GIS-Based Multi-Criteria Evaluation for Suitable Clam Farming Sitein Vembanad Lake, India

ABSTRACT

The present study identifies and quantifies appropriate sites for black clam farming in the Vembanad Lake using a geographical information system (GIS). The black clam, *Villoritacpyrinoides*, is the most important clam landed in India. Despite being a candidate species for aquaculture, the trials on farming of clams are very limited. The aim of this study was to select most suitable sites for clam farming in Vembanad Lake based on the use of GIS-based models. For this, the importance of soil quality, water quality and infrastructure facilities were accessed using an analytical hierarchical process. The site suitability map was prepared using each attribute and divided into four classes such as most suitable, moderately suitable, least suitable and poor. The total area covered under this study was 6471 ha out of which, 3121 ha (48%) was identified as most suitable and from the remaining 3350 ha, 1804 ha (28%) was identified as moderately suitable, 946 ha (15%) was identified as least suitable and 600 ha (9%) was identified as the poor site for clam farming in Vembanad Lake.

Keywords :*GIS, Clam Farming, Criteria, VembanadLake*

INTRODUCTION

Just like any other commercial venture, aquaculture also utilizes natural resources and relies on inputs such as water, seed, feed etc. to produce a final product for consumption. This interaction with the environment may have social, economic, and environmental benefits, such as provision of food, employment, increase of income, improved nutrition and health, decreased pressure on natural stocks, etc[1]. In spite of being a promising field, the progress of aquaculture is interfered with a variety of obstacles. These include limited suitable sites, concerns regarding impacts on the environment, and multi-use conflicts. Improper aquaculture development may result in over exploitation and un-sustainability in the use of natural resources. Aquaculture needs to reduce negative impacts on other resource users in the same location whilst also earning the respect of other users in regard to its own development [2].

To ensure a sustainable development of the aquaculture industry, there is a great need to allocate aquaculture to suitable locations (site selection) to resolve competing demands for coastal space, avoid undesirable impacts on the environment, as well as ensure the profitability of the operation [3]. The selection of suitable site forms the key element for the proper management of aquaculture activity. The rapid growth of aquaculture worldwide has stimulated considerable interest among international technical assistance organizations and national-level governmental agencies in countries where aquaculture is still in its infancy, and has resulted in increased concerns about its sustainability in countries where the industry is well established.

For sustainable development, it is important to have an analytical frame work that can integrate spatial (and temporal) dimensions of parameters, which influence the sustainability [4]. Sustainable management practices to foster aquaculture all over the world adhere to a spatial component. This is because of the differences among biophysical and socio-economic characteristics from location to location. Criteria pertinent to water quality (e.g. temperature, dissolved oxygen, alkalinity, salinity, turbidity, and pollutant concentrations), water quantity (e.g. volume and seasonal profiles of availability), soil type (e.g. slope, structural suitability, water retention capacity and chemical nature) and climate (e.g. rainfall distribution, air temperature, wind speed and relative humidity) form the biophysical characteristics. Administrative regulations, competing resource uses, market conditions (e.g. demand for fishery products and accessibility to markets), infrastructure support and availability of technical expertise are considered as the socio-economic characteristics that influence aquaculture activities. Geographical information systems (GIS) support the spatial information needs for decision-makers who evaluate such biophysical and socio-economic characteristics as part of aquaculture planning efforts.GIS is an integrated assembly of computer hardware, software, geographic data and personnel designed to efficiently acquire, store, manipulate, retrieve, analyze, display and report all forms of geographically referenced information geared towards particular set of purposes [3]. It is an integral component of natural resource management activities globally.The first application of GIS in aquaculture date from the late 1980s. Despite, application of GIS in aquaculture is surprisingly quite diverse, targeting a broad range of species (fish, crustacean, and mollusc) as well as geographical scales, ranging from local areas (i.e., small bays: [5]; and big bays: [6]), to sub national regions (i.e., individual states/provinces; [7]), to national [8] and continental [9] expanses. They also vary with regard to the degree to which GIS outcomes have been used for practical decision making [10].

At present, the extent of GIS applications in aquaculture include site selection for target species such as fish [11], oysters [12], clams [13], scallop [14], shrimp [15], and seaweed [16]; environmental impact assessment [17]; conflicts and trade-offs among alternate uses of natural resources [18]; and consideration of the potential for aquaculture from the perspectives of technical assistance and alleviation of food security problems [3].

The black clam, *Villoritacpyrinoides*, is the most important clam species landed in India, which contributes about two-thirds of the total clam landings of Kerala.The black clam catch from Vembanad lake during 2016 was estimated as 37,129 tonnes. Majority of this clam harvest is done from Vembanad lake of Kerala state. Coastal communities around the lake depend on the fishing of clams and finfishes for their livelihood [19]. About 6,000 fishermen harvest the black clams year-round.

Despite being a candidate species for aquaculture, the trials on farming of clams are very limited. In India, the utilization of clams still relies on a collection of wild stock, which has to be replenished naturally. The majority of the clam population faces multiple risks due to habitat destruction, overfishing, pollution, etc [20]. The seed clams are destroyed by anthropogenic and natural activities. They are fished accidentally and sorted out for use in poultry feed or discarded as trash. A proper farming technique would facilitate relocation of clam seeds to the farming sites, where they could be raised to marketable sizes. It could also reduce the fishing pressure on the natural stock and generate employment opportunities for rural fisher folk, especially women thereby enhancing their economic status. Culture can be carried out as an artisanal mariculture programme and also as a large scale mariculture enterprise oriented towards export market.

The aim of this study was to select the most suitable sites for clam farming in Vembanad lake based on the use of GIS-based models to support the coastal zone management decision making process. At present, there are no clear designated guidelines for aquaculture site selection for clam farming in Vembanad ecosystem and this study was aimed to be the first of its kind.

MATERIALS AND METHODS

2.1 Sampling

The soil and water samples were collected on monthly basis from eight locations of Vembanad lake (6471 ha) for 16 consecutive months. Soil texture parameters like percentage of sand, silt and clay were analyzed. Water temperature was measured using thermometer. pH was measured with digital pH meter and organic carbon was determined following Walkey and Black by chromic acid liberation method [21]. Other water quality parameters such as, dissolved oxygen, alkalinity, nitrate and phosphate were estimated adopting standard methods of American Public Health Association [22]. Data on accessibility to the site, availability of clam seed and marketing facility were collected from officials of black clam lime shell co-operative societies, farmers as well as from field visits and available literature. In this study, fifteen base layers such as water quality (temperature, pH, dissolved oxygen, salinity, total alkalinity, hardness, phosphate, nitrate); soil quality (pH, texture and organic matter) and infrastructure facilities such as distance to water body, distance to road and distance to market were prepared. A procedure was set up using GIS for each attribute of water, soil and infrastructure facilities and divided into four classes such as most suitable, moderately suitable, least suitable [23] and unsuitable based on requirements for clam farming.

2.2 Hardware and Software

The software Geomedia Professional 6.0 was used for various analysis. Map Editing, Raster Analysis, Map Layout modules of this software were used to digitalize the study area and all the features such as, road network and market facilities. In addition, Geomedia Grid software was used to interpolate and for mathematical calculation of different grid layers.

The pair-wise comparison method developed by Saaty [24 & 25] in the context of analytical hierarchy process (AHP) was used to develop a set of relative weights for each parameter. Consequently, information about the relative importance of the criteria was required. At this stage, farmer's preferences with respect to the evaluation criteria were incorporated into the decision model. The preferences were typically defined as a value assigned to an evaluation criterion that indicates its importance relative to other criteria under consideration. Criteria were rated according to literature reviews and experts' opinions based on their relative importance using the pair-wise comparison method. By making pair-wise comparisons at each level of the hierarchy, it can develop relative weights, called priorities, to differentiate the importance of the criteria [24]. Depending on the weight obtained for each parameter, the suitability maps for soil, water and infrastructure facilities were prepared by adding all the criteria using the formula:

$$Grid_{result} = \sum_{r=1}^{n} (grid_i * weight_i)$$

and are presented in Equations (1) to (3)

$$\text{Soil grid} = \text{Grid}_{\text{pH}} \times 0.32 + \text{Grid}_{\text{Texture}} \times 0.21 + \text{Grid}_{\text{OM}} \times 0.47 \qquad ....(1)$$

$$\text{Water grid} = \text{Grid}_{\text{Temperature}} \times 0.13 + \text{Grid}_{\text{pH}} \times 0.14 + \text{Grid}_{\text{Dissolved oxygen}} \times 0.14 + \text{Grid}_{\text{Salinity}} \times 0.21 + \text{Grid}_{\text{Alkalinity}} \times 0.12 + \text{Grid}_{\text{Hardness}} \times 0.12 + \text{Grid}_{\text{Phosphate}} \times 0.06 + \text{Grid}_{\text{Nitrate}} \times 0.06 \qquad .... (2)$$

$$\text{Infrastructure grid} = \text{Grid}_{\text{water source}} \times 0.40 + \text{Grid}_{\text{road}} \times 0.16 + \text{Grid}_{\text{market}} \times 0.21 \qquad .... (3)$$

The overall site suitability map was prepared as per the weight of each parameter and presented as below:

$$\text{Site suitability grid} = \text{Grid}_{\text{Water}} \times 0.51 + \text{Grid}_{\text{Soil}} \times 0.21 + \text{Grid}_{\text{Infrastructure}} \times 0.26 \qquad ....(4)$$

RESULTS AND DISCUSSION

Site selection is considered a key factor for establishing a successful and sustainable aquaculture industry. It is clear that aquaculture site selection requires geographically related data and information, with multiple feasible alternatives, which are often conflicting and involve incompatible evaluation criteria. GIS technology offers unique capabilities of automating, managing, and analyzing a variety of spatial data for decision-making. At the same time, multicriteria decision-making and a variety of related methodologies offer a rich collection of techniques and procedures to reveal preferences objectively and incorporate them into GIS-based decision-making. Hence, this study is based on extensive use of GIS because besides performing straightforward database functions, it can also be used to explore relationships by querying data in different ways combining relevant thematic data layers and exploring the possible relationships between them, using overlaying functions and more complex modeling structures. This allows exploration of sensitivities of the models and investigation of different scenarios, leading to optimization of site location, exploration of visual and environmental impacts and estimation of sustainable production benefits.

Table 1. Average of data of water quality parameters for eight sampling stations of Vembanad lake

Sampling station No.	Lat. (N)	Long. (E)	Temp. (°C)	pH	Dissolved Oxygen (DO) mg/l	Salinity (ppt)	Alkalinity mg/l	Hardness mg/l	Nitrate mg/l	Phosphate mg/l
1	9°32.45'	76^{0}21.19'	26.4	7.4	5.0	7	31.6	443	0.62	0.34
2	9°44.34'	76^{0}24.87'	27.9	8	6.2	8	35.7	540	0.34	0.14
3	9°52.01'	76^{O}22.55’	28.2	8.2	5.9	9	37.8	572	0.47	0.09
4	9°39.27'	76^{O}23.45’	29.2	7.5	6.4	10	43.2	620	0.42	0.24
5	9°37.32'	76^{O}22.55’	30.3	7.7	5.7	6	32.4	510	0.66	0.22
6	9°59.28'	76^{O}16.34’	29.3	8.3	5.1	6	40	680	0.47	0.11
7	9°50.03'	76^{O}23.09’	27.4	8.2	4.6	4	39.5	564	0.59	0.14
8	9°46.38'	76^{O}19.89'	30.1	7.9	4.7	4	46.4	527	0.48	0.27

The average values for all the water quality parameters during the sampling period are presented in Table 1. The interpretation of suitability classes for each factor was classified on a scale from 3 to 1 [26] and presented in Table 2. Pair-wise comparison for assessing the relative importance of different soil quality parameters, water quality parameters and parameters on infrastructure facilities are shown in Table 3 (a) to (c).

Table 2. Suitability levels for water quality, soil quality and infrastructure facilities for clam farming in Vembanad lake

Parameters	Suitability rating and score			
	Most suitable	Moderately suitable	Least suitable	Unsuitable
Soil quality				
pH	7.5-8	8-8.5	7-7.5	<6.5 and >9.0
Texture (% clay)	6-10	4-6	2-4	<2
Organic matter (% carbon)	Up to 1	1-2	2-2.5	>2.5
Water quality				
Temp. (°C)	27-30	25-27	23-25	<23 and >32
pH	7.5-8	8-8.5	7-7.5	<6.5 and >10
Dissolved Oxygen (mg/l)	6.5-8	5-6.5	4-5	<4
Salinity (ppt)	8-10	6-8	4-6	<4 and >20
Total alkalinity (mg/l)	35-45	30-35	25-30	<25 and >60
Hardness (mg/l)	200-500	500-600	<200	<200 and >600
Phosphate (mg/l)	0.05-0.25	0.25-0.35	0.35-0.45	>0.45
Nitrate (mg/l)	0.3-0.5	0.5-0.8	0.2-0.3	<0.2 and >0.9
Infrastructure facilities				
Distance to water body (m)	<500	500-800	800-1000	>1000
Distance to road (m)	<500	500-800	800-1000	>1000
Distance to market (m)	<2000	2000-3000	3000-4000	>4000

(Source: Fact Sheet, Primary Industries and Resources, Australia: **www.pir.sa.gov.au,** 2000)

Table 3a. Pair-wise comparison matrix for assessing relative importance of different soil quality parameters

Parameters	pH	Texture	Organic matter	Weight

pH	1	2	½	0.32
Texture (Clay content)	½	1	1/3	0.21
Organic matter	2	3	1	0.47

Consistency ratio (C.R.) = 0.0092

Table 3b. Pair-wise comparison matrix for assessing relative importance of different water quality parameters

Parameters	Temperature	pH	DO	Salinity	Alkalinity	Hardness	Phosphate	Nitrate	Weight
Temperature ($^{\circ}$C)	1	3/2	1	2/3	2/3	1	2	2	0.13
pH	2/3	1	2/3	2	5/3	5/3	3	2	0.14
Dissolved oxygen (DO) (mg/l)	1	3/2	1	2/5	5/4	5/3	2	2	0.14
Salinity (ppt)	2	1	2/3	3	2/3	3	4	4	0.21
Alkalinity (mg/l)	1/3	3/5	4/5	3/2	1	1	2	2	0.12
Hardness (mg/l)	1/3	3/5	3/5	3/2	1	1	2	2	0.12
Phosphate (mg/l)	1/5	1/5	¼	3/2	½	½	1	1	0.06
Nitrate (mg/l)	1/5	1/5	1/4	3/2	1/2	1/2	1	1	0.06

Consistency ratio (C. R.) = 0.0532

Table 3c. Pair-wise comparison matrix for assessing relative importance of different infrastructure facilities parameters

Parameters	Distance to water source	Distance to road	Distance to market	Weight

Distance to water source	2	3	3/2	0.40
Distance to road	2/3	2	½	0.16
Distance to market	2/3	1	1	0.21

Consistency ratio (C.R) = 0.0124

Table 3d. Pair-wise comparison matrix for assessing relative importance of different parameters for clam farming site suitability in Vembanad lake

Parameters	Water quality	Soil quality	Infrastructure facilities	Weight
Water quality	1	2/3	1/2	0.51
Soil quality	1/3	½	3/2	0.21
Infrastructure facilities	1/3	2/3	1	0.26

Consistency ratio (C.R) = 0.0768

The results for fifteen criteria were presented separately in three sub-models, namely soil quality, water quality, and infrastructure facilities. Based on the AHP model, the salinity registered the highest importance (0.21) for the water quality suitability map as compared to other parameters like pH and dissolved oxygen which were found to be of moderate importance (0.14 each). Alkalinity, hardness (0.12 each) as well as phosphate and nitrate (0.06 each) had lesser importance as indicated in Table 3(b). Similarly, organic matter (0.47) and distance to the water source (0.40) were recorded as having higher importance in comparison with soil quality and infrastructure facilities as shown in Table 3(a) and Table 3(c) respectively. Overall, water quality is found to play a major role (54%) compared to soil quality (24%) and infrastructure facilities (22%) for development of clam farms in Vembanad Lake (Table 3d). The total area covered under this study was 6471 ha out of which, 3121 ha was identified as most suitable for clam farming in Vembanad Lake and from the remaining 3350 ha, 1804 ha was identified as moderately suitable, 946 ha was identified as least suitable and 600 ha was identified as unsuitable site for clam farming. Different criteria were grouped into three submodels as stated in equations (1) to (3), which were combined to generate a final output using equation (4) which demarcated the suitable areas for clam farming in Vembanad Lake. The suitable areas were identified from the output map as shown in Fig. 1 and are classified as most suitable (3121 ha, 48%); moderately suitable (1804 ha, 28%), least suitable (946 ha, 15%) and unsuitable (600ha, 9%) as indicated in Table 4 and Fig.1. In most suitable areas, farmers can easily obtain support services for and sell their products in short time to earn more profit than other areas. In contrast, moderately suitable areas can enable moderate production with moderate levels of profit. The suitable areas identified from the study were also physically verified and evaluated for suitability. The present study is an effort to apply the GIS in selecting suitable site for clam farming in Vembanad Lake. The zoning approach can provide important information enabling potential developers/investors to identify suitable zones that meet requirements, ensuring maximum benefit for a long period [27].

Table 4. Area and percentage of suitable sites for clam farming in Vembanad lake

Suitability Classes	Area (ha)	Percentage
Most suitable	3121	48
Moderately suitable	1804	28
Least suitable	946	15
Unsuitable	600	9
Total area	6471	

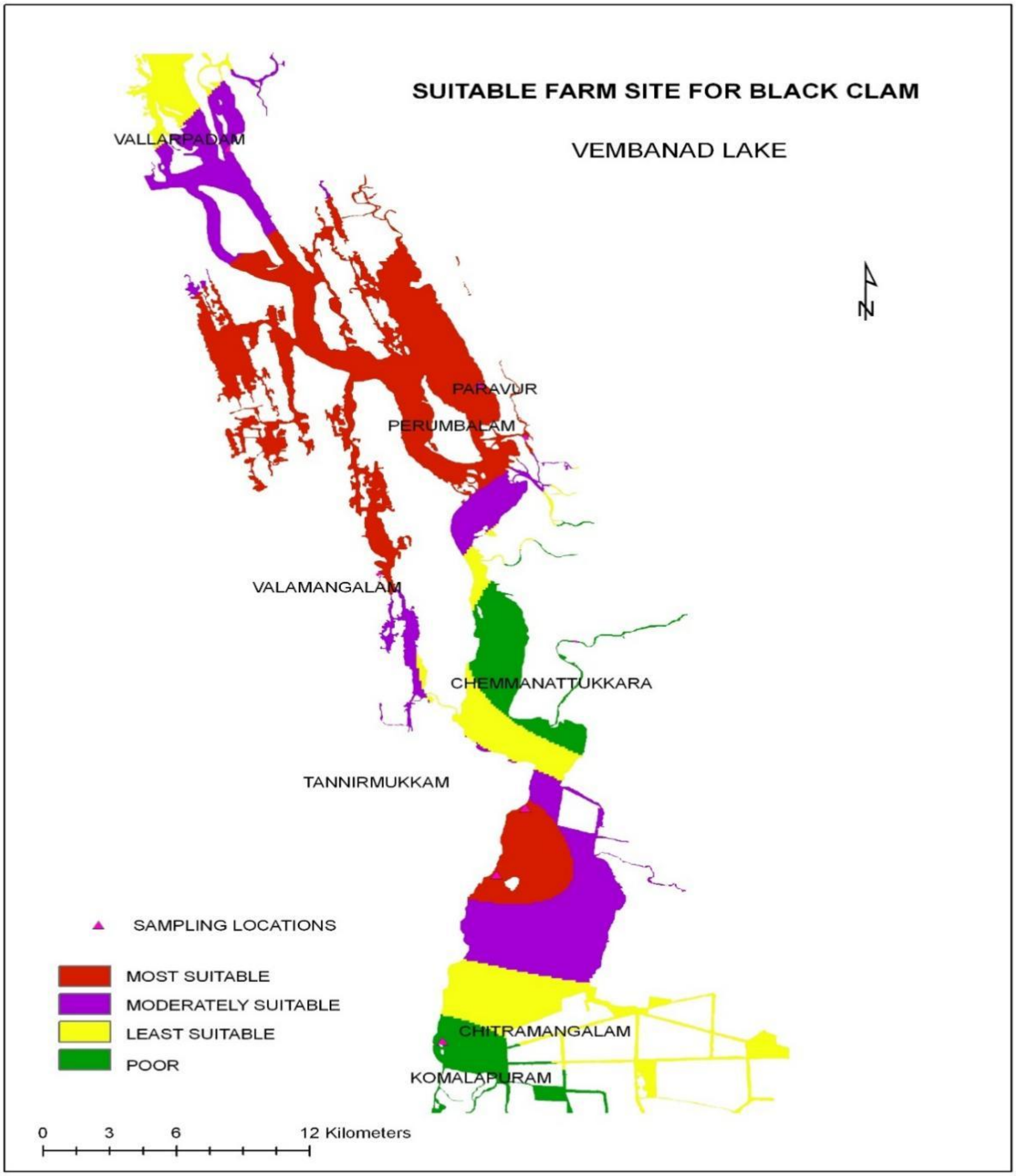

Fig.1. GIS map showing suitable farm site for clam farming in Vembanad lake

CONCLUSION

The GIS-based multicriteria analysis may be useful for evaluation in larger areas for the identification of suitable sites for clam farms. This will minimize the loss incurred due to ignorance of many environmental and social aspects during the pre-establishment of the clam farms. This study is a preliminary step to explore suitable clam farming areas in Vembanad Lake and the model can be replicated in similar kinds of geographical areas. Despite the fact that Vembanad Lake was chosen as the study area, the developed methodology could be applied to any other coastal areas worldwide. For some areas, it is most likely that the model assembled in this study could not be applied exactly as presented. Some of the criteria may be of little importance, while perhaps new ones would need to be added. Nevertheless, despite these small differences, the framework and methodology should remain the same independent of the study location. Overall, this study revealed the usefulness of GIS as a coastal aquaculture planning and management tool.

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