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Land suitability modelling for enhancing fishery resource development in Central Himalayas (India) using GIS and multi-criteria evaluation approach

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ABSTRACT

In recent years, fish production from open waters in Central Himalayas, especially from riverine system, has declined considerably. Degradation of soil and water quality and poor infrastructure facilities are among the major causes of declined fish production in this region. Keeping this in view, the present investigation was carried out to assess the soil, water and infrastructure facilities by using geographical information system (GIS) and multi criteria evaluation approach which helped in understanding the key elements to develop and improve resource management strategies that are vital to ensure sustainable fish stocks in this region. Various important parameters of soil, water and infrastructure facilities of this mountainous region were thoroughly assessed by analytical hierarchy process (AHP) for development of fish culture. Based on these characteristics, sixteen thematic layers were prepared using the Geomedia Professional software to develop a series of GIS models/ sub-models. In this process, the region was categorized to different suitable locations for the development of highland and lowland fishery. The model output clearly indicates the location and extent for the development of this sector in different suitability scales *viz.*, most suitable (51,112 ha, i.e. 13%) and moderately suitable (61,164 ha i.e. 15%) out of the total land cover area of Nainital district (about 402,000 ha). The study will help planners to design plans to harness maximum fish biomass and to derive social benefits from inland open waters in the region.

1. Introduction

The land cover resources in hilly regions of India have greatly declined due to the increased population and other developmental projects of inevitability, in spite of prevailing environmental protection policies. Information on land use/ land cover and their changing pattern is essential to avert further environmental degradation for future planning and management of the available land and water resources. Therefore, inventories of these aspects play an important role in various resource sectors mainly in agriculture and fishery. Presently, aquaculture has a significant contribution towards socio-economic development of local population in hilly regions where they depend exclusively on the available water resource for their livelihood as well as nutritional security through aqua ranching and fishing (Ayyappan and Krishnan, 2004).

Freshwater aquaculture contributes over 90% of the total fish biomass production in India. The dynamism of Indian aquaculture and capture fisheries sector has been marked by 12-fold increase in fish production in just six decades, i.e. from 0.75 million tons in 1950-51 to 9.57 million tons in 2013-14. This resulted in an average annual growth rate of 4.5% over the years (Mohanty et al., 2017), thus putting India on the forefront of the global fish production scenario, only after China. However, declined fish supply against the increased demand is mainly due to stagnated capture fisheries output mainly in the medium and high altitude areas (Kapetsky and Nath, 1997; Tyagi et al., 1999; Singh and Akhtar, 2015.). The Kumaon region of the Uttarakhand is among the sites bestowed with low, medium and high altitude aquatic resources ideal for fisheries development in these areas. In addition to numerous freshwater subtropical lakes, there are other aquatic resources (streams, rivers, ponds and small reservoirs) having great potential for fish farming (Jalal, 1988; Vass, 2002). Inland fish production in Uttarakhand (3940 t) utilizing the total water bodies of 21,000 ha corresponds to productivity of 0.18 t ha^{-1} (DAHD, 2014). Conventional fishing in Kumaon hills, is an additional source of livelihood for a large section of economically backward population, besides their nutritional security.

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There are certain limitations in manual data collection, analysis and interpretation to solve the complex issue of fisheries development using the soil, water and infrastructure related parameters due to the location in the mountainous region of Central Himalayas. The traditional methods for natural resource mapping and monitoring are not only cumbersome and uneconomic but also time consuming. GIS and Remote sensing techniques deliver quick and relatively reliable data on required information and helps in resource monitoring of a particular region. The multi criteria decision making is the concept, model and method that aids in evaluating expressions using weights, values or intensities of preference. This technique has been used by many workers in Asian and other countries (Bahuguna et al., 1995; Voogd, 1983; Kapetsky et al., 1988; Aguilar-Manjarrez and Ross, 1995; Kapetsky and Travaglia, 1995; Pérez et al., 2005). Karthik et al., (2005) applied GIS and remote sensing technology for identification of potential sites in India for the development of brackish water aquaculture. Banerjea (1967) and Girap (2006) have also comprehensively studied relationships between individual soil properties and fish production for eighty different pond aquaculture environments in India. However, the aquaculture land suitability information for hilly regions, particularly in Central Himalayas is flimsy. Therefore, an attempt was made to demarcate the suitable sites for aquaculture development in this region using GIS and multi criteria evaluation approach. This approach marks the first time a thorough fishery assessment evaluation was undertaken in the Kumaon region by using GIS and other techniques by treating many spatial components simultaneously. The results will help in identifying most suitable locations for aquaculture and fisheries development.

2. Materials and methods

2.1. Study area

The study area covers the Nainital district of Uttarakhand in the Kumaon region of India having geographical area of approximately 402,000 ha and lying between 28° 59′ and 29° 36′ N latitudes and 78° 52′ and 79° 58′ E longitudes (Fig. 1). The Nainital district constituting of eight blocks are grouped into three altitude ranges: Haldwani, Ramnagar and Kotabagh blocks in low altitude range (150–700 m asl); Bhimtal and Dhari blocks in mid altitude range (700–1800 m asl) and Betalghat, Okhalkanda and Ramgarh blocks in high altitude range (> 1800 m asl). The study area has a mixed climate from subtropical in lower altitude to temperate in higher altitude with an average annual rainfall of 1618 mm (IMD, 2012).

2.2. Data and methods

Remote sensing data of IRS-1C Linear Imaging Self Scanning Sensor (LISS III) from National Remote Sensing Centre, Hyderabad, India was used for the study area Nainital district. The data was geo-referenced with demarcating ground control points (GCPs) using global positioning system (GPS). Digital data were processed by using ERDAS Imagine software (8.7 version) for assessment of water bodies such as streams, rivers, lakes etc. of the study area. Corresponding Survey of India toposheets 53 O/3, 53 O/6, 53 O/7, 53 O/8, 53 O/10, 53 O/11, 53 O/12 and 53 O/15 along with village boundary database in 1:50,000 scale of Nainital district were also used in Geomedia professional software (Version 6.0). The procedure followed in modelling the land suitability for fisheries development is presented in Fig. 2. Digital topographic maps and related information were used for ground truthing for development of suitable sites for aquaculture development. Soil and water samples from 32 sites of different rivers, streams and lakes in this region were collected. The soil samples were collected once during the study, whereas water samples were collected on quarterly basis for the year 2010 and 2011. Soil textural parameters such as sand, silt and clay percentages were analyzed. Soil pH was determined using pH meter (DM 13, Takemura Electric Works Ltd. Japan). Organic carbon was determined following the method of Walkey and Black (1934). Water quality parameters such as temperature, pH, dissolved oxygen, alkalinity, nitrate and phosphate etc. were estimated by using standard

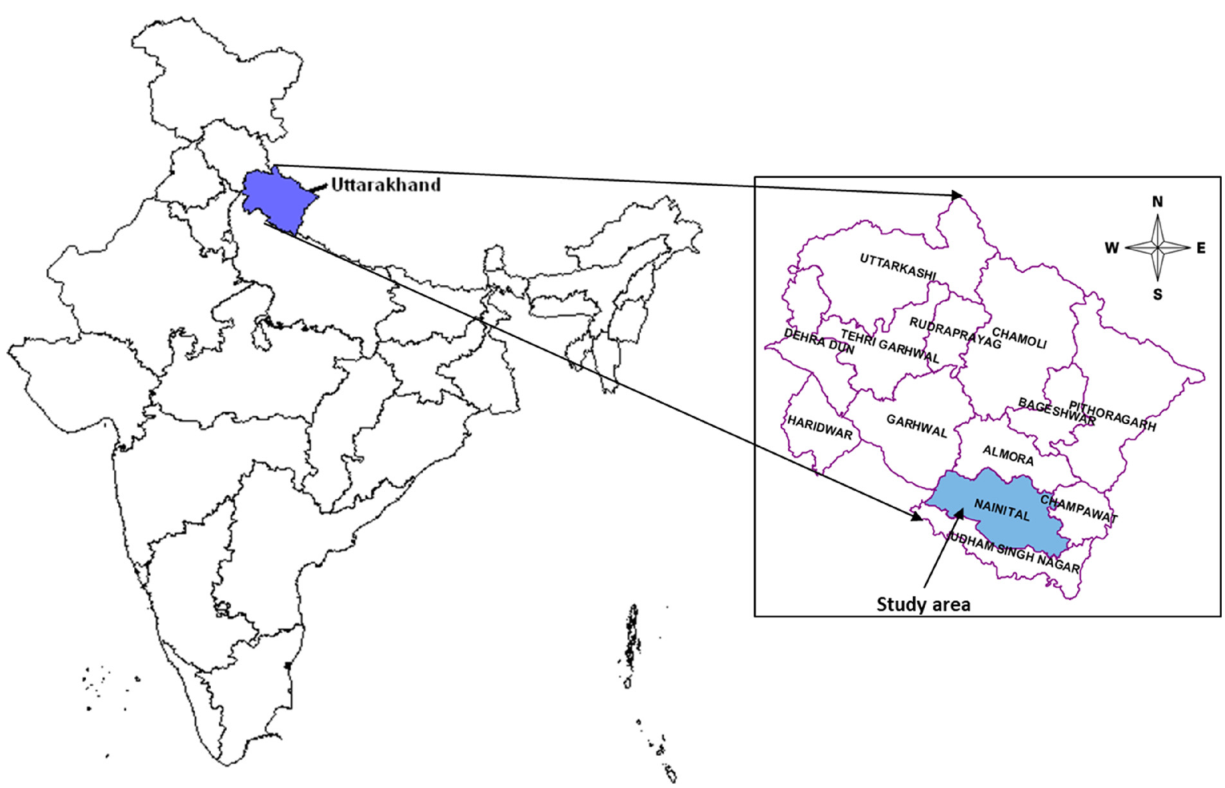

Fig. 1. Geographical location of study area, Nainital district of Uttarakhand, India.

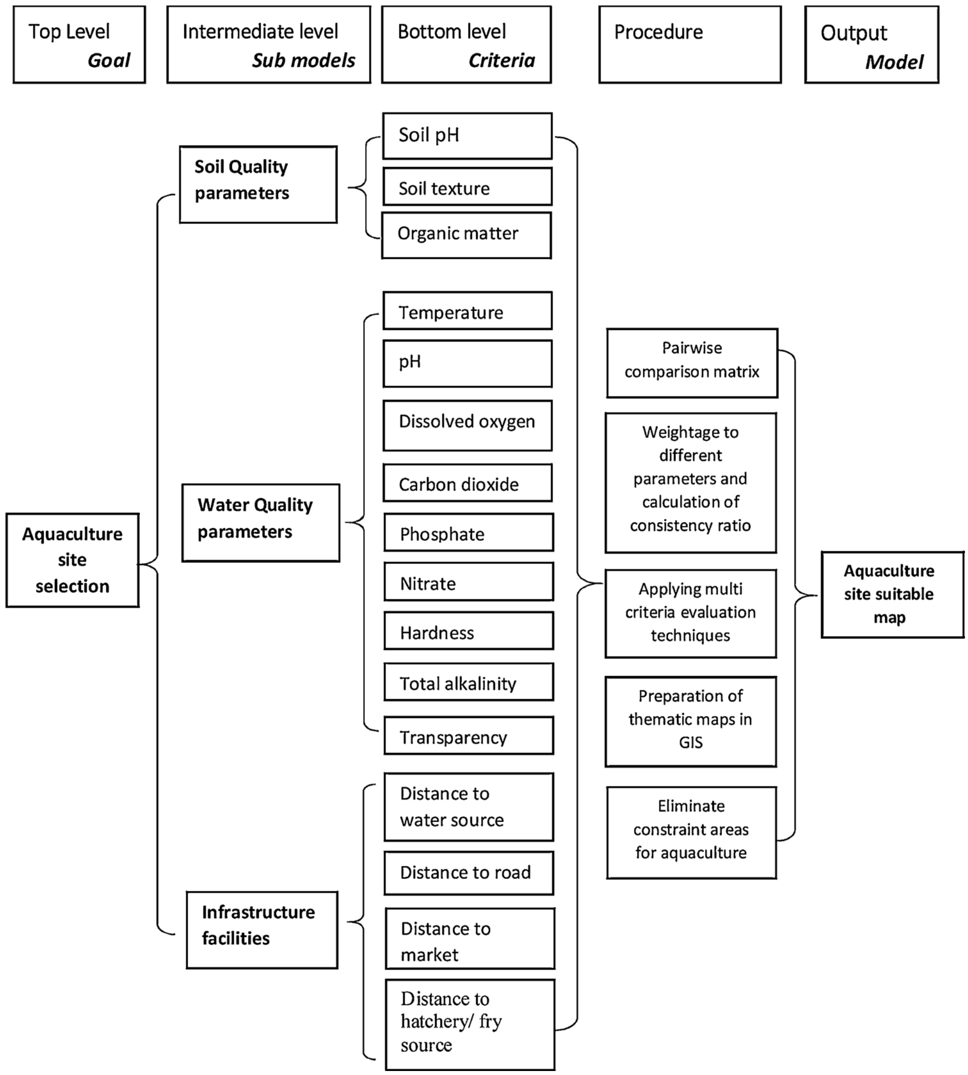

Fig. 2. Schematic diagram of modelling procedure for development of aquaculture.

methods (APHA, 1995). Data on accessibility to the site along with availability of inputs for fish culture such as seed, feed and marketing facility were collected from authorities of the line department, farmers, field visits and available secondary data. The areas falling under the forest cover was demarcated as constraint areas where aquaculture development cannot be carried out. The villages and forest cover map was prepared for the study area in development of site suitability study as shown in Fig. 3. The available water resources and drainage systems in the study area were digitized in a GIS platform (Fig. 4).

2.3. Spatial analyses

Resource and facility maps were prepared based on the toposheets and satellite data. A procedure was set up using GIS for each attribute of soil, water and infrastructure facilities and divided into three classes such as most suitable, moderately suitable and not suitable on the basis of requirements for aquaculture (FAO, 1993). Sixteen base layers *viz.* three layers for soil quality (soil pH, soil texture and organic matter); nine layers for water quality parameters (temperature, transparency, pH, dissolved oxygen, free carbon dioxide, total alkalinity, hardness, phosphate, nitrate) and four layers for infrastructure facilities (distance to water sources, distance to road, distance to market and distance to hatchery/ fry source) were prepared.

The Geomedia Professional 6.0 software (developed by Intergraph Corporation, USA) was used for GIS analysis. Grid module of the software was used for interpolation of non-spatial data using inverse distance weighting (IDW) method and mathematical calculation of different grid layers. The interpretation of suitability classes for each factor was then classified on a scale from 3 to 1 (FAO, 1976) as presented in Table 1.

2.4. Determination of weights by AHP

An important stage is to establish a weightage for each criterion and factors. The pair-wise comparison method developed by Saaty (1977) in the context of AHP was used to develop a set of relative weights for each parameter. Preferences for fisheries development with respect to the evaluation criteria were incorporated into the decision model for the relative importance of each criteria. The preferences were typically defined as a value assigned to an evaluation criterion that indicates its importance relatively to other criteria under consideration. These criteria were rated according to literature reviews and experts opinion based on their relative importance using a pair-wise comparison (FAO, 2002; Giap et al., 2005; Tyagi, 2009). By making a pair-wise comparison matrix at each level of the hierarchy, relative weights were developed, called priorities, to differentiate the importance of each criteria (Saaty, 1994). The intensity of importance is 1 if both parameters are of equal importance, 3 for moderate importance, 5 for strong, 7 for very strong and 9 for extreme importance whereas the reciprocals are values for inverse comparison (Saaty, 1977).

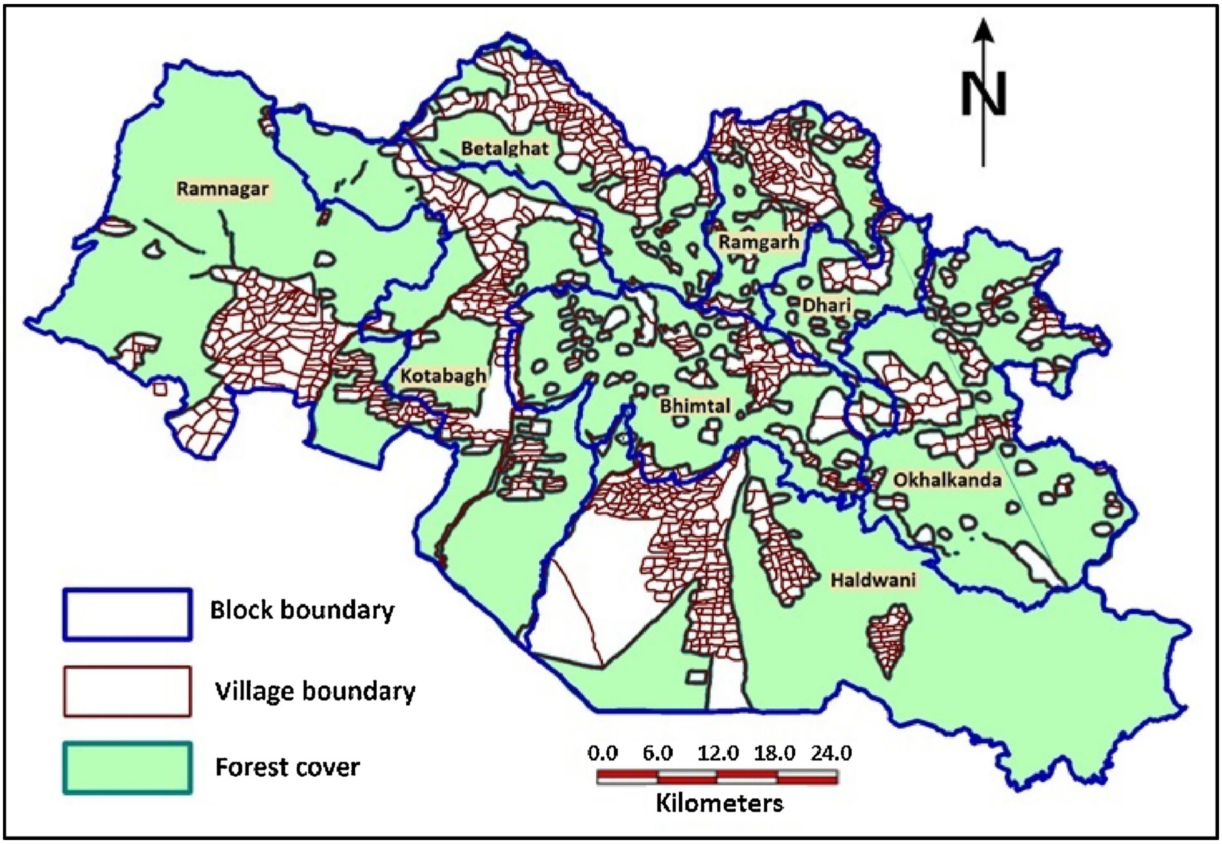

Fig. 3. Forest cover and villages with block boundary of the study area.

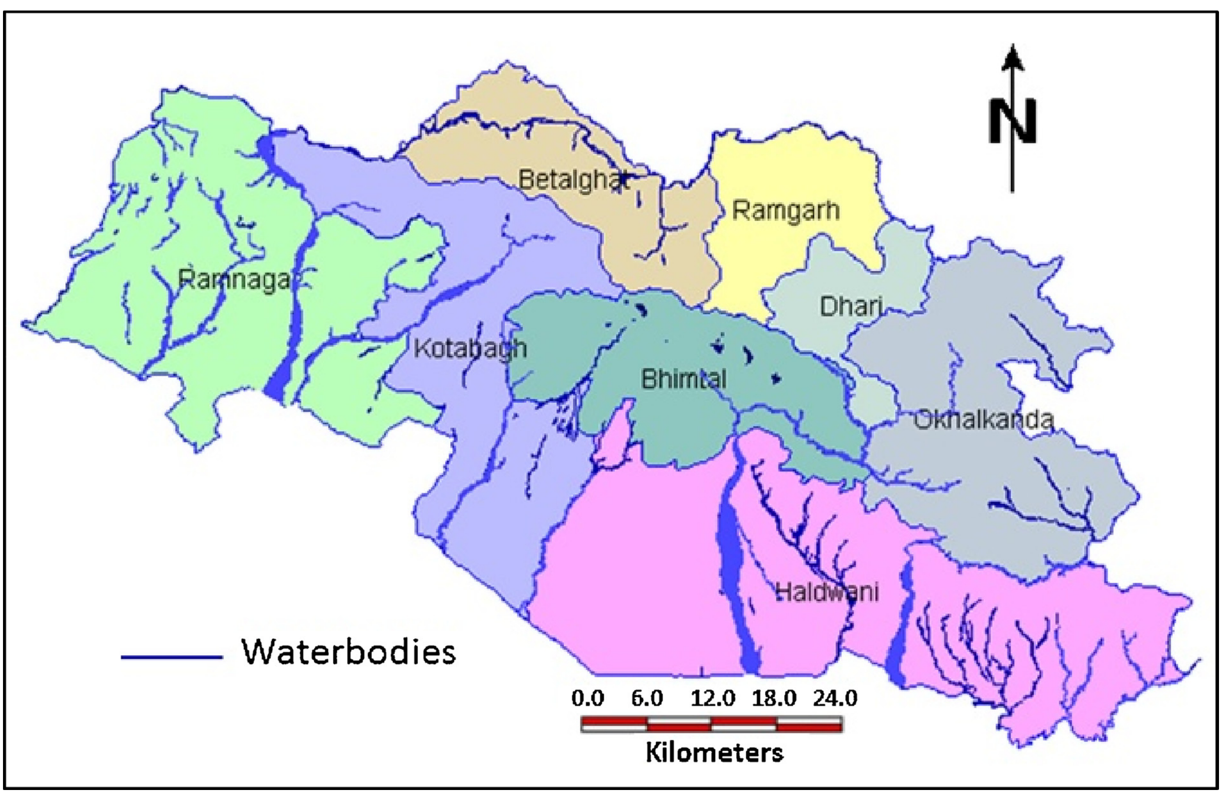

Fig. 4. Block boundaries with water resource and drainage system of the study area.

Table 1
Suitability levels of soil quality, water quality and infrastructural facilities for aquaculture in Central Himalayas, India.
(Source: Banerjea, 1967; FAO, 1976; Hajek and Boyd, 1994; Tyagi et al., 2005,; Mohanty et al., 2017)

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) (% of carbon)	< 1	1–2	> 2
Water Quality			
Temperature (°C)	> 20.0	10.0–20.0	< 10.0
pH	7.0 - 8.5	5.5-7.0 and 8.5-10.0	< 5.5 and > 10.0
Dissolved oxygen (mg/l)	> 5.0	3.5–5.0	< 3.5
Carbon dioxide (mg/l)	0-5	5–20	> 20
Phosphate (mg/l)	< 0.25	0.25–0.40	> 0.4
Nitrate (mg/l)	< 1.0	1.0–2.0	> 2.0
Hardness (mg/l)	50-200	20–50 and 200–500	< 20 and > 500
Total alkalinity (mg/l)	90-150	30–90 and 150–300	< 30 and > 300
Transparency (cm)	30-60	15–30 and 60–120	< 15 and > 120
Infrastructure Facilities			
Distance to water source (m)	< 500	500–1000	> 1000
Distance to road (m)	< 500	500–1000	> 1000
Distance to market (m)	< 2000	2000–4000	> 4000
Distance to hatchery/fry source (m)	< 5000	5000–10000	> 10000

Table 2
Random Consistency Index (RI).
Source: Saaty (1990)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

A consistency ratio {CR = Consistency index (CI) / Random Consistency Index (RI)} of less than 0.1 shows a consistent comparison between the criteria and it was considered as acceptable (Saaty, 1990). The Random Consistency Index (RI) is presented in Table 2 and CI was calculated as follows:

$$CI = (\lambda max - n) / (n-1)$$

Where λ max is the Principal Eigen Value; n is the number of factors

λ_{max} = Σ of the products between each element of the priority vector and column totals.

Based on the technique, the relative weightage was calculated for different parameters for fishery development in the region. The site suitability rating for each factors and spreadsheet calculations were done for consistency ratio (CR) as shown in Table 3. The consistency ratios calculated for soil quality, water quality, infrastructure facilities and land use requirement were 0.0096, 0.0611, 0.0181 and 0.0769 respectively. The CRs were well within the ratio of equal to or less than 0.1 recommended by Saaty (1990), signifying a small probability that the weights were developed by chance.

Depending on the weightage obtained from Table 3 for each parameter, the suitability maps for soil, water and infrastructure facilities were prepared by adding all the criteria using the formula: $grid_{result} = \sum_{i=1}^{n} (grid_i * weight_i)$ presented in Eqs. (1)–(3)

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

$$Water_{grid} = Grid_{Temp} \times 0.23 + Grid_{pH} \times 0.17 + Grid_{DO} \times 0.18 + Grid_{CO2} \times 0.10 + Grid_{Alkalinity} \times 0.09 + Grid_{Hardness} \times 0.08 + Grid_{Phosphate} \times 0.05 + Grid_{Nitrate} \times 0.05 + Grid_{Transperancy} \times 0.05 \quad (2)$$

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

The soil, water and infrastructure grids (Eqs. (1) to (3)) were overlaid by Eq. (4) for developing the aquaculture site suitability as follows:

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

2.5. Model validation

Model validation was carried out by making comparison between predicted suitable land and existing farm locations. A stratified simple random sampling from different land cover areas was performed to identify 20 sites for subsequent visits and assessments. The approach was to compare the locations and site-related performances of existing fish farming facilities with locations and location ratings provided by the GIS system.

3. Results

The present study identifies and quantifies appropriate sites for fishery development in the Kumaon region of Uttarakhand using remote sensing and GIS. According to AHP model, the temperature has the highest importance (23%) for water quality suitability map compared to other water quality parameters. Since the region was a highland area, the temperature plays a major role in growth performance of fish. The case of soil quality parameter presents the soil organic matter having a major role (54%) over soil pH (30%) and soil texture (16%) for fish culture in the region. In infrastructure facilities parameters, the distance to water source (40%) was recorded as major important factor for fish culture. Water quality played a major role of 54% compared to soil quality of 24% and infrastructure facilities of 22% for fishery development in the region. Thematic maps were prepared for soil pH, soil texture and soil organic matter based on the interpolation techniques. These maps were then re-converted to suitability maps for each parameters and finally a soil quality suitable map was prepared based on the Eq. (1) as presented in Fig. 5. Thematic maps were also prepared for nine water quality parameters based on the interpolation techniques. These maps were then re-converted to suitability maps for each parameters. The water quality suitable map was prepared based on the Eq. (2) which is presented in Fig. 6. The most suitable areas for coldwater aquaculture are recognized as good water quality with favourable temperature, pH and dissolved oxygen. Individual thematic maps were prepared for different parameters of infrastructure facilities such as distance to road, distance to market, and distance to hatchery/fry source based on the interpolation techniques. These maps were then categorized to suitability maps for each parameter. The results for infrastructure facilities suitability map was prepared by using Eq. (3) and presented in Fig. 7.

Modeling was carried out with all thematic maps with an output of suitable sites for development of fish culture in Uttarakhand. The forest cover and other constraint areas of the region were masked out since developmental activities cannot be carried out in these areas. The thematic map for aquaculture site suitability in Nainital district is shown in Fig. 8. The area and their percentage for different categories of site suitability for fish culture are depicted in Table 4. Out of the total area of 402,000 ha, around 13% is most suitable whereas 15% is moderately suitable for fish culture in the region. The region having

Table 3
Pair-wise comparison matrix for assessing relative importance of different factors for aquaculture development in central Himalayas.

Soil quality

	pH	Texture (Clay content)	OM	Weight
pH	1	2	1/2	0.30
Texture (Clay content)		1	1/3	0.16
OM (Organic matter)			1	0.54
Consistency ratio (C.R.) = 0.0096				

Water quality

	Tempe-rature	pH	DO	Carbon dioxide	Alkalinity	Hardness	Phosphate	Nitrate	Transparency	Weight
Temperature	1	3/2	1	2	3	3	5	5	6	0.23
pH		1	2/3	2	5/3	5/3	5	5	3	0.17
Dissolved oxygen (DO)			1	5/4	5/3	5/3	4	4	4	0.18
Carbon dioxide				1	3/2	3/2	2	2	3/2	0.10
Alkalinity					1	1	2	2	3/2	0.09
Hardness						1	2	2	4/3	0.08
Phosphate							1	1	1	0.05
Nitrate								1	1	0.05
Transparency									1	0.05
Consistency ratio (C.R.) = 0.0611										

Infrastructure facilities

	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 head		1	1/2	1/2	0.12
Distance to hatchery			1	3/2	0.26
Distance to market				1	0.22
Consistency ratio (C.R.) = 0.0181					

Land use requirement

	Soil quality	Water quality	Infrastructure facilities	Weight
Soil quality	1	1/3	3/2	0.24
Water quality		1	2	0.54
Infrastructure facilities			1	0.22
Consistency ratio (C.R.) = 0.0769				

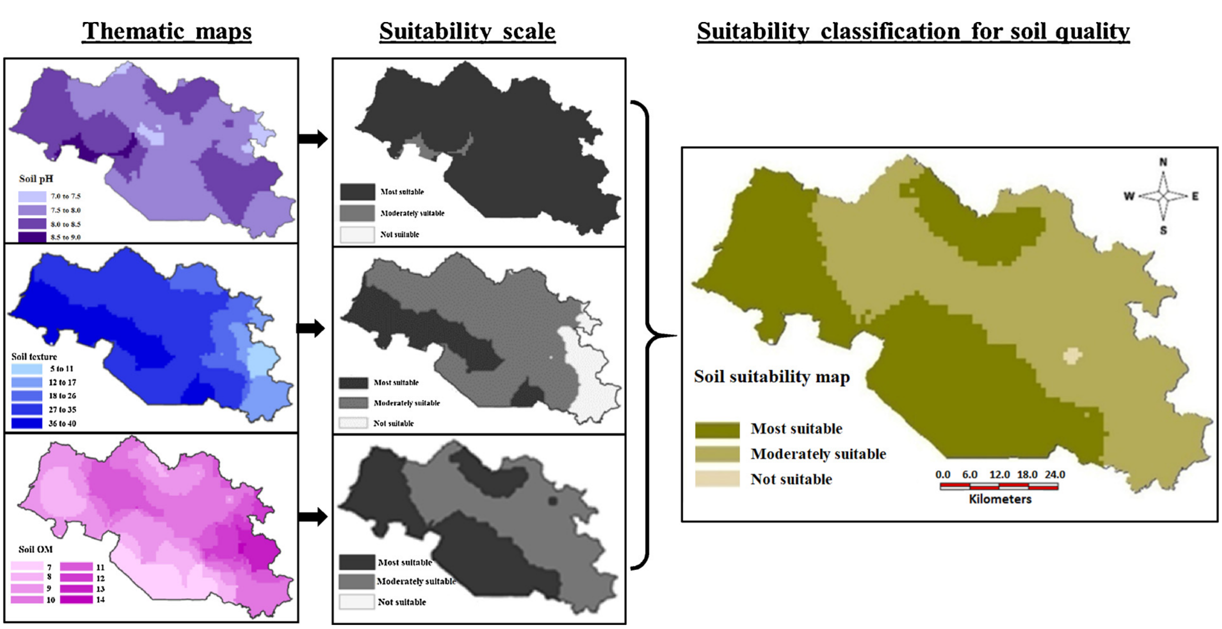

Fig. 5. Process of combining soil quality parameters for aquaculture development.

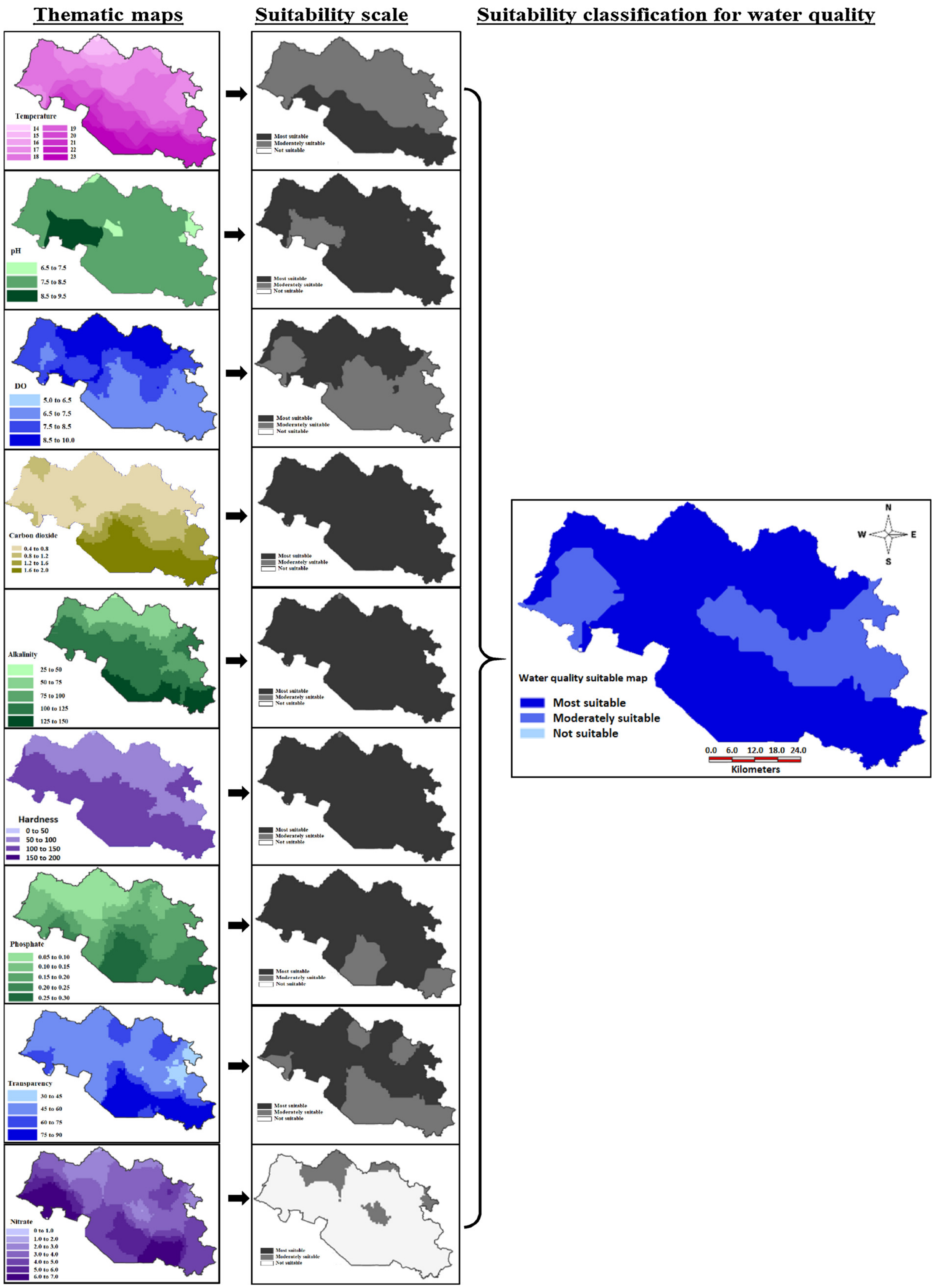

Fig. 6. Process of combining water quality parameters for aquaculture development.

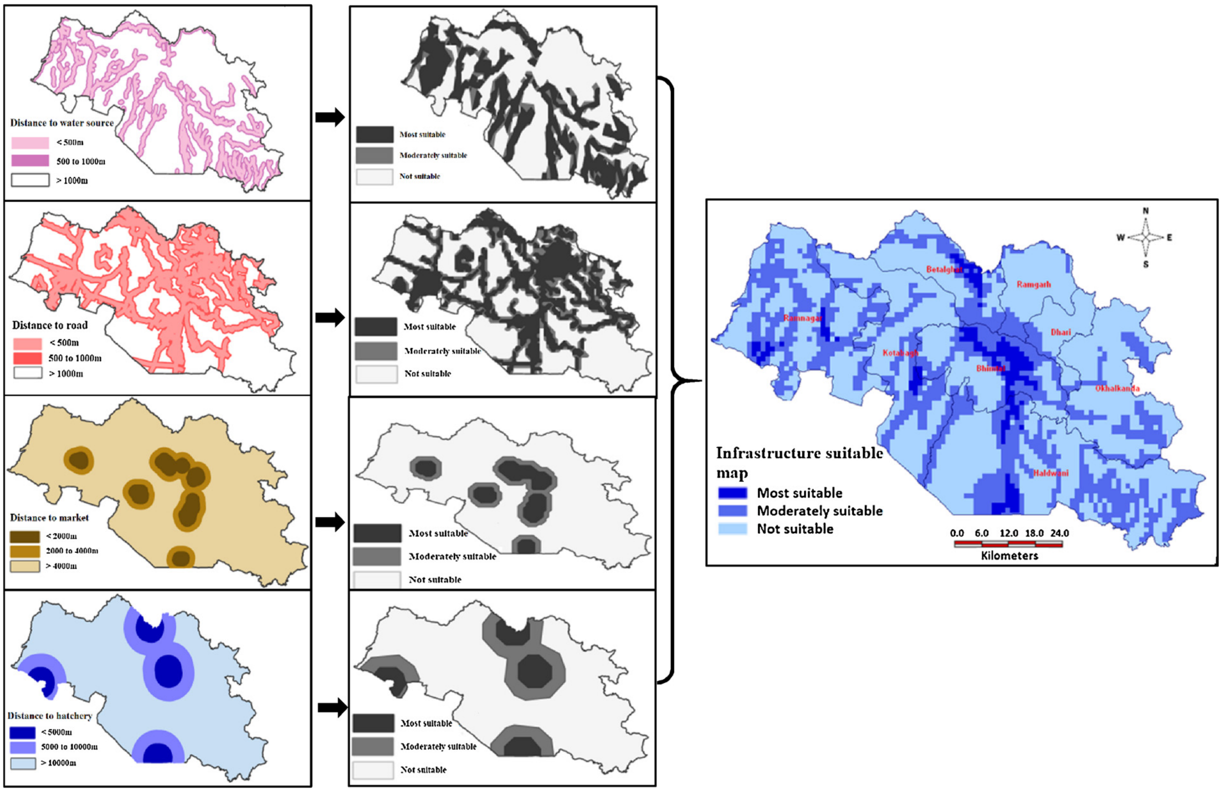

Fig. 7. Process of combining Infrastructure facilities parameters for aquaculture development.

major constrains areas around 69% including forest cover, lakes, streams, rivers, roads etc. After deducting the major constraints from the total geographical area of Nainital district, around 40% of the remaining area are found to be most suitable for aquaculture development. Model validation showed that around 65% of the existed ponds are located in most suitable areas while rest of the ponds fall under moderate suitable areas.

4. Discussion

The socio-economic benefits derived from aquaculture expansion provide nutritional security, improved life style, income generation and

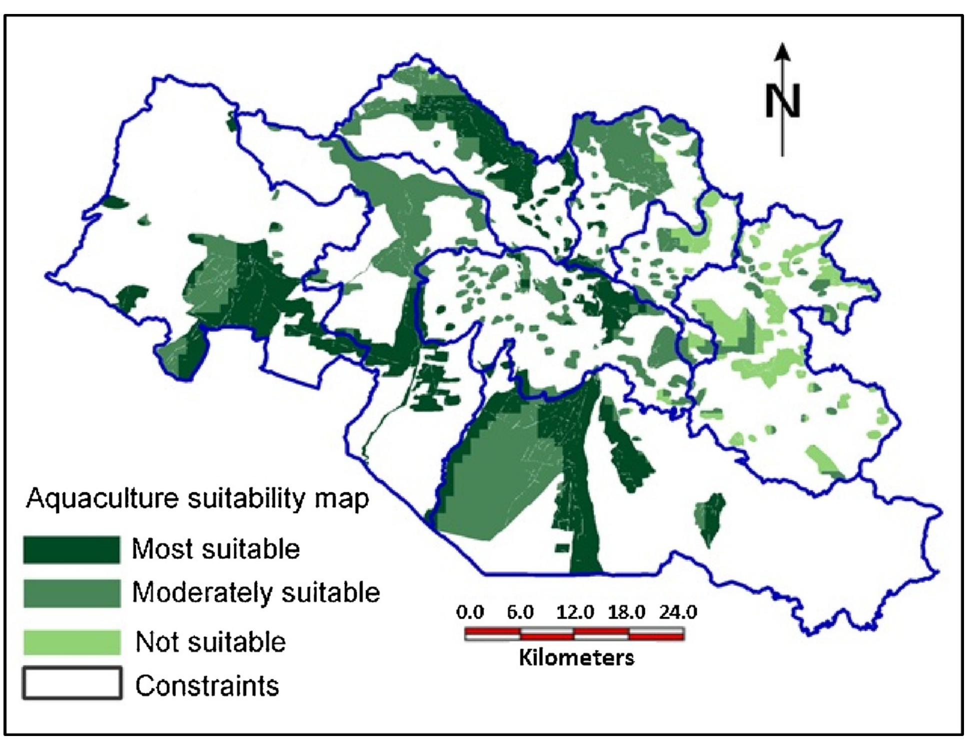

Fig. 8. Site suitability map for aquaculture in Nainital district, Uttarakhand in Central Himalayas, India.

Table 4
Area and percentage of aquaculture suitable sites in Nainital district in Central Himalayas, India.

Sl. No	Suitability class	Area	Percentage
1	Most suitable	51,112 ha	13%
2	Moderately suitable	61,164 ha	15%
3	Not suitable	13,852 ha	3%
4	Constraints (forest, lakes, streams, rivers, roads etc.)	275,872 ha	69%
	Total area	402,000 ha	

employment opportunity. However, site selection plays a key role in any aquaculture expansion, operation, and diversification affecting both success and sustainability as well as making rational use of the land (Hadipour et al., 2015). Applications of GIS has played a key role in various different aquaculture practices such as: hard clam culture in Florida (Arnold et al., 2000), site selection for land-based shrimp farming in the Australian Coastal Zone (McLeod et al., 2002), shrimp and crab farming in Bangladesh (Salam et al., 2003), coastal brackish water aquaculture site selection (Karthik et al., 2005; Vafaie et al., 2015), assessing suitable carp farming areas in Bangladesh (Salam et al., 2005), tilapia farming areas in Bangladesh (Hossain et al., 2007), and land suitability modeling for giant prawn in Bangladesh (Hossain and Das, 2010). However, the main problem in the selection of suitable sites for aqua farming is the lack of baseline information on the physico-chemical and topographic conditions as well as existing land use patterns. The expansion of aquaculture areas without site suitability study, may change ecological and environmental conditions which ultimately impact aquatic biodiversity (Vafaie et al., 2015). The present study was an effort to apply GIS in selecting potential sites for the development of fishery in Nainital district of Uttarakhand state incorporating water quality, soil characteristics and infrastructure parameters that influence the suitability for the intended purpose. Inappropriate land use without considering the above factors can lead to misuse of natural resources and degradation of the environment and other social conflicts.

The consideration of soil condition in the region for fish culture observed 48% area with most suitable whereas around 51% was moderately suitable. It seems that the region is suitable for fish culture in respect of soil features. A similar trend was found in water quality parameters. Around 73% of the total water body was most suitable and remaining area was moderately suitable. When considering infrastructure facilities, only 5% area was most suitable whereas around 34% area falls under moderately suitable.

The success of a productive aquaculture system, is primarily dependent on a site having suitable qualities of soil, water and infrastructure facilities (MacPherson et al., 1991). The present study suggests that the land should be divided into different zones on the basis of suitability for aquaculture, i.e., most suitable, moderately suitable and unsuitable zones. The zoning approach can provide important information for potential farmers/ investors to identify the suitable zone that could meet certain objectives for their maximum benefit (Hossain and Lin, 2001). Zoning of land and water can protect aquaculture from environmental deterioration and adverse social and environmental interactions. Local people prefer more suitable locations based on their indigenous knowledge that justify the well-known expression “farmers are the real scientists”; thus the present land suitability evaluation identified the most favorable areas that is also validated by the existing location of fish farms in the study area.

The GIS based multi criteria analysis may also be useful for land evaluation in larger areas which would minimize the loss incurred for aquaculture development due to ignorance of many social and environmental aspects (Kapetsky and Travaglia, 1995). From this study it was observed that the region was suitable for aquaculture in respect to soil and water characteristics whereas it was less suitable with respect to infrastructure facilities. The study will also help in optimum utilisation of fisheries resources for socio-economic development of rural people in the region.

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