GIS-Based Aquaculture Site Suitability Study for Clam Farming in Vembanad Lake

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Introduction

Aquaculture, as with any other economic activity which uses natural resources, depends upon inputs (e.g., water, seed, feed) and attendant processes (e.g., capacity of the environment to degrade wastes) to produce a final product (e.g., fish, clam, mussels, shrimp, crab) for consumers. 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. (Beveridge, 2004). Despite the rapid growth, aquaculture development continues to be hindered by a number of constraints. These include limited suitable sites, concerns regarding impacts on the environment, and multi-use conflicts. Improper aquaculture development may result in overexploitation and un-sustainability on the use of natural resources. To prevent such problems, stock enhancement has been practiced in harmony with the environment and is clearly reflected in the increased production (Uki, 2006). 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 (Stead et al., 2002).

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 impact on the environment, as well as ensure the profitability of the operation (Kapetsky and Nath, 1997). Site suitability analysis may form the basis for control and management of aquaculture development. 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.

To make development sustainable, it is necessary to develop an analytical frame work that can incorporate spatial (and temporal) dimensions of parameters that effect sustainability (Frankic, 2003). Planning activities to promote and monitor the growth of aquaculture in individual countries (or larger regions) inherently have a spatial component because of the differences among biophysical and socio-economic characteristics from location to location. Biophysical characteristics may include 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). Socio-economic characteristics that may be considered in aquaculture development include administrative regulations, competing resource uses, market conditions (e.g. demand for fishery products and accessibility to markets), infrastructure support, and availability of technical expertise. The spatial information needs for decision-makers who evaluate such biophysical and socioeconomic characteristics as part of aquaculture planning efforts can be well served by geographical information systems (GIS) (Kapetsky and Nath, 1997).

GIS is a system specifically designed to work with data referenced by spatial or geographic coordinates. Geographical information systems (GIS) are becoming an increasingly integral component of natural resource management activities worldwide. 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 a particular set of purposes (Kapetsky and Nath, 1997).

GIS can allow for the analysis of both qualitative and quantitative data types, identify associations between components, and therefore, build a “living database” with exploratory data analysis, interpretative and mapping capabilities. GIS has several advantages for aquaculture development programs. It not only provides a visual inventory of the physical, biological, and economical characteristics of the environment, it also allows rational management without complex and time-consuming manipulations. The first applications of GIS in aquaculture date from the late 1980s (Kapetsky, and Nath 1997). Since then, the use of GIS has been quite limited. Despite this, GIS applications in aquaculture are 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; Ross et al., 1993; and big bays; Scott and Ross 1999), to sub national regions (i.e., individual states/provinces; Aguilar-Manjarrez and Ross, 1995), to national (Salam, 2000) and continental (Aguilar-Manjarrez and Nath, 1998) expanses. They also vary with regard to the degree to which GIS outcomes have been used for practical decision making (Nath et al., 2000).

At the present time, the extent of GIS applications in aquaculture include site selection for target species such as fish (Benetti et al., 2001), oysters (Cho et al., 2012), clams (Arnold et al., 2000), scallop (Halvorson, 1997), shrimp (Alarcon and Villanueva, 2001), and seaweed (Brown et al., 1999); environmental impact assessment (Gupta, 1997); conflicts and trade-offs among alternate uses of natural resources (Biradar and Abidi, 2000); and consideration of the potential for aquaculture from the perspectives of technical assistance and alleviation of food security problems (Kapetsky and Nath, 1997).

The black clam, *Villorita cpyrinoides*, is the most important clam species landed in India. The State of Kerala has been, by far, the leading producer of the species. Nearly all the landings, about 25,000 tons (t)/year are harvested in Vembanad Lake, the largest estuary, 96 km (54 miles) long, on the west coast of India. About 6,000 fishermen harvest the black clams year-round. The fisheries for the clams and the finfish provide the major livelihood for coastal communities around the lake (Sathiadhas et al., 2004).

Despite being a candidate species for aquaculture, the trials on farming of clams are very limited. In India, utilization of clams still relies on collection of wild stock, which has to replenish naturally. Majority of the clam population faces a multiple risk due to habitat destruction, over fishing, pollution etc (Suja and Mohamed, 2010). 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. Being in the lower part of the food chain, bivalves are energy efficient and cause least pollution to the culture system and the environment. 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 clearly designated guidelines to follow for aquaculture site selection for clam farming in the Vembanad ecosystem and this study was aimed to be the first of its kind.

Materials and methods

Study area

Vembanad Lake

Vembanad Lake is the largest brackish water lake on the west coast of India. Narrow and sinuous in the north and much broader in the south, the lake parallels the coast of the Arabian Sea. It is 96 km (54 miles) long and 14 km (8 miles) wide at its widest point and has a surface area of 24,000 km^2. It consists of estuaries, lagoons, some manmade canals, marshes, and mangroves (Ravindran et al., 2006). The salinity ranges from 0.3 at the lower end of the southern part to 18 ppt near the inlets. The water temperature ranges from 26^0 to 33.5^0 C. Aside from some shipping channels that are maintained to a 10-13 m depth, the major portion of the lake has a depth range of 2-7 m (Menon et al., 2000). Two major rivers, the Pamba and the Periyar, and four smaller rivers that all originate in the Sahya Mountains to the east, flow into the lake. The lake opens to the Arabian Sea through in two locations, one at Azheekode, that is at least 100 m (325 feet) wide and fairly deep, and the other at Cochin Gut that is 450 m wide (Menon et al., 2000). At the two openings, the rise and fall of tide is from 0.6 to 0.9 m. The bottom sediments where the black clams occur are a mixture of fine sand, clay, and silt and they extend over wide areas. Broad wetlands surround the lake. They are included in the wetlands of international importance, as defined by the Ramsar Convention for the Conservation and Sustainable Utilization of Wetlands in 2002, in part because they support more than 20,000 waterfowl in the winter.

The lake has both brackish and nearly freshwater environments. They are separated from each other by a man-made bund or barrier, the Thanneermukkom, which runs across the middle of the lake. Its purpose is to prevent the entry of substantial amounts of salt water to the southern area because it used to reduce the production of rice in paddy fields off the southeast side of the lake.

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 an ordinary thermometer. pH was measured with digital pH meter and organic carbon was determined by the method of Walkey and Black (1934). Other water quality parameters such as, dissolved oxygen, alkalinity, nitrate and phosphate were estimated adopting standard methods (APHA, 1985). 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 (soil pH, soil 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 (FAO, 1993) and poor on the basis of requirements for clam farming.

Hardware and Software

The software Geomedia Professional 6.0 was used for the 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. Geomedia Grid software was used to interpolate and for mathematical calculation of different grid layers in the present study.

The pair-wise comparison method developed by Saaty (1977) 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 (Saaty, 1994). Depending on the weight obtained from Table 3 (a) to (c) 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) - (3)

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

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

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

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

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

Results and Discussion

Site selection is considered as 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 involving incompatible evaluation criteria. GIS technology offers unique capabilities of automating, managing, and analysing 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 to 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 modelling 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.

The average value 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 (FAO, 1976) and presented in Table 2. Pair-wise comparison for assessing relative importance of different soil quality parameters, water quality parameters and parameters on infrastructure facilities are as shown in Table 3 (a) to (c).

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

Sampling station No.	Lat. (N)	Long. (E)	Temp. (^{O}C)	pH	Dissol-ved Oxygen (DO) mg/l	Salinity (ppt)	Alkalinity mg/l	Hardness mg/l	Nitrate mg/l	Phosphate mg/l
1	9^{O}32.45'	76^{0}21.19'	26.4	7.4	5.0	7	31.6	443	0.62	0.34
2	9^{O}44.342'	76^{0}24.874'	27.9	8	6.2	8	35.7	540	0.34	0.14
3	9^{O}52.018'	76^{O}22.55	28.2	8.2	5.9	9	37.8	572	0.47	0.09
4	9^{O}39.276'	76^{O}23.452	29.2	7.5	6.4	10	43.2	620	0.42	0.24
5	9^{O}37.324'	76^{O}22.554	30.3	7.7	5.7	6	32.4	510	0.66	0.22
6	9^{O}59.286'	76^{O}16.344	29.3	8.3	5.1	6	40	680	0.47	0.11
7	9^{O}50.032'	76^{O}23.090	27.4	8.2	4.6	4	39.5	564	0.59	0.14
8	9^{O}46.387'	76^{O}19.895'	30.1	7.9	4.7	4	46.4	527	0.48	0.27

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	Poor
Soil quality				
Soil pH	7.5-8	8-8.5	7-7.5	<6.5 and >9.0
Soil 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. (^{O}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	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)	1	3/2	1	2/5	5/4	5/3	2	2	0.14
Salinity	2	1	2/3	3	2/3	3	4	4	0.21
Alkalinity	1/3	3/5	4/5	3/2	1	1	2	2	0.12
Hardness	1/3	3/5	3/5	3/2	1	1	2	2	0.12
Phosphate	1/5	1/5	¼	3/2	½	½	1	1	0.06
Nitrate	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	1/2	3/2	0.21
Infrastructure facilities	1/3	2/3	1	0.26

Consistency ratio (C.R) = 0.0768

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
Poor	600	9
Total area	6471	

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 highest importance (0.21) for 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 water source (0.40) were recorded 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 impart 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 poor 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 poorly suitable (600ha, 9%) as indicated in Table 4. 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 (Hossain and Lin, 2001). The GIS based multicriteria analysis may be useful for further evaluation in larger areas for development of clam farms. This will minimise the loss incurred due to ignorance of many environmental and social aspects during pre-establishment of clam farm. The study is a preliminary step to explore suitable clam farming areas in Vembanad Lake and the model can be replicated in similar kind of geographical areas. Despite the fact that Vembanad Lake was chosen as the study area, the developed methodology could be applied to 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 no 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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