA (2016) Rates and drivers of mangrove deforestation in Southeast Asia, 2000–2012. *Proc Natl Acad Sci Unit States Am* 113(2):344–349. <https://doi.org/10.1073/pnas.1510272113>
- Saaty TL (1977) A scaling method for priorities in hierarchical structures. *J Math Psychol* 15(3):234–281. [https://doi.org/10.1016/0022-2496\(77\)90033-5](https://doi.org/10.1016/0022-2496(77)90033-5)
- Saaty TL (2008) Decision making with the analytic hierarchy process. *Int J Serv Sci* 1(1):83–98. <https://doi.org/10.1504/IJSSCI.2008.017590>
- Salam MA, Ross LG, Beveridge CM (2003) A comparison of development opportunities for crab and shrimp aquaculture in southwestern Bangladesh, using GIS modeling. *Aquaculture* 220(1–4):477–494. [https://doi.org/10.1016/S00448486\(02\)00619-1](https://doi.org/10.1016/S00448486(02)00619-1)
- Senarath U, Visvanathan C (2001) Environmental issues in brackish water shrimp aquaculture in Sri Lanka. *Environ Manag* 27(3):335–348. <https://doi.org/10.1007/s002670010153>
- Stelzenmüller V, Gimpel A, Gopnik M et al (2017) Aquaculture site-selection and marine spatial planning: the roles of GIS-based tools and models. In: Buck B, Langan R (eds) *Aquaculture perspective of multi-use sites in the open ocean*, Springer, Cham. https://doi.org/10.1007/978-3-319-51159-7_6

- Thomas N, Lucas R, Bunting P et al (2017) Distribution and drivers of global mangrove forest change, 1996–2010. *PLoS ONE* 12(6):1–14. <https://doi.org/10.1371/journal.pone.0179302>
- Vafaie F, HadipourA HV (2015) GIS-based fuzzy multi-criteria decision making model for coastal aquaculture site selection. *Environ Eng Manag J* 14(10):2415–2425
- Young N, Brattland C, Digiovanni C et al (2019) Limitations to growth: social-ecological challenges to aquaculture development in five wealthy nations. *Mar Pol* 104:216–224. <https://doi.org/10.1016/j.marpol.2019.02.022>