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APPLICATION OF REMOTE SENSING AND GIS IN SITE SELECTION FOR SUSTAINABLE AQUACULTURE IN INDIA - A REVIEW

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ABSTRACT

Non scientific and unplanned development in aquaculture has led to many controversies in the society and in other sectors of agriculture, and the sector has itself been affected adversely by many environmental problems. Scientific and sustainable development of aquaculture essentially needs better site selection. This paper briefly discusses the importance of proper site selection for sustainable aquaculture development. The requirement of a proper and systematic approach in data acquisition with high level of accuracy made remote sensing and GIS ideally suited for resource assessment and maintenance of the sustainability in aquaculture. The site selection in aquaculture is a complex task involving identification of the areas that are economically, socially and environmentally suitable, which can be available for aquaculture. Remote sensing combined with GIS is an effective tool in sustainable aquaculture development by providing information on land use and land cover, water quality, productivity, tidal influence and coastal infrastructure. In this paper we examine selected cases of site selection for aquaculture from India where remote sensing and GIS technologies are effectively used in sustainable aquaculture. The case studies reviews on the different GIS methods and criteria used depending on the area for site selection of aquaculture depending upon the type of pattern and the species used.

KEY WORDS: Remote sensing, GIS, Sustainability, Aquaculture

INTRODUCTION

The word "aquaculture" is defined by the Food and Agriculture Organization of the United Nations (FAO) as follows " the farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants. Aquaculture 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. It is a source of livelihood for a large section of economically backward population. Asia accounted for 88.8 percent of world aquaculture production by quantity and 78.7 percent by value in 2008, while China ranks first in world aquaculture production with 9.4 percent and India ranks second as world aquaculture producer with 7.1 percent by quantity (2008). The rapid growth of aquaculture worldwide, over the last three decades has resulted in increased concerns about its sustainability, especially in countries where this industry is well established. Aquaculture has been attracting heavy investment due to sound technologies and limitless potential for export. Development of aquaculture has given raise to many environmental issues such as conversion of mangroves, conversion of agricultural lands and water bodies, salinization of drinking water resources and agricultural farms adjacent to agricultural farm. In order to overcome these problems, a comprehensive development planning based on the evaluation of the biophysical and socio-economic characteristics the specific location is needed. Therefore, an approach is needed, which can rapidly identify areas of a country, a state, or smaller units, suitable for various aquaculture activities as assistance to the development planning.

A vast majority of problems arising from aquaculture could be avoided by proper site selection. The fisheries sector of India contributes Rs 268,500 million to the Gross Domestic Product (GDP) during 2002-03, which was 1.19% of the total GDP. India by virtue of its geographical stretch, varied terrain and climate supports a wide variety of inland and coastal resources. India is endowed with coastline length of 8,129 km, 2.02 million sq km of Exclusive Economic Zone (EEZ) comprising 0.86 million sq km on the East coast, 0.56 million sq km in the West coast and 0.60 million sq km around Andaman and Nicobar Island and 0.5 million sq km of continental shelf with a annual catchable marine potential of 3.93 million tons. The western coast is dominated by rocky shores the eastern coast is low lying with lagoons, marshes, beaches etc. India with its 14 major rivers has led to the formation of wide network of creeks, estuaries in the coastal areas. The Ministry of Environment and Forest, Government of India, estimated about 3.9 million hectares of estuarine area and 3.5 million hectares of backwaters, of which 1.2 million identified suitable for coastal aquaculture. The government agencies which are involved in issuing new aquaculture permits should perform the spatial analysis of the proposed site to identify its environmental and socio-economic impacts on the other locations. The investor interested in aquaculture development requires spatial information mainly at the time of site selection from among a range of alternative locations with different environmental and socio-economic characteristics (Kepetsky and Travaglia, 1995). The problems of identifying the suitable areas for aquaculture were done by performing field trips to assess the condition of the site. These conventional methods do not do the assessment of the site comprehensively and temporally. A perfect data to establish the topology, land use intensity and the diversity are very essential. These data should relate the time dimension to each land use and land cover which is connected to a sustainable situation. The monitoring and management of the coastal resources and maintain the pollutant levels below the carrying capacity of the environment is required for proper aquaculture management. Water quality indicators including the physical, chemical and biological parameters were traditionally determined by collecting samples from field and analysis in the laboratory. Although it provides a high accuracy, it is labour intensive and time consuming.

Importance of site selection for sustainable aquaculture

Sustainability refers to the ability of a society, ecosystem, or any such on-going system to continue functioning into the indefinite future without being forced into decline through exhaustion or overloading of key resources on which that system depends. The sustainable development principle was accepted by Brundtland Commission defining it as one that meets the needs of the present generation without compromising the ability of the future generation to meet their own needs' (WCED, 1987). The sustainable development would thereby conserve land, water, plant and animal resources and would lead to environmentally non-degrading, technically appropriate, economically viable and socially acceptable production systems. Sustainable development demands the meeting of the development of humans simultaneously sustaining the ability of the natural systems to provide the natural resources and ecosystem services where the society and the economy depend.

In the context of sustainable aquaculture, it is important to address the factors affecting the sustainability of the environment. Aquaculture has developed quickly over the last three decades and has become an important economic activity worldwide. The availability of modern technologies and the limitless potential for export has attracted it for heavy investment. The forecast for the demand for aquatic foods is expected to be 183 million tonnes by 2030. Unplanned, unregulated and unscientific development of aquaculture in private sector has led to environmental and social issues in certain areas. The pressure on the coastal and marine resources have increased in past few years, due to the development and deteriorating water quality. The selection of a particular aquaculture system is based mainly on the geographic location, type of water body, target aquatic species, availability of resources and skilled professionals, availability of seed of the target species at the desired time of stocking, apart from a set of different socioeconomic factors. The parameters such as brackish/ freshwater supply (i.e. proximity to sea), soil and water properties, seeds and palletized feeds availability etc (Gupta and Sreshty, 1993) are the major deciding parameters for aquaculture site selection. A sustainable development of aquaculture can contribute to the prevention and control of impacts on multiple time and spatial scales to understand and plan for the consequences of aquaculture development options. Sustainable aquaculture must not only maximize the benefits but also minimize the accumulation of detriments and also other type of negative impacts on natural and social environment. Most of the potential coastal areas in the potential areas do not have infrastructural facilities such as electricity; road, communication etc and these areas are overcrowded.

Appropriate site selection is the important factor to determine the sustainability of an aquaculture farm. The water retention capacity of the soil and its fertility is to be noted as it influences the response to organic and inorganic fertilization of the aquaculture site. The site should have adequate water supply round the year for filling up of the site with unpolluted water. The topography of the area is to be noted, as in swampy and marshy areas, bunds should have a greater accumulation of soil. Self draining ponds are ideal for higher elevation ponds. The site should be easily accessible by roads or any other form of transports to reach the market for easy fish disposal (Jayanthi and Ravichandran 2009). The accessibility of the inputs like feeds, seed, and fertilizer and construction material should be available near to the site. It should be free from pollution, industrial waste and any other harmful activities. For the proper site selection for sustainable aquaculture following aspects are needed to be considered

- Ecological factors –water and soil quality
- Hydro-meteorological parameters
- Topography and land use
- Site elevation
- Infrastructure facilities
- Conflict zones
- Population Size

Remote sensing and GIS

The conventional method previously used to demarcate suitable areas for aquaculture was mainly manual surveying and collection of secondary data from field which was very tedious, labor and time consuming, inaccessible to remote areas and low in accuracy. Remote sensing combined with GIS can provide real time data with associated features of larger area so that the aquatic resources can be used effectively to get maximum production potential. These tools can help in maintaining sustainability in aquaculture through proper site selection by providing information on land use/land cover, water quality, productivity, tidal influence and coastal infrastructure. Every individual investor in aquaculture development requires spatial information at the time of site selection among a range of alternate locations with different biophysical and socio-economic characteristic (Kepetsky and Travaglia, 1995). This need made remote sensing and GIS, which is a systematic approach in data acquisition and have high level of precision ideally suited for resource assessment and maintenance of sustainability in aquaculture. Remote sensing techniques have become useful tool to achieve the goals in site selection with the advances in space science and the increasing use of computer applications and computing powers over the recent decades. This can help in monitoring and identification of large scale regions and water bodies having qualitative problems in an effective manner. Remote sensing data collection occurs in a digital form and is easily readable in computer processing. GIS is also a powerful tool for helping the decision makers and is being effectively used for many such purposes in some places. The requirement of a proper and systematic approach in data acquisition with high level of accuracy made remote sensing and GIS ideally suited for resource assessment and maintenance of the sustainability in aquaculture.

Remote sensing can be defined as a technique for collection of data by a sensing device not in contact with the object being sensed and evaluation of collected data presented in a map form or as statistics (Howard, 1985). This senses the earth's surface from space by making use of the properties of electromagnetic radiation emitted, reflected or diffracted by the sensed object for the purpose of improving management of natural resource, land use and protection of the environment. This refers to the satellite imagery to aerial photographs, evolving from pure visual imagery (panchromatic images) to multi-spectral imagery (e.g. Thematic Mapper). This allows changes to be monitored in a systematic and orderly way, efficiently and cost effective manner per km^2 terms, can overcome many data collection problems and provides instantaneous updating of the information (Campbell, 1996). Satellite systems e.g. SPOT acquire data for larger areas in a shorter time period, providing repeated coverage with respect to certain date and detail. In India, significant contribution was done by Department of Space emphasizing the application of GIS for Natural Resource Management, during the last decade. Natural Resource Information System

(NRIS), Integrated Mission for Sustainable Development (IMSD) and Biodiversity Characterization at National level are notable among them. Advances in remote sensing and GIS have led way for development of hyperspectral sensors. This can help the researchers in the detection and identification of minerals, terrestrial vegetation, and man-made materials. There are many applications which can take advantage of hyperspectral remote sensing are geology, ecology, and coastal water. Remote sensing and GIS techniques in conjunction with traditional in-situ sampling are most effective, cheaper and more reliable. Newly developed hyper spectral satellite imageries, which can simultaneously record up to 200 spectral channels, such as Hyperspectral Imager for Coastal Ocean (HICO), are much more powerful systems for detecting water quality parameters (Gholizadeh, 2016). Therefore, monitoring and assessing water quality issues through remotely sensed data can result in effective management of water resources. GIS can integrate common database operation like queries, statistical and geographical analysis with unique visualization using maps. With the usage of several methods such as classification, overlaying, and connectivity analysis spatial information can be integrated into useful format for decision making. Remote sensing has been widely used to measure the qualitative parameters of water bodies like suspended sediments, colored dissolved organic matter, chlorophyll-*a* and pollutants. Different sensors on board of various satellites and other platforms such as airplanes are being used to measure the amount of radiation at different wavelengths reflected from the water's surface. The chlorophyll, phytoplankton, dissolved organic materials, suspended sediments can be monitored using remote sensing techniques. Kallio (2000) has mentioned advantages of applying remote sensing with other water quality monitoring programs as synoptic view of entire water body, synchronized view of water quality, comprehensive historical record of water quality in an area over a time and prioritizes sampling locations and field surveying times. Remote sensing technology was by Kumar (2001**)** for developing spatial database for physio-chemical parameters of soil and water of Sagar Island, West Bengal. This can provide detailed information on geomorphologic changes, resource inventory, water quality parameters and fishery resources for management of water body.

GIS and Remote Sensing for site suitability studies in aquaculture

Suitable site selection is a form of decision making process that lead to a choice of a set of alternatives. All types of decision making have a degree of uncertainty, ranging from a predictable situation to an uncertain situation. In some cases, this involves the risk of making wrong decision, as the information acquired may be insufficient or the method was inappropriate. In such cases this uncertainty can be quantified and other decision criterion can be added for evaluation process. GIS integrates remote sensing data into spatial context which suites to support decision making. The decision maker is the one who determines the criteria, responsible factors, constrains, weightage to be given**.** Kepetsky and Travaglia (1995) pointed out that individual investor interested in aquaculture requires spatial information particularly at the time of site selection among a range of alternative locations with different biophysical and socio-economic characteristics. The site selection in aquaculture is a complex task involving identification of the areas that are economically, socially and environmentally suitable, which can be available for aquaculture. GIS and remote sensing facilitate the integration and analysis of spatial and attribute data from multiple sources. This technology has been widely used for selecting suitable sites for different land uses. The issues in aquaculture have two main sources those which originate from aquaculture and other that effect aquaculture owing to the external activities. Each of these issues possesses a number of components that vary by location and can be noted by spatial analyses. In this paper we examine selected cases from perspective of their applications for special decision support in sustainable aquaculture. Selection of brackish water aquaculture sites requires careful consideration of many aspects to make it more efficient and economically viable. It requires both spatial and non-spatial information to assess the suitability of sites for aquaculture development.

There has been history of using GIS technology for planning in aquaculture. GIS has been used in fisheries management during mid 1990s (Gifford, 2002). The studies using GIS in aquaculture has been discussed in FAO technical paper and this has been combined along with the information of GIS and remote sensing in inland aquaculture and aquaculture by Meaden and Kepetsky (1991). A number of studies have been published on the application of GIS and remote sensing in aquaculture (Kapetsky *et al*., 1997; Aguilar Manjarrez and Ross, 1995; Aguilar-Manjarrez and Nath, 1998 ; Salam *et al*., 2003). This include selecting shrimp farm sites using SPOT imagery, finding oyster culture sites, cat farm development by mapping and analyzing the physical characteristics of soils, salmanoid cage culture in Camas Bruich bay and to find best fish farming locations in Ghana. The application of remote sensing and GIS is quite diverse, mainly targeting a broad range of species (fish, crustacean, mollusks etc) and geographical scales, ranging from local areas to sub national regions (Aguilar Manjarrez and Ross, 1995) to national (Salam and Ross, 2000) and continental (Agilar-Manjarrez and Nath, 1998) expanses. Shahid (1992) et al conducted a study for coastal shrimp farming at Paikgacha upaxil of Khulna district, Bangladesh using Landsat MSS and TM data, sequential and Infrared aerial photographs. Area of land available for different types of aquaculture development in Khulna region, southwestern Bangladesh was estimated using remote sensing and GIS by Salem et al. (2005). Potential watershed ponds for aquaculture development in Dai Tu district of Thai Nguyen, Vietnam was assessed by Giap *et al.* (2003) by integrating socioeconomic and environmental data into GIS database, detecting land use changes, identifying and estimating potential areas for aquaculture development. A series of GIS models were created in order to identify and quantify the most suitable areas for brackish water shrimp and crab farming. A detailed listing of Remote Sensing and GIS application for site selection in aquaculture is presented in Table 1.

A variety of weighting techniques exist for the fitness ratings for criteria depending on different species and situations. Different criteria affecting the sustainable aquaculture has to be selected and compiled, weights were assigned for each parameter subjectively. Thematic maps derived from multi-temporal satellite maps were used for deriving weighted overlay of these maps. The weightages of parameters are assigned in two ways according to i) the relative importance of the parameters and ii) sensitivity within the individual parameter. This was then used as input for multi-criteria evaluation (MCE) technique. Multiple-criteria decision analysis was established as a concept with corresponding terminology by Roy, who developed the ELECTRE family of multi-criteria decision analysis methods and, in doing so, gave rise to the French school of decision making. This is the concept that aid in evaluation of expression by weights, values or intensities of preference for better decision making. The multi-criteria decision making is the concept, model, and method that aids in evaluating expressions using weights, values or intensities of preference. The technique has been used by many workers in Asian and other countries. (Aguillar-Manjarrez and Ross, 1995 ; Kepetsky and Travagllia,1995;). Banerjea (1967) and Grap (2006) have studied the relationships between the soil properties and fish production for eighty different pond aquaculture environments in India using this technique. In this technique, the information from several criteria are combined to form a single index for evaluation. This is then used for generating the site suitability map. The areas required for different land uses were set with certain limits and the requirements for uses of the areas were assigned. This technique is the multi-criteria land allocation (MOLA) which can solve the land use conflicts in the study area.

The Analytic hierarchy process (AHP) is a method for organizing and analyzing complex decisions using a powerful and comprehensive method that provides groups and individuals with the ability to incorporate both qualitative and quantitative factors in the decision-making process. It was developed by Thomas L. Saaty,(1997) which has been refined since then. The AHP, developed, has been studied extensively and used in almost all the applications related with multiple criteria decision making in the last decades. AHP has been adopted in areas such as education, engineering, government, industry, management, manufacturing, personal, political, social and sports. The wide applicability is due to its simplicity, ease of use, and great flexibility and its ability to be integrated with other techniques. For example, in mathematical programming this method considers not only qualitative and quantitative factors, but also the real-world resource limitations. This approach is regarded as the integrated AHP which can definitely make a more realistic and effective decision. AHP can be considered as the broader category of pair wise comparison techniques where attributes are ranked against each other to assess their relative importance.

Table 1. GIS application in sustainable aquaculture (adopted and updated from Nath, S.S. et al 2000)

Purpose	Geographical area	GIS software/ data used	Author(s)
Salmanoid cage culture	Camas Bruaich Ruaidhe, Scotland	PC based GIS	Ross *et al.* (1993)
Warm water aquaculture	Continental Africa and Madagascar	ERDAS and ARC/INFo	Kepetsky (1997)
Land based aquaculture	Mexico		Anguilar-Manjarrez *et al.* (1995)
Inland aquaculture	Latin America	ARC/INFO	Kepetsky and Nath (1997)
Inland Aquaculture	Continental Africa	ARC/INFO	Anguilar-Manjarrez and Nath (1998)
Trout Farms	England and Wales	GIMMS	Meaden (1991)
Tilapia and Clarius culture in ponds	Ghana	ARC/INFo and ERDAS	Kapetsky *et al.* (1997)
Small reservoir fisheries	Zimbabwe	ARC/INFO	Chimowa and Nugent (1993)
Shrimp Culture in ponds: fish culture in cages	Johor Malaysia	ERDAS	Kapetsky (1997)
Fish and crayfish farming in ponds	Louisiana, USA	ELAS	Kapetsky *et al.* 1990
Pond and cage culture	Tabasco Mexico	IDRISI	Anguilar-Manjarrez (1992)
Fish. Shrimp and Mollusc Culture	Tunisia	ARC/INFO	Ben Mustafa 1994
Land aquaculture .	Sinaloa Mexico	IDRISI	Anguilar-manjarrez and Ross (1995)
Shellfish and salmon aquaculture	British Colombia, Cananda	ARC/INFO	LUCO 1998
Small reservoir fisheries	Southern Africa	MapInfo, Windisp	ALCOM (1998)
Catfish farming	Louisiana, USA	ELAS	Kapetsky *et al.* (1998)
Shrimp and fish farming in ponds	Gulf of Nicoya, Costa Rica	ELAS	Kepetsky *et al.* (1987)
Brackishwater aquaculture	Lingayen Gulf, Philippines	SPANS	Paw *et al.* (1994)
Shellfish culture	Price Edward Island, Cananda	CARIS	Legult (1992)
Salmonis cage culture	Ruaidhe Bay, Scotland	OSU-MAP	Ross *et al.* (1993)
Shellfish culture	Septiba bay, Brazil	IDRISI	Scott *et al.* (1998)
Shellfish culture	Indian River lagoon, Florida, USA	Arc View	Arnold *et al.* (2000)
Shrimp and mud crab	Southwestern Bangladesh	Arc. GIS	Salam *et al.* (2000)
Shrimp farming	Haiphong, Vietnam	GIS	Giap *et al.* (2003)
Shrimp farming	Coastal areas of Bangladesh	ERDAS, Arc.GIS	Quader *et al.* (2004)
Mangrove oyster raft culture	Margarita Island, Venezuela	Arc.GIS	Buitrago *et al.* (2005)
Marine aquaculture	New Brunswick, Cananda	-	Michael *et al.* (2009)
Indian Scenerio			
Brackish water aquaculture	Coast of Orissa, Andaman Nicobar Islands	IRS LISS II	Bahuguna *et al.*, (1994)
Brackish water aquaculture	West Bengal	Arc.Info	Gupta *et al.* (1995)
Coastal aquaculture	Vedarananyam & Tuticorin, Tamil Nadu	IDRISI-GIS	Ramesh and Rajkumar (1996)
Brackish Water Aquaculture	Cannanore (Kerala)	Arc. Info	Gupta *et al.* (2001)
Shrimp farming	Kandleru creek, Andhra Pradesh	Arc.GIS	Hossain *et al.* (2003)
Brackish water aquaculture	Thane district , Maharashtra	GRAM++ GIS	Karthik *et al.* (2005)
Pearl oyster culture	Minicoy island, Lakshadweep	ERDAS, SURFER	Pandey *et al.* (2005)

Table 1. GIS application in sustainable aquaculture (adopted and updated from Nath , S.S. et al 2000)

Purpose	Geographical area	GIS software/ data used	Author(s)
Aquaculture	Midnapur district, West Bengal)	ERDAS, Arc. GIS	Ashwani *et al.* (2009)
Brackish water aquaculture	Krishna district, Andhra Pradesh	Arc. GIS	Jayanthi and Rekha (2009)
Pearl oyster culture	Minicoy island, Lakshadweep ERDAS, SURFER		Pandey *et al.* 2005
Freshwater aquaculture	Mid/High Himalayan regions of Uttarakhand	Geomedia 6ERDAS Imagine 8.7	Nayak *et al.*, 2007

Site suitability case studies using Remote sensing and GIS from India

In this section some selected cases were identified for the representing a broad sampling across geographic cases ranging from local areas to sub national regions. They also vary in criteria used and the degree to which GIS outcomes are used for practical decision making of site selection. These case studies demonstrate the extent of GIS applications possible in aquaculture including site selection for targeted species, conflicts and trade-offs among alternate use of natural resources. Potential of aquaculture from the perspective of technical assistance and minimize the severity of food scarcity. The analytical method used varies in its complexity i.e ranging from simple overlay to weighed overlay for using sophisticated models.

In India, work on aquaculture site selection using GIS has been carried out by Gupta (1995) and Ramesh and Rajkumar (1996). Gupta *et al*. used Remote sensing and GIS for site selection of brackish water aquaculture. Thematic maps of engineering, ecological, meteorological, and infrastructural socio-economic data were prepared for site selection. In this the creation of GIS database and the use of the same through a querying system were discussed. A map showing wetland conditions and land use features along the Karnataka coast on 1:50000 scale using IRS 1A LISS II data, for brackish water aquaculture site selection and area of each land use category was prepared by Sheedhara *et al*. (1995). Ramesh and Rajkumar (1996) used Remote sensing and GIS for coastal aquaculture site selection and planning in Vedaranyam and Tuticorin region of Tamil Nadu. A composite map was generated by integrating the digitized the spatial and non-spatial data collected from various sources like IDRISI-GIS. Ranking was provided various sites according the priority and maps were generated according to it. A mathematical model has already been developed by Gupta *et al.* (1993) in consultation with Gujarat state

Fisheries Department, Brackish Water Fish Farmer Development Agency (BFDA), and the Marine Products Export Development Authority (MPEDA), Gupta *et al.* (2001) identified suitable site for brackish water aquaculture using remote sensing and GIS to reduce the impact on aquaculture on the environment in the Cannanore tract of Kerala coast was done In this study GIS was intended as a tool to assess land suitability for aquaculture and provide guidance for exploring the consequence of land use decisions before they are been adopted. Brackish water aquaculture is practiced mainly on the low lying fields which were once part of the backwaters and have been reclaimed for paddy cultivation by construction of dykes. The conversion of mangroves and agricultural areas for aquaculture, salination of surface water resources and agricultural lands besides causing pollution and diseases has caused negative impact in the environment and has led to social conflicts. So a proper site selection for sustainable aquaculture is necessary so that there is reduction in the impact of unplanned aquaculture on environment on the Kerala coast. The study area covered is about 428 sq. km and lies in Cannanore coast, which a part of Malabar coast of Kerala, bounded by Kavayi river in the north, Mahi river in the south and the Arabian sea in the west. Land use map of the study area prepared by visually interpreting IRS LISS-II geo-coded imagery of Feb. 3, 1991, showed the major land use categories as agriculture land, fallow land, barren land, wetland areas such as mangroves, mudflats etc. The model prepared in this case study includes engineering, ecological, infrastructure, demographic and meteorological parameters. Mudflat area which is about 1690 ha under excellent category includes the sites near Payyanur, Cherukunnu, Dharmadom and Eranholi. Vast mud/tidal flats along the Kerala coast which has been converted into filtration ponds or reclaimed mudflats which generally consists of clay, silt etc are associated with estuary and lagoons. The outcome is valuable with some limitations in the quality or the extent of data available. The criteria used in the study reflect their importance to fish farming as well as practical consideration of data availability for Kerala coast. .The estimate of the area aquaculture potential in the study area was influenced by many factors may be originated from data inaccuracy, analytical approach and assumptions involved. In order to generate the assessment suitable for national level planning activities, GIS is to be used with additional country specific information.

Karthik *et al.* (2005), created suitability/priority map for shrimp farming using remote sensing and GIS by extracting the current land use pattern of Palghar Taluk in Thane district of Maharashtra using the satellite imegery LISSIII IRS ID (1: 50,000 scale). In this study, an effort has been made to demonstrate the application of GIS, remote sensing and GPS techniques to develop a multi-criteria decision making system for site selection for brackish water aquaculture of *Penaeus monodon.* Vaitarna river, provides brackish water area for aquaculture in the coastal land in the form of mud flats. These intertidal areas (mud flats) were evaluated for the development of brackish water aquaculture and the data for six criteria like engineering parameters, water quality parameters, soil quality parameters, infrastructure facility, meteorological parameters and social restriction were analyzed using GIS software GRAM++ (Geo referenced area management system). Out of the total area of 20431.034 ha, 0.377% (76.95 ha) is highly suitable, 9.873% is suitable (2017.13 ha), 1.772% is moderately suitable (362.065 ha), 85.02% is unsuitable, and 2.951% is already under aqua farms. The suitable areas were further classified into 11 sub categories based on the priority for development. A comprehensive analysis of site suitability must also include the impacts of the brackish water aquaculture on the surface and ground water resources. The output of the GIS can also be integrated with the economic analysis and marketing tools which deals with the examination of the benefits associated with aquaculture.

Pandey *et al.* (2006), used remote sensing and GIS application for identifying pearl oyster culture areas and assessment of environmental factors effecting them in Minicoy Island, Lakshadweep**.** This study helped in assessing loss of natural pearl stocks, conflicts between different coastal activities and poor management practices. Satellite data IRSP6 LISS- IV MX used for carrying out the coastal landforms and bio-resource classification. The criteria such as bathymetry, water quality parameters and social restriction due to fishing and other reef related activities were used for the identification of the suitable sites for marine pearl culture in Minicoy. Out of the total lagoon area of 29.23km^2 11% highly suitable (HS), 45% suitable area(S) and 44% less or moderately suitable (LS). This was further classified into two sub-categories indicating areas suitable for rack as 77% and raft culture as 23%. The results and outcomes from the work are clearly valuable, with some limitations information on the analytical method used as consideration of any alternative land use types and the sensitivity of the results to GIS procedures. The pearl oyster requires moderate water current for the proper growth which can be marked as a limitation in this case study. The economic aspect of the pear oyster culture considering the stake holders (sell meat, shell and pearls), the business opportunities in the area (restaurant, jewel shop, oyster shell as ornament) with the infrastructure facilities and the source of employment to the islanders can also be considered as criteria for assessing the suitable site.

Wanganeo *et al.* (2009) conducted a study aquaculture site selection in Midnapur district of West Bengal using Remote Sensing and GIS. The study area covers an area of 74465.044 ha which is 23 meters above sea level. Data on soil texture, Infrastructure and water source was extracted from the NDVI (Normalized Difference Vegetation Index) image and IRS P6 LISS IV FCC imagery of the study area. The total study area was 74465 ha of highly suitable area identified was 3382 ha, moderately suitable 28952 ha, Poor/less suitable 24852 ha, not suitable 1801 ha and restricted area 15476.2 ha. The study demonstrated the potential use of remote sensing and GIS techniques for aquaculture site selection and planning for responsible aquaculture. The map prepared can be used for selecting potential aquaculture sites in the area with limited field verification. Using this approach, planning of aquaculture development could effectively be adapted to local context in order to introduce appropriate aquaculture related livelihood options and help increase the rural poverty of Midnapur district. This case study can be used as a reference by the government for supervising and suggesting the scientific method for site selection for aquaculture and take steps for minimizing the leakage of saline water from the aquaculture pond.

Nayak *et al.* (2007) conducted land suitability modeling for enhancing fishery resources development in Central Himalayas (India) using GIS and multi-criteria approach. The study was to identify and demarcate the sites for aquaculture in mid/high Himalayan regions of Nainital distict ofUttarakhand in Kumaon regions. The study area covers the Nainital district of Uttarakhand in the Kumaon region of India, having geographical area of approximately 402,000 ha. This district has three altitude ranges low altitude range (150-700m asl), mid altitude range (700-1800m asl) and high altitude range (> 1800 m asl). Survey of India toposheets along with the village boundary in 1: 50000 scale of Nainital district and Indian Remote Sensing Satellite-1C – LISS-III satellite data were used for studying soil and water quality parameters, infrastructural facilities and constrain areas (forest cover areas). The pair wise comparison method (Saaty, 1977) in the context of Analytical Hierarchy Process was used to develop set of relative weights for each parameter. By interpretation of AHP model, the temperature was given highest importance (23%) compared to other water quality parameters, in water quality suitability map, as the region was a highland area where temperature plays a major role in the performance of the fish. In soil quality parameter, soil organic matter has the major role (54%) for fish culture in the region. In the infrastructure facilities suitability map, distance to water source was (40%) was noted as the major component. From all the three criteria water quality plays a major role (54%). The thematic maps modeling was carried out with an output of suitable sites for development of fish culture in Uttarakhand, after masking the forest cover and other constrain areas. Out of the total area around 40% was assessed to be most suitable for aquaculture development. The present study is very helpful in the expansion of aquaculture, operation and the diversification which affects the successful and sustainable aquaculture, which makes the use of land in an impartial manner with agriculture. The study can be recommended to undertake a broad scale economic and social comparison of highly suitable sites identified by utilizing economic indicators such as cost of land, transport and the power.

Research requirements

The global production of food fish from aquaculture, including fin fishes, crustaceans, molluscs and other aquatic animals for human consumption, reached 52.5 million tones in 2008. Aquaculture remains a growing, vibrant and important production sector for high protein food. Fisheries is a sunrise sector in Indian agriculture, with high potentials for diversification of farming practices, rural and livelihood development, domestic nutritional security, employment generation, export earnings as well as tourism. The possibilities of aquaculture in India extend from vast seas to high mountains with valued coldwater species. The fish production in India has registered excellent growth in past half a century from 0.75 million tons in1950s to around 7.5 million tons in 2008. To the fisheries sector of India, capture fisheries contributes around 4.1 million tons and aquaculture contributes around 3.4 million tons.

The usual sequence in aquaculture practices has been 'development and research' rather than 'research and development', resulting in environmental damage in many cases. When more research is conducted, more information is gathered, and more case studies are evaluated, the levels of uncertainty will be reduced and our predictions should get better. With the areas suitable for aquaculture have been sited, aquaculture development in India should be encouraged as means for local people to earn a living while minimizing their impact on the environment. The GIS can effectively be used to analyze complex data to evaluate suitable sites for aquaculture development. An economic aspect is to be incorporated into GIS applications for the determination of economic suitability and also physical suitability.

Establishment and implementation of environmental site suitability indicators for sustainable aquaculture development is necessary. Indicators which are denoted as key variables that signal change, and can be physical, biological, chemical, social, or/and economic, may be directly measurable or calculated from measurements of a number of data sets, derived from other information or derived from indicators. In addition, indicators can and should guide policy and help direct scientific research. The best available practices and technologies for the environmental monitoring of impacts and modeling of carrying capacity at farm sites should be used at the farm sites. Multiple criteria analysis is to be considered when determining the suitability of a site for different types of aquaculture. Regions characterized by poor circulation, extensive accumulations of organic sediment, recreational and commercial areas like marinas, race-courses, diving, fishing, port activities, etc will, generally, not be effective for aquaculture sites. The assessment process for suitable site has to include environmental assessment and EIA (Environment Impact Assessment), Social and cultural heritage assessment, economic development assessment, land use/land cover, acquire satellite images to identify each crop type, which relates to better information on pesticide pollution and negative impacts of land based activities especially in the areas within 1 km of water and use conflict assessment and analysis, taking into account current and future regional and local development plans. Difficulties that aquaculture activities face today with regard to impact on wildlife (disease spread from farmed species to wild species), can be avoided through a active stance. The site selection and evaluation must ensure that the proposed site should be capable of operating in an economically viable way for aquaculture practice in environmentally sustainable manner, and in accordance with this Code of Practice. The code of practice is the Best Practice for Environmental Management for a selected activity is the management of the activity to achieve reduction of environmental harm through cost-effective measures assessed against the measures currently used nationally and internationally. The Code of Practice is designed only after considering the possible effects of that particular activity for aquaculture and every activity related to it. In evaluating potential aquaculture site for developers or farmers, the identification of the features of the site and its environment is necessary. For the evaluation of the site one should obtain expert opinion after obtaining the following data

- Ability and the carrying capacity of the site to dilute and assimilate the discharge waters.
- Environmental assessment of the site and surrounding area with attention to special natural features.
- The potential impacts from the proposed site and activity on environmental features and biodiversity.
- The assessment route to marine or estuarine waters.
- Water quality of the site selected and tidal hydrology of the area
- Existing flora and fauna of the site and its surrounding area
- Soil quality and types of the selected site including clay content, erosion potential, and acid sulfate soil.
- Topography and flood levels, land use patterns and purposes
- Freshwater influences to and from the site for brackish water aquaculture.
- Existing water users and patterns of the area.
- Distance and effects to the adjoining environmentally fragile areas (Marine Parks, Fish Habitat Areas, Erosion Prone Areas, Ramsar Sites and World Heritage Property)
- Legal requirements according to the executive councils, government and Central Aquaculture authority for the project.
- The previous land uses and patterns of that area that will help to identify previous experiences.

Adoption of suitable technologies along with the improvement in the government regulations and guidelines with effective utilization of the aquaculture resources can lead to its sustainable development. The application of remote sensing and GIS in sustainable aquaculture is a challenge of using new technology in a real life context. This becomes a pathway of utilizing remote sensing and GIS in legislative and regulatory application. This can be utilized not only in academics but also in governmental, public, established private sector examination. The combination of conventional data collection methods with the modern technology of remote sensing and GIS is proven to be a powerful tool making it cost effective and efficient management tool. The implementation of remote sensing and GIS continues to be very slow in aquaculture community and for usage in spatial decision support, as these tools are receiving less attention among them. One of the drawbacks for enhancing the process concerning aquaculture techniques is lack of data and method for optimizing the production locations. The reason for this is the failure in grasping the significant part where spatial variations, in physical, economic or social factor play in the success of aquaculture. The failure in attaining attention for remote sensing and GIS is attributable to many constrains including lack of appreciation of the technology, limited knowledge of GIS and its methodology and lack of commitment by the organization for the continuity of the spatial decision support tools.

Sustainable management of aquaculture ensures reliability in quantifying the water quality parameters of water bodies of the study area. The primary productivity of the water bodies can be estimated by the spatial and temporal scale of water quality parameters, which help in aquaculture site selection. The traditional method of water quality monitoring although can give accurate measurement, it is time consuming. This also does not provide a spatial coverage of all the areas which is necessary for sustainable management in aquaculture. Remote sensing water quality studies using satellite sensors are very effective for frequent, synoptic observations over large areas. This can also provide a comprehensive historical record of water quality in an area and represent trends over time. The optically active constituents of the water which interact with light and change the energy spectrum of reflected solar radiation from water bodies can be measured using remote sensing. Spectral remote sensing has been limited by the sensor configuration and the algorithms used in processing to a few pre-defined spectral bands**.** The monitoring of coastal margin reflecting the CRZ zones in the coastal regions, where human impact and changes in biogeochemical processes is necessary for sustainable aquaculture. This needs accurate remote sensing algorithms for the assessment of the coastal margins. Due to the lack of adequate technology and data only a few models in regional levels are present. So, sustainable aquaculture needs the use of high resolution data for building accurate and precise models.

Enhancing equipments and techniques

Remote sensing and GIS technology, like any other branches of science and technology or other areas of computing and information management, is continuing to evolve at a rapid pace. Many advances in this regard is on the management of large datasets (>100MB), sharing of the information of the datasets among different systems, collection and initializing of datasets and the use of GIS in preparing larger decision support system. GIS or remote sensing practitioners had only limited data sources so they are forced to adapt to scale or resolution of their work to the quality of the available remote sensing data, often greater resolution, and poor penetration depth for the highly turbid waters. The aquaculture area which ranges from fresh water to the coastal zones requires a spatial resolution that has been difficult or expensive to acquire. The practitioners working in the field of identification of aquaculture zones has limited to few data sources. Many of the technological advancements have increased the number of observation platforms and sensor capabilities. If this trend continues, the production of unprecedented volume of data is possible, that can support national research and other applications which need shorter processing times with greater data and accuracies in algorithms.

The sustainable management of aquaculture it is necessary to quantify the water quality parameters. Remote sensing techniques is an efficient tool for monitoring effectively and efficiently the surface water bodies with its spatial and temporal view. This makes use of the digital imagery for acquiring surface sampling measurements. The correlations between measurements at sampling sites and scanner data at these points are used for developing relationships between water quality parameters and satellite radiances. Chlorophyll-*a* shows absorbance between 450-475nm(blue) and 670 nm(red) and reflectance peak at 550 (green) and 700nm (NIR). The reflectance peak is used to develop a variety of algorithms to estimate its value in turbid waters. For chlorophyll retrieval in inland waters Advanced Visible Infrared Imaging Spectrometer (AVIRIS) is most sensitive. Landsat-5TM, IKONOS data, ASTER, Compact Airborne Spectrographic Imager (CASI), Airborne Imaging Spectroradiometer (AISA) sensors, Moderate Resolution Imaging Spectrometer (MODIS), Sea-viewing wide Field of view Sensor(Sea WiFS), Medium Resolution Imaging Spectrometer (MERIS) and Rapid Eye are used for estimation of chl-*a*. Due to the interfering of Spectral signals of Colored Dissolved Organic Matter (CDOM) with chl-*a*, hyperspectral sensors like EO-1 Hyperion and ALOS/AVNIR-2 are preferred for CDOM estimation. TIR images (0.2-0.4m) images is precice in estimation of radiant temperature (Gholizadeh *et al*., 2016). These are attractive sauce of broad scale data due to low cost, capability of regional coverage. TIR imaging sensors with multiple spectral bands located at different wavelengths make them suitable for water temperature measurement. Moisture and Ocean Salinity Satellite (SMOS) employing Microwave Imaging Radiometer using Aperture Synthesis (MIRAS) is being used to measure sea surface salinity have higher accuracy. The newly developed hyperspectral satellite imageries, such as Hyper spectral Imager for coastal ocean (HICO) which can record up to 200 spectral bands are more powerful for the detection of the water quality parameters. The management of the water resources through remote sensing data is effective in monitoring and assessing its quality issues. The retrieval of the geophysical aspects in algorithms is difficult due to non linear nature of problems and computational difficulties. This requires knowledge of mathematical techniques and scientific aspects of the physical systems for analyzing the remote sensing data accurately. With the help of the computational techniques (CI) such as Artificial Neural Network (ANN), (Renjitha *et al*., 2007) it is possible to examine the complex data without the detailed knowledge of the physical system. This method is better than the regression models for retrieving the water quality parameters from satellite images.

Geographical information system, which is evolving at a rapid pace, for its use, act as a component for larger decision support system. The Arc Info (version 8, ESRI) is being replaced with an object based component model which combines GIS technology with broader application framework. So the technologist can install the GIS enabled applications with the software supporting the geographic manipulation and with visual effects (Nath *et al*., 2000). Thus the developers can produce specialized applications using the spatial datasets, which allows interaction with the models, datasets, and for map displays. Virtual photographs plays an important role in landscape visualization and its future aspects which can model a change in it after allowing the view in three dimensions. In this GIS datasets are mapped into elevation grids with appropriate textures which result in visualization in a realistic photo simulation of particular area of actual view of a particular set of assumptions. The increasing capabilities of PCs and increasing cost of the storage devices allows the GIS analysis to be readily used in these platforms. The mobile data collection devices like pen driven hand held personal digital assistant (PDAs) to GPS units and laser telemeter helps in efficient data collection with sophistication and ease of use. Increasing GIS functionality by making it readily established in internet, makes it distributed geographic information (DGI), so that it gets available to larger audiences.

The sustainable aquaculture development should be practiced in such a manner that it helps in usage of different alternatives for other users through effective utilization of advanced techniques like remote sensing and GIS. To enhance aquaculture development capabilities, a country or local community should acquire and maintain a comprehensive inventory of the physical and biological resources available in the area as well as their uses and users. This inventory can provide a database for making decisions about long-term goals, such as ecosystem preservation, that might conflict with the immediate development of aquaculture. Determination of suitability for aquaculture involves an evaluation of natural and anthropogenic limitations of a certain area in order to decide if the locality can support the activity. In order to develop consensus in an area like aquaculture that requires access to unbiased scientific knowledge, it is critical that all the stakeholders have confidence in their background information. In order to create 'sustainable aquaculture', it is essential that a balance between the need for aquaculture development and the natural resources conservation is maintained.

Final Comment

Remote sensing data is becoming available from many rich set of satellite sources. The commercial industry is is focusing on the development and supply of broader range of datasets. The distribution of the dataset is through internet. The government agencies are now beginning to distribute many data sets online. The water quality studies using remote sensing mainly focuses on the optically active variables, such as chlorophyll-*a,* total suspended solids, turbidity etc .Other variables such as pH, total nitrogen, ammonia nitrogen, nitrate nitrogen, phosphorus show weak optical characteristics and low signal ratio. The developed data from remote sensing require adequate calibration and validation while using the measurements and this can be used only in the absence of clouds. The atmospheric interference also restricts the optical signals from the water bodies. The cost of the hyper spectral or airborne data and the equipment for in situ measurement is very high. The application of computational intelligence technique like Artificial Neural Network, for the retrieval of water quality data from hyperspectral imagery is in the infant stage. A focused research on the application of ANN for retrieval of water quality parameters for the success of sustainable aquaculture using the hyper spectral data is necessary. These water quality indices are important in aquaculture studies and is a challenging aspect for water quality assessment using remote sensing, which should stimulate and motivate the scientist and researchers for further efforts. An open and effective discussion is needed between scientists, policy makers and the stakeholders at national and regional level for the realization of the application potential of remote sensing technologies. In the administrative aspect the managers and the policy makers lack the knowledge of technical expertise of remote sensing techniques. The clarification of the perceptions of the aquaculture managers is necessary which is not easily achievable. The future tools in GIS and remote sensing will provide a range of functions combined with various components that can be used for specific purposes. In future GIS tools will provide range of functions combined with various components which can be joined for specific uses especially for sustainable aquaculture and its management. The barriers of using these tools for the real world of decision making in aquaculture and management needs special attention and is needed to be overcome The training and workshops for the end users and the stake holders will expand the knowledge of remote sensing and GIS. The migration of these tools from the academic to the end users, analysts, subject matter experts can address the issues which are relevant for the sustainable growth of aquaculture. With the knowledge of the areas suitable for sustainable aquaculture, the aquaculture development can be encouraged which can be a means for local people to earn a living while minimizing the impact on the environment.

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REFERENCES

Aguilar-Manjarrez, J. and Ross, L.G. 1995. Geographical information system (GIS) environmental models for aquaculture development in Sinaloa State, Mexico. *Aquaculture. Int.* 3: 103-115.

Aguillar-Manjarrez, J. 1992. Construction of GIS for Tobasco State Mexico. Establishment of technical and social decision models for aquaculture development. MSc. Thesis University of Stirling, UK

Aguillar-Manjarrez, J. and Nath, S.S. 1998. A strategic reassessment of fish farming potential in Africa. CIFA Techical paper no. 32. Rome, FAO.

Aguilar-manjarrez, J. and Ross, L.G. 1998. A strategic assessment of fish farming potential in Africa. CIFA technical pape.32, FAO, Rome.

Aguilar-manjarrez, J. and Ross, L.G. 1995. GIS environmental models for aquaculture development in Sinaloa state, Mexico. *Aquaculture Int.* 3: 103-115.

ALCOM, 1998. The SADC water Resource database. htt P://www.fao.org/WAICENT/FAOINFO/FISHERY/alcom/alcom.htm

Arnold,W.S., Norris,H.A., White, M.W., 2000. Integrated resource management using GIS : shellfish aquaculture in Florida, USA. Aqua.Eng.

Banerjea. S.M. 1967. Water quality and soil conditions of fish ponds in some states of India in relation to fish production. *Ind. J. Fish.* 14 (1&2) : 115-144.

Campbell, J.B. 1996. Introduction to Remote Sensing. Guilfor Press, New York.

Chimowa, M. and Nugent, C. 1993. A fisheries GIS for Zimbabwe: an initial analysis of numbers, distribution and size of Zimbabwe's dams. AGRITEX Fisheries Unit -Technical Report.

Gholizadeh, M.H., Assefa, M.M. and Lakshmi, R. 2016. A Comprehensive review of water quality parameters estimation using remote sensing techniques. *Sensors.* 16 (8): 1298.

Gupta, M.C. 1995. Brackish water aquaculture site selection using techniques of geographical information system (GIS). Space Application Centre, ISRO, Ahmedabad.

Gupta, M.C. and Gopalakrishna Sreshty, I.V. 1993. Development of Models for Brackish water Aquaculture site selection in India. 2-14.

Giap, D.H.Y. and Yakupitiyage, A. 2005. GIS for land evaluation for shrimp farming in Haiphong of Vietnam. *Ocean Coast, Management.* 48: 51-63.

Giap, D.H. and Yang, Y. 2003. Application of GIS and Remote Sensing for Assessing Watershed Ponds for Aquaculture Development in Thai Nguyen, Vietnam. In: Map Asia Conference 2003. GIS development, net.

Girap, M. 2006. Remote sensing and application of GIS in natural resource management with reference to land use/land cover in the state of Goa. In: Multiple Dimensions of Global Environmental Change. TERI press, New Delhi 83-100.

Gupta, M.C., Krishnarajan, V.P. and Nayak, S. 2001. Brackish Water Aquaculture Site Selection in Coastal Track of Cannanore (Kerala) Using Remote Sensing and GIS Techniques. *Journal of the Indian Society of Remote Sensing.* 29 (I & 2) : 79-83.

Hossain,M.Z., Mutitanon,W.,Tripathi,N.K., Philips,M., 2003. Monitoring shrimp farming development from space. *Gis Development.* 7:1-6.

Howard, J.A. 1985. Overview of Remote Sensing " in Report of the ninth International training Course on application of remote sensing to aquaculture and inland fisheries. RSC Series 27, FAO Rome. 51-21.

Jayanthi,M ., Rekha.P.N 2004. Role of RS and GIS for natural resource assessment in brackish water aquaculture. In *Proceeding of Natural Resource Management and Agro-Environment Engineering. International conference on Emerging Technologies in Agricultural and Food Engineering, IIT Kharagpur, India.* Dec 14-17. Pp 41-48.

Jayanthi, M. and Ravichandran, P. 2009. Optimizing site selection for the development of sustainable aquaculture. In: Training Manual On Better Management Practices In Shrimp Farming, CIBA Special Publication No. 44 : 12-20.

Kalio, K. 2000. Remote sensing as a tool for monitoring lake water quality. In. Hydrological and Limnological saspects of lake monitoring, JohnWiley & Sons. New York, USA 200. 237.

Kepetsky, J.M. 1989. A geographical information system for aquaculture development in Johore state. Field document , FAO, Rome.

Kepetsky, J.M., Hill, J.M. and Worthy, D.L. 1988. A geographical information system for catfish farming development. *Aquaculture.* 68: 311-320.

Kepetsky, J.M.McGregor, L., H.E. 1987. A GIS and remote sensing plan for aquaculture development: a FAO-UNEP/GRID cooperative study in Costa Rica. FAO Fish. Paper 287.

Kepetsky, J.M. and Nath, S.S.1997. A strategic assessment of the potential for freshwater farming in Latin America.COPES-CAL Technical paper No.10.FAO, Rome,128pp

Kepetsky, J.M. and Travaglia, C. 1995. Geographical information system and remote sensing : an overview of the present and potential Applicatons in aquaculture. In Nambiar.K.P.P., Singh T.(Eds). Aquaculture Towards m 21st Century. INFOFISH, Kuala Lampur. Pp.187-208.

Kepetsky, J.M. 1994. A strategic assessment of warm water fish farming potential in Africa. CIFA. Technical paper, 27, FAO, Rome

Kapetsky, J.M., Hill, J.M., Worthy, D.L. and Evan, D.L. 1990. Assessing potential for aquaculture development with GIS. J. World Aua ish Ataman,E.,Caponera, F., 1990. Where are the best oppurtunities for fish farming in Ghana ? The Ghana aquaculture GIS as decision making tool, FAO Field Technical Report 5, FAO, Rome.

Karthik, M., Suri, J., Neelam, S. and Biradar, R.S. 2005 Brackish water aquaculture site selection in Palghar Taluk, Thane district of Maharashtra, India using Remote sensing and geographical information system. *Aquaculture Engineering.* 32 : 285-302.

Kumar, P., Meenakumari, B. and Bandyopadhyay, J.K. 2001. Geomorphological changes in Sagar Island: A Remote Sensing Study. In: Reverine and Reservoir Fisheries of India. Society of Fisheries Technologist (India). pp 43-47.

LUCO, 1998. Guide to spatial land and resource information in LRMP. Land use and Coordination office, British Columbia.

Meaden, G.J. and Kepetsky, J.M. 1991. Geographical Information system and remote sensing in inland fisheries and aquaculture. FA Fisheries Technical Paper. 318: 186-233.

Meaden, G.J. 1987. Where should trout farms be in Britain ? Fish Farmer March/ April, 33-35.

Nayak, A.K. 2007. Framework for development of GIS based decision support system for aquaculture in Kumaon Hills, In: Book of Abstract- 8th Asian Fisheries Forum Organized by Asian Fisheries Society during 20-23 Nov. 2007, Kochi, India. p .99-100.

Nath, S., Bolte, J.P., Ross, L.G. and Aguilar-Manjarrez, J. 2000. Application of geographical information system (GIS) for spatial decision support in aquaculture. *Aquacult. Eng.* 23 : 233-278.

Nayak, A., Pant, D., Kumar, P., Mohanta, P.C. and Pandey, 2014. GIS based aquaculture site suitability study using multi-criteria evaluation approach. *Indian Journal of Fisheries.* 61(1): 108-112.

Pandey, R.K., Mishra, A.K. and Mukhopadhyay, A. 2006. Remote sensing and GIS for assessment of environmental factors and pearl oyster culture areas in Minicoy Island, Lakshadweep. International Achievers of photogrammetry and Remote sensing (IAPRDS &SIS) 36 (4) : 800-805

Paw J.N., Domingo, F., Alojado, Z.N. and Guiang, J. 1994. Land Resource assessment for brackishwater development in Lingayen Gulf area, Philippines. Technical Report on GIS application for Coastal Area Management & Planning. Lingayen Gulf Area, Philippines, Part II.

Quader, O., Islam, Z., Rahman, H., Rahman, M., Sarkar, M.H. and Khan, A.S. 2004. Suitable site selection of shrimp farming in the coastal areas of Bangladesh using remote sensing techniques (4S Model). In: Proceeding of the XXth ISPRS (International society for Photogrammmetry and Remote Sensing) Congress. Istanbul. Turkey, July 12-23.

Rajitha, K., Mukherjee, C.K. and Vinu, C. 2007. Application of remote sensing and GIS for sustainable management of shrimp culture in India. *Aquaculture Engineering.* 36 : 1-17.

Ramesh, R. and Rajkumar, R. 1996. Coastal aquaculture site selection and planning in Tamil Nadu usingremote sensing and GIS. *Asian-Pacific Remote Sens. GIS J.* 9 (1): 39-49.

Ross, L.G.,Mendoza, E A., Beveridge, M.C.M., 1993. The application of GIS to site selection for coastal aquaculture: an example based salmanoid cage culture. *Aquaculture.* 112: 165-178.

Saaty, T.L. 1977. A scaling method for priorities in hierarchical structures. *J. Math Psychol.* 15: 234-280.

Saaty, T.L. 1980. The Analytical Hierarchy Process. McGraw Hill, New York.

Salam, M.A., Lindsay, G.R. and Beveridge, C.M.M. 2003. A comparison of development opportunities for crab and shrimp aquaculture in south-western Bangladesh, using GIS modelling. *Aquaculture.* 220: 477-494.

Salam, M.A. and Ross, L.G. 2000. Optimizing site selection for development of shrimp (Penaeus Monodon) and mud crab(Scylla serrata) culture in Southwestern Bangladesh. In: 14th Annual Conference on Geographic Information Systems, Proceeding of GIS 2000, Toronto, Canada, March 13-16.

Scott, P.C., Cansado, S. and Ross, L.G. 1998. A GIS assisted mollusk culture potential determination for Septiba Bay, Brazil. Paper presented at the GIS planet 98 Conference, 7-11 sept 1998, Lisbon

Shahid, M.A., Pradanik, M.A.H. and Ali, S. 1992. Remote Sensing applications in coastal shrimp farming and agricultural areas. *Asian Pacific Remote Sensing Journal.* 4 (2): 1-10.

Shreedhara, V. Sherieff, A.N., Bannur, C.R., Rao, R.S. and Nayak, S. 1995. Coastal Landuse Mapping of the Karnataka Coast for Brackishwater Aquaculture Site Selection, Space Applications Centre (ISRO), Ahmedabad.

Wanganeo, A., Chandran, V.R. and Kumar, A. 2009. Aquaculture site selection in Midnapur district (West Bengal) using remote sensing and GIS. *Pollution Research.* 28(3): 395-398.

WCED (World Commission on Environment and Development) 1987. Our Common Future. Oxford University Press. Oxford. New York. 400.