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Note

GIS-based aquaculture site suitability study using multi-criteria evaluation approach

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ABSTRACT

The present study identifies and quantifies appropriate sites for aquaculture development in the mid/high Himalayan region of Uttarakhand using remote sensing and geographical information system (GIS). The GIS has an increasingly important role in management and utilisation of natural resources, particularly in fisheries resource assessment and management. Aquaculture has become one of the fastest growing food industries in the world. For aquaculture development in the region, the importance of each parameter of soil quality, water quality and infrastructure facilities were accessed using analytical hierarchical process. Various thematic layers were prepared for categorising suitable aquaculture sites based on three sub-models *viz.,* soil quality, water quality and infrastructure facilities. The site suitability map for aquaculture development was prepared for Betalghat Block of Nainital District, Uttarakhand. The total area suitable for aquaculture development was computed as most suitable (8426 ha forming 27%); moderately suitable (5623 ha forming 18%) and not suitable (198 ha forming 1%) with constraints of forest cover and infrastructure facilities of around 16617 ha (54%) of the total land area.

Keywords: Analytical hierarchy process, Aquaculture site selection, GIS, Multi-criteria evaluations

Aquaculture is one of the fastest growing food production systems in the world. The fisheries sector occupies an important place in the socio-economic development of the country. It has been recognised as a powerful income and employment generator and is a source of cheap and nutritious food besides being a foreign exchange earner. Most importantly, it is the source of livelihood for a large section of economically backward population of the country (Ayyappan and Krishnan, 2004). To meet the minimum protein requirement of the ever-increasing population of the country, the fish production needs to be enhanced. The inland aquaculture sector has a great scope to meet the demand of the nation. The success of aquaculture is dependent on the site that has suitable qualities of soil, water and infrastructure facilities. Application of geoinformatics may provide various ways of handling, analysis and interpretation of data, as well as decision making process for aquaculture development.

The Kumaon region of Uttarakhand State is blessed with an abundance of aquatic resources. In addition to the lake resources, the low and mid Himalayan Kumaon region has small ponds and has great potential for exploring more water areas for aquaculture development (Jalal, 1988; Vass, 2002). A network of river systems, lakes and reservoirs, in addition to ponds are the primary inland water resources for potential fish production and has greatly helped to improve the rural economy. However, these resources have not been judiciously used, and the scientific management of these vast inland water resources can boost fish production. This requires a thorough understanding of physico-chemical and biological characteristics of the water bodies. The GIS may help in making authentic decision, which are purely based on ground realities and can be used for scientific in-hand information for exploring the suitability towards aquaculture development. The site suitability is the preliminary study for sustainable development of land area available for aquaculture development. Bahuguna *et al.* (1995) proposed the site suitable for brackishwater aquaculture in Andaman and Nicobar group of Islands by using IRS LISS II data of land use map on 1:50,000 scale. Kumar *et al.* (2002) selected the aquaculture site through geoinformatics in Sagar Island, Hugli Estuary, Sundarbans. Karthik *et al.* (2005) applied the GIS and remote sensing technology for identification of potential sites for brackishwater aquaculture. The Ghana GIS agency has developed a decision-making tool for developing fish farming in Ghana (MacPherson *et al.,* 1991). Evaluation criteria of water quality, quantity, availability, soil type, land use/land cover and infrastructure facilities were used for developing suitable aquaculture sites for freshwater fish farming (Girap, 2006). The multi-criteria evaluations (MCE) is another concept and model that aid in evaluation by expression in terms of weights, values or intensities of preferences, which ultimately lead to a better decision making. The integration of MCE within a GIS context could help users to improve decision making processes (Hossain *et al.,* 2009). With reference to the altitudinal zones, a few studies have been conducted for aquaculture development in Kumaon region (Tyagi *et al.*, 1999; Tyagi, 2005).

The study area, Betalghat Block, is situated in the northern part of the Nainital District lying between lat. 29^0 23' and 29^0 36' N and long. 79^0 13' and 79^0 32' E which occupies an area of 30864 ha (Fig. 1). Remote sensing data of IRS-1C LISS III of the study area for the year 2004 were

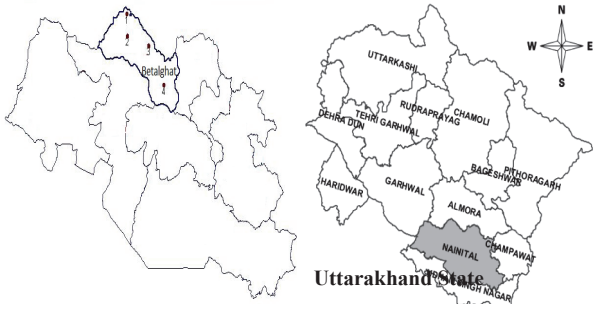

Fig. 1. Location of the study area along with sampling stations (1-4) of Betalghat Block in Nainital District, Uttarakhand

collected from National Remote Sensing Centre (NRSC), Hyderabad. Corresponding Survey of India toposheets 53 O/6, 53 O/7, 53 O/10 and 53 O/11 of 1:50,000 scale and village boundary map of Nainital District were used in the study.

The soil and water samples were collected from the four locations of the block which represented the whole block. Soil samples were collected once during the study whereas water samples were collected on quarterly basis. Soil texture parameters like percentage of sand, silt and clay were obtained using a soil-hydrometer. pH of soil was measured with pH meter and organic carbon was determined by the method of Walkey and Black (1934). Water quality parameters such as temperature, pH, dissolved oxygen, alkalinity, nitrate and phosphate were estimated adopting standard methods (APHA, 1985) and the average value for the four quarters are presented in Table 1. Data on accessibility to the site, availability of inputs for aquaculture such as seed, feed and fertilizers and marketing facility were collected from Government officials, farmers as well as from field visits and available literature.

Resource and facility maps were prepared based on the toposheet and satellite data. A procedure was set up using GIS for each attribute of water, soil and infrastructure facilities and divided into three classes such as most suitable, moderately suitable and not suitable (FAO, 1993) on the basis of requirements for aquaculture. In this study, fifteen base layers such as water quality (temperature, pH, dissolved oxygen, carbon dioxide, 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, distance to market and distance to hatchery, were prepared. The software Geomedia Professional 6.0 was used for the analysis. Map Editing, Raster Analysis, Map Layout modules of this software were used to digitise the study area and all the features such as rivers, streams, lakes, 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 interpretation of suitability classes for each factor was classified on a scale from 3 to 1 (FAO, 1976) and presented in Table 2.

The pairwise 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 in MCE as shown in Table 3 (a) to (c). Consequently, information about the relative importance of the criteria was required. At this stage, aquaculturist'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 pairwise 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) – (c) for each parameter, the suitability maps for soil, water and infrastructure facilities were prepared by adding all the criteria using the formula:

$$Grid_{result} = \sum_{i=1}^{n} (grid_i * weight_i)$$ and are presented in Equations. (1) - (3)

$$Soil_{grid} = Grid_{pH} \times 0.30 + Grid_{texture} \times 0.16 + Grid_{OM} \times 0.54 \quad ....(1)$$

$$Water_{grid} = Grid_{Iemperature} \times 0.24 + Grid_{pH} \times 0.17 + Grid_{Dissolve\ oxygen} \times 0.17 + Grid_{Carbon\ dioxide} \times 0.10 + Grid_{Alkalinity} \times 0.10 + Grid_{Hardness} \times 0.10 + Grid_{Phosphate} \times 0.06 + Grid_{Nitrate} \times 0.06 \quad .... (2)$$

$$Infrastructure_{grid} = Grid_{water\ source} \times 0.40 + Grid_{road} \times 0.12 + Grid_{fry\ source} \times 0.26 + Grid_{market} \times 0.22 \quad .... (3)$$

The overall site suitability map was prepared as per the weight of each parameter from Table 3(d) and presented as below:

$$Site\ suitability_{grid} = Grid_{water} \times 0.54 + Grid_{soil} \times 0.24 + Grid_{infrastucture} \times 0.22 \quad ....(4)$$

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 water temperature registered highest importance (0.24) for water

Table 1. Average of quarterly data for four sampling stations of Betalghat Block, Nainital

Sampling station No.	Lat. (N); Long. (E)	Temp. (°C)	pH	Dissolved oxygen (DO) (mg l^{-1})	Carbon dioxide (CO_2) (mg l^{-1})	Alkalinity (mg l^{-1})	Hardness (mg l^{-1})	Nitrate (mg l^{-1})	Phosphate (mg l^{-1})
1	$29^0$35'57" ; $79^0$20'14"	14.9	7.5	9.6	0.5	46.0	48.0	0.16	0.06
2	$29^0$33'06" ; $79^0$20'24"	15.5	7.7	9.7	0.6	63.5	64.0	0.28	0.06
3	$29^0$31'50" ; $79^0$25'13"	16.1	8.5	9.7	0.6	54.5	55.0	0.32	0.12
4	$29^0$26'46" ; $79^0$28'39"	17.6	8.3	9.2	0.6	63.5	65.0	0.34	0.06

Table 2. Suitability levels of water quality, soil quality and infrastructural facilities for aquaculture in Nainital District, Uttarakhand

Parameters	Suitability rating and score		
	Most suitable (3)	Moderately suitable (2)	Not suitable (1)
Soil quality			
Soil pH	6.5-8.5	5.5-6.5 and 8.5-9.0	<5.5 and >9.0
Soil texture (% clay)	>35	18-35	<18
Organic matter (OM) (% carbon)	1	1-2	>2
Water quality			
Temp (^{0}C)	20.0 – 25.0	10.0 - 20.0	<10.0
pH	6.5 - 8.5	5.0-6.5 and 8.5-10.0	<5.0 and >10.0
DO (mg l^{-1})	>8.0	5.5-8.0	<5.5
CO_2 (mg l^{-1})	0-5	5-20	>20
Total alkalinity (mg l^{-1})	50-200	20-50 and 200-500	< 20 and >500
Hardness (mg l^{-1})	50-200	20-50 and 200-500	< 20 and >500
Phosphate	0.05 - 0.25	0.25 - 0.40	>.4
Nitrate	1	1.0 - 2.0	>2.0
Infrastructure facilities			
Distance to water body (m)	<500	500-1000	>1000
Distance to road (m)	<500	500-1000	>1000
Distance to market (m)	<2000	2000-4000	>4000
Distance to hatchery (m)	<5000	5000-10000	>10000

(Source: Banerjea, 1967; Hajek and Boyd, 1994; Tyagi, 2009)

quality suitability map in coldwater region as compared to other parameters like pH and dissolved oxygen which were found to be of moderate importance (0.17 each). Alkalinity, hardness, carbon dioxide (0.10 each) as well as phosphate and nitrate (0.06 each) had lesser importance as indicated in Table 3(b). Similarly, organic matter (0.54) 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 aquaculture development in Kumaon hills (Table 3d).

The total land area covered under this study was 30864 ha out of which, 16617 ha was identified as areas with constraints (forest and infrastructure facilities) and remaining 14147 ha was classified for aquaculture development as per Survey of India village boundary database. 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 aquaculture in Betalghat Block of Kumaon region. The suitable land areas were identified from this output map as shown in Fig. 2 and are classified as most suitable (8426 ha, 27%); moderately suitable (5623 ha, 18%) and not suitable (198 ha, 1%) with 16617 ha (54%) with constraints as indicated in Table 4. This indicates that the region is suitable for aquaculture, except for some of the constraints areas. In most suitable areas, farmers can easily obtain support services for aquaculture development 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 observed that many ponds suitable for aquaculture are available in the most suitable and moderately suitable areas. For example, the village Majhera, which falls under the most suitable area by the study, was found to have many earthen ponds and other aquaculture activities being carried out there.

The present study is an effort to apply the GIS in selecting suitable site for aquaculture development in the region. 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

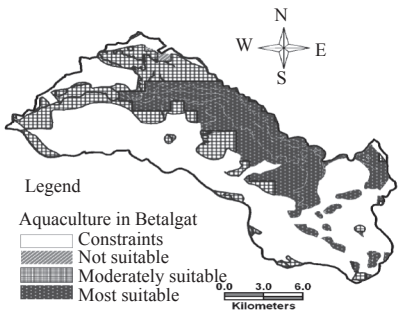

Fig. 2. Suitable sites for aquaculture in Betalghat Block, Nainital, Uttarakhand

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

Parameters	pH	Texture (Clay content)	OM (Organic matter)	Weight
pH	1	2	1/2	0.30
Texture (Clay content)	1/2	1	1/3	0.16
OM (Organic matter)	2	3	1	0.54

Consistency ratio (C. R.) = 0.0096

analysis may be useful for land evaluation in larger areas for aquaculture development. This will minimise the loss incurred due to ignorance of many environmental and social aspects during pre-establishment of aquaculture farm. The study will help in optimum utilisation of fisheries resources of Kumaon region as well as the model can be replicated in similar kind of geographical areas.

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

Parameters	Temperature	pH	DO	CO_2	Alkalinity	Hardness	Phosphate	Nitrate	Weight
Temperature	1	3/2	1	2	3	3	5	5	0.24
pH	2/3	1	2/3	2	5/3	5/3	5	5	0.17
Dissolved oxygen (DO)	1	3/2	1	2/5	5/4	5/3	4	4	0.17
Carbon dioxide (CO_2)	1/2	1/2	5/2	1	2/3	2/3	2/3	2/3	0.10
Alkalinity	1/3	3/5	4/5	3/2	1	1	2	2	0.10
Hardness	1/3	3/5	3/5	3/2	1	1	2	2	0.10
Phosphate	1/5	1/5	1/4	3/2	1/2	1/2	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.) = 0.0754

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

Parameters	Distance to water source	Distance to road	Distance to hatchery	Distance to market	Weight
Distance to water source	1	3	2	3/2	0.40
Distance to road	1/3	1	1/2	1/2	0.12
Distance to hatchery	1/2	2	1	3/2	0.26
Distance to market	2/3	2	2/3	1	0.22

Consistency ratio (C.R.) = 0.0181

Table 3(d). Pair-wise comparison matrix for assessing relative importance of different land use requirements for aquaculture site suitability in Betalghat Block of Nainital District, Uttarakhand

Parameters	Water quality	Soil quality	Infrastructure facilities	Weight	
Water quality	1	3	2	0.54	(54%)
Soil quality	1/3	1	3/2	0.24	(24%)
Infrastructure facilities	1/2	2/3	1	0.22	(22%)

Consistency ratio (CR) = 0.0769

Table 4. Area and percentage of suitable sites for aquaculture in Betalghat Block, Nainital District, Uttarakhand

Suitability classes	Area	Percentage
Most suitable	8426 ha	(27%)
Moderately suitable	5623 ha	(18%)
Not suitable	198 ha	(1%)
Constraints (forest cover, lakes, streams, rivers, roads *etc*.)	16617 ha	(54%)
Total area	30864 ha	

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