Aquacult Int (2007) 15:425–443
DOI 10.1007/s10499-007-9109-y

ORIGINAL PAPER

Multi-criteria evaluation approach to GIS-based land-suitability classification for tilapia farming in Bangladesh

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Received: 4 February 2007 / Accepted: 13 April 2007 / Published online: 25 May 2007

Abstract Site selection is a key factor in any aquaculture operation, because it affects both success and sustainability. It can, moreover, solve conflicts between different activities, making rational use of the land. This study was conducted to identify suitable sites for development of Nile tilapia (*Oreochromis niloticus*) farming in Sitakunda Upazila (sub-district), Bangladesh, using GIS-based multi-criteria evaluation of water and soil quality, topography, infrastructure and socio-economic factors. ASTER image and eighteen thematic layers were analyzed using ENVI and ArcView software to identify the suitable areas for tilapia farm development. A constraint layer was used to exclude areas from suitability maps that cannot be allowed to implement tilapia farming. A series of GIS models were developed to identify and prioritize the most suitable areas for tilapia farming. The output of the model clearly indicates the location and extent of tilapia farming areas on different suitability scales, i.e. most suitable (7,744 ha), moderately suitable (2,479 ha), and not suitable (838 ha). Model outputs were assessed against field verification data, and were consistent. Because existing aquaculture covers only 1,540 ha of land in the study area, the potential for expanding tilapia farms should take into consideration socio-political and environmental issues. The results are encouraging in terms of tilapia culture development and suggest that grassland–agriculture areas could be used for sustainable development of tilapia farming to diversify the economic activities of rural communities.

Keywords Analytical hierarchy process · GIS · Land suitability · Multi-criteria evaluation · Tilapia farming

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Introduction

A suitability study is a preliminary step when assessing whether land or any other area is likely to be practical and successful for sustainable development of an intended venture. In many instances aquaculture has been promoted in regions which are unsuitable in terms of climatic conditions, water and soil quality, and other facilities. A suitable site is a prerequisite for successful aquaculture. Fish have traditionally been cultured in the Sitakunda region without adopting any scientific and systematic inputs. In recent years horizontal expansion of fish farming (Nile tilapia, carp, and catfish) has been increasing in the Sitakunda area without consideration of the suitability of the locations. To ensure sustainable aquaculture development there is, therefore, a great need to allocate aquaculture to suitable locations to resolve competing demands for land, avoid undesirable effects on the environment, and ensure the profitability of the operation (Kapetsky 1987; GESAMP 1997).

Satellite remote sensing data are useful for updating an existing map or generating new thematic maps. During observations many earth features of interest have already been identified, mapped, and studied on the basis of their spectral characteristics (Lillisand and Kiefer 2000). GIS and remote sensing are essential tools for planning of aquaculture development (Burrough 1986). GIS also serve as an analytical and predicting tools for aquaculture development and to test the consequence of various development decisions before their use in the landscape (Aguilar-Manjarrez and Ross 1995). Other uses of GIS include efficient storage, management, and analysis of spatial and non-spatial data (Kapetsky et al. 1987; Burrough and McDonnel 1998). Similar observations were made by Vibulsresth et al. (1993), Venkataratnam et al. (1997), Pérez et al. (2003), Giap et al. (2005), and Rajitha et al. (2007). In recent years, significant advances have been made in remote sensing in Bangladesh, especially in shrimp-farming development in the coastal zone (Hossain et al. 2001), detection of changes in Sunderbans mangrove forest (Islam et al. 1997), mapping shrimp farming and agricultural areas (Shahid et al. 1992), mapping suitable areas for saltpan development (Hossain et al. 2003a), mangrove afforestation (Hossain et al. 2003b), and assessing suitable carp-farming areas (Salam et al. 2005).

The main problem in selecting suitable sites for tilapia farming is the lack of baseline information about physicochemical and topographic conditions, and existing land-use patterns. In Sitakunda the land area used for Nile tilapia farming has increased in recent years, because of steadily increasing demand in local and city markets. Expansion of Nile tilapia culture in traditional carp farming areas, grassland, and agriculture fields may, however, change ecological and environmental conditions and affect aquatic biodiversity. Thus, site selection incorporating water quality, soil characteristics, topography, infrastructure and socio-economic factors that affect suitability for the intended purpose is essential for Nile tilapia farming development. Inappropriate land use for tilapia farming without considering these factors can lead to misuse of natural resources and degradation of the environment, breeding poverty, and other social conflicts. The failure of shrimp farms in Ecuador, Taiwan, Thailand, Bangladesh, Vietnam, and elsewhere has been attributed to the deterioration of environmental conditions (Hossain et al. 2004). Farms in some areas are located on unsuitable sites and some are also constructed too densely for the carrying capacity of the environment. Site selection is rarely based on thorough assessment of the natural or men-made environment, however, and limited consideration is often given to technical, economic, logistic, and socio-political factors (Fegan 1994). To alleviate these potential problems, land evaluation can be used to predict land performance on the basis of its attributes by using a variety of analytical models. The structures of these models range from qualitative to quantitative, functional to mechanistic, or specific to general (Rossiter 1996). The objective of this study was to evaluate, using GIS-based models, quantitative land suitability for Nile tilapia farming development in Sitakunda Upazila, Bangladesh.

Study area

The study area, Sitakunda Upazila, is situated in the northwestern part of Chittagong district, between 22°34′ N and 22°43′ N latitude and 91°38′ E and 91°41′ E longitude (Fig. 1); it occupies an area of 18,488 ha and the population is 168,648. Soils are generally loamy, sandy loam, clay loam, and clay. Grey piedmont soils and brown hill soils formed in hill outwash alluvium along the hill ranges. Water bodies, for example ponds, stream corridors, canals, and natural depressions support multitudes of species of plants, fish, prawns, and other organisms suitable for culture. Fisheries are the most important resource in the aquatic ecosystem that is a major source of employment for the poor and also the main dietary source of protein for the rural population. The rural people are engaged in growing seasonal vegetables, paddy cultivation, fishing, and, to a lesser extent, fish culture.

The area, like other parts of the country, is much affected by seasonal monsoon winds. Mean annual rainfall in the study area is 3207 mm and mean annual temperature is 26.24°C. The monsoon or rainy season (June–October) is characterized by high rainfall, humidity, and cloud cover. Sediment load and water levels of the area also increase during this period. The salinity along the coast is reduced because of the effect of onrushing fresh water from the nearby upstream hilly regions. Occasional thunderstorms, cyclones, and storm surges occur during the monsoon season. The winter season (November–February), with a northeast monsoon wind, is characterized by dry, cool, and sunny weather with occasional rain. The lowest temperatures (8–10°C) occur in December–January, when days are dry and sunny but heavy dewfall at night and morning greatly disturbs navigational activity. The summer or pre-monsoon (March–May) with a southwest monsoon wind is characterized by southerly winds, high temperature, and evapotranspiration rates with occasional heavy thunderstorms (locally called Kalbaishakhi) and hail. Sunshine hours are minimum during the rainy and winter seasons and maximum in summer. Annual mean

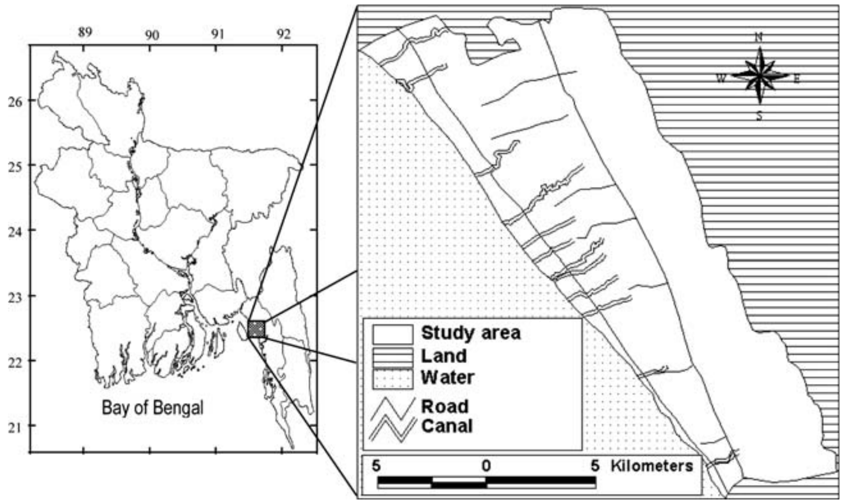

Fig. 1 Geographical location of the study area in Sitakunda Upazila, Bangladesh

sunshine is approximately 5 h per day and the mean annual wind speed recorded for the years 1991–2001 in Sitakunda was 1.8 knots (Khan et al. 2003).

Materials and methods

Data

An ASTER (advanced spaceborne thermal emission and reflection radiometer) image acquired on 29 November 2003 was used for this study. Topographic maps, soil maps, and land-use maps of 1:10000, 1:50000, and 1:50000 scale, published by the Survey of Bangladesh in 1999, SRDI in 1990, and LGED in 1998, respectively, were used for geometric correction. Geometric correction was performed with a fourth-order polynomial (Research Systems 2000a) and the monitored error (0.47) was less than one pixel (15 m) for 35 ground control points (GCP). Road junctions, crossing points of roads and railways, historical hard infrastructure, and prominent features were selected as most of the GCPs in the image. The image processor for the analysis was ENVI (the environment for visualizing image; Research Systems, USA). Ground data were obtained by field investigation of approximately 55 plots, some of which were permanent. Other ancillary data, for example water quality, soil quality, slope, elevation, land use, and infrastructure and socio-economic data are also important for the analysis.

Classification procedure

ISODATA unsupervised classification (use of information from the image itself to identify spectral clusters, which are interpreted as classes) was performed by considering minimum and maximum classes of 5–10, 10–15, and 15–20, among which the 10–15 classes were found to be useful. Supervised classification was performed on the basis of regions of interest (ROIs), in which the ground truth, or so-called training areas (collected during field investigation), were regions of terrain with known properties or characteristics (Research Systems 2000b). Maximum likelihood classification strategy was applied and found to be most useful for discriminating the category of interest.

Water and soil quality conditions, topography, road networks, markets, sources of fish fry, electricity, and population density were weighted and scored in terms of significance for tilapia farming. After image processing, reference points were chosen for ground verification. All the reference points were surveyed for the ground truthing of Sitakunda Upazila and compared on the preliminary map with real position. ArcView (Environmental Systems Research Institute, USA) and MS Office (Microsoft, USA) software were used to digitize and analyze all the classified and other necessary maps.

Weight and score

Within the framework of a GIS system (ArcView), a procedure was set up to attribute suitability classes to individual land units and to present the results of the classification on maps. The range of land characteristics was divided into three classes—most suitable, moderately suitable, and not suitable (FAO 1993)—on the basis of requirements for tilapia farm development. This study focused on basic factors, for example, eighteen base layers (thematic maps) were developed for tilapia farming, namely water source and quality (temperature, salinity, pH, dissolved oxygen, transparency), soil quality (pH, salinity, organic matter, texture), topography (slope, elevation, land-use type), infrastructure and socio-economic factors (road network, markets, sources of fish fry, electricity, population density). Weight was given according to the effectiveness of the criteria. Each class was also given a score according to suitability, i.e. most suitable scored 3, moderately suitable scored 2, and not suitable scored 1 (FAO 1976; Hossain et al. 2003a, b) (Table 1).

The analytical hierarchy process (AHP) is a proven, effective means of dealing with complex decision making and can assist with identifying and weighting selection criteria, analyzing the data collected for the criteria, and expediting the decision-making process. By making pair-wise comparisons at each level of the hierarchy, participants can develop relative weights, called priorities, to differentiate the importance of the criteria. The scale recommended by Saaty (1994) is from 1 to 9, with 1 meaning no difference in importance of one criterion in relation to another and 9 meaning one criterion is much more important than another, with different degrees of importance in between. The essence of AHP calculations is solution of an eigenvalue problem involving the reciprocal matrix of comparisons. Saaty (1980) suggests that if the CI/RI is smaller than 0.10, the degree of consistency is satisfactory; if, however, the CI/RI is larger than 0.10, there are inconsistencies and the AHP method may not yield meaningful results. Liberatore et al. (1992) suggested the structured approach of AHP could better capture the subjective judgments. Millet (1998) found that the process could enhance shared understanding of decisions, save time, and facilitate consensus. Liberatore and Nydick (1997) noted that AHP forced individuals to think through the strength of relationships leading to a process that was less biased and less political, and had more consistency than in the past. In the current study the weight for each factor was determined by pair-wise comparisons in the context of a decision-making process known as the analytical hierarchy process (Saaty 1977, 1990), which has also been recommended by Pereira and Duckstein (1993), Malczewski (1999). The suitability rating for each level of a factor was determined from the survey results and professional judgment of experts (Table 2). An example of spreadsheet calculations for consistency ratio of topographic criteria for tilapia farming is presented in Table 3.

Identification of variables and database generation

The model structure for selecting the best sites for tilapia farming in Sitakunda was built on the basis of hierarchical structures. Hierarchical structures break down all criteria into smaller groups (or submodels). To breakdown a hierarchy into clusters, first it was decided which elements to group together in each cluster. This was done according to the similarity of the elements with regard to the function they perform or the property they share (Saaty 1988). Figure 2 depicts suitability analysis for tilapia farming site selection in Sitakunda as a hierarchical structure. The top or first level in the hierarchy is the ultimate goal of the multicriteria decision-making analysis process. The intermediate or second hierarchy level lists the relevant evaluation criteria that were compared pair-wise to assess their relative weights. Each of these clusters was regarded as a submodel. The lowest level in the hierarchy contains the evaluation objects. All these criteria are identified as affecting the goal of the study and may represent primary data or be the result of secondary data (Table 4).

All data included in the database needed manipulation and reclassification to create the thematic layers, and registration of each layer to a common coordinate system. Given the variety of scales on which all criteria were measured, multicriteria decision analysis requires that the values contained in the different layers be transformed into comparable

Table 1 Suitability of water and soil quality, topography, and infrastructure and socio-economic factors for Nile tilapia farming in Sitakunda Upazila, Bangladesh

Criteria	Unit	Suitability rating and score			Refs.
		Most suitable[a] (3)	Moderately suitable[b] (2)	Not suitable[c] (1)	
Water sources		Stream corridor, canal	Irrigation	Underground	Giap et al. (2005)
Water temperature	°C	25–35	15–25	<15, >35	Minimum 15°C (Gannam and Phillips 1993), optimum 33°C (Caulton 1982) and maximum 41°C (Denzer 1967). Average 29°C (Yi and Lin 2001) and 28.5°C (Diana et al. 1996).
Water salinity	‰	0–10	10–20	>20	Tilapia can grow in both freshwater and brackish water (Al-Ahmed et al. 1988; Clark et al. 1990), 3–5‰ (Ridha et al. 1985) and 10–20‰ (Suresh and Lin 1992).
Water pH		6–8	4–6, 8–9	<4, >9	pH range 6.8 to 8.0 (Yi and Lin 2001), 6.6 to 8.4 (Yi et al. 1996) and 7.78 (Diana et al. 1996).
Water DO	mg l^{-1}	>2	1–2	<1	DO range 3.30–4.83 mg l^{-1} (Yi and Lin 2001) and 2.46 mg l^{-1} (Diana et al. 1996).
Water transparency	cm	20–30	30–40	>40	Hossain et al. (2004)
Soil pH		6–8	4–6, 8–9	<4 or >9	Hossain et al. (2003b)
Soil salinity	‰	<2	2–4	>4	Hossain et al. (2003b)
Soil OM	% carbon	<1	1–2	>2	Hossain et al. (2001)
Soil texture	Texture	Clay loam	Sandy clay	Loam, sand	Hossain et al. (2001) mentioned clay loam as most suitable and Mittelmark and Landkammer (1990) calculated seepage of 2.5–15 mm day^{-1} for clay loam soil.
Slope	%	0–5	5–15	>15	Hossain et al. 2001)
Elevation	m	0–5	5–10	>10	Hossain et al. (2001)

Table 1 continued

Criteria	Unit	Suitability rating and score			Refs.
		Most suitable[a] (3)	Moderately suitable[b] (2)	Not suitable[c] (1)	
Land-use type		Aquaculture, grassland	Paddy cultivation	Mixed orchard, seasonal vegetable	Land suitability assessment is part of a rational cropping system (FAO 1976) and optimizing the use of a piece of land for a specified use based upon its attributes, either in its present condition or after specified improvements (Rossiter 1996).
Distance to road	m	<500	500–1000	>1000	Giap et al. (2005)
Population density	People km^{-2}	<1000	1000–1500	>1500	Giap et al. (2005)
Distance to electricity	m	<200	200–500	>500	Salam et al. (2005)
Distance to local market	m	<2000	2000–4000	>4000	Giap et al. (2005)
Distance to sources of fish fry	m	<2000	2000–4000	>4000	Salam et al. (2005)

[a] Requires minimum time and investment to develop tilapia farming

[b] Requires modest time and investment and involves substantial intervention before tilapia farming

[c] The area is unsuitable for tilapia farming

Table 2 Pair-wise comparison matrix for assessing the relative importance of different factors for Nile tilapia culture potential in Sitakunda, Bangladesh (numbers show the rating of the row factor relative to the column factor)

	Sources	Temperature	Salinity	pH	DO	Transparency	Weight
Water quality							
Sources	1	2	1/3	1/2	2	1/4	0.09
Temperature	1/2	1	1/6	1/4	1	1/8	0.05
Salinity	3	6	1	3/2	6	3/4	0.27
pH	2	4	2/3	1	4	1/2	0.18
DO (Dissolved oxygen)	1/2	1	1/6	1/4	1	1/8	0.05
Transparency	5	8	4/3	2	8	1	0.36
Consistency ratio (C.R.)	*0.0032*						
	pH	Salinity	OM	Clay content			Weight
Soil quality							
pH	1	1/3	1/2	3			0.16
Salinity	3	1	3/2	9			0.47
OM (Organic matter)	2	2/3	1	6			0.32
Clay content	1/3	1/9	1/6	1			0.05
Consistency ratio (C.R.)	*0.0000*						
	Slope	Elevation	Land-use type				Weight
Topography							
Slope	1	1/2	3				0.30
Elevation	2	1	6				0.60
Land-use type	1/3	1/6	1				0.10
Consistency ratio (C.R.)	*0.0057*						

Table 2 continued

	Distance to road	Population density	Distance to electricity	Distance to market	Distance to sources of fish fry	Weight
Infrastructure and socio-economic factors						
Distance to road	1	1/2	1/3	2	3	0.15
Population density	2	1	2/3	4	6	0.29
Distance to electricity	3	3/2	1	6	9	0.44
Distance to market	1/2	1/4	1/6	1	3/2	0.07
Distance to sources of fish fry	1/3	1/6	1/9	2/3	1	0.05
Consistency ratio (C.R.)	*0.0000*					
	Water quality	Soil quality	Topography	Infrastructure and socio-economic factors		Weight
Land use requirement for assessment of site suitability for tilapia farming						
Water quality	1	3	1/2	1/3		0.16
Soil quality	1/3	1	1/6	1/9		0.05
Topography	2	6	1	2/3		0.32
Infrastructure and socio-economic factors	3	9	3/2	1		0.47
Consistency ratio (C.R.)	*0.0000*					

Table 3 Example of spreadsheet calculations for consistency ratio of topographic criteria for Nile tilapia farming in Sitakunda Upazila, Bangladesh

	Values			Decimal			Normalization			Average (By row)	λ_{max}	CI	RI	CR
	S	E	L	S	E	L	S	E	L					
S	1	1/2	3	1.00	0.50	3.00	0.30	0.30	0.30	0.2998	3.0066	0.0033	0.5	0.0057
E	2	1	6	2.00	1.00	6.00	0.60	0.60	0.60	0.5996				
L	1/3	1/6	1	0.33	0.17	1.00	0.10	0.10	0.10	0.1006				
Sum				3.3333	1.6700	10.0000				1.0000				

S = slope, E = elevation, L = land-use type

(a) Sum the values in each column of the matrix; divide each value in the matrix by the column sum; the resulting matrix is the normalized matrix

(b) Average the values in each row of the normalized matrix; the average value is the score (weight)

(c) Compute the eigenvalue (λ_{max}) for the matrix with three rows and select the maximum eigenvalue, $\lambda_{max} = (3.3333 \times 0.2998) + (1.6700 \times 0.5996) + (10.0000 \times 0.1006) = 3.0066$

(d) The consistency index (CI) is $(\lambda_{max} - n)/(n - 1)$, CI = (3.0066 − 3)/2 = 0.0033

(e) The consistency ratio (CR) is CI/RI, where RI is the random consistency index. For $n = 3$, RI = 0.58 (Saaty 1999). CR = 0.0033/0.58 = 0.0057

units. A scoring system of 1–3 was chosen, 3 being the most suitable and 1 not suitable for developing tilapia culture in Sitakunda. At this stage the decision-maker's preferences with regard to the evaluation criteria were incorporated into the decision model. Eventually the criteria layers and their weights were integrated to provide an overall assessment of the alternatives. This step is known as multicriteria evaluation and was accomplished by use of appropriate decision rules, which are formal mathematical expressions that combine the weights and scores of each of the layers used.

Verification

The model was verified by comparing predicted suitable sites with existing farm locations. Stratified random sampling was performed to identify 28 sites for subsequent visit and assessment. The purpose of verification was to discover whether the existing fish farm locations matched the suitability sites or not. An important assumption was that local people had a preference for more suitable locations based on their indigenous knowledge.

Results

Existing land use areas (Fig. 3) and suitability ranking for Nile tilapia culture are presented in Table 5. Taking into consideration existing land-use pattern, topographic conditions, and financial involvement in converting the existing land, the ranking was performed on the basis of the professional judgment of the researchers and the knowledge of indigenous people. The land-use classification shows that the dominant land-use activities are hill forest (5,758.11 ha), grassland (3,694.76 ha), seasonal vegetables (3,059.29 ha), paddy cultivation (2,801.18 ha) and aquaculture (1,540.96 ha), which account for 31, 20, 17, 15, and 8%, respectively, of total land area. Hill forest, mangrove forest, and town and built-up areas, comprising approximately 7,250 ha (40% of the total land area) are regarded as constrained areas for tilapia farming (Table 5). The results for 18 criteria are presented

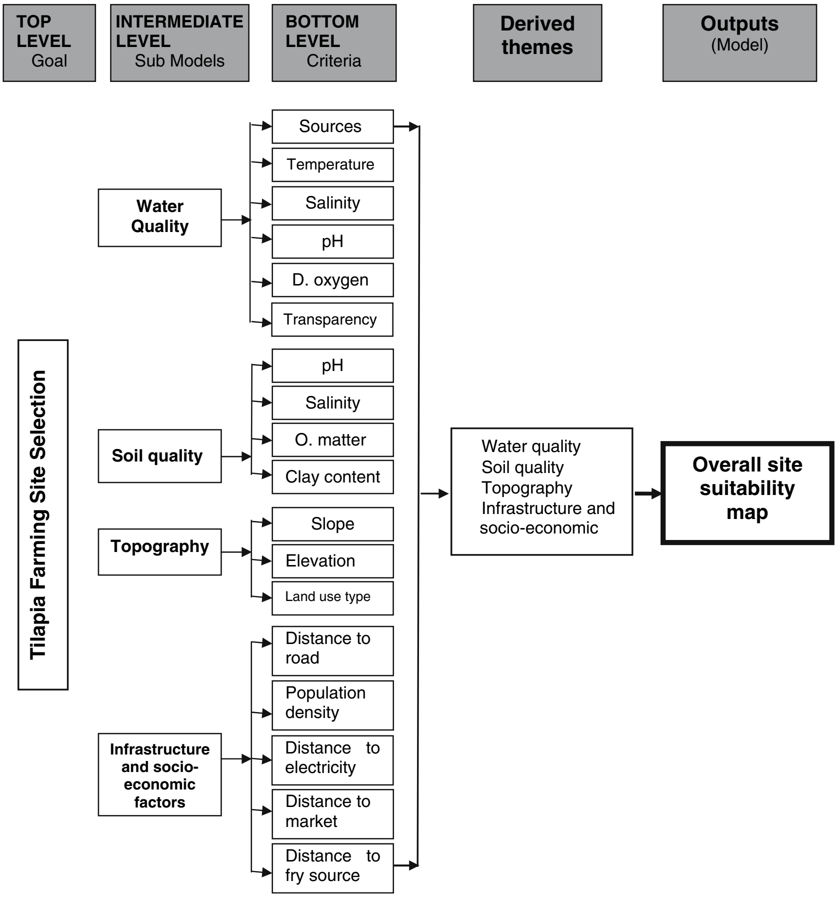

Fig. 2 Schematic diagram of modeling procedure for Nile tilapia farming area selection in Sitakunda Upazila, Bangladesh

separately in four submodels, namely water quality, soil quality, topography, and infrastructure and socio-economic factors, enabling comprehensive analysis. The potential area in each submodel is summarized in Table 6 and Fig. 4.

The most suitable areas for tilapia farming are recognized as those with water of good quality which is well-oxygenated and of favorable temperature, salinity, and pH. Such areas cover existing agriculture, aquaculture, and grassland. Approximately 100% of land area is most suitable for tilapia farming in terms of temperature, dissolved oxygen, salinity, and pH (Table 6). Moderately suitable areas (22% of land) with regard to water quality are located in areas of paddy and seasonal vegetable cultivation. All hilly streams of the nearby Chandranath reserve forest join together and form two waterfalls, Sahasradhara and Suptadhara. Numerous streams (locally called chhara), and canals (locally called khal) flow in the east-west direction and criss-cross the study area. The road and embankment behind ditches and homestead ponds also retain rainwater that can be used for aquaculture and to enhance agriculture and aquaculture activity in the nearby areas through irrigation. The coastal embankment with afforested greenbelt protects the study area from saline water.

Table 4 Criteria used for Nile tilapia culture potential in Sitakunda Upazila, Bangladesh

Criteria	Interpretation of criteria	Data sources
Water quality		
Water temperature	Temperature favored for tilapia culture.	This study
Water salinity	Slightly saline water in some samples.	This study
Water pH	Potential acid sulfate soil or high aluminium ion concentration resulting in low pH is the most common cause of failure of fish production.	This study
Water DO	Tilapia can tolerate low DO and survive in water where only air-breathing species can exist (Boyd 1990).	This study
Water transparency	Indicate the presence of suspended and dissolved solids.	This study
Soil quality		
Soil pH	Pyrites become oxidize and acidify the soil.	This study
Soil salinity	Afforested greenbelt-cum-embankment protect salinity intrusion but slight salinity recorded because of seepage.	This study
Soil OM	Accumulation of toxic metabolites such as ammonia and carbon dioxide can lead to chronic or acute toxicity.	This study
Soil texture	Water-holding capacity, reduce water pumping cost.	This study
Topography		
Slope	Affects the retention and movement of water, soil material, rate and amount of runoff, potential for soil slippage and accelerated erosion	SRDI soil map of 1990
Elevation	Increase water pumping cost	1:10,000 topographic map of Survey of Bangladesh, 1996
Land-use type	Current land-use pattern	This study
		SRDI soil map of 1990
Water from rain fed, stream corridor, canal, irrigation, underground	Available water	Bangladesh Water Development Boards
		Upazila Agriculture Office
Local and town market	Market for buying and selling goods	Field survey
		LGED map of 1994
		Survey of Bangladesh, 1997
Road network	Good communication	Satellite image
		LGED map of 1994
		Survey of Bangladesh, 1997
Nursery/hatchery	Sources of fish fry	Field survey
		Upazila Fisheries Office

LGED: Local Government Engineering Department and SRDI: Soil Resources Development Institute

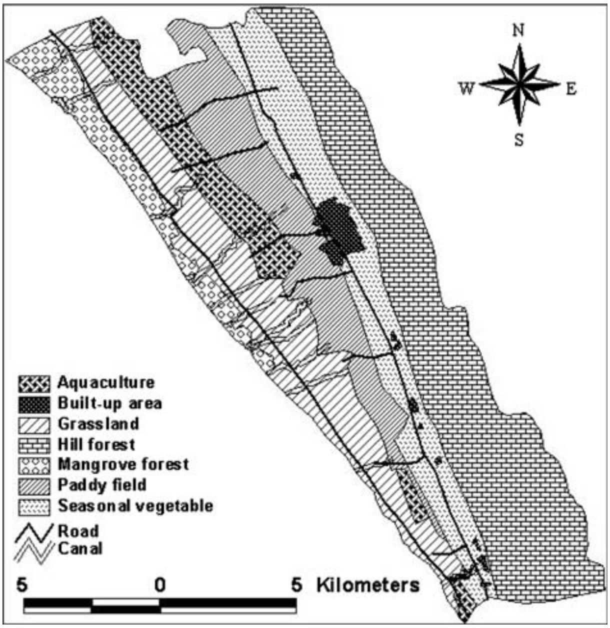

Fig. 3 Existing land-use patterns in Sitakunda Upazila, Bangladesh

Table 5 Land-use pattern and its suitability ranking for Nile tilapia farming

Land-use type	General characteristics	Area		Ranking
		ha	%	
Grassland	Natural grasslands and wet meadows	3694.76	20.14	Most suitable
Mangrove forest	Vegetation located along the coastal belt and tidal flats	1171.78	6.39	Constraint
Seasonal vegetables	Seasonal vegetables have been produced since time immemorial and distributed throughout the country	3059.29	16.68	Not suitable
Paddy	Paddy cultivation during monsoon months. Part of the land used for vegetables in winter months	2801.18	15.27	Moderately suitable
Aquaculture	Ponds, ditches, wetlands for traditional fish farming	1540.96	8.40	Most suitable
Town and built-up area	This land-use type comprised commercial, town, services, and industrial areas	319.33	1.74	Constraint
Hill forest	Mixed wood trees in hills and hillocks	5758.11	31.39	Constraint
Total		18,345.41	100.00	

Table 6 Areas (ha) and different suitability (%) of land for Nile tilapia farming in the study area (total land area for suitability analysis is 11,061 ha, excluding 7,250 ha constraint area)

Land characteristics	Most suitable		Moderately suitable		Not suitable	
	ha	%	ha	%	ha	%
Water quality						
Sources	7,744	70	2,479	22	838	8
Temperature	11,061	100	0	0	0	0
Salinity	11,061	100	0	0	0	0
pH	11,061	100	0	0	0	0
Dissolved oxygen	11,061	100	0	0	0	0
Transparency	6,874	62	4,187	38	0	0
Sub-overall	7,744	70	2,479	22	838	8
Soil quality						
pH	10,670	96	391	4	0	0
Salinity	10,863	98	198	2	0	0
Organic matter	9,545	86	1,516	14	0	0
Texture	9,200	83	1,861	17	0	0
Sub-overall	10,472	95	198	2	391	4
Topography						
Slope	6,881	62	4,180	38	0	0
Elevation	7,000	63	4,061	37	0	0
Land-use type	8,184	74	2,755	25	122	1
Sub-overall	5,841	53	2,200	20	3,021	27
Infrastructure and socio-economic factors						
Distance to road	8,620	78	2,441	22	0	0
Population density	7,778	70	3,284	30	0	0
Distance to electricity	3,864	35	1,481	13	5,717	52
Distance to market	7,740	70	3,322	30	0	0
Distance to sources of fish fry	8,681	78	2,380	22	0	0
Sub-overall	8,174	74	482	4	2,405	22
Overall suitability of site	7,744	70	2,479	22	838	8

The area is the output of map calculation in the GIS environment. For example, infrastructure and socio-economic factors were calculated by multiplying the mask file (shape file converted to grid with cell size 15 m of ASTER image) by the surface file (interpolated grid with cell size 15 m, spline with tension method for each criterion) and the weight as follows:

([Reclass of map calculation_road distance] × 0.15 + [Reclass of map calculation_population density] × 0.29 + [Reclass of map calculation_electricity distance] × 0.44 + [Reclass of map calculation_market distance] × 0.07 + [Reclass of map calculation_source of fish fry] × 0.05)

The soil affects the initial cost of pond construction, because soil permeability affects the capacity of the pond to hold water. Permeable soils are least suitable for ponds, inasmuch as water loss from seepage increases the demand for water, and pumping costs. The area of most suitable soil quality for tilapia farming is 95% of the total land area (Table 6). Only 4% of the area is not suitable for tilapia farming, and this covers that currently used for seasonal vegetable cultivation. Approximately 83–98% of land area is most suitable in terms of clay content, organic matter, pH, and soil salinity.

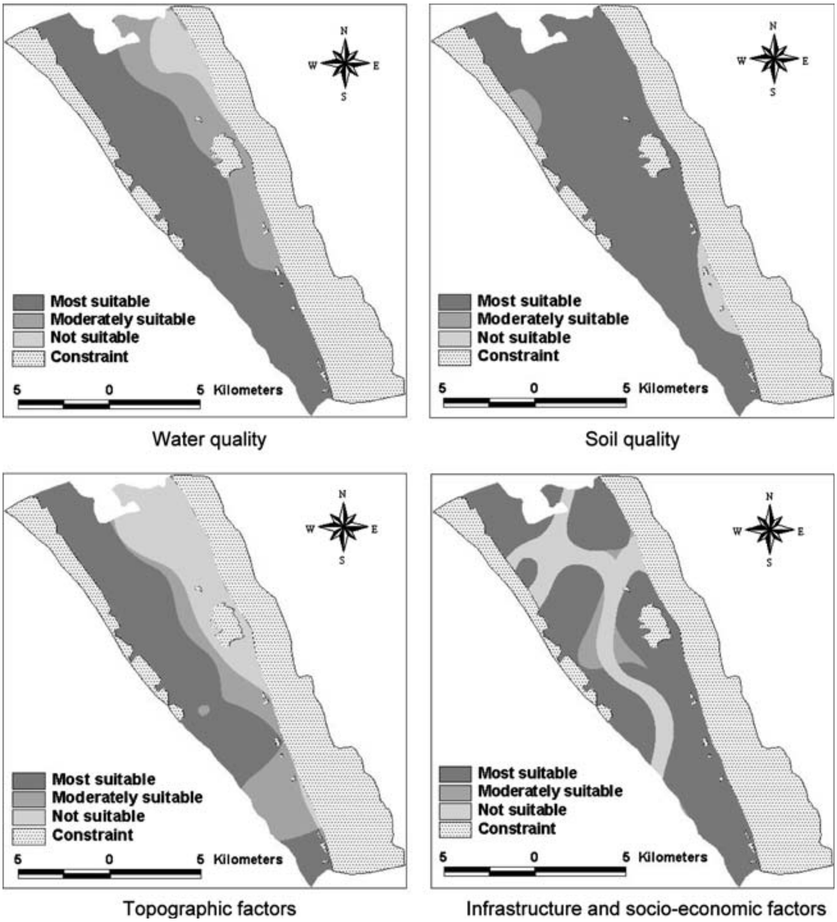

Fig. 4 Suitability maps for different land and water use requirements for Nile tilapia farming in Sitakunda, Bangladesh

The most suitable areas with regard to topography are found to be 53% of the land area along the coastal embankment with low slope (0–5%) and elevation of less than 5 m with appropriate land-use types and with access to water, a source of fish fry, and markets. These areas cover the existing grassland and aquaculture area and also include 20% of the moderately suitable area. The unsuitable zone of 27% of land area is located mainly in the seasonal vegetable and paddy cultivation areas with higher slope and elevation.

Infrastructure and socio-economic factors limit areas most suitable (74%) for tilapia farming (Table 6). This is mainly because electricity is not available in the area. Electricity is available in the study area within 200–500 m of the Asian Highway in an almost north–south direction; everywhere else is still in the dark, which means 52% is not suitable for tilapia culture. Population density is also important, because high human population, increasing industrialization, and agricultural intensification have resulted in significant pollution—excreta and sewage from the human population, waste and effluents from industry, and runoff from agricultural fields affect tilapia farming. Although the Asian Highway and all-weather motorways serve as the main transportation network, dirt roads

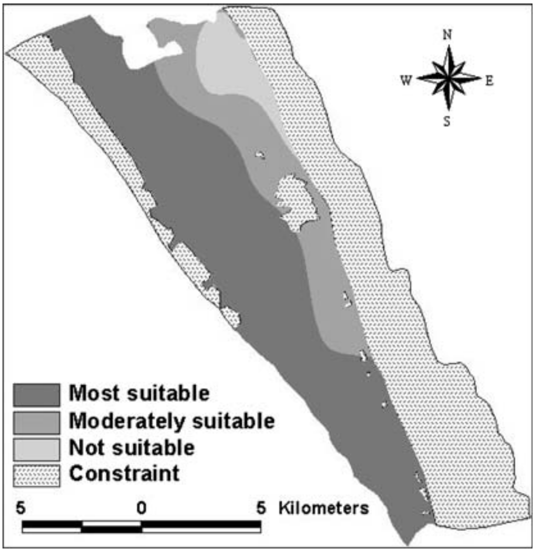

Fig. 5 Overall potential land-suitability map for Nile tilapia farming in Sitakunda, Bangladesh

are also significant to the local community for developing a network among the forward and backward-linked industries of tilapia farming. Availability of sources of fish fry and easily accessible well-established marketing facilities favor tilapia farming development in the study area. Approximately three-fourths of the total area (74%) is classified as suitable for tilapia farming in terms of infrastructure and socio-economic factors.

The overall evaluation shows that 70% of the total land area (7,744 ha) located in grassland, aquaculture, and paddy fields of the study area is most suitable for tilapia farming (Table 6, Fig. 5). The moderately suitable 22% land area (2,479 ha) is located in the paddy and seasonal vegetable cultivation areas. The remaining 8% of the land (838 ha) is classified as not suitable and is located mainly in the elevated seasonal vegetable areas.

Discussion

The total land area in this study is 18,311 ha, of which 7,250 ha (hill forest, mangrove forest, and town and built-up areas) were identified as constraint and the remaining 11,061 ha as classifiable area for Nile tilapia culture development. Different criteria were grouped in four submodels (water quality, soil quality, topography, and infrastructure and socio-economic factors), which were combined to generate a final output showing the most suitable areas for tilapia culture development. Land evaluation using GIS techniques led to estimates that 7,744 ha (70%) and 2,479 ha (22%) of the land were most suitable and moderately suitable, respectively, for tilapia farming. Results predicted as most favorable from this GIS evaluation are validated by the existing location of tilapia and other fish farms in the study area. The compactness of vast flood-free derelict common land with suitable water and soil quality and infrastructure facilities can be an appropriate option for commercial-scale tilapia farming to diversify the economic activities of different stakeholder groups. Polyculture of tilapia with carp can also be adopted, as is commonly practiced in other Asian countries. The most suitable areas for tilapia culture are those in which most of the variables coincide with each other and there is high potential for tilapia production. Farmers in these areas can easily obtain support services and sell their product in good time to earn more profit than in other areas. In contrast, moderately suitable areas can enable moderate tilapia production, although costs may be higher than in the most suitable areas because of the time required to obtain support services, transport requirements, and sell the product.

This study suggests that the land should be divided into different zones on the basis of suitability for tilapia farming, i.e. most suitable, moderately suitable, and not suitable zones. 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). Zoning of land and water for tilapia farm development can help in the control of environmental deterioration at the farm level and in the avoidance of adverse social and environmental interactions. Local people prefer more suitable locations on the basis of their indigenous knowledge, which justifies the well known expression ‘‘farmers are the real scientists’’; thus the present land-suitability evaluation identified the most favorable areas that were also validated by the current location of fish farms in the study area. Grassland and wet meadows are currently used solely for buffalo and cow grazing, although this derelict land can be converted for commercial-scale tilapia farming with added economic benefits and no environmental loss. A fragmented culture system, without any management practice, has occupied only 1,540 ha of the land in the study area, however. The most notable approach consists of stocking fish in water bodies followed by recapture after a period of several months or even a year. These results are very encouraging in terms of tilapia culture development and suggest that the grassland–agriculture areas could be used for Nile tilapia farming to diversify economic activity. After completion of the harvest the pond bottom effluent can be lifted up on to the dike and dried in the sun to produce manure for cultivation of dike-based vegetables. The decision to convert agriculture and wet-meadow grassland to fish ponds is often related to food security and social aspects. To maintain a balance between social and economic aspects, integrated farming systems, for example rice–fish culture (Gregory and Guttman 2002) or garden–pond–livestock and garden–pond–livestock–forest (Luu et al. 2002) may be examined. Other important factors, for example detailed environmental, climatic, economic, and political issues should be considered in the decision-making process. These factors are not considered, because of little variation within the study area and difficulties in spatial surface modeling from a small number of collected samples. These factors may be useful for land evaluation in larger areas.

Members of the local community reported there is a strong bond and social harmony among the religious groups (Muslims 75% and Hindus 25%). Most members of the community extend a helping hand to neighbors during crises or problems. The local community invites their neighbors to religious and social festivals. Women are quite conservative and feel shy about meeting outsiders, for example this research team. No social conflict, poaching, or robbery have been reported in the study area. Incorporating key socio-economic and environmental factors into land evaluation for Nile tilapia farming will enable planners and policy makers to develop better land use policies and make decisions based on objective characteristics and requirements or the overall potential of the land. This study shows that GIS databases of different format and from different sources can be used effectively to establish spatial models in land evaluation for tilapia farming. It is expected that land-evaluation modeling will be useful for identifying areas suitable for tilapia farming in terms of efficient income generation, effective conservation, and sustainable land management. The results of this study could be improved by use of site-specific data for tilapia culture. An important advantage of GIS is the ability to update current ratings easily when new or better information becomes available (Rajitha et al. 2007) and the ability to obtain output from the improved model ''on-the-fly''. A new map can be generated in a relatively short time with less effort and lower cost than for additions to files on paper, manual planimetry, and conventional map updating (Kapetsky 1994; William 1994).

References

Aguilar-Manjarrez J, Ross LG (1995) Geographical Information System (GIS), environmental models for aquaculture development in Sinaloa state, Mexico. Aquacult Int 3(2):103–115

Al-Ahmad T, Ridha M, Al-Ahmad AA (1988) Production and feed ratio of the tilapia *Oreochromis spilurus* in seawater. Aquaculture 73:111–118

Boyd CE (1990) Water quality in ponds for aquaculture. Auburn University, Auburn, AL

Burrough PA (1986) Principles of Geographic Information System for land resources assessment. Oxford University Press, New York

Burrough PA, McDonnell RA (1998) Principles of Geographical Information Systems. Oxford University Press, New York, p 333

Caulton MS (1982) Feeding, metabolism and growth of tilapias: some quantitative considerations. In: Pullin RVS, Lower-McConnell RH (eds) The biology and culture of tilapias. ICLARM Conference Proceedings 7, 2–5 September 1980, Bellagio, Italy. International Center for Living Aquatic Resources Management, Manila, Phillippines, pp 157–180

Clark JH, Wantanabe WO, Ernst DH, Wicklund RI (1990) Effect of feeding rate on growth and feed conversion of Florida red tilapia reared in floating marine cages. J World Aquacult Soc 20:16–24

Denzer HW (1967) Studies on the physiology of young tilapia. FAO Fish Rep 44:358–366

Diana JS, Lin CK, Yi Y (1996) Timing of supplemental feeding for tilapia production. J World Aquacult Soc 27:410–419

FAO (1993) Guidelines for land use planning. FAO Development Series 1. Food and Agriculture Organization of the United Nations, Rome, Italy

FAO (1976) A framework for land evaluation. Soils Bulletin, vol. 32. Food and Agriculture Organization of the United Nations, Rome, Italy

Fegan DF (1994) Environmental assessment and management of aquaculture development: an industry perspective. Workshop on environmental assessment and management of aquaculture. Third meeting of the Technical Advisory Committee (TAC 3) of the Network of Aquaculture Centres of Asia-Pacific, Hanoi, S. R. Vietnam, 27–30 September 1994, pp 18–29

Gannam A, Phillips H (1993) Effects of temperature on growth of *Oreochromis niloticus*. In: Egna HS, McNamara M, Bowan J, Astin N (eds) Tenth annual administrative report. Pond Dynamics/Aquaculture CRSP, Oregon State University, Corvallis, OR, pp 136–142

GESAMP (IMO/FAO/UNESCO/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution) (1997) Towards safe and effective use of chemicals in coastal aquaculture. Rep Stud GESAMP 65, p 40

Giap DH, Yi Y, Yakupitiyage A (2005) GIS for land evaluation for shrimp farming in Haiphong of Vietnam. Ocean Coast Manage 48:51–63

Gregory G, Guttman H (2002) Developing appropriate interventions for rice-fish cultures, In: Edwards P, Little DC, Demaine H (eds) Rural aquaculture, CABI Publishing, Wallingford, UK, pp 15–28

Hossain MS, Alam SMN, Lin CK, Demaine H, Khan YSA, Das NG, Rouf MA (2004) integrated management approach for shrimp culture development in the coastal environment of Bangladesh. World Aquacult 35(1):35–45

Hossain MS, Lin CK, Demaine H, Tokunaga M, Hussain MZ (2003a) Land use zoning for solar salt production in Cox's Bazar coast of Bangladesh: A Remote Sensing and GIS analysis. Asian J Geoinformatics 3(4):69–77

Hossain MS, Lin CK, Tokunaga M, Hussain MZ (2003b) Remote Sensing and GIS application for suitable mangrove afforestation area selection in the coastal zone of Bangladesh. Geocarto Int 18(1):61–65

Hossain MS, Lin CK (2001) Land use zoning for integrated coastal zone management: Remote Sensing, GIS and RRA approach in Cox's Bazar coast, Bangladesh. ITCZM Publication Series, No.3, Asian Institute of Technology, Bangkok, Thailand, p 25

Hossain MS, Lin CK, Demaine H, Tokunaga M, Hussain MZ (2001) Integrated GIS and Remote Sensing approaches for suitable shrimp farming area selection in the coastal zone of Bangladesh. Asia-Pacific Rem Sens GIS J 14:33–39

Islam MJ, Alam MS, Elahi KM (1997) Remote sensing for change detection in the Sunderbans, Bangladesh. Geocarto Int 12(3):91–100

Kapetsky JM (1994) A strategic assessment of warm-water fish farming potential in Africa. CIFA Technical Paper, vol. 27. Food and Agriculture Organization, Rome, Italy

Kapetsky JM (1987) Satellite remote sensing to locate and inventory small water bodies for fisheries management and aquaculture development in Zimbabwe. CIFA Occasional Paper (14). FAO, Rome, Italy.

Kapetsky JM, McGregor L, Nanne LH (1987) A geographical information system and satellite remote sensing to plan for aquaculture development: A FAO-UNESCO/GRID cooperative study in Costa Rica. FAO Fisheries Technical Paper (287), p 51

Khan YSA, Hossain MS, Chowdhury MAT (2003) Resource inventory and land use mapping for integrated coastal environment management: remote sensing, GIS and RRA approach in greater Chittagong coast. Ministry of science and information & communication technology, Government of the People's Republic of Bangladesh, Dhaka, p 59

Liberatore MJ, Nydick RL (1997) Group decision making in higher education using the analytic hierarchy process. Res High Educ 38(5):593–614

Liberatore MJ, Nydick RL, Sanchez PM (1992) The evaluation of research papers (or how to get an academic committee to agree on something). Interfaces 22(2):92–100

Lillisand TM, Kiefer RW (2000) Remote sensing and image interpretation, 4th edition. John Wiley & Sons, Inc., New York, p 724

Luu LT, Trang PV, Cuong NX, Demaine H, Edwards P, Pant J (2002) Promotion of small-scale pond aquaculture in the Red River Delta, Vietnam, In: Edwards P, Little DC, Demaine H (eds) Rural aquaculture, CABI Publishing, Wallingford, UK, pp 55–76

Malczewski J (1999) GIS and multicriteria decision analysis. New York: Wiley, p 392

Millet I (1998) Ethical decision making using the analytic hierarchy process. J Bus Ethics 17:1197–1204

Mittelmark J, Landkammer D (1990) Design and construction of diversion ponds for aquaculture. Department of Fisheries and Wildlife, University of Minnesota, St. Paul, Minnesota USA

Pereira JMC, Duckstein L (1993) A multiple criteria decision-making approach to GIS-based land suitability evaluation. Int J Geogr Inf Syst 7:407–424

Pérez 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 31:355–366

Rajitha K, Mukherjee R, Chandran V (2007) Applications of remote sensing and GIS for sustainable management of shrimp culture in India. Aquacult Eng 36:1–17

Research Systems Inc (2000a) *ENVI user's guide*. ENVI version 3.4. Research Systems Inc., USA

Research Systems Inc (2000b) Exploring ENVI, training course manual. Better Solutions Consulting Limited, Liability Company, USA

Ridha M, Al-Ahmad T, Al-Ahmad AA (1985) Tilapia culture in Kuwait: spawning experiments. Kuwait Institute for Scientific Research. Report KISR 1875, Kuwait, p 19

Rossiter DG (1996) A theoretical framework for land evaluation (with discussion). Geoderma 72:165–202

Saaty TL (1977) A scaling method for priorities in hierarchical structure. J Math Physiol 15:234–281

Saaty TL (1980) The Analytic Hierarchy Process. McGraw–Hill, New York, NY

Saaty TL (1988) The analytic hierarchy process. Typesetters Ltd, Beccles, Suffolk

Saaty TL (1990) The analytic hierarchy process: planning, priority setting, resource allocation. RWS Publications, Pittsburgh, p 287

Saaty TL (1994) How to make a decision: the analytic hierarchy process. Interfaces 24(6):19–43

Saaty TL (1999) Decision making for leaders (3rd ed.). RWS Publications, Pittsburgh, PA

Salam MA, Khatun NA, Ali MM (2005) Carp farming potential in Barhatta Upazilla, Bangladesh: a GIS methodological perspective. Aquaculture 245:75–87

Shahid MA, Pramanik MAH, Jabbar MA, Ali S (1992) Remote sensing application to study the coastal shrimp farming area in Bangladesh. Geocarto Int 2:5–13

Suresh AV, Lin CK (1992) Tilapia culture in saline waters: a review. Aquaculture 106:201–226

Venkataratnam L, Thammappa SS, Sankar TR, Anis S (1997) Mapping and monitoring prawn farming areas through remote sensing techniques. Geocarto Int 12(2):23–29

Vibulsresth S, Ratanasermpong S, Dowreang D, Silapathong C (1993) Mangrove monitoring using satellite data. TRSC Newsl 10(1):1–2

William RG (1994) A role for comprehensive planning, Geographical Information System (GIS) technologies and program evaluation in aquatic habitat development. Bull Mar Sci 55(2–3):995–1013

Yi Y, Lin CK (2001) Effects of biomass of caged Nile tilapia (*Oreochromis niloticus*) and aeration on the growth and yields in an integrated cage-cum-pond system. Aquaculture 195:253–267

Yi Y, Lin CK, Diana J (1996) Influence of Nile tilapia (*Oreochromis niloticus*) stocking density in cages on their growth and yield in cages and in ponds containing the cages. Aquaculture 146:205–215