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M. Jayanthi, S. Thirumurthy,
M. Muralidhar, M. Kumaran, R. Yoganandhan,
M. Samynathan, M. Duraisamy, J. Ashok Kumar,
C.P. Balasubramanian, K.K. Vijayan

ICAR-Central Institute of Brackishwater Aquaculture
(Indian Council of Agricultural Research)
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*For correspondence - jayanthiciba@gmail.com

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Foreword

Brackishwater aquaculture has been acknowledged as the fastest growing food sector in the coastal areas at global and national level contributing to the development of unused lands, food security, nutritional requirement and also generating foreign revenue. Out of 1.2 million hectares of brackishwater lands available in India, only 14% have been used for aquaculture so far. But unplanned, unregulated and profit-driven early development of the aquaculture sector faced environmental and social issues, led the aquaculture to the regularity mode with licensing guidelines and environmental regulations.

To develop aquaculture with long-term sustainability and social acceptance, spatial planning incorporating ecologically important ecosystems characteristics, and extent of coastal resource use in an environmentally-integrated mode are essential. Shrimp farming is faced with several issues in relation to climate change impacts due to global warming. With increasing, extreme events such as floods, cyclones, drought, tsunami, brackishwater aquaculture are vulnerable to climate change due to its total dependence on the coastal ecosystems. The emerging scenario necessitates the Central Institute of Brackishwater Aquaculture to have research programmes on scientific climate resilient planning on a proactive mode utilizing the advanced spatial technologies.

Advancement in remote sensing technology coupled with Geographical Information System (GIS) has emerged as indispensable tools in spatial planning due to analytical capabilities to handle multiple criteria with a high level of precision for the time series data of larger areas. The institute has focused research programmes for monitoring, planning, impact assessment of aquaculture using Remote Sensing (RS) and GIS.

This book provides the way in which aquaculture can be planned at district level incorporating resources assessment, potential areas for expansion, climate variability, extreme events in a spatial mode, to ensure its sustainability. The book describes the climate resilient, sustainable aquaculture planning for Nagapattinam District of Tamil Nadu as a model which can form the basis for state or national level planning of environmentally sustainable, socially acceptable and economically viable aquaculture.

Dr. K. K. Vijayan

Director

About the Book

The initial phase of shrimp aquaculture was unplanned in India, which led to alleged impacts about the conversion of productive lands and ecosystems. Though brackishwater aquaculture is the only viable option which converts the wastelands to wealthy ones, however, hasty growth in an unregulated manner overshadowed its real benefits. Andhra Pradesh and Tamil Nadu have seen the fast aquaculture growth compared to other coastal states in the country. Nevertheless, it attracted societal criticism due to its so-called negative impacts and failure to consider the needs of other resource users. There have been calls from environmentalists and policymakers to explore the resource base and analyze its characteristics to locate the barren lands for aquaculture. In a way, Coastal Aquaculture Authority Act 2005 is a mandatory rule imposed on coastal aquaculture in the country for regulated development. This book is based on the study carried out for identifying areas, problems, action plans for expanding aquaculture through geospatial planning in the climate hazardous coastal district, Nagapattinam in Tamil Nadu as a model study.

An effort has been made in the book to include spatial tools, data, and techniques relevant to aquaculture planning. This book contains ten chapters that cover issues, regulations, resource quality & availability, and suitability for sustainable aquaculture expansion. Present issues in aquaculture, Remote Sensing (RS) and Geographical Information System (GIS) capabilities to address them are given in chapter 1 while Chapter 2 describes the policy framework and legal regulations for aquaculture in India. Chapter 3 presents the methodology used in spatial planning incorporating land use, soil, and water resource characteristics and existing rules for aquaculture. Chapter 4 indicates the study area nature, details of climate vulnerability. Chapter 5 presents land and water resource availability, extent and current status of shrimp farms. Chapter 6 details the water and soil resource characteristics related to aquaculture planning. Chapter 7 describes the delineation of area available for aquaculture expansion. Chapter 8 presents the climate variability and its impacts on coastal resources particularly on aquaculture farms and potential regions. Focus group discussion, survey in the farmer's fields and Stakeholders workshop formed the basis to derive the issues and problems faced by the farmer's, listed in chapter 9 while adaptation measures for sustainability are listed in Chapter 10. I hope the book will be useful for policy makers and planners in inclusive planning and developing sustainable aquaculture.

This book would not have been possible without the help of several individuals and organizations at the right time in one way or another. First and foremost, sincere thanks to the aquaculture farmers of Nagapattinam district, for their participation in attending all the meetings organized by CIBA and cooperation in sharing their views. Sincere thanks to Dr.A.G.Ponniah, the former director of CIBA for supporting and providing the necessary facilities with a very positive note for carrying out this work. A great deal of thanks goes to Dr.P.Ravichandran, the former HOD, Crustacean Culture Division, for constantly guiding and encouraging this research and his involvement in the stakeholders' workshop. Funding support from National Innovations in Climate Resilient Agriculture (NICRA) of Indian Council of Agricultural Research the climate variablity impacts assessment and stakeholder workshop is greatly acknowledged. I am very much thankful to ICAR for Extramural grant for the project on "Identifying suitable brackishwater sites for increasing aquaculture areas in the coastal state of India using multi criteria decision support system," which provided the funding support for the printing of this book. Support received from the Fisheries, Forest, Public works, Agriculture, Agricultural Engineering and Irrigation Departments of the Government of Tamil Nadu deserves a special note of thanks.

Dr. M. Jayanthi
Principal Scientist

Contents

Overview of RS & GIS Capabilities in Aquaculture

Remote sensing technology had advanced manifolds in recent years and proved to be an appropriate method for spatial planning due to extensive and inaccessible area coverage and synoptic viewing capabilities. The orderly approach in data capturing through satellites, high resolution of multispectral and temporal satellite images, affordability and high level of accuracy has made the technology as an indispensable tool in earth resource management. Satellite images are increasingly utilized as data sources in conjunction with a Geographical Information System (GIS) in the decision-making process which involves multiple criteria ranging from local to global level decision making with the past, present and future scenario. Remote sensing (RS) and GIS can serve as a data creation and management system that permits researchers, environmentalists, planners and policy makers to collect, analyze, recover and evaluate different types of sophisticated, complex spatial data separately or in an integrated manner. In addition to RS and GIS, a Global Positioning System (GPS), a satellite navigation system assists to locate the position on the earth precisely and enables to get any feature data that can be imported to GIS for further investigation.

Growing world population demands the ways and means to increase the food production to meet the demand and nutritional stability. Though fisheries and aquaculture contribute to food security, dietary requirement and employment globally, the stagnated capture fisheries makes aquaculture as the only viable option for further increasing fish production throughout the world. Aquaculture farming is one of the fastest growing food sectors, expanded at an average annual rate of 8 percent in the last three decades (FAO, 2016). But, the rapid growth has confronted the sector with many environmental issues and multiuser conflicts, apart from the viral disease outbreak. Major shrimp farming countries of the world have faced environmental problems due to unplanned development, which has resulted in several complex social issues, led to litigation at national and international levels. The majority of the issues faced by the aquaculture is in the spatial domain; hence RS and GIS can play a pivotal role in its planning, monitoring, and management.

Issues and challenges in aquaculture development

Sustainable use of natural resources for developmental activities is one of the most crucial issues in today's world. The unplanned explosion of aquaculture farms for increasing short-term returns without addressing sustainability has made concerns worldwide, particularly in Southeast Asia. Comprehensive planning for the aquaculture is still uncommon, and the facts that many farms are abandoned or are suffering significant disease problems demonstrate the lack of such plan. Hence, there is a need to address those issues logically with advanced spatial tools.

Unplanned and uncontrolled development

Shrimp aquaculture sector has developed initially without any proper comprehensive spatial planning, however, faced with sudden collapse due to a massive disease outbreak in many shrimp growing countries. Shrimp pond abandonment has become common in disease hit areas, but there was not much effort made for the reuse. The imbalance due to fast unregulated growth of the sector on one side and vast abandoned areas available on other side necessitated the spatial planning at the administrable level of the state.

Conversion of mangroves

Mangroves ecosystems serve as a breeding ground for fishes and play a very productive role in cyclone/Tsunami protection, sediment and nutrient retention, shoreline stabilization, preventing coastal erosion, storm flood and flow control, carbon sequestration and maintaining coastal water quality. But the fast development of shrimp aquaculture was one of the reasons for the loss of mangroves globally. Researchers have indicated that one-third of the mangrove forests worldwide have disappeared in the last 20 years and 35% of loss was contributed by shrimp farming (Simard et al., 2008). The highest rates of mangrove losses were recorded in the last 30 years in Southeast Asia, possess 35% of the mangrove forests in the world, showed damage of 0.18% per year, mainly to aquaculture and agriculture (Richards and Friess, 2016).

In some shrimp producing countries, this mangrove deforestation is still taking place, even though the importance of mangroves is well recognized (Lebel et al., 2002). It has been estimated that the loss of the mangroves may reach 60% by 2030. Studies have indicated that the mangroves have been lost due to natural changes and developmental activities in India (Jayanthi et al., 2018).

Conversion of agricultural lands

Shrimp aquaculture initially started in the coastal fallow lands close to the source water bodies such as estuaries and creeks. But the short-term gains and increasing demand in the international market expanded the shrimp farming activities in the neighboring agricultural lands in Thailand, Vietnam and also in India. The growth of shrimp farming in other productive land types, particularly in agricultural lands and mangroves led to the litigation at the international and national level. In India, issues have been raised over the conversion of the agricultural farms to shrimp culture (Jayanthi et al., 2007; Alagarswami, 1995)

Salinization of lands and water resources

Development of brackishwater aquaculture has been cited as one of the causes of salinization of agricultural lands and potable water resources. Salinization of freshwater aquifers have been reported in Taiwan, The Philippines, India, and Thailand, as a result of groundwater extraction for intensive shrimp culture, seawater intrusion due to excessive pumping into inland water (Phillips et al., 1993, NEERI 1995, Park et al., 2005). The agriculture farms nearby shrimp farms turned saline due to seepage from shrimp farms and prolonged stagnation of salt water for the entire crop period of 4 months.

Competing on resources and multi-user conflicts

Coastal areas are not only under mounting pressure due to natural events such as flooding, saltwater intrusion, storm surges, siltation, erosion, cyclones but also due to unmanaged developmental activities, viz. pollution, intense urbanization, recreation, overfishing, industry development, unplanned aquaculture, etc. Increased demand for limited coastal zone resources has often resulted in a conflict among competing user groups. The industrial development on the coast has resulted in degradation of coastal ecosystems and diminishing the living resources of Exclusive Economic Zone (EEZ) (Nayak, 2001), in the form of changing coastal and marine biodiversity.

Changing climate

Natural disasters have become one of most severe problems in coastal regions, particularly in low lying areas, which can be strongly affected by flooding and sedimentation and pose the most severe consequences for the local communities. Climate change may affect aquaculture directly by damaging the facilities and altering the availability of fish/species, indirectly by changing the price of fish products and inputs. The impacts of sea level rise will bring a reduction in the land available for aquaculture, loss of coastal ecosystems, saltwater intrusion and shift in species abundance and distribution. Increase in frequency of cyclones or storm surges will result in inland flooding, salinity changes and the introduction of disease or predators into aquaculture facilities and also result in substantial crop losses if it occurs during culture days. Drought will bring the changes in salinity and river flows and lead to water shortages and quality for aquaculture. Sea surface temperature changes will decrease the dissolved oxygen in water bodies and also increase the occurrence of harmful algal blooms, disease outbreaks and growing seasons in aquaculture and the impact of climate change on coastal resources demands the assessment of site-specific vulnerability and mitigative strategies.

Abandonment of shrimp farms

Large areas of shrimp farms have been abandoned after only a short-term use for shrimp culture due to disease problems and environmental regulations in shrimp growing countries viz. India, The Philippines, Vietnam, Cambodia, Sri Lanka, Thailand, and China. Disused shrimp ponds are actively deteriorating and may represent a danger to adjacent habitats, and need immediate attention for restoration. Conversion of coastal lands for aquaculture and abandonment presents a significant challenge for both farmers and also coastal resource managers and demands the alternative reuse plan for abandoned farms (Ravisankar et al., 2014).

Remote sensing tools for aquaculture

Remote sensing captures raster data in different bands and offers a varied range of data products from aerial photographs to high-resolution images for various applications. Satellite data products are available with different temporal and spatial resolution to cater the needs of multiple uses and user requirements. The data resolution can be need-based and vary from sub-meter high resolution to 120 m low resolution. Generally, data may not be available in the exact format to respond to the question. It has to be converted to a suitable form to get the required information. All image processing software has abilities to rasterize or vectorize, in addition to importing and exporting data ideal to a GIS environment. Many preprocessing tools are available in remote sensing as well as GIS packages.

Selection of data

The selection of satellite data depends on objectives of the study, the spatial extent of the study area, the frequency of time series data requirement, information to be derived, facilities available, additional data to be linked and the budget. For example, land use of macro-level studies can be mapped from Landsat data available freely online, whereas micro-level studies need high-resolution images. It is worth to note that salinity requires different sensor dataset compared to temperature. Table 1.1 provides the satellite data available for coastal aquaculture use in India. Though optical remote sensing data and radar data caters the need for spatial planning of aquaculture, optical data is considered the most suitable for developing countries.

Image processing software

The acquired satellite data needs to undergo different processing techniques (Fig. 1.1) such as image enhancement and rectification, to improve the quality and also to make it in a suitable form in GIS. ERDAS and ENVI are most commonly used proprietary ones for image processing applications.

- ERDAS imagine is most used image processing software in the world, supports optical, panchromatic, multispectral, hyperspectral, radar and LiDAR RS data. The capabilities include user-friendly ribbon interface, spatial modeling with raster, vector and point cloud operators, high-performance terrain preparation, mosaicking, and change detection. It also can convert more than 190 image formats into all major file formats, including img, GeoTIFF, NITF, CADRG, JPEG, JPEG2000, ECW and MrSID.

- Envi is capable of user-friendly interface solutions for spectral image processing and image analysis technology of LiDAR, SAR, multispectral or hyperspectral imagery.

- Idrisi can be used for short-term projection of land modeling as long as the period of the forecast is homogenous.

Table 1.1 Satellite products available for aquaculture planning

Satellite	Sensor	Resolution (m)	No. of Bands	Data Availability	Data cost - Free / Commercial
Landsat 1	MSS	60	4	1972 -1978	Free
Landsat 2	MSS	60	4	1975 - 1982	Free
Landsat 3	MSS	60	4	1978 - 1983	Free
Landsat 4	MSS ,TM	60 , 30	4, 7	1982 - 87,87 - 2011	Free
Landsat 5	MSS, TM	60 , 30	4, 7	1982 - 87,87 - 2011	Free
Landsat 7	ETM + SSLC ON, ETM+SSLC OFF	30	7	1999 - 2003, 2003 - Present	Free
Landsat 8	OLI+TIRS	30	11	2013 - Present	Free
SRTM (DEM)	C/X	90	10-14	2000 - 2014	Free
ASTER (DEM)	TIR	30	14	2009 - Present	Free
Cartosat DEM	PAN	2.5	1	2005 - Present	Free
TERRA	MODIS	250 ,500, 1000	36	2000 - 2016	Free
TERRA	ASTER	15, 30, 90	14	1999 - 2011	Free
Ikonos	PAN, MS	0.82 , 3.2	1, 4	1999 - Present	Commercial
QuickBird	PAN, MS	0.6, 2.4	1 , 4	2001 - 2016	Commercial
WorldView-1	PAN	0.5	1	2007 - Present	Commercial
WorldView-2	PAN, MS	0.5, 1.8	1, 8	2009 - Present	Commercial
WorldView-3	PAN, MS, CAVIS-MS	0.31, 1.24, 30	1, 8, 12	2014 - Present	Commercial
RapidEye	MS	6.5	5	2008 - 2015	Commercial
GeoEye-1	PAN, MS	0.5, 2	1, 4	2008 - 2015	Commercial
SkySat-1	PAN, MS	0.9, 2	1, 4	2014 - Present	Commercial
IRS-1A	LISS-I , LISS-II	72.5, 36.25	4	1988 - 1991	Commercial
IRS-1B	LISS-I, LISS-IIA, LISS-IIB	72.5, 36.25, 36.25	4	1991 - 2001	Commercial
IRS-1C	PAN , LISS III, WiFS	6 , 23.5, 189	4	1996 - 2007	Commercial
IRS-1D	PAN , LISS III, WiFS	6 , 23.5, 189	5	1998 - 2009	Commercial
IRS- P3	WiFS, MOS, IXAE, CBT	188	5	1996 - 2004	Commercial
IRS-P4 (Oceansat)	OCM	236 -360	8	1999 - 2010	Free
IRS-P6 (Resource sat-1)	LISS -4 (MSS), LISS- 3 (MSS) AwiFS	5.8 , 23.5, 56	4	2003 - 2018	LISS-4 Commercial
IRS-P6 (Resource sat-2)	LISS-4, LISS-3, AWiFS	5.8 , 23.5, 56	4	2011 - 2016	LISS-IV-Commercial
Cartosat-1	PAN	2.5	1	2005 - 2010	Free

(Cont ....)

Cartosat-2	PAN	1	1	2007 - 2012	Commercial
Cartosat-2A	PAN	1	1	2008 - 2013	Commercial
Cartosat-2B	PAN	1	1	2010 - 2015	Commercial
RISAT-1	SAR	1	1	2012 - Present	Commercial
SPOT 1	HRV PAN, MS,	10, 20,	1, 3,	1986 - 1990	Commercial
SPOT 2	HRV PAN,MS	10, 20	1, 3	1990 - 2009	Commercial
SPOT 3	HRV PAN,MS	10, 20	1 ,3	1993 -1996	Commercial
SPOT 4	HRVIR PAN, MS,	10, 20	1, 4	1998 - 2013	Commercial
SPOT 5	HRG PAN,MS, HRS	5, 10 & 20, 10	1, 4, 1	2002 - 2015	Commercial
SPOT 6	NAOMI PAN, NAOMI MS	1.5, 6	1, 4	2012 - Present	Commercial
SPOT 7	NAOMI PAN, NAOMI MS	1.5 ,6	1, 4	2014 - Present	Commercial
ERS-1	ATSR	26.3	3	1991 - 2000	Commercial
SPIN 2	MK-4	15	Nil	1988 -1995	Commercial
Resurs-DK1	ASPOS	0.9	4	2006 - 2016	Commercial
Sentinel-2 ESA	MS	10 - 60	13	2015 - Present	Commercial
Envisat	MERIS (MS)	300	15	2002 - Present	Commercial
KOMPSAT-2	PAN, MS	1, 4	1, 4	2006 - 2012	Commercial
KOMPSAT-3	PAN, MS - AEISS	0.7, 2.8	1, 4	2012 - Present	Commercial
KOMPSAT-3A	AEISS-A PAN, AEISS-A MS	0.5, 2.2	1, 4	2015 - Present	Commercial
EROS A	PAN	1.8	1	2000 - 2015	Commercial
EROS B	PAN	0.7	1	2006 - Present	Commercial
TopSat 1	RAL Cam PAN, MS,	2.5, 5	1, 3	2005 - Present	Commercial
NigeriaSat-X	SLIM6	22	3	2003 - Present	Commercial
NigeriaSat-2	PAN, MS, MS - MRI	2.5, 5, 32	1, 4, 4	2011 - Present	Commercial
Beijing-1	PAN , MS	4 , 36	1, 4	2005 - 2010	Commercial
Gaofen-1	PAN, MS WF, MS	2, 16, 8	1, 4, 4	2013 - Present	Commercial
TeLEOS-1	PAN	1	1	2015 - Present	Commercial
NOAA11	AVHRR	Nil	Nil	1998 - 1994	Commercial
NOAA12	AVHRR	Nil	Nil	1994 - 1995	Commercial
NOAA14	AVHRR / 2	1100	5	2000 - 2001	Commercial
NOAA16	AVHRR/3	1100	6	2001 - 2005	Commercial
NOAA17	AVHRR/3	1100	6	2004 - 2013	Commercial
NOAA18	AVHRR/3	1000	6	2005 - Present	Commercial
NOAA19	AVHRR	Nil	Nil	2009 - Present	Commercial
AQUA	MODIS	250 m	Nil	2002 - Present	Commercial

*Present indicates December 2018.

MSS - Multispectral Scanner; TM - Thematic Mapper; ETM + - Enhanced Thematic Mapper Plus; PAN – Panchromatic; MS – Multispectral; OLI -Operational Land Imager; MODIS - Moderate Resolution Imaging Spectroradiometer; LISS - Linear Imaging Self-Scanning System; SAR - Synthetic Aperture Radar; AWiFS - Advanced Wide Field Sensor; AVHRR - Advanced Very High-Resolution Radiometer.

Other remote sensing software's such as Geomatica, ER Mapper, Imagine, Maphinx are also available with different capabilities for satellite data processing and analysis.

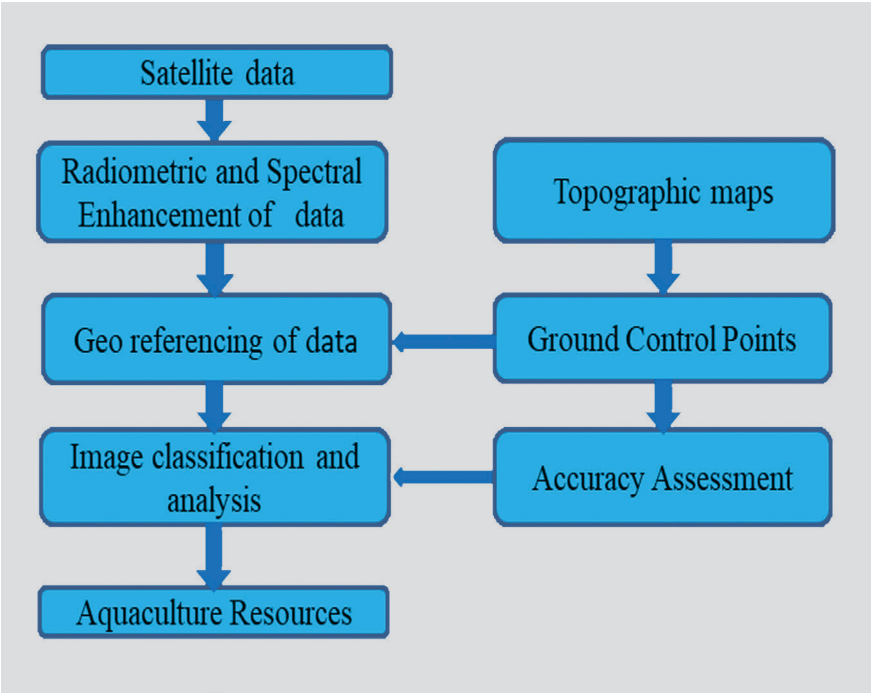

Fig. 1.1 Image processing and classification to map aquaculture farms

Spatial and spectral image transformation

Spatial tools enhance the image to make it clear without the noise, atmospheric attenuation, and salt pepper effect. The tools are specially tailored to work with multispectral images. Pan sharpen tool can increase the resolution of a color image using the high-resolution Panchromatic image. For example layer stacking enhances spectral images by stacking multiple single band images as bands/layers into a single output multi-band image file.

Mosaic and subset tools

Mosaic tools combine the multiple images into single, color balanced combined imagery where subset helps to extract the smaller area from a larger area based on the area of interest. The planning of the district or state or county level requires multiple numbers of images, to be combined to get the image for the region of interest.

Image rectification

Rectification transforms the data from one grid system into another grid system using a geometric transformation and associates the data with the location on earth with reference coordinate systems such as geographic coordinates (Lat/Lon) or Universal Transverse Mercator. Orthorectification corrects the terrain displacement of elevation data. A transformation matrix calculates the root mean square error (RMSE) to assess how accurately the source ground control points (GCP) are placed on the rectified image. For all images, the RMSE of the geometric correction to be below 0.25 pixel, thus facilitating accurate land-cover change detection.

Georeferencing provides simple linear corrections as well as image to image registration or image to map rectification using ground control points (Fig. 1.2), a location within an image for which the map coordinates are known. In aquaculture planning, the satellite data needs to take inputs from the topographical maps to delineate the reserve forest boundary or ecologically important ecosystems to make it as a restricted boundary for aquaculture development.

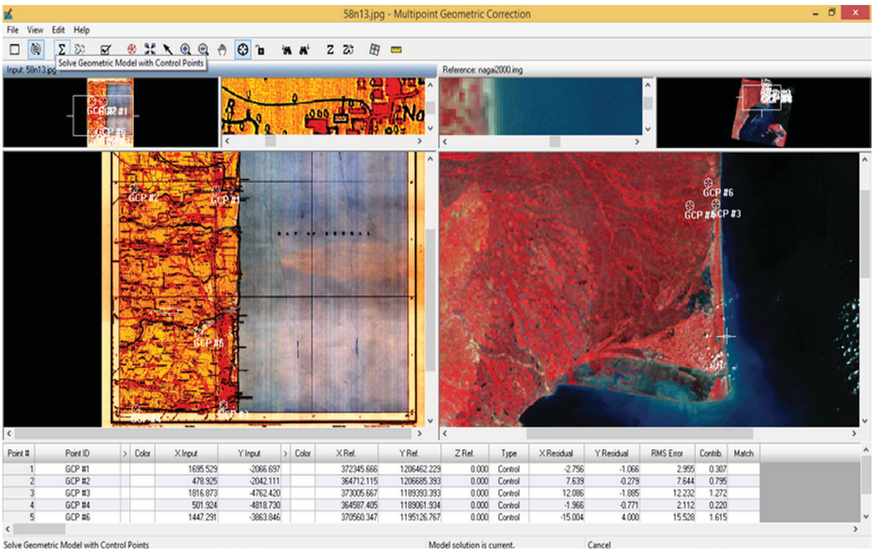

Fig. 1.2 Georeferencing of satellite image with topographic maps to delineate the boundaries of the ecologically important area

Image classification

Coastal areas have different types of water resources such as shallow water bodies, creeks, estuary, aquaculture ponds, tanks and salt pan. Supervised classification can be used with high-resolution data in aquaculture planning as it applies user inputs to derive the rules for mapping. Aquaculture ponds are square or rectangular sized water enclosed structures near estuary or creeks. But the traditional aquaculture farms will be in the regular or irregular shape of varying size. On-screen visual interpretation followed by ground truth verification will give better results in aquaculture mapping with low-resolution data compared to automated processes. Researchers have also used NDVI differential imaging tool to delineate aquaculture.

Accuracy assessment

The satellite data after classification has to be checked for the accuracy to assess how precisely the location in the map indicates the field scenario. Generally, the error matrix is used for the assessment, consists of the number of sample units assigned to a particular category relative to the actual class as confirmed on the ground. The reference data and land use map must register the same classifications at the same level of detail.

Errors of omission and errors of commission represented by users accuracy and producers accuracy denote how accurately the image was classified. The overall accuracy of 85% or above can be accepted in the mapping of land use land cover (Campbell and Wynne, 2011). Global Positioning System (GPS) identifies the position on the earth by using the satellites in space. The coordinates measured at each feature class is used for the accuracy assessment.

Spatial modeling

The change detection using multiple images, the future projection for the period based on the previous two temporal images can be performed using IDRISI Selva STCHOICE land change modeler to assess the trend of aquaculture development.

GIS for decision making in aquaculture

GIS has spatial analytical tool for a range of investigative purposes allowing various spatial aspects to be integrated to arrive a decision. We aim to use GIS to plan for increasing aquaculture production with sustainability regarding

1. Social acceptability to meet food demand, nutrition requirement, the health of society.
2. Environmental sustainability to maintain optimum resource use pattern, preserve soil and water quality, sharing resources without multiuser conflicts.
3. Economical viability to identify the new areas for development and also to optimize the productivity.

Many GIS platforms are available for different type of applications. The commercial and open source GIS software's available are listed with its main functions, collected from "Gisgeography" available online.

Commercial GIS software's

GIS functions can be executed in raster and vector formats based on the user prerequisite and query. Each GIS package has its benefits and restrictions. ArcGIS is a leader in the country followed by Geomedia and map info among the commercial GIS.

- ArcGIS from ESRI is the market leader in commercial GIS software since the 1970s and is the most innovative, cutting-edge GIS software in the industry. Arc Map has a standard mapping with data-driven pages to save time and cost. The extensions Such as Network analyst, spatial analyst, Arc publishing, model builder, with broad interoperability and flexibility makes this as the choice of every organization if funding is available.

- Geomedia is a competitor for ArcGIS for many decades, provides advanced data management, visualization, analysis, and cartographic tools. With three-dimensional display models, it is capable of cadastral data management with completeness and robust commands.

- MapInfo Professional has a clear focus on location intelligence optimal positions for business outlets, uncover geographic patterns and improve insurance risk with GIS.

- Manifold GIS is a combination of mapping, CAD, DBMS and image processing with a wide range of functions and limited cartography options.

- Global Mapper is flexible enough to satisfy both the beginner and advanced GIS user. It is more helpful for working with elevation data, 3D rendering, watershed delineation, and LiDAR handling.

- Smallworld GIS can manage, design and plan network infrastructure with the capability to capture and visualize complex spatial networks. It provides the foundation to manage the lifecycle of network assets.

- Bentley Map is 2D and 3D Desktop GIS, that provide a foundation for top-notch visualization in shadow studies, 3D intersects and clash detection. It include advanced 2D and 3D design productivity innovations from basic mapping to tracking infrastructure lifecycle and optimal choice for organizations massive on the CAD end.

- MapViewer and Surfer is powerful contouring, gridding and surface making package, able to create some unique maps in XYZ directions with delivery options including wireframe, 3D surface maps, and vector-scale maps.

- AutoCAD Map 3D bridges the gap between CAD and GIS, can act as interface to manage spatial data and underlying asset information with the cartographic output.

- TatukGIS features include scripting/customization, 3D mapping, advanced data editing, topology, and error-checking tools. On-the-fly projections with the support of over 900 datums and database engine for a wide-open choice enterprise-level data storage.

- MicroImages (TNTgis)-TNTmips, TNTedit, TNTview, and TNTscript, TNTview can be used for map design and thematic cartography. TNTedit has all features from TNTview and additional data editing features for georeferencing. TNTmip has LiDAR support, terrain analysis, web map publishing and a load more of useful GIS tool software. TNTscript Process GIS data locally or through cloud computing resources.

- MapMaker Pro can display spatial data on a map and has capabilities to manipulate 3D, GPS, vector and raster data with limited options.

- ZZZXMap can create forms to collect data in the field easily and has tools to import, organize, query and edit data for small-scale GIS operations and very compatible with ESRI software.

Open source GIS

Free GIS software serves as weapons for GIS analysis without investment for software and performs to an extent on comparison with commercial software applications.

- QGIS, Formerly Quantum GIS is the most popular free GIS software package for Automated map production, processing geospatial data, and generating cartographic figures.

- gVSIG outperforms QGIS for 3D visualization with effective GI AD tools with limited capabilities.

- Whitebox GATGIS and remote sensing software package, replaced Terrain Analysis System (TAS) and suitable for hydrology theme.

- SAGA GIS delivers a fast-growing set of geoscientific methods in terrain analysis and most suitable for environmental modeling.

- GRASS GIS can be used for land management and environmental planning with options for analysis, image processing, digital terrain manipulation, and statistics.

- MapWindow is suitable for planners, biologists, water managers and geospatial users with auDEM for automatic watershed delineation.

- ILWIS is suitable for basic applications digitizing, editing, displaying geographic data, and also used for remote sensing image classification, enhancements, and spectral band manipulation.

Other open source GIS domains GeoDa, uDig, OpenJump, and OrbisGIS helps the user with initial, limited spatial analysis. Biologists use diva GIS for environmental modeling and extraction of climate data.

Features of data

For the GIS applications, the data should have five aspects to indicate such as theme, scale, period, geographic representation and quantity. Our aim is to devise the mechanism for climate resilient aquaculture using RS and GIS as a model case study for a particular district in India.

- Subject/theme - To the development of coastal aquaculture theme, salinity, land use, water quality, transport and water availability may play as input themes.
- Scale - GIS can be applied at geographic extent for the local, district, state, country and global level and capable of handling a large volume of complex data. It varies with the objectives of the study, whereas potential site identification of aquaculture at the national level requires low-resolution data compared to high-resolution data requirement of impact assessment studies.
- Temporal - It is essential to know the period or age of data. Monitoring aquaculture development requires a regular assessment to quantify the conversion of resources to aquaculture. Importance of age in the evaluation varies with the objectives of the study.
- Spatial - It indicates the location of the object on the earth. GIS data have geographic coordinates to show the spatial representation in the form of point, line, and polygon.
- Quantity specifies the measure or amount for a theme.

For example, mapping of aquaculture by RS and GIS uses all the above five facet of data: Aquaculture development (theme) in the coastal states (scale) of India (spatial) in the year 2016 (temporal) was 2 lakh ha (quantity).

Capabilities of GIS

The capabilities of GIS to derive real-time locations based on the satellite data has greatly aided spatial accuracy, in most spatial cases replaced the use of conventional surveying techniques. Globally, GIS has been broadly used for the planning and management of coastal aquaculture. The capability to perform many functions such as spatial data collection, storage, interpolation, analysis, and geographical projection, differentiates GIS from other information systems. GIS, as an analysis tool, distinguishes relative location by giving the spatial relationships among all map elements. GIS is regularly used for identifying new sites, assessing the impact of past development and monitoring the growth of aquaculture. Every GIS software has got its functional capacity to perform the range of functions to support the different decision-making process. Here we narrate the overview of tasks that apply to aquaculture planning and management.

Data preprocessing

Each GIS package provides the tool to do the transformation or conversion from one format to other. Generally, creating a spatial reference, conversion of the coordinate system, defining projection, subset the data to an area of interest, applying same projection, can make the data suitable for GIS analysis. All data need to be in a similar format with corresponding projections to carry out the spatial analysis. The data can be of geographic or projected nature whereas geographic denotes the data with angular degrees and projected coordinates are expressed for linear measurements. The planning and management of

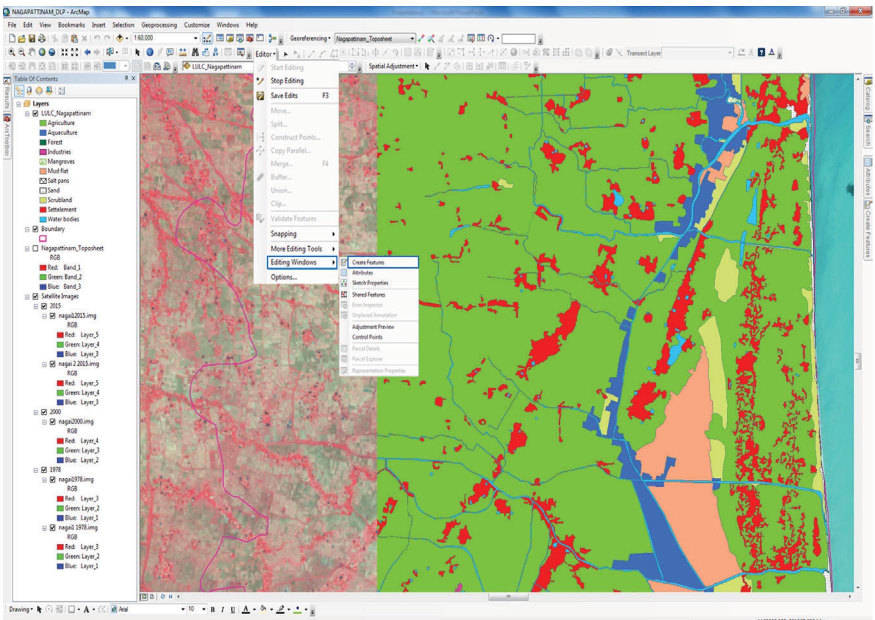

Fig. 1.3. Onscreen digitization and interpretation of land categories from satellite data

aquaculture farms mostly make use of geographic coordinates or Universal Transverse Mercator (UTM) projection with World Geodetic System (WGS 84) datum.

Data input

GIS data can be collected using a variety of primary and secondary data collection methods. Once the image has been assigned coordinates, GIS can indicate the location of the image that belongs to. Image can be used for either identifying any particular features or as a background image (Fig. 1.3). If the data resolution is low, automated processes may not be accurate. Hence on-screen digitizing directly on the computer monitor for the identification and classification of features will give better outputs.

Some primary data derived from the ground (e.g., water quality in the aquaculture farms or source water bodies) typically requires physical entry to transform to a digital format. Variety of GIS editing procedures to correct the errors occurred at the time of digitizing are available. In aquaculture applications, shapefile format is mostly used to indicate the geometry of the feature, containing vector coordinates and its attributes.

Spatial analysis

GIS techniques such as extract, overlay, convert, weighted overlay, proximity, interpolation are commonly used in aquaculture. Extract tools help to get the required data for the particular domain by the clip, select, split functions. Overlay tools are capable of merging two feature class information to derive the answers to query using intersect, union, identify and spatial join functions, that can be used for site selection or impact assessment studies of aquaculture. Environmental regulation in India restricts any commercial aquaculture

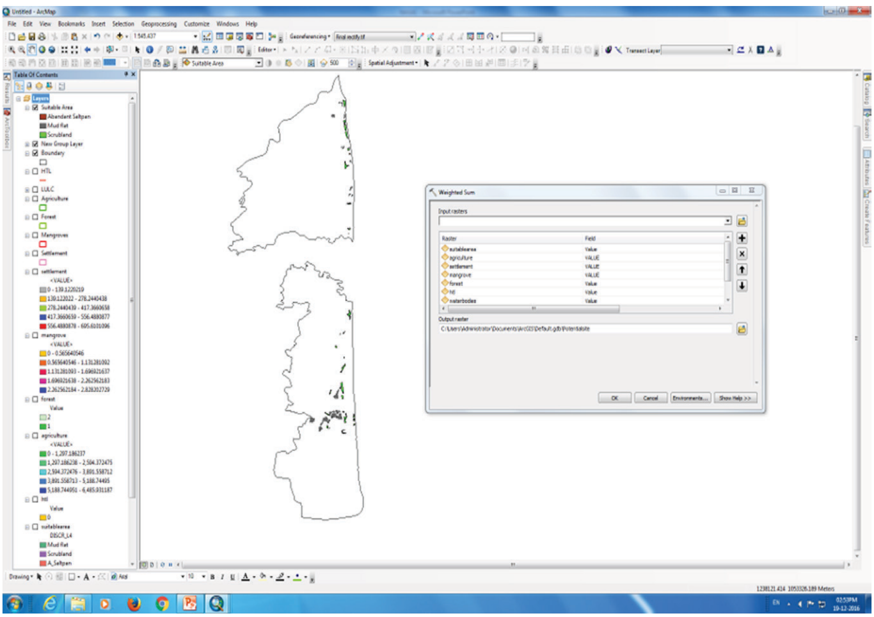

Fig. 1.4. Spatial analysis in Arc Map for aquaculture site selection

development for a distance of 50 - 100 m from ecologically essential areas such as mangroves, agricultural lands.

Weighted overlay analysis is used in locating optimum sites for aquaculture by combining multiple criteria weights and rank the sites. The criteria used in aquaculture site selection (Fig. 1.4) are land use, distance from a water source, soil texture, proximity to drainage and transport.

Proximity tools allow to draw buffer for environmental protection in planning for aquaculture or to assess the distance from the point of importance to other point or polygon neighbor.

Conversion tools are capable of converting the coverage to shapefile, a geodatabase, raster and also metadata. Data management tools allow raster reclassification and conversion from feature class, raster, terrain, TIN and from the file.

Interpolation tools are to assess values from known locations to other locations. Commonly used Interpolation methods are Kriging, spline and natural neighbor.

Interpolation is used to extent the resource characteristics from the known values to other areas. (Fig. 1.5). The “local” interpolation method uses only a local sample of the available known points to complete the estimation. Here, we have used the interpolation tools for soil and water characteristics and climate change variablities.

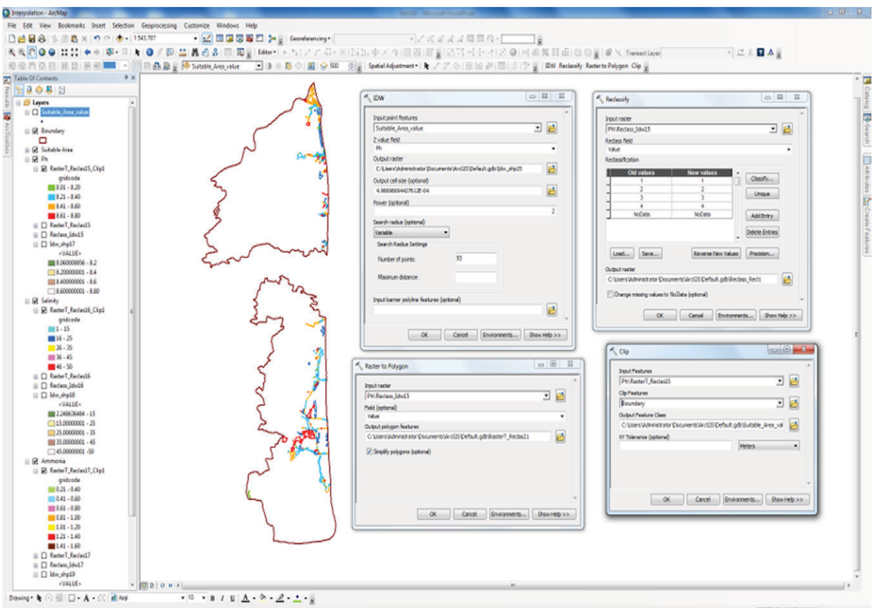

Fig. 1.5. Interpolation tools used in aquaculture planning

Applications of RS and GIS in aquaculture

The available coastal resources form the basis for the development of aquaculture in the country, but most of the developing nations including India do not have enough database on its resources. The coastal area faces challenges and a wide range of problems due to population pressure, environmental degradation, urbanization, and industrial development. In developing countries, policy makers and planners seldom incorporate current and accurate information based on scientific tools. Aquaculture demands production space, available in very restricted supply. RS and GIS are indispensable tools in resource assessment due to its far-ranging functions and analytical capabilities of handling large spatial data, analytical and mapping skills. The best mechanism for coastal resources use is to assess the resources available in the country and then derive the plan considering the other resource users and the sustainability of the ecosystems.

Site selection and zoning

The problems faced by the shrimp aquaculture industry in India in the recent past could have been evaded if planning and site selection were appropriately made. Aquaculture planning depends on the availability of land and water resources, through an understanding of the environment, resource use pattern, and nearby resources. Site selection for aquaculture farms is an essential management measure, that can mitigate adverse effects if any. The site selection needs multiple criteria such as land availability, nearby ecosystems, water availability, suitable soil texture, adequate water quality, and other infrastructure availability and its proximity. GIS can handle and spatially relate the multifaceted data to derive the decision for aquaculture site selection (Fig. 1.6) and rank the sites based on the site suitability index.

Estimation and monitoring

RS and GIS help to get accurate, and quantifiable information about the coastal resources on a repetitive basis (Fig. 1.7), assist in monitoring the aquaculture development without multi-users conflict. The characteristic absorption feature of water bodies can be utilized for their detection. It helps to plan for expansion or restriction based on the nearby resources, quality and carrying capacity of source waterbodies.

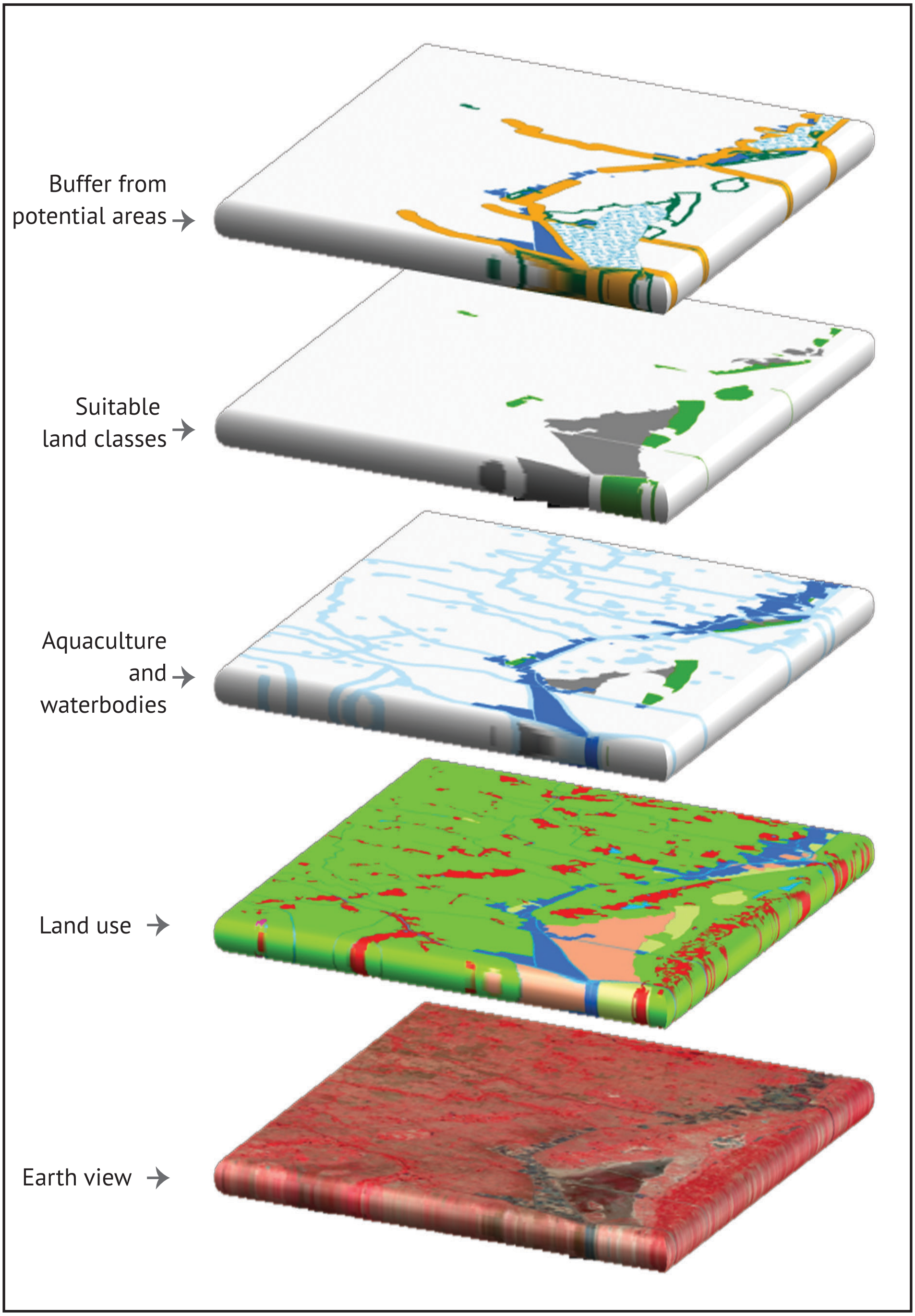

Fig. 1.6 Spatial planning for aquaculture

Fig. 1.7 Aquaculture farms view from high resolution data

Spatial spread of shrimp farms, the extent of existing farms, past and present scenario of adjoining resources, can be derived from the satellite data.

Environment impact assessment

Major environmental issues have been raised over the aquaculture development, such as the conversion of mangroves and agricultural lands to aquaculture farms. The loss of mangrove forest area due to shrimp farming has been widely recognized as a main environmental issue. It is believed that this deforestation is still taking place in different forms, even though the importance of mangroves is known. Salinization of agricultural lands, drinking water resources have also been raised due to unregulated expansion. These issues are the major threats for the future development of the aquaculture in most of the shrimp growing nations. RS together with GIS can be a platform to assess the impact of aquaculture with multi-temporal data analysis to evaluate the periodical, quantifiable changes on the coastal environment due to aquaculture.

Quantification of abandoned shrimp farms

Disease problems, environmental issues and Government regulations made the vast areas of shrimp farms unused after short-term use. The shrimp ponds in disuse pose major danger to the sustainability of coastal resource use. The scenario of abandoned shrimp farms in Southeast Asian countries has reached an alarming trend. RS coupled with GIS can provide detailed information on abandoned farms with its past land use and the future direction to devise the reuse plan with specified time.

Assessment of climate change vulnerability

The changing climate variabilities such as an increase in extreme events, heavy rain in shorter duration can damage the farm facilities and shrimp culture. Also, the projected growth in sea level rise expected to bring more areas under water. The elevation of region above mean sea level, high intensity rainfall zones, frequency and intensity of floods, water flow in source water bodies, monsoon pattern, changing water salinity during rainfall, topography of the site, geomorphology, slope, shoreline changes and wave height are some of the factors need to be involved in the site selection. GIS can help to spatially integrate and interpolate the data to assess the calculation of changes and identify the vulnerable coastal area, which demands the special resilient management measures for the successful aquaculture.

Addressing aquaculture planning in the Indian context

Optimum site selection requires answers to the query about the proposed site before planning for aquaculture that can be answered through RS and GIS along with field investigation.

1. What is the distance between the site and the high tide line of the sea?
2. What was the earlier land use in the identified site?
3. What is the distance from the source water bodies?
4. How much area of aquaculture farms are supported by the source water body nearer to the site?
5. What is the network of drainage from existing farms and also site?
6. How near is the site to critical ecosystems such as Mangroves and Reserve forest?
7. What type of soil texture and electrical conductivity present in the site? And how suitable is it for aquaculture?
8. Whether the site is accessible to the transport network and what type of system exist?
9. What is the topography of the site?
10. How far is the site elevated above mean sea level?
11. What is the frequency of floods in the locality?
12. What are the characteristics of source water bodies?
13. How far is it from human habitations and existing freshwater aquifers?
14. What is the tidal inundation and drainage over each tidal cycle?
15. What is the freshwater flow during an annual cycle?

2

Status and Legal Framework of Aquaculture –Indian Context

The Indian coastal zone is governed by several official legislations that regulates developmental activities including construction, industrial activity, and coastal infrastructure. Some of these legislations have an explicit mandate to protect the coastal ecology and natural resources of the region. One such protective legislation is the CRZ Notification that was promulgated in 1991 and then in 2011, using the provisions of the Environment (Protection) Act, 1986 and the Environment (Protection) Rules, 1986. Through such a notification, the coastline of the country was identified as an ecologically sensitive area, where development activities were regulated.

Status of aquaculture resources use

Shrimp aquaculture started a century ago as the traditional practice, undergone a metamorphosis in the past three decades, and has scaled great heights and consequently attained the status of the fastest food producing sector. Modern scientific aquaculture is a relatively new initiative since the late 1980s in India, and has grown tremendously and contributes 6.3% of global fish production of 66.6 million tons (FAO, 2016) by making use of around 2 lakh ha of land resources.

India by its long coast length of 8118 km, supports a wide diversity of inland and coastal wetland habitats. It has been estimated that 3.9 million ha estuaries and 3.5 million ha of brackishwater areas present in the country. Out of this, 1.2 million ha of coastal area has been stated as suitable before the enactment of CAA guidelines. Out of 1.2 million ha, 21.37% and 8.02% of area has been utilized in Eastcoast and Westcoast respectively (Table 2.1) indicating the immense potential remaining for further development (MPEDA, 2016).

Table 2.1 Status of coastal resources availability and its utilization

State	Coastal length (km)	Continental shelf (Sq.km)	Potential (ha)	Developed (ha)	Extent used (%)	Available potential (%)
Tamil Nadu and Pondicherry	1121	41412	56,800	8263	14.5	85.5
Andhra Pradesh	974	275068	1,50,000	42462	28.3	71.6
West Bengal	158	17000	4,05,000	58285	13.3	86.7
Orissa	480	26000	31,600	10778	29.4	70.6
East Coast	**2733**	**359480**	**6,43,400**	**1,19,788**	**21.37**	**82.3**
Kerala	590	40000	65,000	12622	19.4	80.6
Karnataka	300	27000	8000	2281	17.7	82.3
Goa	104		18,500	10	0	99.9
Maharashtra	720	110000	80,000	1413	1.8	98.2
Gujarat	1600	184000	3,76,000	4552	1.2	98.3
West Coast	**3314**	**361000**	**5,47,500**	**20,878**	**8.02**	**96.4**

Aquaculture systems in India

Shrimps are generally cultured in land-based earthen ponds where suitable water and soil environment exists. The farming operations are many types, like intensive, semi-intensive and extensive by stocking density, location, and environment, species under culture and inputs involved.

Fig. 2.1 Traditional aquaculture farm

Traditional system is low input system (Fig. 2.1) characterized by low stocking densities, with little or no external nutritional inputs, tidal water exchange, with shrimp yield less than 500 kg/ha. Improved traditional/extensive system is tide-fed traditional system of culture where selective stocking and feeding with local feed is done to increase the production and productivity. Stocking density varied from 40,000 to 60,000 numbers/ha, fed with high protein diets. The productivity is less than 1 t/ha.

Under semi-intensive culture, stocking density increased up to 2-3 lakhs/ha. Aerators are used to maintain dissolved oxygen. Shrimps are fed with high protein diets with strict feed management. Improved health management practices and water quality monitoring are followed. The production ranged from 1-1.5 t/ha. Licensing is needed from coastal aquaculture authority of India to carry out the shrimp culture.

Super-intensive/intensive culture is done under fully controlled conditions with high stocking densities. *Penaeus vannamei* culture is carried out with strict regulations, with the permitted stocking density of 60/m^2 (Fig. 2.2). Continuous aeration is provided to maintain the dissolved oxygen level of more than 5 mg/l in the water. The productivity ranges from 8 to10 t/ha.

Fig 2.2. Intensive aquaculture farm

Shrimp farming in India

Brackishwater aquaculture in the country is almost synonymous with Penaeid shrimp namely *Penaeus monodon* (Fig. 2.3) initially and then *P. vannamei* (Fig. 2.4) since 2009 after its introduction in the country. Early nineties witnessed a phenomenal growth of the sector which was entirely dependent on the tiger shrimp, *P. monodon*. During this period, the shrimp culture was a low-risk, high-profit venture. There were serious problems of viral diseases particularly white spot syndrome virus (WSSV) and environmental safety issues in late 90s, because of the lack of planning and regulation, has made *P. monodon* culture as a high-risk, low-profit venture. The area under shrimp culture has been more or less stagnant during 1997 to 2007 at around 140,000 to 150,000 ha due to WSSV disease outbreak (Fig. 2.5).

In 2008-2009, the culture area has drastically reduced to about 100,000 ha which is equivalent to the pre-1995 level. After a thorough analysis of pros and cons at various levels the *P. vannamei* has been permitted for culture by Government of India after the risk assessment study carried out by CIBA to cope up with poor performance, slow growth rate and disease susceptibility of the major indigenous cultured shrimp species *P. monodon*. Introduction of *P. vannamei* in 2009, led to the recovery of the sector with the production levels reaching 497622 MT in 2018.

Fig 2.3. Black tiger shrimp *P. monodon*

Fig 2.4. White shrimp *P. vannamei*

However, as of now, out of 1.2 million ha of the potential area available for aquaculture, 15% is only utilized and the remaining vast land is still available. In spite of the limited utilization of resources, it has confronted many problems such as environmental issues, quality input, lack of facilities, lack of schemes and sector competition. The aquaculture planning without affecting other coastal resources users, coping up with changing climate is very much needed in the present context.

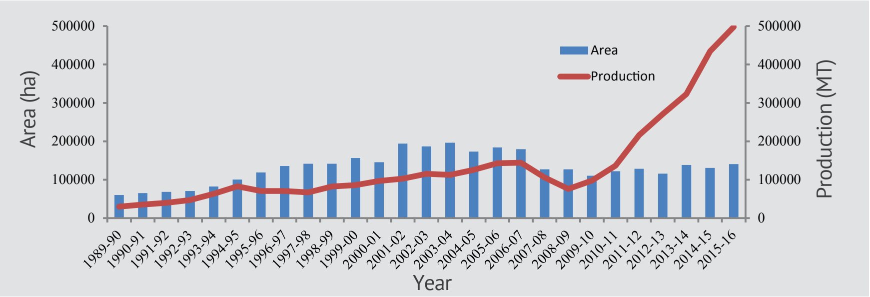

Fig. 2.5 Area and production of shrimp aquaculture in India

Review of legislation and Coastal Regulation Zone (CRZ)

At the central level, several fundamental laws and regulations may be relevant to coastal areas relating fisheries. They include the century-old Indian Fisheries Act (1897) which penalizes the killing of fish by poisoning water and using explosives; the Environment (Protection) Act (1986), an umbrella act containing provisions for all environment related issues. They also include the Water (Prevention and Control of Pollution) Act (1974) and the Wild Life Protection Act (1972). All these legislations must be read in conjunction with one another to gain a full picture of the rules that apply to aquaculture. The state governments also enacted laws for the regulation of fishing in their respective territorial waters. However, there were no comprehensive policy guidelines to promote or regulate the coastal and brackishwater aquaculture at Central or State level, till the enactment of CAA Act.

Classification of areas based on CRZ 2011 notification

The need for a comprehensive review of the information to ensure that the management of the coastal resources is based on sound scientific principles has remained pending for a considerable period till the introduction of the concept of CRZ. Under the Coastal Regulation Zone (CRZ) Notification, 1991, the Indian coast is classified into four zones namely CRZ I, II, III and IV for the regulation of the activities in the coast. It stipulated uniform regulations for the entire Indian coast line, failed to take in to account the environmental diversity. The same is retained in 2011, and the change is in CRZ IV, particularly inclusion of water area upto territorial waters and the tidal influenced waterbodies.

Category-I (CRZ-I): Covers (i) areas that are ecologically sensitive and important, such as national parks/marine parks, sanctuaries, reserve forests, wildlife habitats, mangroves, corals/coral reefs, areas close to breeding and spawning grounds of fish and other marine life, areas of outstanding natural beauty/historical/heritage areas, areas rich in genetic diversity, areas likely to be inundated due to rise in sea level consequent upon global warming and such other areas as may be declared by the Central Government or the concerned authorities at the State/Union Territory level from time to time (ii) Area between the Low Tide Line (LTL) and the High Tide Line (HTL).

Category-II (CRZ-II): Includes the areas that have already been developed up to or close to the shoreline. For this purpose, "developed area" is referred to an area within the municipal limits or in other legally designated urban areas which is already substantially built up with drainage and approach roads and other infrastructural facilities, such as water supply and sewerage mains.

Category-III (CRZ-III): Includes areas that are relatively undisturbed and those which do not belong to either Category-I or II. Two separate categories were made such as densely populated with a population density of 2161 per sq. km shall have a no development zone of 50 m from HTL; less densely populated regions will have 200 m from HTL.

Category-IV (CRZ-IV): Includes the water area from the Low Tide Line to twelve nautical miles on the seaward side; the water area of the tidal influenced water body from the mouth of the water body at the sea up to the influence of tide which is measured as five parts per thousand during the driest season of the year.

Areas requiring special consideration to protect the critical coastal environment and difficulties faced by local communities: CRZ area falling within municipal limits of Greater Mumbai; the CRZ areas of Kerala including the backwaters and islands; CRZ areas of Goa. Critically Vulnerable Coastal Areas (CVCA) such as Sunderbans region of West Bengal and other ecologically sensitive area identified as under Environment (Protection) Act, 1986 and managed with the involvement of coastal communities including fisherfolk. It includes coastal stretches in the Andaman & Nicobar, Lakshadweep and small islands except those designated as CRZ-I, CRZ-II or CRZ-III.

Under the Coastal Zone Notification Regulation 2011, area up to 50 or 200 m from HTL on the landward side in case of seafront based on population density, and 100 m along tidal influenced water bodies or width of the creek whichever is less is to be earmarked as "No Development Zone (NDZ)." As per CAA act 2005, No new shrimp farms are permitted upto 200 m from HTL.

Regulations in aquaculture

Coastal aquaculture entails managed farming or culture of organisms in saline or brackishwater areas to enhance the aquatic animal production, both for domestic and export markets. Coastal aquaculture in the broader sense includes culturing of crustaceans like shrimp, prawn, lobsters, crabs; finfishes like groupers, sea bream, mullets; and mollusks like clams, mussels, and oysters. Environmental issues raised over the unplanned aquaculture led to litigation at Honorable Supreme Court of India. Based on the judgment delivered, an Authority (the Aquaculture Authority) was formed by Government of India under the Environmental Protection Act to specifically deal with the situation created by the shrimp culture industry in the country.

A rational policy to combine environmental sustainability and economic developments for regulating shrimp farming has been a difficult goal to achieve due to potentially conflicting interests and lack of an integrated vision of coastal phenomena. The first legal initiation specifically taken for regulating shrimp farming in the country was by the state government of Tamil Nadu with the enactment of the Aquaculture Regulation Act in 1995. However, this Act complicated the issues further because of the bureaucracy in (i) issuing licenses, (ii) certification and leasing of land, (iii) permission for the utilization of groundwater, etc.

The Aquaculture Authority has brought out guidelines for the development of aquaculture via Coastal Aquaculture Authority Act 2005. Coastal Aquaculture Authority was instituted as per the Gazette Notification No. 1336 dated 22nd December 2005. It laid down certain conditions, related to the nature and conversion of the land used for shrimp farming, banning intensive and semi-intensive farming systems in ecologically important regions, the requirement of effluent treatment ponds, EIA, etc., for issuing approval (license) for the shrimp farms. The State Governments constituted the committees at State and District level for screening the applications based on the above guidelines for recommendation to the Aquaculture Authority for the issue of license.

Coastal Aquaculture Authority act 2005

The Coastal Aquaculture Authority (CAA) act 2005 regulates coastal aquaculture in the country (CAA, 2014). The following guidelines of CAA, which are mandatory, should be adopted for permitting shrimp farms and site selection and also to avoid subsequent social and environmental impacts in India.

- Under this CAA Act, coastal area for aquaculture includes the land within a distance of two kilometres from the HTL of seas, rivers, creeks, and backwaters.
- The delineating boundaries for coastal aquaculture along rivers, creeks, and backwaters shall be governed by the distance upto which the tidal effects are experienced and where salinity concentration is not less than 5 ppt. In the case of ecologically fragile areas, such as Chilka Lake and Pulicat Lake the distance would be up to 2 km from the boundary of the lakes.
- No license for aquaculture should be granted allowing aquaculture within 200 meters of the high tide line or any area within the coastal regulation zone. However, this is subject to the provision that it does not apply to any aquaculture farm in existence at the time of the establishment of the Aquaculture Authority, and noncommercial and experimental aquaculture farms operated by any research institute of the Government or by the Government.
- Mangroves, agricultural lands, saltpan lands, ecologically sensitive areas like sanctuaries, marine parks, etc., should not be used for shrimp farming.

- Shrimp farms should be located at least 100 m away from any human settlement in a village/hamlet of less than 500 population and beyond 300 m from any village/hamlet of over 500 population. For major towns and heritage areas, it should be around 2 km.
- All shrimp farms should maintain 100 m distance from the nearest drinking water sources.
- The shrimp farms should not be located across natural drainage canals/flood drain.
- While using common property resources like creeks, canals, sea, etc., care should be taken that the farming activity does not interfere with any other traditional activity such as fishing, etc.
- The spacing between adjacent shrimp farms may be location specific. In smaller farms, at least 20 m distance between two adjacent farms should be maintained, particularly for allowing easy public access to the fish landing centers and other common facilities. Depending upon the size of the farms, a maximum of 100-150 m between two farms could be fixed. In case of better soil texture, the buffer zone for the estuarine based farms could be 20-25 m. A gap having a width of 20 m for every 500 m distance in the case of sea-based farms and a gap of 5 m width for every 300 m distance in the case of estuarine based farms could be provided for easy access.
- Larger farms should be set up in clusters with free access provided in between clusters.
- A minimum distance of 50-100 meters shall be maintained between the nearest agricultural land (depending upon the soil condition), canal or any other water discharge/drainage source and the shrimp farm.
- Water spread area of a farm shall not exceed 60 percent of the total area of the land. The rest 40 percent could be used appropriately for other purposes. Plantation could be done wherever possible.
- Areas where already a large number of shrimp farms are located should be avoided. Fresh farms in such areas can be permitted only after studying the carrying/assimilation capacity of the receiving water body.

Shrimp farm registration and renewal

The Coastal Aquaculture Authority Act 2005 has come into practice, which encompasses the farming of shrimp, prawn, fish or any other aquatic life under controlled conditions in ponds, pens enclosures or any other brackishwater bodies (excluding freshwater aquaculture).

All persons carrying out aquaculture in the coastal areas shall register their farm with the CAA for five years with a facility for further renewal. Aquaculture will not be permitted within 200 m from HTL and also in creeks, rivers, and backwaters within the CRZ. However, it is not applicable to the existing farms set up before CAA act 2005. Every application for the registration of a coastal aquaculture farm shall be made to the District Level Committee (DLC).

On receipt of an application, the DLC shall verify the particulars given in the application in respect of all coastal aquaculture farms irrespective of their size; and

(a) In the case of coastal aquaculture farms up to 2.0 ha water spread area, the DLC upon satisfaction of the information furnished therein shall recommend the application directly to the Authority for consideration of registration under intimation to the State Level Committee.

(b) In the case of coastal aquaculture farms above 2.0 ha water spread area, the DLC shall inspect the concerned farm to ensure that the farm meets the norms specified in the guidelines with specific reference to the siting of coastal aquaculture farms and recommend such applications to the State Level Committee, which upon satisfaction shall further recommend the application to the Authority for consideration of registration.

As per the CAA guidelines, integrated coastal zone management plans should be prepared for each coastal State by the States concerned with zoning for different activities. This could at best be only a rolling plan (dynamic) in the initial stages so that improvements can be effected annually or biannually, with improved databases and knowledge on site-specific interactions of aquaculture with other sectors. Detailed master plans for development of aquaculture through macro and micro-level surveys of the potential areas and delineating the areas suitable for aquaculture using the remote sensing data, ground truth verification, Geographical Information System (GIS) and socio-economic aspects should be prepared.

Methodology for Planning Aquaculture

Planning for aquaculture development at district level need resource use pattern, future resource potential, financial requirement and infrastructure availability to utilize the resources sustainably. District level planning will be more efficient for aquaculture as most of the schemes are implemented through the district administration in India, possess desirable heterogeneity. Analysis of data at each district will present a clear picture of the issues, problems, requirements and is sufficient to undertake people in planning and execution. Aquaculture planning depends primarily on available land and water resources and its characteristics. Hence its spatial location and extent need to be documented as prerequisite information. Assessment of existing resources, the present status of development of aquaculture, characteristics of resources, potential area for expansion, issues faced by the resource users, information on changing climate, perceived vulnerability, adaptation measures, and financial outlay will form the basis for any district or state level aquaculture development.

Mapping of aquaculture resources

Aquaculture expansion requires details on site-specific land-use, water quality, the presence of ecologically important areas, wasteland, source water availability, distance from the water source and soil texture. ERDAS Imagine for satellite image processing, Arc GIS for spatial analysis, and Global Positioning System (GPS) for ground truth verification were used in mapping land and water resources. The projection applied was geographic Latitude/Longitude and datum WGS 84. The georeferenced image was enhanced to produce a clear image using different (e.g., spatial, spectral, radiometric) enhancement techniques that are available in ERDAS Imagine.

Different land types were identified from satellite image using visual interpretation keys such as color, tone, texture, pattern, size, shape and its associated features (Table 3.1) developed by Space Application Centre, Ahmedabad (NRSA, 1995). Field surveys were carried out after classifying land resources through satellite data and also to assess the accuracy of interpretation. The latitude and longitude of the different classes were verified with its extent, and doubtful areas were mapped and corrected using ArcGIS through GPS readings. The number of checkpoints and their location for ground-truth were decided based on the visual separability between classes. Data collected from the checkpoints were used for the accuracy assessment.

Table 3.1. Interpretation keys used in mapping land use land cover

Category	Tone	Texture	Patterns
Aquaculture	Dark blue, light blue	Smooth	Square or rectangular shape, Slightly rough pattern, associated with creeks or estuaries
Estuary	Dark blue	Smooth	Continuous, Semi enclosed body. Part of the lower river course that is affected by mixing of seawater with fresh water
Creek/river	Blue	Smooth	Continuous, Intricate network of narrow inlets of sea water in tidal flats
Agriculture land	Bright red	Medium to Smooth	Continuous to Noncontinuous pattern
Scrub land	Yellow to light red	Medium to Smooth	Dispersed, Continuous
Sand/Beach	White/Half white	Fine	Smooth Pattern
Mangrove	Dark red	Medium Coarse	Smooth pattern, Occurs with coastal elements categories such as mud/tidal flats, waterways and beach sand
Salt Pan	Grey/white	Medium Coarse	Square or rectangular shape, Slightly rough pattern, Close to creeks

The onscreen visual interpretation approach has been used for extracting the land use information using image characteristic keys. As aquaculture farms were associated with other creeks and estuaries, to eliminate the classification errors by the supervised classification, manual digitization was found appropriate to delineate aquaculture farms. Aquaculture ponds, agricultural fields, creeks, reserve forest boundaries and fallow lands were manually digitized. The extent and spatial distribution for each dataset was estimated using 'ArcMap' attributes.

Status of aquaculture

Details on total number of shrimp farms in private and government lands, active and non active farms, land leasing schemes, species cultured, subsidies provided by the government, status of licencing applications submitted and cleared, hatchery and feed mill services, processing and storage requirements, and possibility for diversification of species need to be known. Socio economic status of farmers needs to be assessed using field survey, focus group discussion to identify the capabilities for facing climate vulnerability and implement adaptation measures.

Mapping of soil and water resource characteristics

Resource characteristics include water quality in source waterbodies, soil quality in wastelands and shrimp farms. Water quality parameters such as pH, salinity, ammonia, nitrite, nitrate, and phosphate and soil characteristics such as pH, electrical conductivity, organic carbon have been assessed using standard methods. The texture map was derived from the source map of the National Bureau of Soil Survey and Land Use Planning.

Suitable areas for aquaculture expansion

As per the CAA Act, no new farms are permitted within 200 m from the high tide line and such areas were delineated as 'no development zone' in the land use map. Further conversion of mangrove forests, wetlands, salt pans, and agricultural lands are not permitted for aquaculture. It also stipulates specific buffer zones between aquaculture area and agriculture land, drinking water sources and settlements. From land-use maps, these restricted areas were removed, and the potential regions where aquaculture farms could be developed were delineated.

Site suitability index was developed to classify the suitable sites into different categories, and the weightage was assigned to each class. Land use was considered a major important factor followed by the distance from a water source, which assigned the weightage of 45 and 30 respectively. Water availability, soil texture, and infrastructure were assigned the weightage of 15, 5 and 5 respectively. Most suitable land classes were abandoned shrimp farms and wastelands. Mudflats and scrublands were assessed for its suitability based on its distance from water source and availability. Soil texture was incorporated to derive the proper adaption measures. The methodology involves multi-criteria analysis of soil texture, drainage pattern, water salinity, distance from water source and transport network. The sites suitable for the development of brackishwater aquaculture were classified into three groups namely highly suitable, suitable and moderately suitable based on multiple criteria decision support system (MCDSS).

The financial requirement was estimated to expand aquaculture, includes desilting of water bodies, reviving abandoned farms, seed and feed requirement, diversification of species, farm infrastructure development, demonstration of techniques, capacity building, postharvest facilities, cold storage and hatchery development, in a way to make the comprehensive development of brackishwater aquaculture in the district.

Climate variability and its impacts

Coastal aquaculture is extremely vulnerable to climate change extreme event such as the torrential rain, flash flood and cyclone. Vulnerability of shrimp farming to climate change was operationalised as the perceived susceptibility of shrimp farming to climate disturbances and determined by its exposure to perturbations, sensitivity to perturbations, and the capacity to adapt.

Trend of precipitation

Decadal information on the frequency of extreme events, assessment of very heavy rainy days, rainfall variability in the region, the spatial distribution of seasonal rainfall concerning aquaculture farms were evaluated to assess the impact of these changes on shrimp aquaculture. IMD rainfall data sets of 1985-2014 were used for the rainfall analysis. Spatially interpolation was done to locate the vulnerable shrimp farms in flood-prone regions. As per the classifications by IMD, the rainfall events are grouped light (0.1 – 10 mm), moderate (10.1- 35.5mm), slightly heavy (35.6-64.4 mm), Heavy (64.5 -124.4 mm), Very heavy (124.5 -244.4 mm) and exceptionally heavy (more than 244.4 mm).

Total rainfall received at the rainfall stations in the four seasons namely winter (January -February), summer Pre-monsoon - (March-May), South West monsoon (June–September) and Post-monsoon (October – December) were mapped using GIS and interpolated to the whole district. Aquaculture map was overlaid on the rainfall map to assess the location of farms falling in heavy rainfall intensity regions.

Perceived impacts and vulnerability

The vulnerability of aquaculture to climate change (CC) was operationalized as the perceived susceptibility of aquaculture operations to climate disturbances/variabilities and estimated based on its exposure to perturbations, sensitivity and the capacity of the farming community to adapt. A participatory three stage methodology was adopted, which comprised of focus group discussions with key informant farmers, farm survey in 120 aquafarms and the stakeholders workshop consists of policy planners, development departments, meteorologists, researchers, farmers, inputs dealers and marketers. Perceived impacts, risk assessment, adaptations and mitigations climate change risks, who should do what and when were thrashed out and a district level climate resilient plan was evolved.

Exposure was measured as experiencing a particular climate change event or phenomena by the farmer and the frequency of its occurrence. Measured on a five-point rating scale as Certain - (Exposed many times a year = 5); Regular- (Exposed once a year = 4); Likely – (Exposed once in 2 to 3 years = 3); Possible – (Exposed once in 3 to 5 years= 2) and Rare – (Exposed once in 5-10 years = 1). The total exposure score was arrived by adding exposure score of all the events the individual experienced.

Sensitivity as the consequences (positive and negative) of a climate change event or phenomena on aqua farming regarding economic gain/loss was evaluated. The positive impact was assigned a score of 10. Negative impacts were measured on a five-point rating scale as 5 for disastrous (complete loss of livelihood i.e., loss of stock and infrastructure), 4 for extremely negative (more than 50% loss in production), 3 for moderately negative (25 to 50% loss in production), 2 for minor negative (10-25% loss in production), and 1 for little negative (less than 10% loss in production). The total sensitivity score was arrived by adding a sensitivity score of all the events experienced by the individual.

Adaptive capacities and resources available with the farmers to cope with CC impacts are considered to measure the adaptive capacity of individuals. Adaptive capacity indicators are the combined effort of individual, household, community and public/private institutions. Based on extensive literature survey and relevancy, the following 21 indicators such as educational level, occupational status, family size, family earning capacity, family annual income, training attended, social participation, mass media exposure, information seeking behaviour, awareness on better management practices of aquaculture, farm ownership, farm size, farming experience, cropping intensity, farm infrastructure, access to insurance, access to institutional credit, local infrastructure status, access to market, access to institutions during climate extremes and perceived adaptability of the individual were identified in assessment of adaptive capacity. The score of an individual farmer was obtained by adding the scores of all the 21 identified indicators. The data for the indicators except perceived adaptability were collected using suitable measurement procedures.

Perceived adaptability refers to the adaptation measures and their relative usefulness in minimizing the CC impacts. Adaptations refer to planned (with the help of the government) and autonomous (individuals themselves). Planned adaption was operationalized as the extent of provision of adaptive measures by the government and public institutions during the CC events and their perceived usefulness in minimizing the negative consequences. Autonomous adaptations were operationalized as the measures adopted by the individual farmer in response to the CC event and their perceived worth in reducing the negative consequences. Each adaptation measure score was calculated by multiplying its score with salvage value based on a six-point continum as Additional gain = 5 (positive consequence or added advantage), Significant salvage = 4 (100% livelihood protection), Highly salvage = 3 (loss reduction by more than 50%), Medium salvage = 2 (loss reduction by 25 to 50%), Lesser salvage = 1 (loss reduction by 10-25%) and No salvage = 0 (Not at all a salvage measure). Likewise, the planned and autonomous adaptation scores were added to get an individual's adaptation score.

The exposure, sensitivity and adaptive capacity scores were normalized to render it as a dimensionless measure using the formula.

Si normalized = 5 (Si-Si min / Si max- Si min), where Si is the ith indicator value. The vulnerability was calculated using the formula suggested by World Bank (2010) as Vulnerability = 1/3 (Exposure + Sensitivity + (1-Adaptive capacity).

Vulnerability levels were categorized on a scale of 0-5 as very low (0 – 1.0), low (1.1 -2.0), moderate (2.1-3.0), high (3.1- 4.0) and very high (4.1- 5.0).

The vulnerability score was evaluated for the district based on the exposure, sensitivity, adaptations for the climatic variability namely floods, cyclones, heavy rains in shorter duration, an extension of summer or winter, early withdrawal or late onset of monsoon, temperature variations, etc. The vulnerability was extrapolated to the entire district using GIS interpolation techniques to identify the areas requires special attention to cope up with climatic variability.

Issues faced by aquaculture farmers and other resource users

Focus group discussion (FGD) with key informants, field survey, stakeholder meetings were organized to understand and evaluate site-specific issues about the development of aquaculture. The farm extent and licensing details were collected from the Department of Fisheries, Government of Tamil Nadu. Also, other government organizations such as Public Works Department, Department of Agriculture, Central Groundwater Board were consulted to assess the water availability and existing schemes. Based on the information generated, analysis was done to highlight and identify strengths, weaknesses, opportunities, and threats (SWOT).

Socioeconomic status of farmers were assessed, include level of education, occupation, farming experience, family type, annual family income, farm size, farm ownership, cropping intensity, awareness, and exposure to mass media and access to market during climate extremes. Survey was done to collect the information on climate change awareness, better management practices, availability of energy, information seeking behavior, daily mass media contact, training attended and social participation.

Measures for sustainable aquaculture

Adaptation measures were derived based on the issues raised by the resource users in consultation with Tamil Nadu Government officials from Department of Fisheries, Agriculture, Agriculture engineering, Public works department, Irrigation, and water resources department based on the findings of the study and the fund availability.

Model District for Geospatial Planning

Nagapattinam district in Tamil Nadu was selected for the study due to the presence of more number of shrimp farmers and also the region is multi-hazard prone with heavy winds, cyclones, floods being a regular feature. District level planning (DLP) is essential in the extreme climate events prone areas as it needs not only common planning methodology but also requires special attention and initiatives to cope up with increasing frequency and intensity of climate extreme events. An integrated plan need to be made based on the resources availability, human resources and financial capacity for each district, incorporating environmental guidelines covering the sectoral activities and schemes. Each district plan should deal with issues, requirements, resource base, skill availability, infrastructure development, climatic conditions, and socioeconomic status.

There are many ways in which aquaculture can be developed in the coastal districts such as increasing the productivity in the existing farms, utilizing the potential area, and species diversification, disease control, etc. The systematic approach involving natural resources assessment, existing facilities, technologies available, meteorological parameters, the investment required, existing issues, constraints, and training needs to be developed and implemented at the district level to ensure the coordinated planning in aquaculture. The present study was conducted with the objective to establish the detailed district plan for the development of brackishwater aquaculture in Nagapattinam district to increase the aquaculture production and productivity through improved technology, increased area under culture, diversification and finding mitigation measures for the local issues and problems. This will serve as a model study for the development of aquaculture in other districts with sustainability.

Geographic location and extent

The Nagapattinam district of Tamil Nadu lies on the east coast of India between 10.10° and 11.20° North latitude and 79. 15° and 79.50° East longitude with an area of 2585 sq.km and coastline of 187 km. It is bordered by Cuddalore district in the North, Thanjavur district on the West, Tiruvarur district on the South and Bay of Bengal on the East. The topography is plain, and the elevation of the study area above mean sea level has ranged from − 3 to 14 m with an average of 9 m. The Cauvery and its offshoots are the principal rivers. The marine land or coastal land has plain lands except for few sand dunes. The most important feature of the district is the Cauvery River spread over with its numerous branches and presence of extensive lagoons. The Point Calimere wild-life sanctuary in the district is a protected area for conserving black buck, an endangered and endemic species of India.

Administrative management

The district is made up the seven taluks namely Sirkazhi, Tharangambadi, Mayiladuthurai (non-coastal), Nagapattinam, Kilvelur, Thirukkuvalai (non-coastal), and Vedaranyam (Fig 4.1). On the coast between Tharamgambadi and Nagapattinam, lies the small district of Karaikal, an enclave belonging administratively to the Puducherry Union Territory. This is the only district in Tamil Nadu to be formed out of two disjoint regions. The district headquarters Nagapattinam is located in the southern part which is less populated than the northern one. The district has two revenue divisions; 4 Municipalities, 11 Panchayat unions, 8 Town Panchayats, 434 Panchayats, and 2508 habitations.

The total population of the Nagapattinam district has grown from 14.89 lakhs in 2001 to 16.16 lakhs in 2011 with a sex-ratio of 1,025 females for every 1,000 male. The average literacy of the district was 75.04%, compared to the national average of 72.99%. The total fishermen population was 47526.

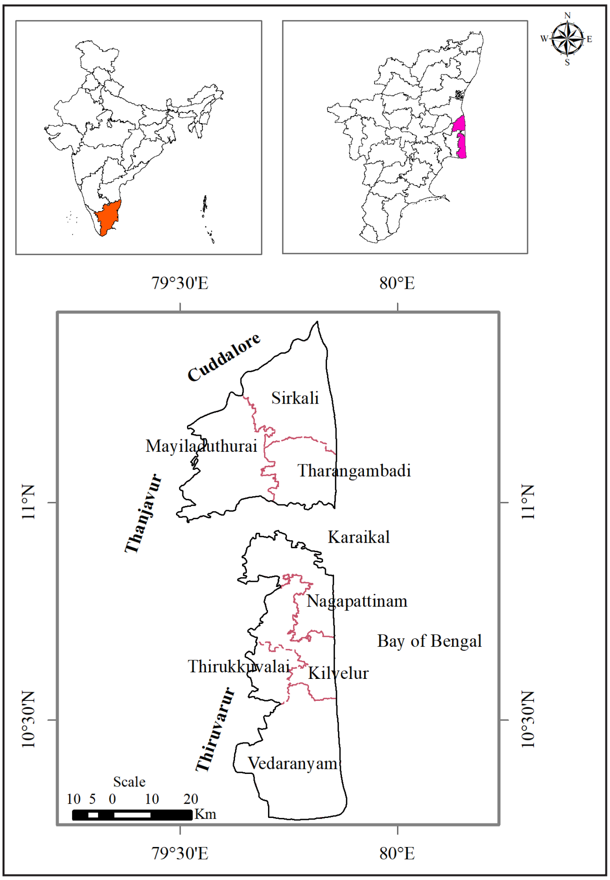

Fig .4.1 Location of Nagapattinam district, Tamil Nadu, India

Climate

The climate is sub-tropical humid, and the district is more prone to extreme events such as floods, cyclone, and Tsunami. The average maximum temperature was about 40.2^{0}C and minimum was about 29.3^{0}C. The hottest months were April and May earlier, and it's extending till July. The coldest months were December and February. The district receives rainfall from Northeast monsoon, which starts during October and blows till January. Cyclonic storm with different wind velocity affects once in 3 or 4 years during the month of November-December. The district receives southwest monsoon (SWM) of about 265.2 mm/year from June to September and northeast monsoon (NEM) of about 908 mm/year from October to December. NEM season was categorized as a period of alert due to extreme climatic events. The Northeast monsoon, which contributes about 60% of the total annual rainfall. The Southwest monsoon accounts equally for the rest of the yearly rainfall. It is classified as a multi-hazard prone district due to heavy winds, cyclones, floods being a regular feature and also worst hit during the last Tsunami in 2004. The wave penetration into the mainland has ranged from 2 to 10 m.

Shrimp farming

Nagapattinam district is the forerunner in shrimp aquaculture production in Tamil Nadu. Prior to the environmental regulations, the potential area available for aquaculture in the district was 6300 ha. The district has 2433 ha estuaries and 20,000 ha brackishwater area. Based on the Government of Tamil Nadu, Department of Fisheries data, 1281 farms are present in the district. The water spread area of the farms was 2105 ha. Of the active farms, 1541 ha was operated with license. The average production of the district was 2 t/ha with *P. monodon* till 2009, increased to 8-10 t/ha after the introduction of *P. vannamei*.

5

Mapping of Aquaculture Resources and Its Status

Land use and water bodies characteristics will play a major role in deciding the success of aquaculture and its sustainability. Efforts were made to assess the status in terms of extent, quality, resource use and potential for expansion.

Mapping of land and water resources

Different land use classes of Nagapattinam district such as agriculture, aquaculture, river, mudflat, reserve forest, abandoned salt pan, sand, scrubland, settlement, wetland, and tank were delineated from Landsat OLI data (Fig.5.1) with a path - 142 and row - 52 & 53 dated 8.6.2015. The topographic maps from Survey of India were used for the delineation of basic features like rivers, reserve forest boundary, railway, and road network, that serves as ground control points in georeferencing the satellite data.

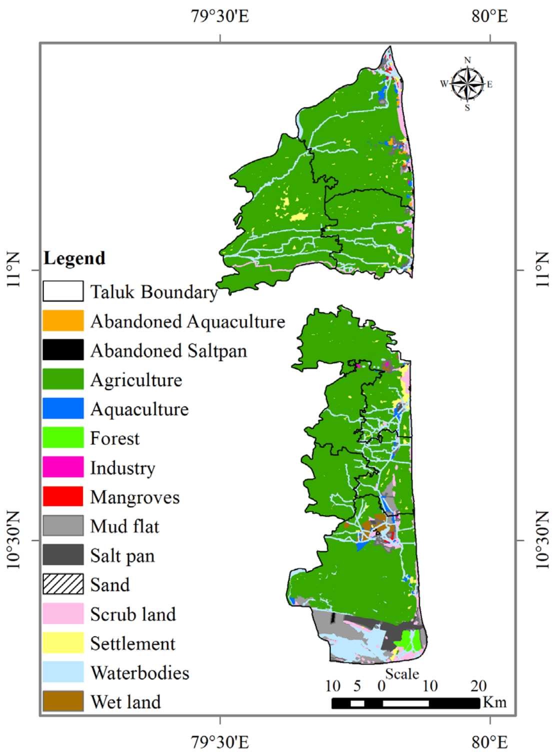

Fig 5.1. Land use Land cover in Nagapattinam district.

Mangroves

Aquaculture farms

Mudflat

Scrubland

Salt pan

Kodiyakarai reserve forest

Fig. 5.2 Resources in Nagapattinam district

The district posers forests of Point Calimere, also known the Vedaranyam forests, one of the last refuges of the dry evergreen forests, and declared as a wildlife sanctuary in 1967 under India's Wildlife Protection Act. The wetland was designated as Ramsar site (No. 1210), that gives the status as a wetland of international importance under Ramsar Convention on 19th August 2002, offers the outline for national and international action for the conservation of wetlands.

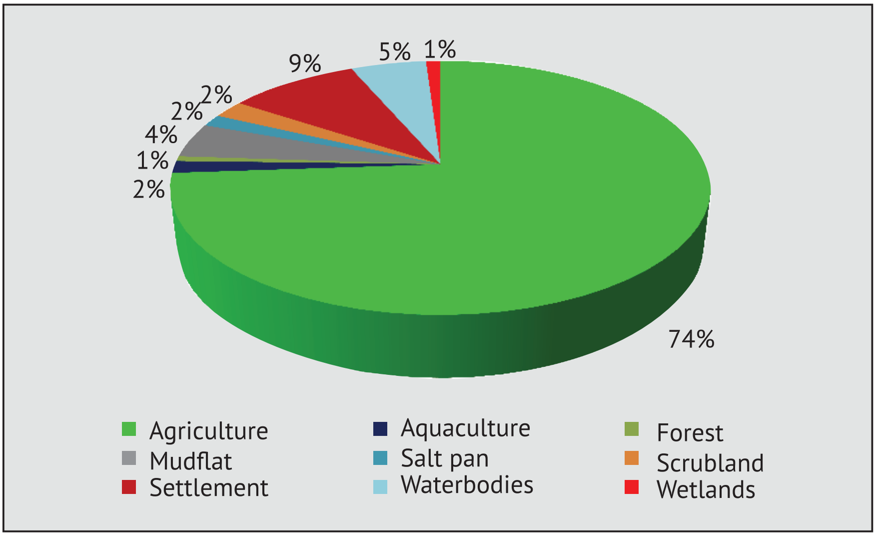

Fig. 5.3. Resource share in the Nagapattinam district

The area under salt pan was 4227 ha, of which 198 ha has been abandoned. Most of the salt pan produced the salt for industrial chemicals, and the production of salt from the salt pan nearer to Maravakkadu forest owned by Government of Tamil Nadu was stopped in 1997, considering the importance of the ecosystem (Fig. 5.2). The location of salt pans along the Kodiyakarai forest necessitates the buffer zone to prevent the influence of salt on the forest plantation. The district has 5778 ha of scrubland which can be used for the developmental purpose.

Agriculture was the major land use (Fig. 5.3) in the district followed by the built-up with an area of 74 % and 9 % respectively. Aquaculture has occupied 1% of the land area. Abandoned saltpans and vast scrubland in the district can be used for developmental and coastal protection measures.

Earlier, aquaculture area is being estimated from the information collected through field-level officers and other agencies related to aquaculture such as feed dealers, technical consultants, etc., but this can represent the information only for the smaller area and not accurate for larger areas. But, with the present development of satellite-era helps to locate or estimate aquaculture farms in larger areas at regular time intervals with its synoptic coverage and repetitive nature. The area developed for aquaculture was 4293 ha in the district of which 393 ha was abandoned.

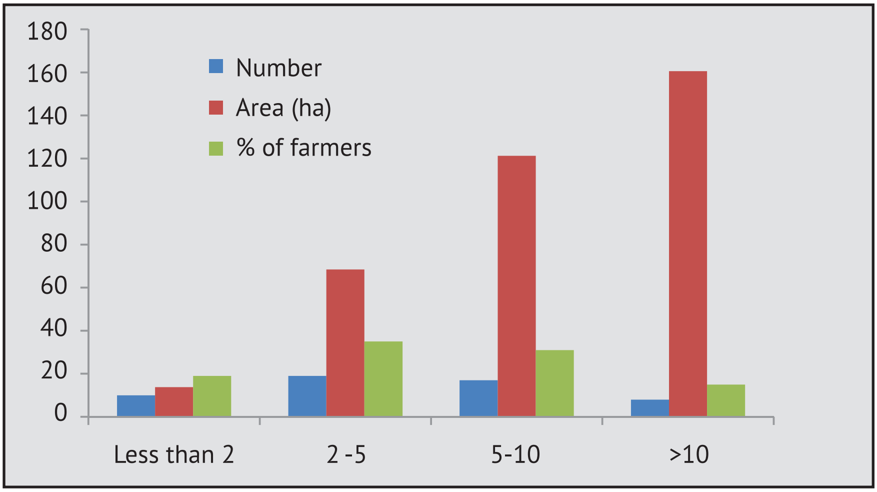

Fig 5.4. Farm holding capacity of *P. vannamei* farms.

As per the Department of Fisheries, Government of Tamil Nadu, a total number of farms was 1281, with water spread area of 2105 ha. There were 107 farms located in Government lands, that occupied 492 ha. Of the 1118 applications received, 824 farms granted a license, 143 rejected and 151 pending with District level committee. Considering the farm holding capacity, the farmers of 19% had less than 2 ha, 35% had 2-5 ha, 31% had 5-10 ha, and 15% had more than 10 ha (Fig. 5.4). The difference in farms mapped from the satellite data and department data revealed the variation, due to farms operations without license. Satellite data showed the exact scenario in the field whereas department data was based on the number of licenses obtained.

Mapping waterbodies association with shrimp farms.

The major water bodies in the coastal areas were mapped to assess the aquaculture farms association with them. (Fig. 5.5). Now *P. vannamei* is cultured at different salinities ranging from freshwater to 50 ppt. The Vedaranyam canal, Vellar River, Harichandra River and Adappar River supports the maximum shrimp farm developed (Table 5.1.)

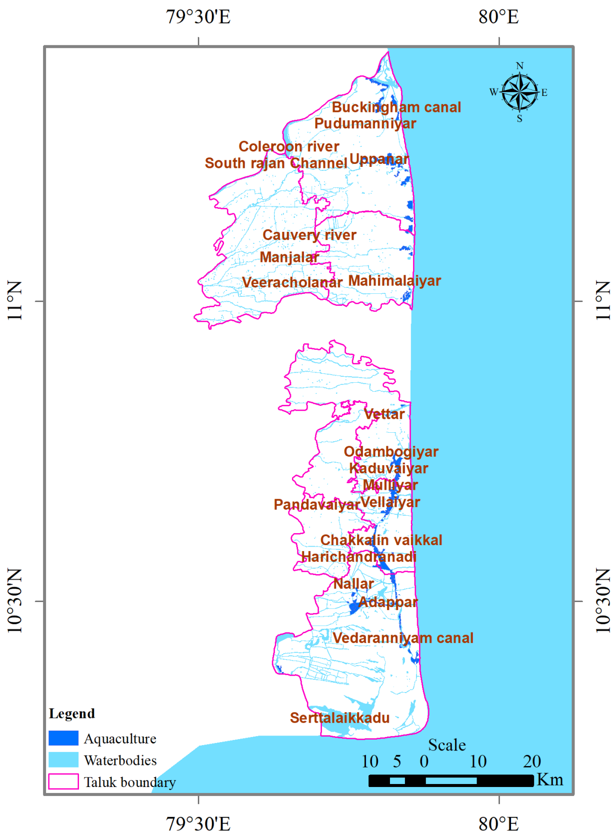

Fig. 5.5 Mapping of source waterbodies and aquaculture farms

T able 5.1. Major waterbodies and associated aquaculture extent

S.No.	Name of the drain / estuary	Aquaculture area (ha) associated with the water body
1.	Mulliyar	140
2.	Adappar	400
3.	Harichandra	250
4.	Vellar	400
5.	Nandalar	290
6.	Vettar	195
7.	Uppanar	50
8.	Vedaranyam	1000

Socioeconomic status of farmers

The socio-economic attributes of the aqua farmers (Table-5.2) were studied to understand their socio-economic status and access to rural institutions at times of extreme climatic events. The shrimp farmers (n=120) from five taluks were randomly selected for the assessment.

Majority of the respondents were educated and had a high school to higher secondary or pre-collegiate level education. Moreover, about one-fourth of the respondents were graduates. The results showed that one-third of the respondents had a middle school level education. This finding is significant that any capacity building material and programme need to be developed in vernacular languages rather than in the English language.

More than half of (60.8 %) respondents had aquaculture as their primary occupation, and their livelihood was totally depended on it. Moreover, around 40% of respondents had other occupations like agriculture or small business which might supplement their income. Similarly, the majority of (71.7%) respondents had a richer farming experience of more than ten years. *P. vannamei* culture is most preferred due to the availability of SPF seed, its tolerance for varying salinity and fast growth rate with a stocking density of $40/m^2$.

Majority of the respondents (69.2%) had own farms which are important that only owners would take up certain adaptation measures rather than the lessees. About 42.5% of farmers had a farm size of 1 to 2 ha. From the findings, it is apparent that private extension service providers like input companies and consultants dominated as technical counselors for the farmers. This finding is also important that capacity building programmes need to be taken up for the respective extension service providers and make use of them as "master trainers" for educating the farmers.

Most of the respondents lived in a nuclear family (95.0%), and family support from siblings and elders may not be available for the respondents in times of climate change extremes. Further, the majority of the respondents had a single source of income which also indicates that at times of extreme impacts due to CC, the respondents need to be supported by the external sources like relief and subsidy from the government while majority (76.7%) respondents had an annual family income of more than Rs.1,21,000 (app 2000 USD).

About 17% of the farmers produced only one crop per year and approximately 83% of the farms cultured two crops. The calendar was February to July for the first crop and August to December was the second crop. With *P. vannamei* culture, some opt to culture throughout the year but winter months can be avoided to prevent WSSV outbreak. Majority of the farms followed biosecurity protocols essential for shrimp production.

Table 5.2. Socio-economic attributes of the aqua farmers

Sl. No	Socio-economic Attributes	(%)	Sl. No	Socio-economic Attributes	(%)
1	Occupation				
	Aquaculture only	60.8	9	Social network	100
	Aquaculture plus others	39.2	10	Farm ownership	
2	Farming Experience			Owned	69.2
	Up to 5 years	6.7		Leased	30.8
	5.1 to 10 years	5.0	11	Farm size in ha	
	Above 10 years	71.7		Less than 1 ha	9.3
3	Education status			1.1 to 2.0 ha	41.5
	Primary level	3.3		2.1 to 3.0 ha	21.7
	Middle school level	32.5		3.1 to 4.0 Ha	10.0
	High school level	26.7		Above 4 ha	17.5
	Higher Secondary	5.0	12	Information Seeking Behaviour	
	Graduation level	15.8		Public funded source	22.5
	Post graduation	20.0		Private source	77.5
4	Family Type		13	Electricity	50.8
	Joint family	5.0	14	Awareness on BMPs	93.7
	Nuclear family	95.0	15	Access to market during extreme CC	5.8
5	Family earning capacity		16	Cropping intensity	
	Single source	96.7		Single crop in a year	16.7
	More than one source	3.3		Two crops in a year	83.3
6	Family Annual Income		17	Access to institutional credit	
	Rs.60000 and less	0.0		Access	0.0
	Rs. 61,000 - 120000	23.3		No Access	100.0
	Rs. 121000 and above	76.7	18	Access to insurance	
7	Social Participation			Access	0
	Member in social institutions	61.67		No Access	83.3
	Office bearer in social institutions	10.0	19	Access to Govt. depts during extreme CC events	
8	Training Attended			Access	23.5
	Training on aquaculture	14.2		No access	77.5

Most of the farmers started with *P. monodon* culture and moved to *P. vannamei*. Shrimp farming (80%) was their primary source of income. The farming size ranged from 0.95 ha to 30 ha with an experience of more than ten years for 60% of farmers. The CAA approved hatcheries located on East Coast Road, Tamil Nadu caters the need of SPF *P. vannamei* seed to the district. Quality of seed is the major concern of the farmers. The seed cost varies from 25 to 35 paise. This district had a Bismi Aqua Hatchery located at Pazhayar.

The FCR feed varied from 1.2 to 1.8 according to the growth, survival, feed type and quality, production system, feeding technique, and water quality conditions. Shrimp farmers used manufactured sinking dry pellets, feed produced by the big aquafeed manufacturers dominate the market. Different brands of feed are available in all shrimp farming areas through local feed dealership. Farmers use branded feed viz. CP, Godrej, Avanti etc, for shrimp farms. Bismi feed from Bismi Aqua Feeds Pvt Ltd with technical guidance from CIBA is functioning in the district with a production capacity of one ton/hour. This feed is performing on par with competitive commercial feed formulations in the farmers' ponds. The processing units are not present in Nagapattinam district and the main buyers are from the export firms of Chennai and Tuticorin.

The majority (61.67%) of respondents had relatively better participation in the social institutions like farmer groups. This finding is also important that the autonomous and planned adaptation measures could be taken up collectively and the social institution like farmer group could be a focal point to deal. The results showed that capacity building programmes for climate change adaptation were not taken up in Nagapattinam district. It is high time that the aqua farmers need to be educated on the potential impacts of climate change on aquaculture and measures for adaptation and mitigation. Capacity development facilitate the sustainability of shrimp farming in India (Kumaran et al., 2017).

Mass media and social network need to be adequately used for creating awareness on climate change related information among the public to prepare them for the change. In the case of farm power, the majority of (51%) respondents had electricity to run their farms. It is an important finding that operating aqua farms with oil engines increase the carbon footprints and hence, provision of power to aquaculture farms is to take upon a priority basis. The majority (93%) of the respondents had better awareness on Better Management Practices (BMP) of aquaculture. Most of the respondents (83%) had two crops in a year.

Most of the respondents felt that they had no access to institutional credit, insurance and development departments in times of extreme climate change events. This is a crucial gap in climate change adaptation and mitigation programme. The coastal aquaculture is synonymous with shrimp farming, and it requires high investment. The value of the stock available in the pond is very high, and any climate change extreme during the cropping cycle would impact badly, and the loss would be unbearable.

6

Mapping of Water and Soil Resource Characteristics

Responsible and sustainable aquaculture production of healthier fish and shrimp depends on the vital key factors of soil and water environment. Maintenance of good soil and water quality is essential for survival, optimum growth and health status of the aquatic animal. The quality of soil and water is essential for the prospect of aquaculture.

Water characteristics in shrimp aquaculture farms

To maintain the water quality, the physical and chemical properties of water should be kept within certain safe levels. The changes in the water quality parameters viz. pH, salinity, dissolved oxygen, nitrite, nitrate, and phosphate were interpolated to assess the spatial changes. The water characteristics with geographic coordinates were used in GIS to interpolate to shrimp farms.

Water pH in shrimp farms

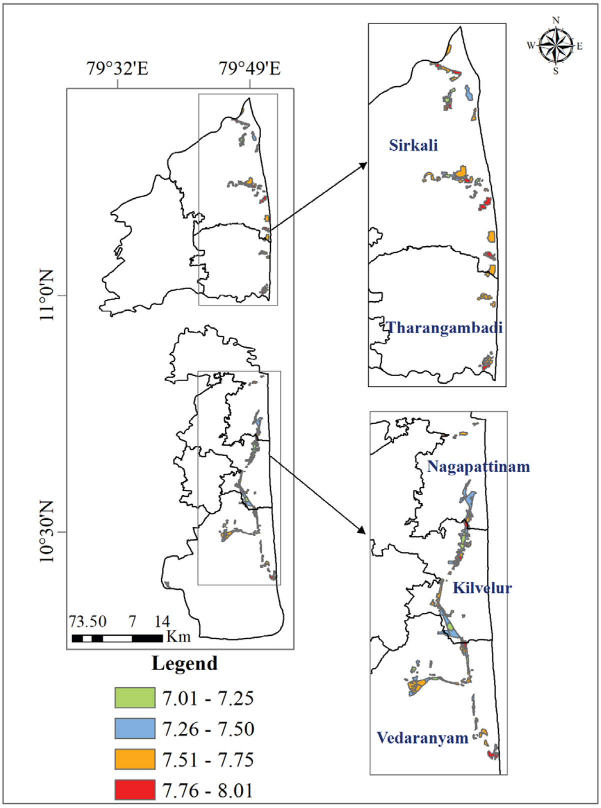

Fig 6.1. Water pH in shrimp farms

The changes in pond water pH have practical significance in the maintenance of the proper nutritional condition of the pond, apart from affecting the physiological function of the organisms cultured. Low pH water will pose serious problems. The shrimp farms water pH ranged from 7.09 to 8.01, which is suitable for aquaculture. For most species, pH of 6.5-9 is optimal. The GIS analysis of pH in the farm pond (Fig. 6.1) indicated that 11 % of farms had 7.01-7.25, 32 % had 7.26 -7.50, 44 % had 7.51 – 7.75 and the remaining 13 % had pH ranged from 8.31 to 8.53.

Water salinity in shrimp farms

The total concentration of all ions in water, referred as salinity, plays an important role in shrimp farming as it is responsible for many functions such as metabolism, growth, osmotic behavior, reproduction, etc.

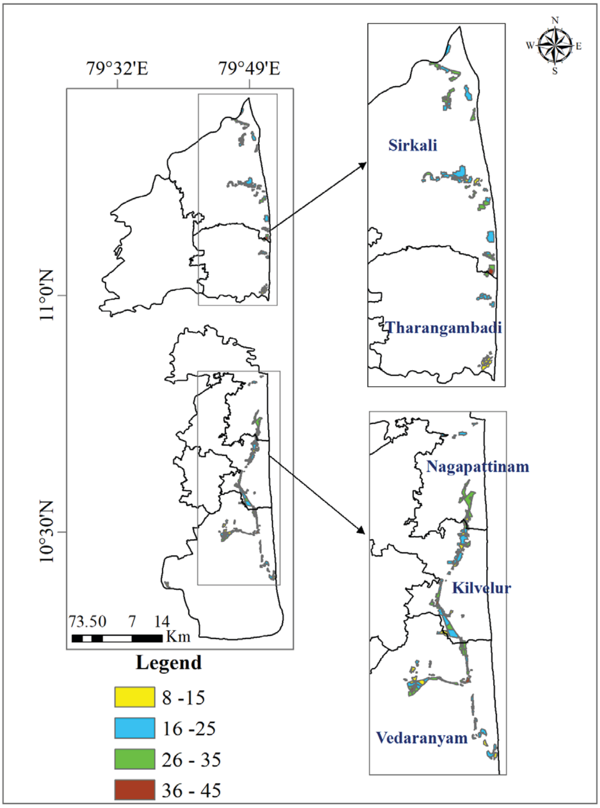

Fig. 6.2 Water salinity in shrimp farms

P. monodon tolerates a wide range of salinity from 5 to 40 ppt. Most species will be growing best at salinities of 15 to 30 ppt. The shrimp farm water salinity varied from 8 to 45 ppt, optimal for shrimp culture. As *P. vannamei* is adaptable to varying salinity, the difference does not have any implication on the growth of animals. Cultured animals tolerate changes in salinity within their tolerance limits if the changes are slow and gradual. But, sudden fluctuations in the salinity associated with the heavy rains result in massive mortality. The GIS analysis of water salinity in the farm pond (Fig. 6.2) indicated that 13 % of farms had 8 -15 ppt, 50 % had 16 – 25 ppt, 34 % had 26 - 35 ppt and the remaining 3 % had a range of 36 -45 ppt.

Ammonia in shrimp farms

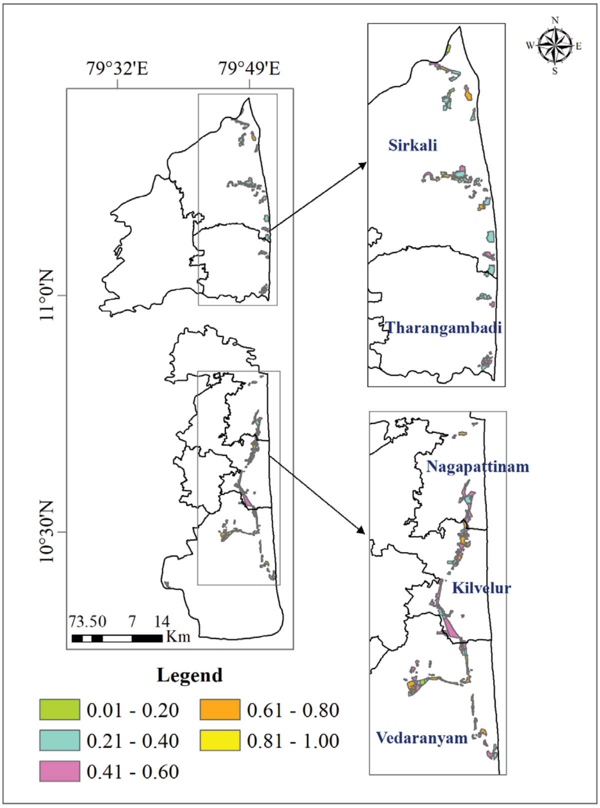

Fig. 6.3 Ammonia level in shrimp farms

Ammonia build up in shrimp culture systems is due to decomposition of microbial organic matter, reduces oxygen concentrations. GIS analysis of ammonia (Fig.6.3) in the farm pond water indicated that 4 % of farms had 0.01- 0.2 ppm, 31 % had 0.21 – 0.40 ppm, 45 % had 0.41 – 0.60 ppm, 20 % had 0.61 – 0.80 ppm and the remaining 1 % of farms had a range of 0.81 – 1 ppm.

Nitrate in shrimp farms

Nitrate is the end product of biological nitrification, and it is an essential nutrient for phytoplankton in seawater. The farm water had the nitrate values 0.0094 to 0. 0597 ppm, which was within optimum for shrimp culture (<0.03ppm).

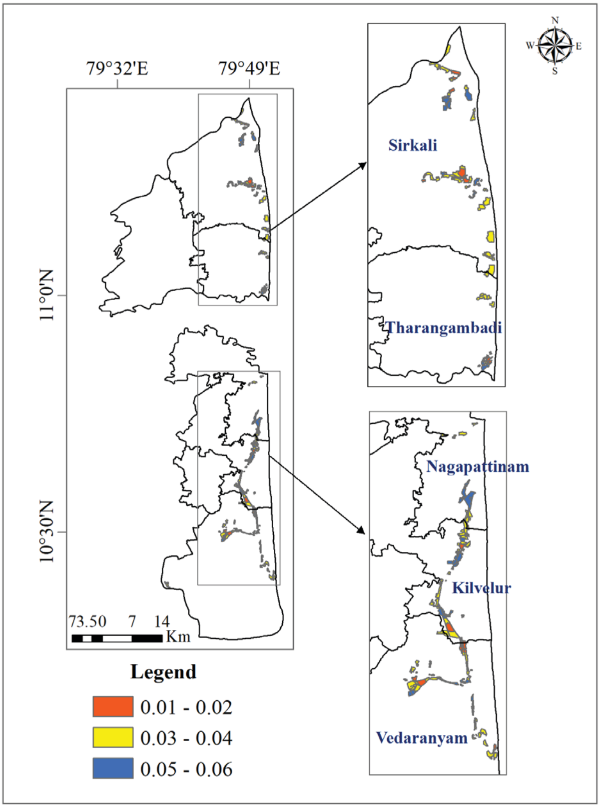

Fig.6.4. Nitrate in shrimp farms

A GIS spatial interpolation analysis of nitrate (Fig. 6.4) in the farm pond water indicated that 15 % of farms had 0.01- 0.02 ppm, 60 % had 0.03 – 0.04 ppm and the remaining 25 % farms had a range of 0.05-0.06 ppm.

Nitrite in shrimp farms

Nitrite is an intermediate product in the bacterial oxidation of ammonia to nitrate. Toxicity of nitrite results in a reduction of the activity of hemoglobin, result in functional anemia. The farm water nitrite ranged from 0.089 - 0.327 ppm, within the optimum of <0.25 ppm.

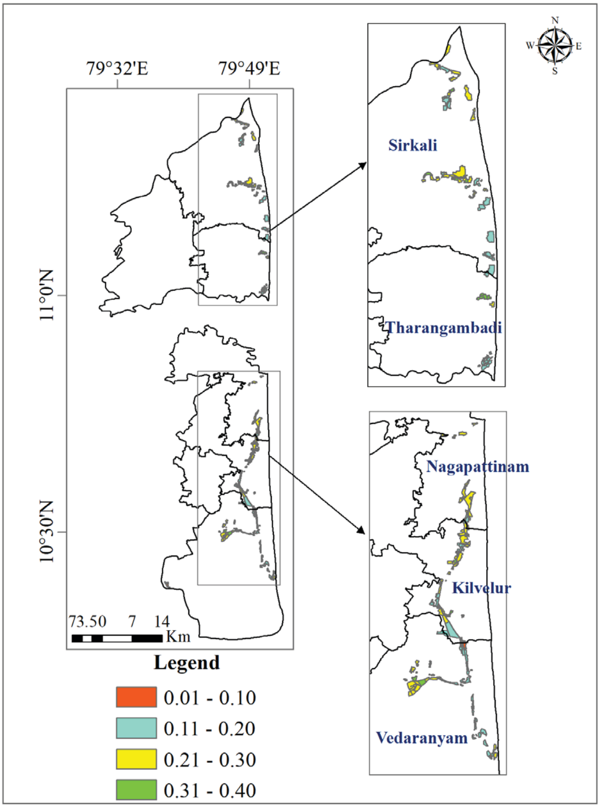

Fig. 6.5 Nitrite in shrimp farms

A GIS analysis of Nitrite in the farm pond water (Fig. 6.5) indicated that 2 % of farms had 0.01-1.0 ppm, 41 % farms had 0.11- 0.20 ppm, 51 % farms had 0.21 - 0.30 ppm and the remaining 6 % farms had 0.31- 0.40 ppm.

Phosphate in shrimp farms

Phosphate in optimum quantity is required for growth and bone development and its high concentration in water may indicate the presence of pollution, and it disturbs the aquatic ecosystem. The principal form of organic phosphorus in pond water is ortho-phosphate, usually designated as phosphate.

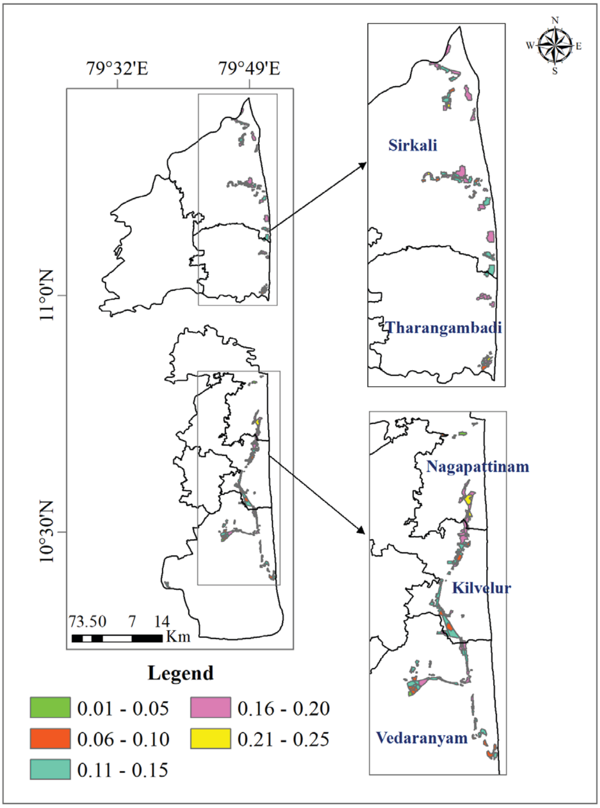

Fig. 6.6. Phosphate in shrimp farms

The range of phosphate in shrimp farms ranged from 0.06-0.21 ppm, compared to the optimum range of 0.1 to 0.2 ppm. A GIS analysis of phosphorus in the farm pond water (Fig. 6.6) indicated that 2 % of farms had 0.01- 0.05 ppm, 13 % had 0.06 – 0.10 ppm, 42 % had 0.11 – 0.15 ppm. 39% had 0.16 - 0.20 ppm, and the remaining 4 % had the range of 0.21-0.65 ppm.

Water quality in source waterbodies for aquaculture

The quality of the water in the site decides the possibility of culture, and species to be cultured. The water pH, salinity and the other pollutants if present need to be screened before the start of shrimp culture. The optimum level of various water quality parameters for better survival and growth are listed by the Coastal Aquaculture Authority. The most important parameters such as pH, salinity and ammonia analyzed from the samples collected from source waterbodies near selected sites were interpolated using GIS techniques.

pH in source waterbodies

The pH in the source water bodies (Fig. 6.7) ranged from 8.01 to 8.80 and conformed the suitability to aquaculture. The pH values in source water bodies of 7% ranged between 8.01-8.20, 45% ranged between 8.21-8.40, 43% ranged between 8.41-8.60 and 6% ranged between 8.61-8.80.

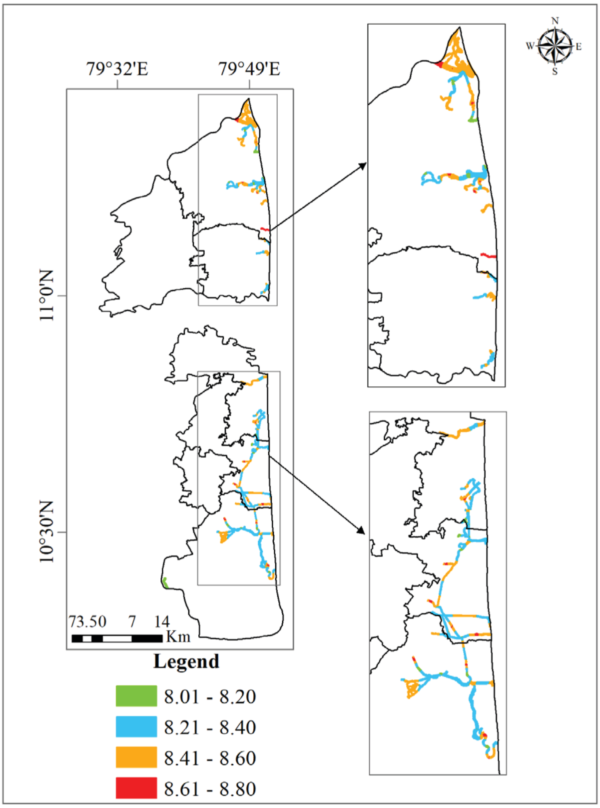

Fig. 6.7. pH in the source waterbodies

Salinity in source waterbodies

Most of the crustacean species can adopt a wide range of salinities. In the case of high saline water, it is better to avoid such places instead of using fresh water to reduce the salinity for sustainability reasons. The measured salinity in the source water bodies was interpolated using GIS (Fig. 6.8) . The salinity in the source water bodies was optimum for 90% of the potential areas, and the remaining 10% is also in the adoptable level of less than 15%.

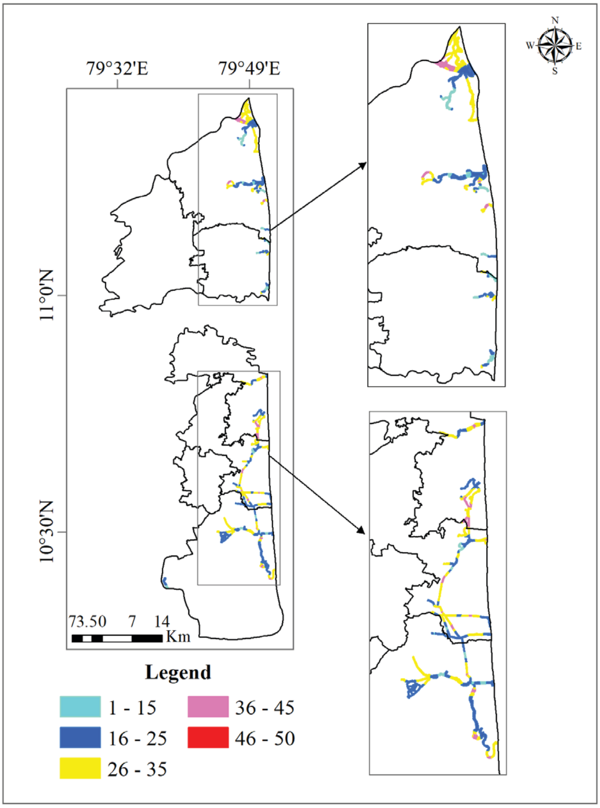

Fig. 6.8 Salinity in the source waterbodies

P. vannamei culture can grow in salinities 0 to 50 ppt, and the outstanding remunerations and importance in the inland low-salinity culture have led to the development and expansion of shrimp aquaculture in many nations.

Ammonia in source waterbodies

Ammonia enters the aquatic environment primarily from the fish excreta and feed plays a vital role within the nitrogen cycle in marine environment. If exceeds above the tolerable level, it leads to toxicity resulting poor growth, less feed intake, and susceptibility to bacterial infections and sometimes death depending on the level of exceedance.

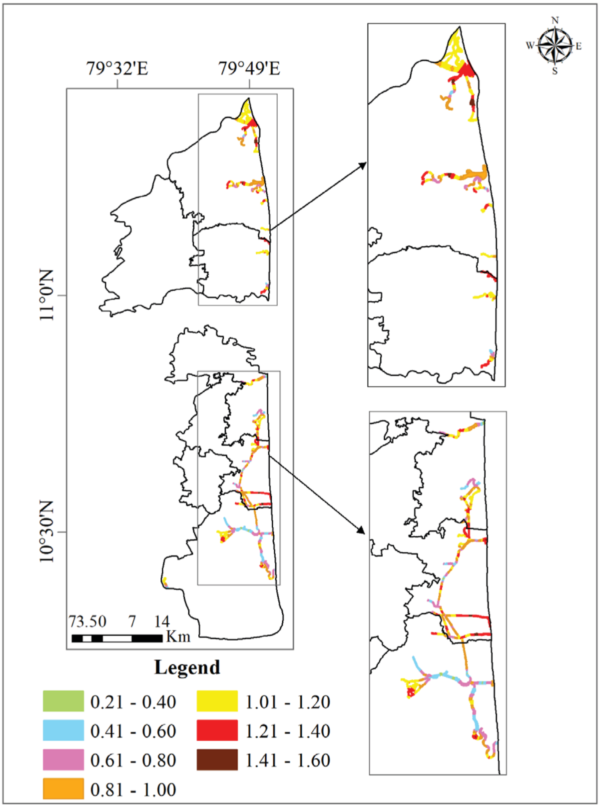

Fig. 6.9 Ammonia in the source waterbodies

The analysis indicated that TAN values (Fig.6.9) in the source water ranged from 0.21 to 1.60 ppm. Its is considered that maximum limit upto 1 ppm is suitable for aquaculture operations.

Soil characteristics in shrimp aquaculture farms

Production will be limited if the soil conditions are unfavorable, hence it is vital for the aquaculturist to understand the aquatic medium in which the organisms/animal inhabits.

Soil pH in shrimp farms

Soil pH is a important factor because of its role in influencing the bacterial activities, fixation of phosphorus and rate of mineralization of organic matter in the soil. The pH values of soil in five taluks are spatially interpolated (Fig. 6.10). Soil pH ranged from 7.41 to 8.53 in the surface soil of farm ponds, indicating alkaline nature of soil, which is suitable for shrimp farming. The optimum range of pH was 7 to 8. The GIS analysis of soil pH in the farm indicated that 11 % of farms had 7.41 – 7.70, 28 % had 7.71 – 8.00, 36 % had 8.01 – 8.30 and the remaining 25 % farms had range of 8.31 – 8.53.

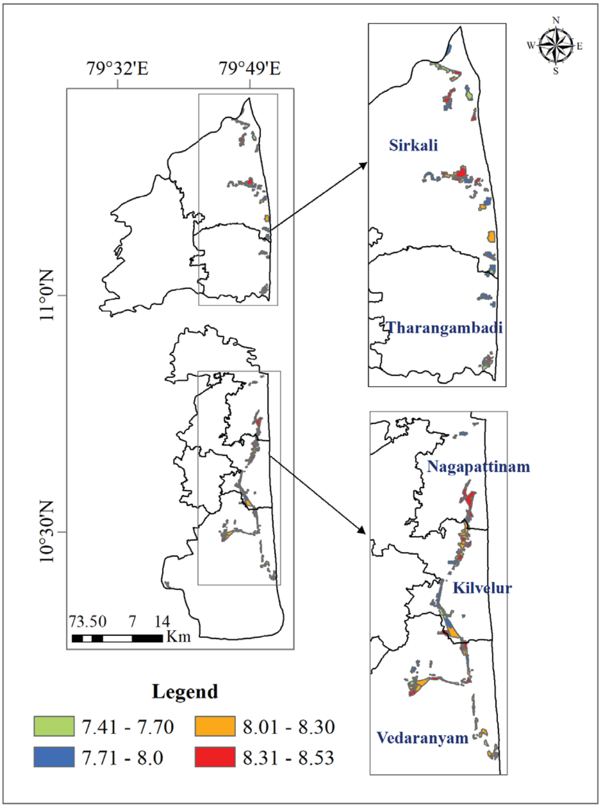

Fig.6.10. Soil pH in shrimp farms

Electrical conductivity in shrimp aquaculture farms

The average electrical conductivity (EC) of the soil samples ranged from 1.73 dS/m to 14.56 dS/m. The variation in EC values at different places may be associated with the relative distribution of cations and anions.

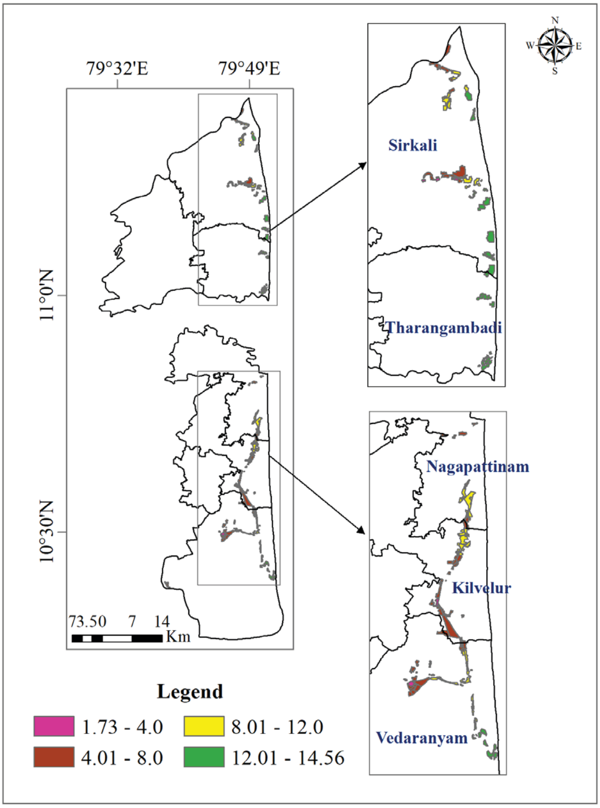

Fig.6.11. Soil EC in shrimp farms

The GIS analysis of electrical conductivity in the farm pond soil (Fig.6.11)indicated that 3 % of farms had 1.73 – 4 dS/m , 28 % had 4.01 - 8 dS/m, 37% had 8.01 - 12 dS/m and the remaining 24 % had 12.01 - 14.56 dS/m.

Organic carbon in shrimp aquaculture farms

Soil organic carbon increases the productivity of shrimp pond. The organic carbon in the farm pond varied from 0.32% to 2.41% (Fig.6.12). Organic carbon range of 1.5% to 2.5% is optimum for the aquaculture operations.

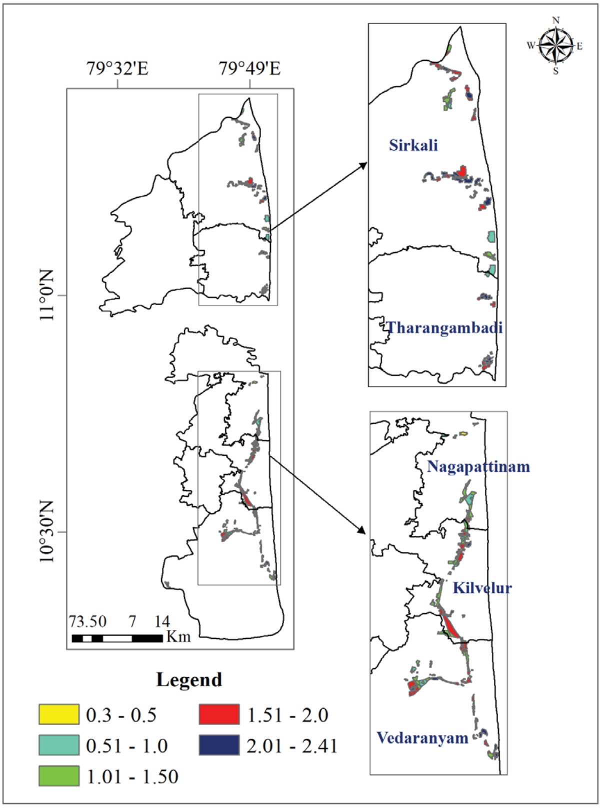

Fig. 6.12 Soil organic carbon in shrimp farms

The GIS analysis of organic carbon in the farm pond soil indicated that 2 % of farm area had 0.30 - 0.50 %, 13 % of fam area had 0.51 – 1 %, 27 % of farm area had 1.01 – 1.5 %, 39% of farm area had 1.51-2 % and the remaining 20 % area had 2.01 – 2.41 %.

Soil characteristics in potential areas for Aquaculture

Understanding the soil parameters helps to decide the management strategies to be followed in terms of liming, fertilization, water management etc before starting the aquaculture. The soil characteristics in the identified sites reveals the required management measures for sustainable aquaculture.

Soil pH in potential areas

The quality of the soil should be assessed before starting the culture. Productivity of an aquaculture pond is greatly influenced by pH value of the soil layers. For the ideal productive conditions, the pH value of pond soil should be neither too acidic nor too alkaline. In extreme conditions of acidity or alkalinity, the health of fish may even be endangered and their growth badly affected. CAA recommends the soil pH below 5 should be avoided for aquaculture.

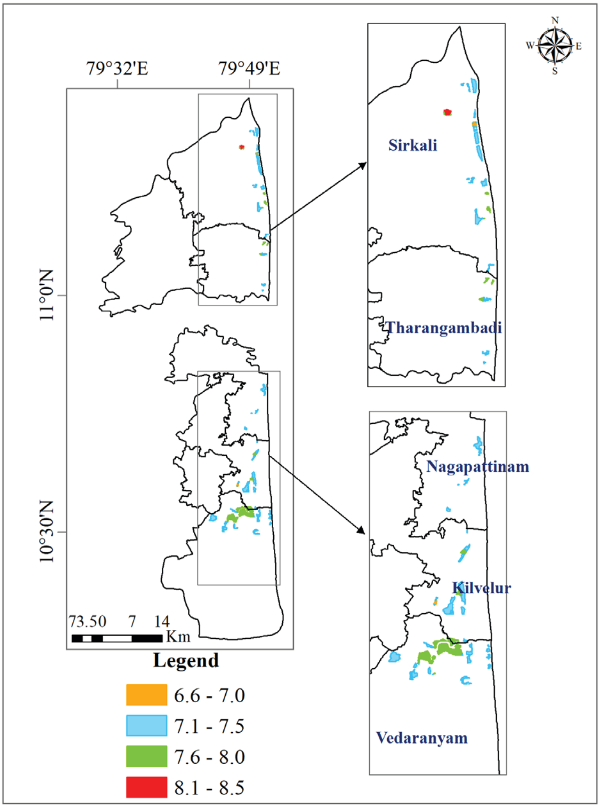

Fig. 6.13. Soil pH in potential areas for aquaculture

The soil pH in the identified sites for aquaculture (Fig. 6.13) indicated that the pH ranged from 6.6 - 8.5, 98% of soil pH is more than 7 in the identified sites for aquaculture, conforming the suitability.

Electrical conductivity in potential areas

Most of the coastal soils are saline since water flows through the creeks and canals nearby mostly have regular flooding with seawater. The primary cause for the coastal area becoming saline is due to the intrusion of saltwater, through backwater swamps due to high waves, also inundating the cultivable adjacent regions through seepage. GIS analysis indicated that 98.5% of the soil had the optimum electrical conductivity of 4 dS/m (Fig. 6.14).

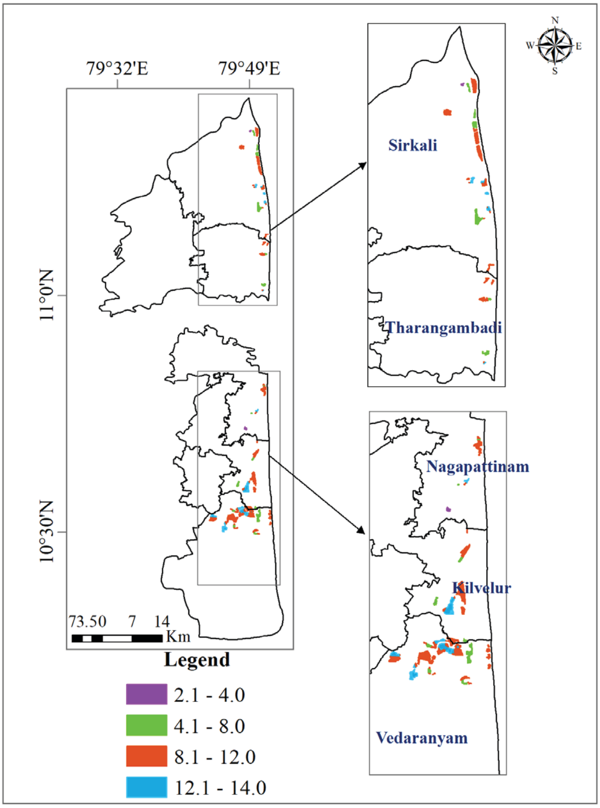

Fig. 6.14. Soil EC in potential areas for aquaculture

The soil electrical conductivity in the suitable area ranged from 4.1-8.0 dS/m, 8.1-12 dS/m and 12.1-14 dS/m in 15%, 57% and 26% of identified area respectively, exceeding the optimum limit for aquaculture in major areas.

Soil organic carbon in potential areas

Soil organic matter is an important index of soil fertility, influences various physico-chemical properties of bottom soils, helps to reduce the seepage, aerability in pond soil bottom and also supplies nutrients.

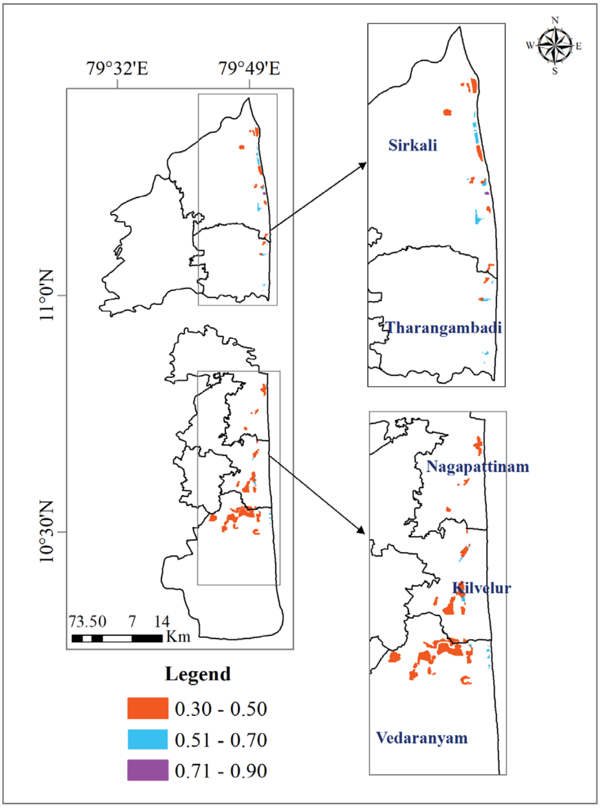

Fig. 6.15 Soil organic carbon in potential areas for aquaculture

The soil organic carbon in suitable areas (Fig 6.15) was assessed for its suitability and mapped using GIS interpolation techniques. The results indicated that 81% sites needs manure application to improve the organic matter before starting aquaculture.

Suitable Areas for Expanding Aquaculture Through MCDSS

Environmental issues raised over the unplanned development of brackishwater aquaculture necessitated the prerequisite of planned site selection and development based on multiple criteria of land and water characteristics. Site selection is an important activity in aquaculture as it can decide the success or failure of shrimp culture. Also, environmental and social issues need to be taken into account before identifying the site. Implementation of coastal aquaculture development regulations on the spatial platform will sustainably make use of the resources. Remote sensing and GIS was used to identify the ecologically important areas and make spatial restrictions imposed on the use of various resources such as mangroves, agricultural lands and freshwater resources for the developmental activities.

The present land use, site-specific parameters, and the proximity of water resources from the source water bodies need to be incorporated before the selection of location. The land classes not permitted for aquaculture development such as mangroves, agriculture were removed from the land use map of Nagapattinam district. The suitability of the site for aquaculture depends on the distance from the water source since the availability of good quality water in required quantities is one of the pre-requisites for a good aquaculture site. The land classes such as abandoned salt pan, mud flat, scrubland, wastelands, and abandoned shrimp farms were taken for MCDSS site suitability analysis.

The criteria assigned based on the distance from the water source as very good - if the distance is less than 1 km, good - if the distance is within 1 km to 2 km, moderate - if the distance within 2 km to 3 km, and unsuitable - if the distance greater than 3 km. The water source and its distance were mapped from the topographical maps of Survey of India. Most of the aquafarms are using Buckingham canal as a source of water and also discharge the pond water into the same canal.

The natural productivity of a farm is dependent on soil quality and nutrient status. Soil texture is the relative proportion of sand, silt and clay content of the soil. In aquaculture, soil quality has a significant influence on construction and maintenance costs and also on productivity. Soil texture map was prepared from the land use and soil survey organization. Clayey and clayey loam areas are the most preferred sites for shrimp farming due to their excellent water retention capacity, and sand is least preferred due to its high seepage characteristics.

Aquaculture site suitability parameters were scored based on the expert's opinion for land use pattern, distance from the water source, soil texture, and drainage facilities. The weightage as described in the methodology section were assigned, and weighted overlay analysis was carried out to find suitable sites from mudflats, scrubland and abandoned salt pan. The buffer of 200 m from High tide line was provided to restrict shrimp farm development as per the CAA act.

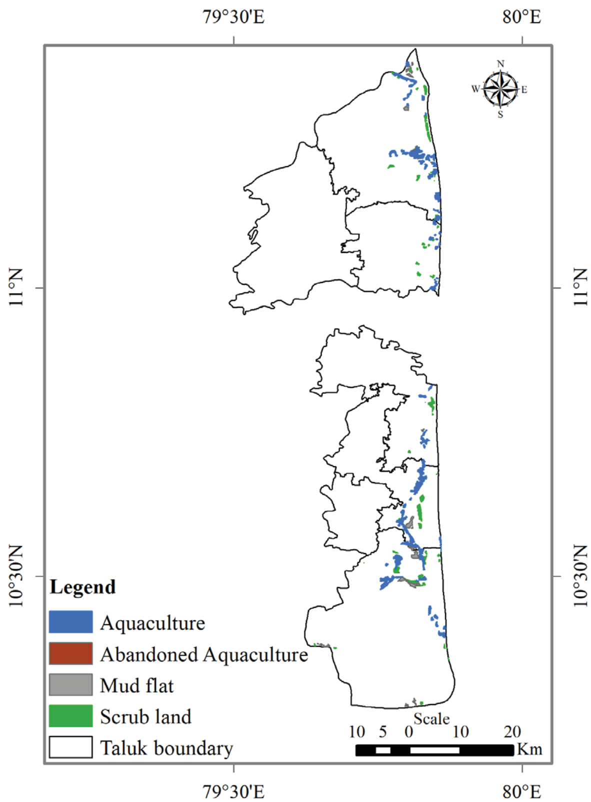

Fig. 7.1 Suitable areas for brackishwater aquaculture

The buffer of 100 m was given between the suitable areas and adjacent productive land types. The area ideal for brackishwater aquaculture development (Fig. 7.1) was delineated by combining selected criteria and deriving overall suitable index.

The analysis indicated that suitable areas (Fig. 7.2) were available from mudflats (680 ha), abandoned aquaculture (113 ha) and scrubland (1078 ha) in addition to existing aquaculture area of 3900 ha.

The present seed requirement for the existing aquaculture area of 3900 ha with stocking density of 40 no/m^2 was 1560 million per crop, and the future additional requirement for 1871 ha with 40 no/m^2 will be 748 million per crop. The seed cost involved at present is

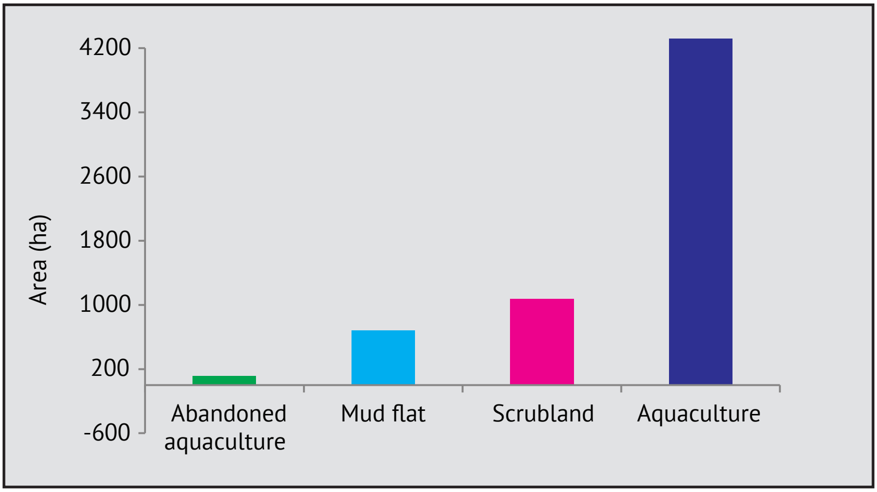

Fig. 7.2 Land classes available for aquaculture and existing farm extent

62.4 crores and will be enhanced by 30 crores due to expansion potential. The initial pond preparation and infrastructure cost will be Rs. 5 lakhs /ha. The present production was 31200 T @ 8000 kg/ha, can be increased by 14968 T. The feed requirement for *P. vannamei* farms with FCR 1: 1.2 was 37440 T, and additional requirement will be 17961 T. The cost of the feed was Rs.80 per kg approximately considering the different brand and varying rate, accounting the feed cost of 299.5 crores per crop at present, and additional requirement will be Rs.143.6 crores per crop. The energy per kg of shrimp production was taken as 5 kW-hr /kg and accounts to Rs.36/kg of production. The expected revenue was 936 crores/crop with an additional possibility of 449 crores/crop after expansion, of which 20 % is the expected profit in successful shrimp culture.

8

Climate Variability and Its Impacts

The frequency and intensity of changes in precipitation, temperature and its consequences are the main factors influences the aquaculture productivity adversely. Understanding the scale, type and severity of climate changes, its impact and vulnerability will help in evolving appropriate site-specific adaptation measures and production systems practices.

Changing rainfall pattern

Tamil Nadu falls under tropical savanna climate and ranges from dry sub-humid to semi-arid. The state is heavily dependent on monsoon rains and thereby is prone to droughts when the monsoons fail. The hot weather sets in and lasts until the middle of June. The highest temperature is often registered in May which is the hottest month in the State. The cold weather commences early in October and comes to an end in the middle of January. The state has three distinct periods of rainfall: advance rainfall; the South West monsoon from June to September, with strong southwest winds; and the North East monsoon from October to December, with dominant northeast winds. The dry season is from February to July. The average annual rainfall of the state is about 945 mm of which 48% was from North East Monsoon and 32% from South West monsoon. Since Tamil Nadu is entirely dependent on rains for recharging its water resources, monsoon failures lead to acute water scarcity and severe drought.

Frequency of extreme events

Nagapattinam District is prone to various natural calamities and disasters such as Tsunami, floods, cyclones, and drought. The impact of extreme climatic events on aquaculture are changed water quality in small ponds, inundation of flood water in aquaculture farms, predators into aquaculture systems, harmful algal blooms, and infrastructure damage subsequently leading to total crop loss.

Nagapattinam District is a multi hazard-prone district (Table 8.1) with heavy winds, cyclones, floods being a regular feature and the increased frequency of extreme events in the last decade. The frequent floods and cyclones in the district, demand the realistic assessment and adaptation measures to cope up with the changing climate.

Table 8.1. Extreme climatic events in the last five decades in the district

Date of occurrence	Calamity	Damages caused
30.11.1952	Storm surge up to 5 miles landward	Four hundred lives
08.12.1967	Cyclone	Seven lives lost and 15,000 rendered homeless
12.11.1977	Cyclone	Five hundred sixty lives lost and 196 missing Damages to port, irrigation systems, road, power supply and communication including a large number of houses
01.12.1984	Floods due to heavy rain	Crops damaged in large scale and normal life affected due to heavy floods
15.11.1991	Heavy rainfall	Crops damaged
04.12.1993	Cyclone	One thousand and hundred people lost their lives, severe damage to crops
29.10.2004	Floods due to heavy rain	Crops damaged, around 12,000 houses damaged
26.12.2004	Tsunami	Six thousand sixty-five dead and 1922 injured. 12821 cattle lost, a large number of houses, boats, and infrastructure damaged. 300 ha of aqua farm infrastructure to the extent of 6 crore
28.10.2005 to 8.11.2005	Floods	One hundred and sixty-two lives lost and severe damage to aquaculture ponds
13.11.2008 to 16.11.2008	Nisha Cyclone	Sixty-two lives, 636 aquaculture farms damaged with the loss of 16.51 crores/ 1000 ha with 150 crore infrastructure.
7.11.2015	Floods	Seven persons have died 5,000 hectares of standing samba paddy crops submerged.
16.11.2018	Gaja Cyclone	52 lives, over 82,000 others were affected, 88102 hectares of agricultural and horticultural crops, 4 lakh coconut trees; fisheries

Changes in the rainfall pattern

Actual daily rainfall data of 30 years from 1985 to 2014 (IMD, 2016) was used to assess the changes in the trend and pattern in Nagapattinam district, indicated the shift in rainfall pattern over the decades. Monthly average decadal rainfall (Fig. 8.1) shows the rainfall quantity in North East Monsoon season has gradually increased from 1985-2014 in addition to shifting the rainfall pattern in other seasons. The maximum rainfall of

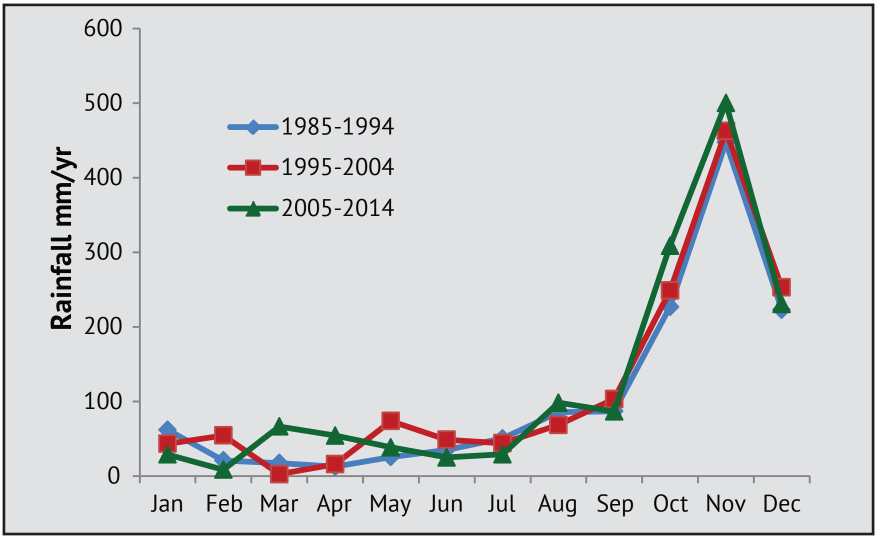

Fig.8.1 Monthly average rainfall over the decades

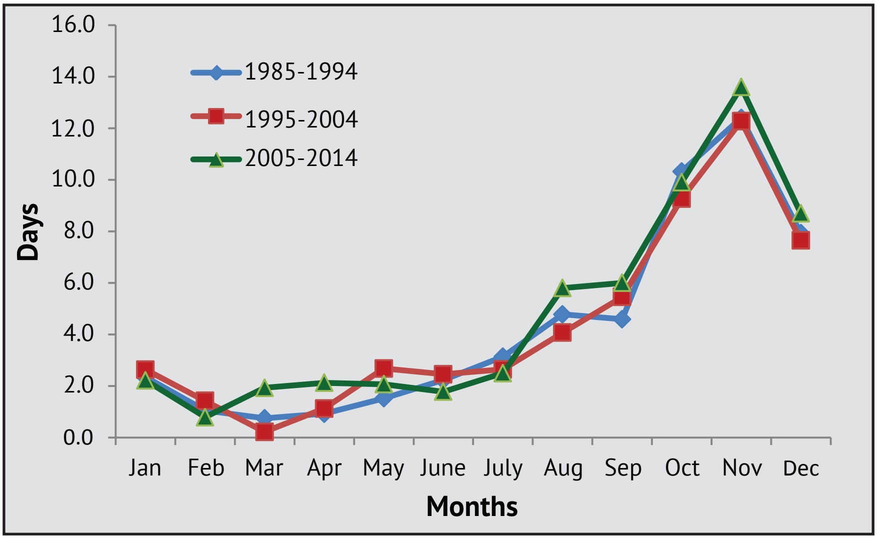

Fig. 8.2 Monthly average rainy days in a year over the decades

447 mm was observed in November 1985-94 and gradually increased to 462 mm in 1995-2004 and 500 mm in 2005-2014. The same trend was observed for all months of NEM. The rainfall intensity at the end of summer season and beginning of South West Monsoon has increased in 1995-2004 compared to 1985-94. The pattern advanced with more intensity in 2005-2014 in the summer season particularly in March and April compared to previous decades.

Rainy days have increased in March – April and October -November months in recent years than previous decades (Fig.8.2). This changing rainfall pattern will have a positive impact on aquaculture as it helps farmers to maintain the salinity level in farm ponds.

Changes in intensity of rainy days

Rainfall days in the district were grouped into three major categories based on the impact on aquaculture. Based on the impact expected, rainfall <64.4 mm rainfall in a day as “low” impact category, heavy rainfall events with rainfall >64.4 and <124.4 mm per day as medium category, and the rest of more than 124.4 mm rainfall as an extreme

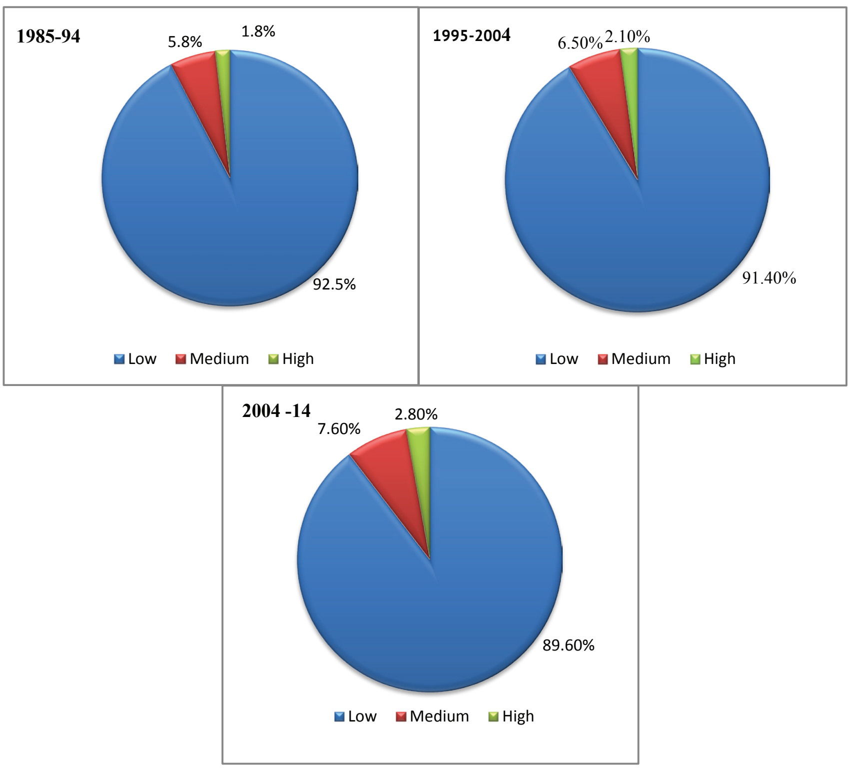

Fig.8.3 Changes in rainy days of varying intensity from 1985-2014

category. We are more interested in the changes in intense category rainfall in short duration (Fig. 8.3) as it adversely affects the aquaculture in terms of salinity reduction, pH fluctuations, reduced dissolved oxygen, breach of pond dikes, submergence of ponds, damage to farm shed, damage to electricity lines & power failure, difficulty in access to shrimp ponds and disease outbreak.

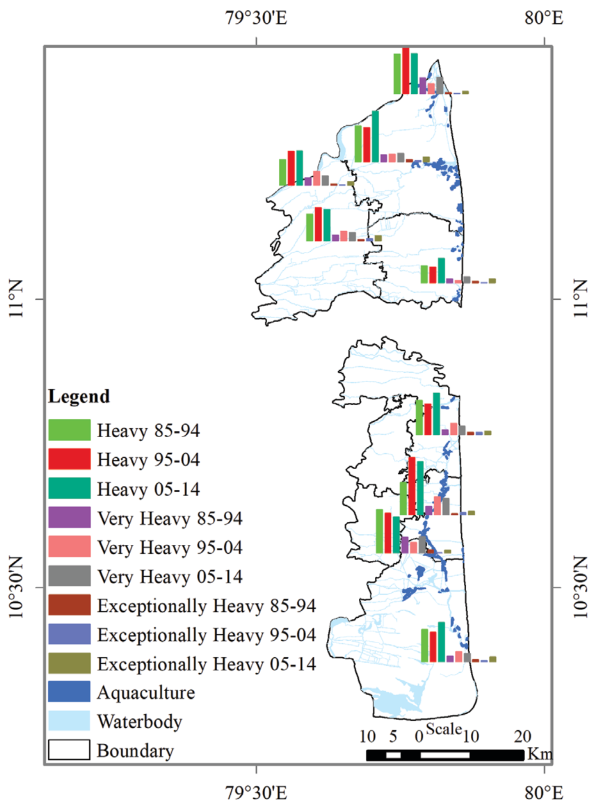

Fig. 8.4 Changes in heavy to extreme rainy days on aquaculture regions

The mapping of heavy, very heavy and exceptionally heavy rainfall days based on station wise data indicated the increasing heavy trend over the decades (Fig. 8.4). Heavy rainfall days increased by 2% in 2005-2014 compared to previous decades. Extremely heavy rainfall has also increased by 1%. The aquaculture farms in low lying areas are to have climate resilient adaptation measures to cope up with climate. The study revealed that the farms located in Tirupoondi, Talanayar and Coleroon taluks needs special measures to prevent flooding compared to other areas, as the intensity of rainfall was more compared to other regions in the district.

Mapping of spatial variation of seasonal rainfall

Northeast Monsoon (NEM) season is the major period of rainfall activity in Tamil Nadu, coastal districts receive nearly 60% of the annual rainfall, and the interior regions get about 40-50% of the annual rainfall. The seasonal variation of the actual rain received at the weather stations was spatially interpolated using GIS techniques to assess the intensity of rain at different places.

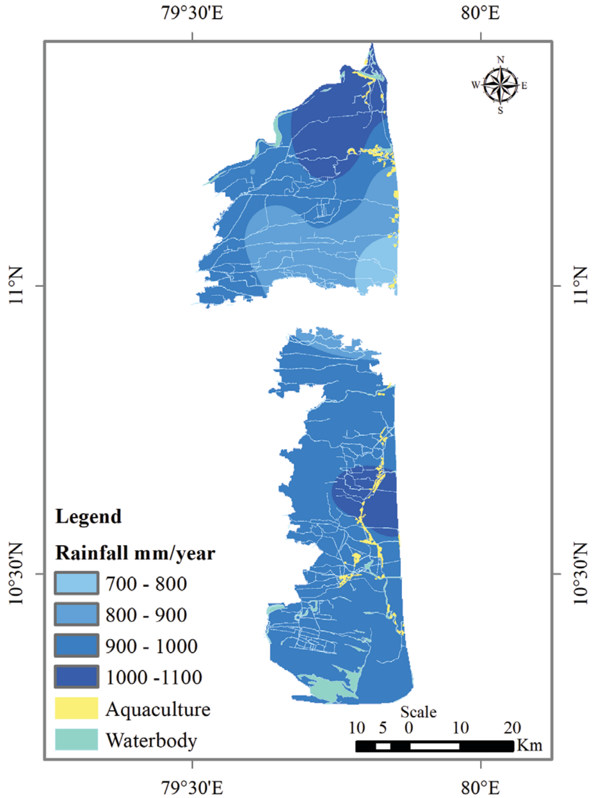

Fig. 8.5 Spatial pattern of NEM and aquaculture farms

The aquaculture farms were overlaid on the spatial pattern of rainfall to locate the vulnerable regions. Rainfall variation analysis in small distances will be helpful to decide the culture management practices in aquaculture. Spatial variation of NEM seasonal rainfall (Fig. 8.5) from 2005 to 2014 indicated that 3% area received 701-800 mm, 16% area received 801-900 mm, 66% area received 901-1000 mm and 16% area received 1001-1100 mm.

Fig. 8.6 Submergence of shrimp farms during NISHA cyclone

Flooding due to heavy rainfall and cyclones have devastated the shrimp farms (fig. 8.6) in 2005, 2008, 2015 and 2018. Spatial mapping helps to know about the variation in surface runoff and decide the management measures during culture period in the low lying regions.

Climate change events, their impacts and risk levels in Nagapattinam

Assessment of climate change events that affects shrimp farmers revealed that they experienced seasonal irregularities, temperature variations, flooding due to heavy rain and cyclone. The extreme events and its impacts are

Heavy Rain, Flood & Cyclone - Loss of stock, infrastructure damage, inundation, breach of bunds, aerators, electrical lines, chances of disease, water quality deterioration.

Seasonal variations - Inability to plan the crop, nonavailability of quality seed, water quality deterioration/stress to animals, low feed intake, slow growth, disease outbreak (loose shell, vibriosis, WSSV, etc.,)

High temperature / unusual temperature fluctuations - Change in optimum water quality parameters (pH, salinity, algal bloom/ DO/ metabolites load) stress to animals / low feed intake / slow growth/disease etc.

Considering their likelihood and consequences, heavy rain followed with flooding was ranked as the major risk followed by seasonal variations and cyclone (Fig.8.7). Changes in water quality parameters, poor shrimp growth, infrastructure damage, biomass loss/escape to the tune of 50-100%, water pollution, disease outbreak and its rapid spread, non-availability of quality seed, mortality and low survival, poor feed intake, poor molting and stunted growth were experienced as the negative consequences due to climate change extremes. Seasonal changes like late onset and early withdrawal of monsoon seasons, an extension of summer/winter seasons beyond their stipulated period are reported as the second highest risk as the seasonal variations hinder in planning and continuing the crop.

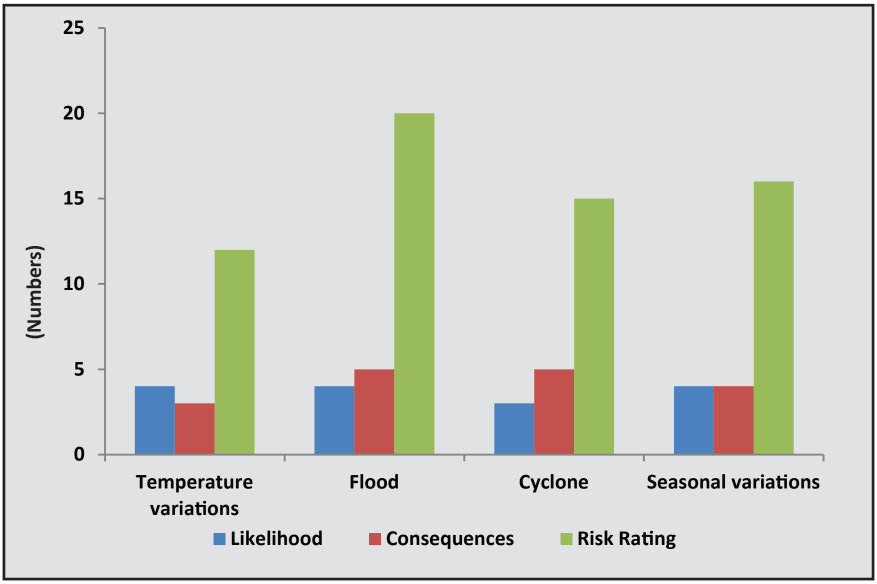

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Fig. 8.7 Climate change events, consequences and their risk rating in Nagapattinam district

The extension of cold seasons beyond the period facilitates the manifestation of disease pathogens and similarly hampering the breeding and seed production of candidate species. Prolonged and unusual high and low temperature for a relatively more extended period affected the physiology of the species, and it spending full energy in maintaining the metabolic rates led to severe stress. The stressed animal is fragile and susceptible to the pathogens. Therefore, temperature variations for a long time are high risk and the farmers felt accordingly. The impacts due to the above consequences include the high cost of production to the tune of 15-20%, 30-50% loss in production, delayed stocking (30-45 days), change in crop plan and prevented the possibility of the second shrimp crop, premature harvesting, and 50 -100% economic loss.

Vulnerability of aqua-farmers in Nagapattinam district

The primary data about the exposure, sensitivity and adaptive capacity of the aqua farmers to the perceived climate change were analyzed to estimate the levels of vulnerability of farmers (Fig.8.8). The results showed that the majority (67%) of the aqua farmers holding of farm extent (94%) were estimated to be under moderate levels of vulnerability. This might be due to the farmers' primary concentration on aquaculture as a livelihood, their education and relatively better socio-economic status. About 4% and 21% respondents were in the high and low levels of vulnerability position, holding aquaculture farm area of 4.4% and 0.8% respectively. The aquaculture vulnerability was spatially interpolated (Fig. 8.9) to assess the extent of farm area under the different scale of vulnerability index showed that 2990 ha of the brackishwater aquaculture farm area in Nagapattinam district was under a moderate level of vulnerability.

Fig. 8.8 Vulnerability of shrimp farmers to climate change

The socio-economic analysis indicated that farmers had relatively higher experience in farming and better aware of good aquaculture practices as the district is major aquaculture hub in Tamil Nadu. However, unlike agriculture, the respondents did not have access to institutional credit and insurance due to high risks and higher coverage. While agriculture was given institutional support and compensation in case of climate change extreme related losses aquaculture was not considered for the same.

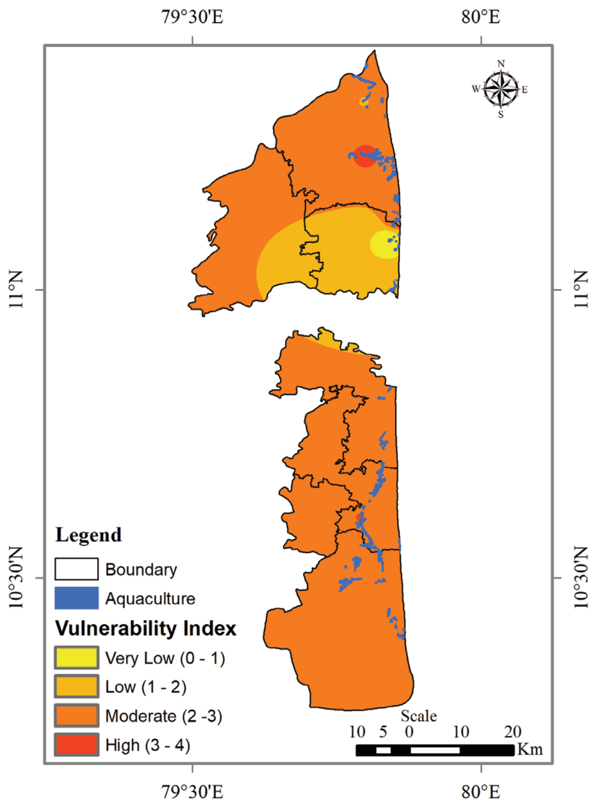

Fig. 8.9 Spatial spread of vulnerability of shrimp farmers to climate change.

Impact of floods, cyclone, and Tsunami on aquaculture

Cyclones often accompanied by large storm surges from the ocean. The sea water flows across the coast as well as inland and then recedes to the sea. Great loss of life and property takes place in the process. The east coast of India is particularly more vulnerable to storm surges than the west coast. Cyclonic Storm Nisha had made landfall in Tamil Nadu on 27th November 2008 over coastal areas of Thiruvarur and Nagapattinam districts with a storm surge of about 1.0 meter above the astronomical tide. Under its influence, heavy to very heavy rainfall was received at most places and isolated extremely heavy falls (>25 cm) at a few places over Tamil Nadu, and Puducherry along with gale winds speed reaching 65-85 kmph gusting to 95 kmph. Number of farms affected were 636, water spread area of 1000 ha, at a total loss of 16.51 crores.

Fig. 8.10. Breaching and inundation of shrimp ponds

Within one night about 4 feet height water level was increased in the source water bodies due to heavy rains, and the subsequent flooding inundated all the ponds in some of the shrimp farming areas of Nagapattinam District. The distance from source water to the farm ponds ranged from 10 to 300 m. The water level in the source water bodies (Koduvayuru River, Harichandra River, Vedaranyam Kaluva, Kallimedu River) increased from 1.5-2 m before heavy rains to 3 to 4 m after the rains. Breaching has occurred, and the ponds were completely inundated for 7-10 days with flood water (Fig. 8.10). The crop duration at the time of inundation was 110 to 120 days. Infrastructure facilities such as motors and huts and also the approach road to the farm sites were damaged. The water level was high even after one month of the inundation, and subsequently, the pond preparation for the next summer crop got delayed. Many farms were affected with the disease after heavy rains and flooding due to the entry of pathogens into aquaculture systems.

Impact of tsunami on aquaculture

The tsunami has damaged the pump houses and motors, eroded the bunds, deposited silts in ponds and source water bodies, inundated farms and led to the loss of stock. The water depth in the backwaters has reduced due to deposition of sediment brought by Tsunami. Assessment by CIBA indicated that shrimp farming in Nagapattinam District has suffered a loss of Rs. 6 crores and damaged the water intake systems in 300 ha. This district had the maximum area under shrimp in the state, producing 1585 T of shrimp from 925 hectares in 2004. Mangroves and other coastal vegetation defended the shore from storm surges that can damage shrimp ponds and other coastal infrastructure.

Gaja cyclone impact on coastal resources at Nagapattinam

Cyclone Gaja shattered Tamil Nadu on November 16, 2018, damaging houses, cattle, agriculture crops, and fish boats. It was estimated by the Government of Tamil Nadu, that 5.27 Lakh households, 221485 cattle and birds, 122063 ha of agriculture crops, 655 transformers, 331772 electric poles, 201 substations. 5662 fish boats, 6157 vessels, and 10648 fishing nets have been devastated. Shrimp farms of 1775 ha, the expected loss was 20412 lakhs including standing crop cost, infrastructure, and post-cyclone impacts on productivity (Fig. 8.11).

Fig. 8. 11 Impact of Gaja on mangroves

Fig. 8. 12 Impact of Gaja on shrimp farm infrastructure

Compensation were provided to agricultural farmers and fishermen. However as stated in earlier cases, shrimp farmers were not provided the support during the natural calamities. Institutional and government support would help the sector to tide over the climate change extremes to the maximum extent and contribute for the resilience.

9

Issues Faced by Aquaculture Farmers and Other Resource Users

Specific issues at taluk level faced by the farmers were collected through focus group discussions (FGD), survey in the farmer's field and stakeholders workshop. Aquaculture has developed in five taluks of the district namely Sirkazhi, Tharangambadi, Nagapattinam, Kilvelur, and Vedaranyam.

Focus Group Discussion : Informal meeting (Fig. 9.1) was held with 20-25 aquaculture farmers at each taluk to assess the specific local issues, that needs to be addressed for sustainable development.

Survey in the farmer's field : Survey was carried out to assess the issues and problems in the farmer's field. Farmers were interviewed (Fig.9.2) based on the questionnaire prepared to evaluate the site-specific issues.

Stakeholder workshop : The workshop at the district level (Fig.9.3) was organized involving representatives of all key resource users to discuss the issues and problems, identify short and long term solutions and prioritize the action plans.

Fig.9.1 Focus group discussion with farmers

Issues and problems faced by the shrimp farmers

The common issues addressed by all farmers were desiltation of canal and de-weeding of waterbodies. Out of 1141 irrigation canals, 526 canals need to be desilted. The total deposition of silt and sand was 607073 m^3. The weeds present in the water bodies accounts to be 35000 sq.m. The total drains were 180, that needs to be repaired to carry the water flow during the rainy season to avoid flooding.

Fig.9.2 Survey in the farmer's field

Fig.9.3 Stakeholder workshop at Nagapattinam

Source water bodies and local issues in Sirkali Taluk

The aquaculture area in Sirkali taluk was developed to the extent of 1376 ha (Fig. 9.4), and supporting source waterbodies are Coleroon River, Buckingham Canal, and Uppanar. The problems raised were high tide, bar mouth opening, disease issues, and obstruction in water flow due to the construction of East Coast Road (ECR). If the water is released in Mettur dam before June month, it is favorable for the aquaculture. There was no biosecurity protocols like bird fencing or reservoir pond system. The primary issue was breaking of Kollidam river bund and frequent floods in the region.

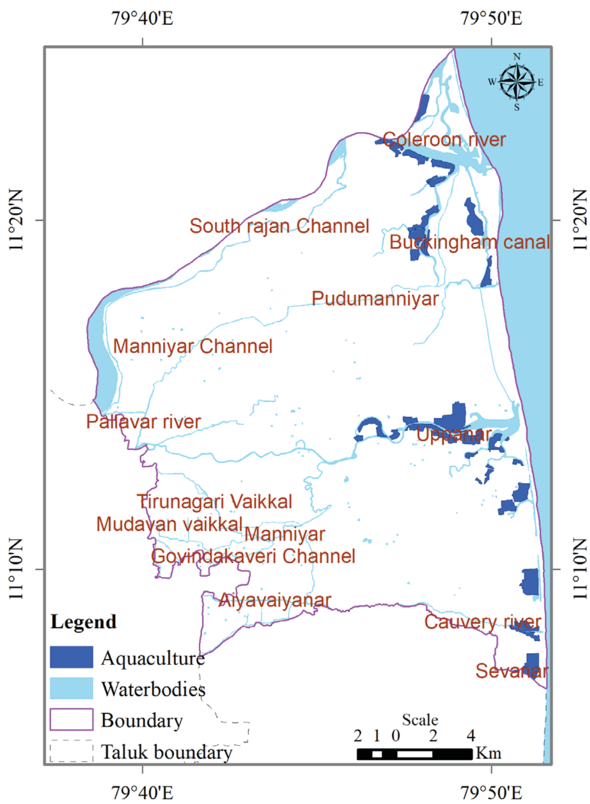

Fig 9.4 Shrimp farms with associated waterbodies in Sirkali

Source water bodies and local issues in Tharangampadi Taluk

The primary source water bodies are Nandalar, and Kadalalaiyar River and the area under aquaculture was 245 ha (Fig. 9.5).

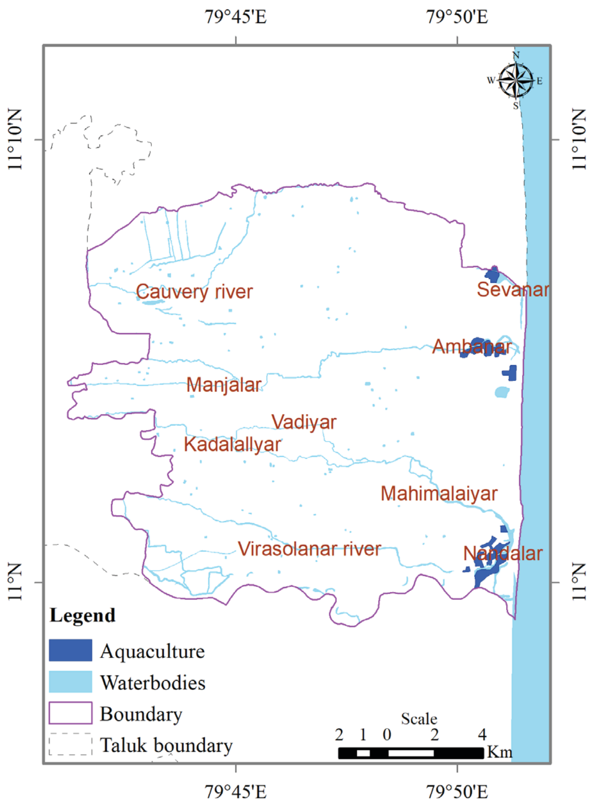

Fig. 9.5. Shrimp farms with associated waterbodies in Tharangampadi

The erratic and insufficient electricity, Palayar port development, land license permission due to Aathinam mutt, Thirumullaivasal bridge and ECR resulting in the reduction of water flow, Mahindrapalli leather industry effluent, Uppanar windmill power generation unit, and power plants were listed issues by the farmers.

Source water bodies and local issues in Nagapattinam Taluk

The major source water bodies in the taluk are Vettar, Vedaranyam canal, and Uppanar. The Nagapattinam Taluk has aquaculture area of 432 ha (Fig. 9.6).

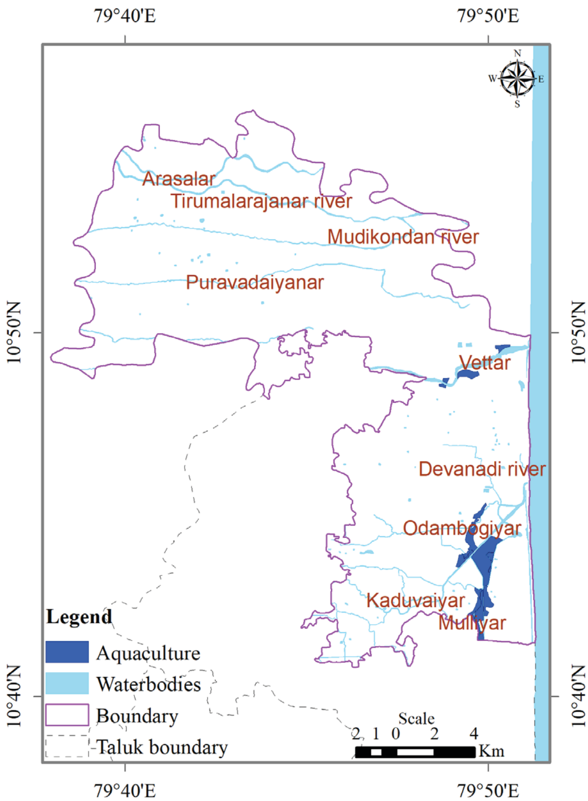

Fig 9.6. Shrimp farms with associated waterbodies in Nagapattinam

Issues revealed by the farmers were the reduction in price at the time harvest, the monopoly on shrimp price fixation, silt deposit in the source water bodies, insufficient electricity, prone to extreme climate events, frequent flooding, ponds below ground level in some areas and no possibility for the direct water pumping from creeks.

Source water bodies and local issues in Kilvelur Taluk

The area of 1034 ha was developed for aquaculture (Fig. 9.7). The major source water bodies are Vedaranyam Canal, Chakkalin Canal, and Harichandra River. Issues faced were disease outbreaks, insufficient electrification facilities, siltation in Harichandra River, power plant, lignite corporation discharge water, and the monopoly in fixing the price.

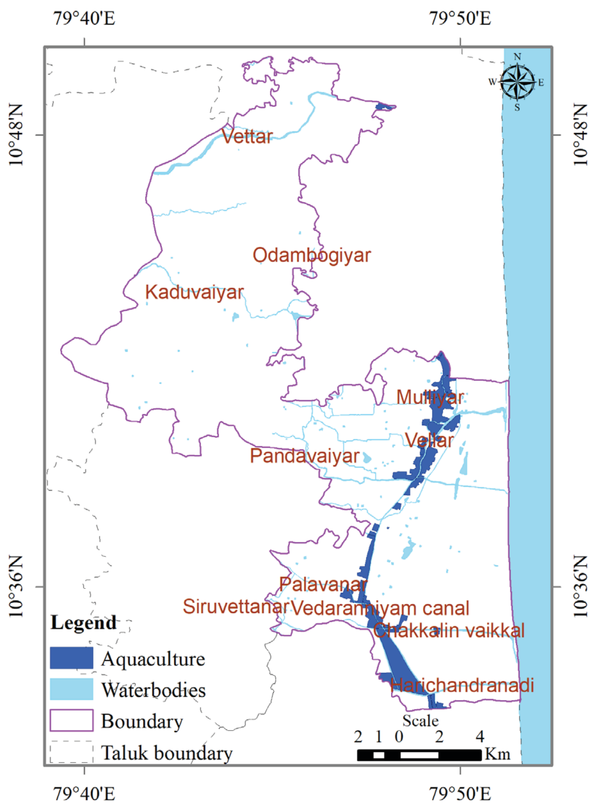

Fig 9.7. Aquaculture farm with associated waterbodies in Kilvelur

Source water bodies and local issues at Vedaranyam Taluk

The area under aquaculture in the taluk was 1086 ha (Fig. 9.8). Harichandra River, Vellar and Adappar are the major source water bodies catering to shrimp farming. The major issues were lack of biosecurity measures, less number of testing laboratory facilities, weeds growth in the water bodies, disease outbreaks, insufficient electrification facilities, siltation in Vellar and Harichandra River and the monopoly in fixing the price.

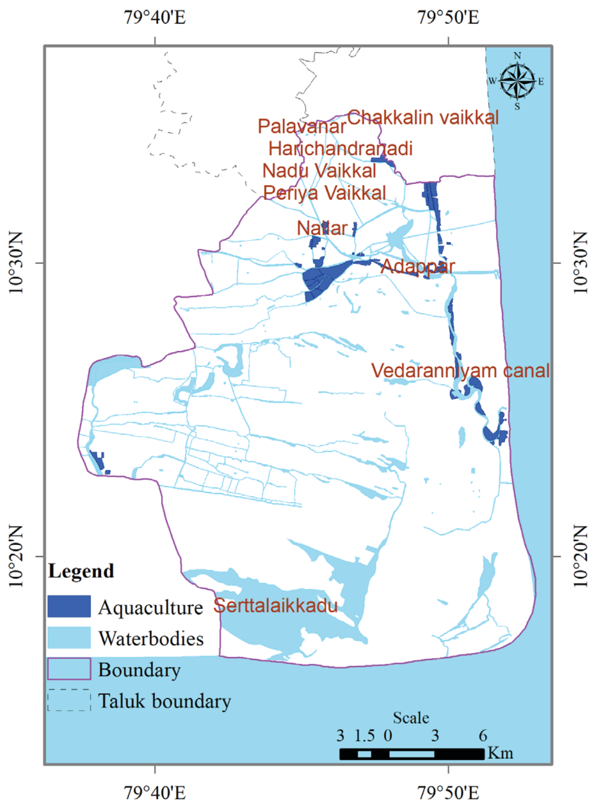

Fig 9.8. Aquaculture farm with associated waterbodies in Vedaranyam

SWOT analysis

SWOT analysis (Strengths, Weaknesses, Opportunities, Threats) was carried out to assess the potential and problems of shrimp culture in the Nagapattinam District. It must be admitted that all the points listed under SWOT may not be complete, but the information provides an opportunity for in-depth study.

Strengths

Larger area under aquaculture - Being the district with large number and area of shrimp farms, this district receives priority for demonstration programmes, government schemes and research efforts from organizations viz. CIBA and MPEDA.

Presence of multiple creeks - The district is situated in the deltaic region of the famous river Cauvery and crisscrossed by a lengthy network of irrigation canals. Kollidam River forms the northern boundary of the district, whereas Arasalar, Tirumalairajanar, Vettar and Vennar Rivers drained the other parts of it. These rivers are tributaries and branches of the river Cauvery. Crisscrossed with rivers and creeks offers ample facilities for source water intake and discharged water drainage network and treatment.

Farm location - The continuous location of farms helps to exchange information at a faster rate during emergency harvest due to disease outbreak and also helps in exchange of knowledge. The supply of feed, technical consultations, updating information made easy due to the continuous location of farms.

NaCSA societies - All the farmers, were grouped into societies through National Centre for Sustainable Aquaculture (NaCSA) and got their ponds insured with the help of the Marine Products Exports Development Authority (MPEDA). The farmers expected a subsidy for electricity charges through NaCSA. Market forces (price and food safety), anti-shrimp farming campaigns, legal and other socio-economic threats have also strongly contributed towards the development of group approach in shrimp farm clusters. Experience has amply shown that farmer groups can ensure responsible and sustainable aquaculture development, empower farmers through collective decision making, offer opportunities to link with markets, improve social, environmental and food safety responsibility, facilitate delivery of farm extension services and contribute to the long-term sustainability of the shrimp farming. This district farmers are highly amenable for cluster farming and registered under NaCSA society.

Innovative farmers - The farmers are educated and creative to adopt different practices such as better management practices and biosecurity protocol that helps to maintain good water quality in farm ponds and prevents massive disease outbreak.

Farmers amenable for cluster farming - Shrimp aquaculture was practiced mostly in clusters, drawing and draining water from the same source. Earlier in the 1990s, farmers have maintained secrecy in all farm operations to produce more shrimp and make huge profits. But the spread of White Spot Syndrome Virus' (WSSV) disease outbreak due to poor farm management and cooperation among the shrimp farmers created the compulsion among the farmers to have "Win-Win" situation. Interventions from research and development institutions encouraged farmers to be open to their fellow farmers and to understand that one's success depends on neighbor's success, also. This realization led to the formation of cluster-based farmer groups to enforce the specific code of practices collectively adopted by the farmers.

Weaknesses

Frequent disease occurrence - Disease outbreak has become common phenomena since 1995 after the outbreak of WSSV disease in India. It has become a significant constraint and challenge to the growth of the shrimp industry. Poor farming practices, bad water quality, poor soil conditions, and inferior quality seeds were identified as the main contributory factors for the disease outbreak. Now, the growth and economic viability of aqua farming primarily depends on the successful prevention or control of disease outbreaks. Unlike the land-based farming, the disease problems in aqua farming were complicated due to the three-dimensional nature of the culture system where the dynamic interaction of biotic fauna comprising the host and opportunistic pathogens and abiotic factors exists. Badly affected were the medium and small farmers who had borrowed heavily to invest in shrimp farming.

Prone to natural disasters - As shrimp aquaculture is coastal land and water-based activity, the impact of a natural disaster such as cyclones and floods on shrimp farming is very high, resulting loss of stock and damage to aquaculture facilities. The district was affected by the extreme events almost once in three years. There is no government scheme to support the farmers in case of disaster events. Apart from the loss of stock and infrastructure facilities, many farms were affected by the disease after heavy rains and flooding due to the entry of pathogens into aquaculture systems.

Fluctuating global market price - The reduction in demand for shrimp in the global market, anti-dumping duties, antibiotic residue problems and recession in developed countries reduced the export opportunity and reduced the number of good buyers. This led to a monopoly of exporters and processors and variation in price fixation based on the vims and fancy of the exporters. Shrimp farmers demanded the price-fixing policy from the government as prevailing in the agriculture sector.

Lack of human resources in the Fisheries department – There were not enough government officials to support the growing shrimp industry. State fisheries departments are expected to carry out the extension activities as well as the implementation of the decisions of the Coastal Aquaculture Authority.

Lack of infrastructure facilities such as processing plants, cold storage - There was no processing plant and cold storage facilities available in the district. It is essential to store the shrimp in case of emergency harvest, but buyers were from Chennai and Tuticorin. The lack of cold storage facilities created the monopoly in price fixation.

Licenses-not completed - Getting project clearance from the Coastal Aquaculture Authority was reported to be a problem. Farmers felt that it takes a lot of time to get a license cleared as their applications have to be processed and verified by various committees from district to a national level.

Lack of cooperation among farmers - Lack of cooperation among shrimp farmers was perceived as a problem by 68 percent of the respondents. This problem was very much pronounced especially during the discharge of water into the canals and creeks as well as the date of stocking, harvesting, etc.

Opportunities

Scope for domestic marketing - As the quantity of shrimp is huge for local supply without proper cold storage and network facilities, the farmers solely depend on processors and exporters. The domestic market network is not yet established due to logistical and organizational problems. There is ample scope for domestic market of shrimp of small count, and the growth of domestic market depends on the establishment of the supply network and infrastructure facilities at a regional and national level.

Scope for species diversity - There is an opportunity for diversification into other shrimp species, fish and crabs and pilot scale schemes should be developed for the adoption of already available technologies like sea bass and mud crab culture. The recent introduction of *P. vannamei* will be successful in the long run if biosecurity and culture practice protocols are fully followed in a rigorous manner.

Scope for post-harvest processing facility - There was no processing, and cold storage facility available, so the creation of such facilities will be helpful to farmers to store and sell their product at their discretion.

Scope for hatchery - There is only Bismi aqua hatchery available in the Nagapattinam district, catering the local need. Most of the farmers buy seed from the hatcheries located close to Chennai on East coast road and transportation of seeds to the distant locations like Nagapattinam makes the seed more costly.

Tuning of crop planning calendar - The calendar was February to July for the first crop and August to December was the second crop. About 80% of the farms culture one crop per year and the rest of farms do two crops in the year. However, farmers are changing their crop calendar now with some farmers stocked their ponds in November this year. For the summer crop, normally stocking was done in February month. Nonavailability of good seed in the market has forced the farmers to postpone stocking to March. The uncertainty of the availability of good seed is the major constraint to follow the crop calendar when *P.monodon* culture was carried out.

Location-specific techniques - Alternative technologies such a zero water exchange system; farm recirculation systems can be used in the areas where the exchange of water is not possible. The sandy areas can be utilized by applying pond lining techniques to prevent seepage.

Better leasing policy - Many shrimp farmers have established shrimp farms in the government leased out Poramboke land and are doing farming successfully. However, the leased out government lands for aquaculture purpose was cancelled since 1993 and farms were lying as unused lands. The lack of leasing policy by the state government would be a big problem for the growth of the shrimp farms. If the Government of Tamil Nadu brings the long term leasing policy of waste lands available in the coastal areas under "wasteland development scheme" for weaker sectors/unemployed youth, this will help for generating employment and upliftment of poor in the coastal regions.

Threats

New emerging diseases - WSSV remains an important pathogen of farmed shrimp. Majority of the farmers were small farmers. The rapid global spread of 'new' diseases, particularly viral diseases of shrimp has emerged as one of the most critical issues in aquaculture today. The additional threat of introduction of exotic pathogens and the resultant production losses will seriously affect the resource-poor small farmers. There is a threat to their livelihood, reduced food availability, loss of income and employment, social upheaval and increased vulnerability.

Variation in water salinity in creeks - Creek water salinity increase is mainly due to siltation of the mouth area and closure of the seaward connection. The salinity in the creek is highly fluctuating from 0 - 50 ppt. The change in salinity adds stress to the animal, affect the growth adversely in case of monodon culture. Bar mouth closes for many months led to limited water availability and water quality problems.

Development of port and power plants - Modernization of port and its development may lead to the destruction of aquaculture farms in the Nagapattinam taluk. Power plants water discharge likely to generate a near-field water temperature exceeding 40°C, that can affect aquatic animal adversely. The incipient lethal temperature of most aquatic species being in the range of 30-35°C, may lead to an adverse impact on fisheries.

Loss of stock due to cyclones - Floods and storms occur once in three or four years in Nagapattinam District and lead to enormous economic losses as it lies below mean sea level. The stock in pond, bunds, pumps, roads, aerators, sluice gates were damaged during natural disasters. There is no government scheme or insurance to support them in need of the hour.

Export market fluctuation - Fluctuation in the export market was due to declining shrimp consumption, dollar value fluctuations, rising market prices, recession in developed countries, antibiotic residue issue, preference for low-cost shrimp in developed nations due to the economic slowdown and competition from western markets. This resulted in the lack of buyers for shrimp and the reduction in prices.

Social issues - The development of shrimp culture in Nagapattinam District has created many environmental and social problems. Though shrimp culture offers many opportunities, the resource use pattern was not planned properly. Environmental problems such as conversion of agricultural lands, salinization of agricultural lands, multi-user conflicts were few among the adverse issues raised by the environmentalist. In most of the places, adverse impacts were not supported by scientific evidences. It is accused that the shrimp farms block the drainage canals at the tail end of the Cauvery delta and prevent rainwater from reaching the sea, resulting in the inundation of agricultural fields in the monsoon as an annual affair. It is also seen as a cause of aggravated impact of the tsunami and completely lacks the social acceptance of agriculture farmers.

High input costs - The cost of the inputs have increased tremendously in the last ten years. There is a huge reduction in the profit levels for the farmers and exporters due to the increase in the cost of inputs, reduction in global price for the produce, appreciation of the rupee value, and anti-dumping duties.

Change in government policies - Lack of government support for shrimp farming has been listed by many famers. There was a greater need for speedy formulation of the government policy on the coastal regulation zone, aquaculture bills, environmental regulation, reduction of electricity charges, export incentives and other measures to create a conducive atmosphere for investors to come forward and take up shrimp culture.

10

Measures for Sustainable Aquaculture

Unplanned expansion and intensification of the culture systems would put pressure on the aquatic environments leading to the degradation of the environment, with negative outcomes such as pollution, poor water quality and the emergence of diseases. Sustainable aquaculture seeks to assure a continued supply of aquaculture products within the ecological, economic and social limits, in the long term. The major challenge that could be expected in the coming years for the brackishwater aquaculture sector is how to ensure the unavoidable intensification to produce more from the unit area, without adversely impacting the environment. In general aquaculture, can generate environmental impact as a function of applied technique, size of production, the capacity of the receiving environment and location.

Aquaculture can be developed in two ways in the coastal districts such as increasing the productivity in the existing farms and expanding the farm area by utilizing potential resources. To ensure the coordinated planning in aquaculture, the systematic approach involving natural resources assessment, existing facilities, technologies available, meteorological parameters, the investment required, existing issues, constraints, and training needs to be considered at the district level.

Sustainability measures

The sector has faced several challenges related to environmental issues, climate change, growing input costs, the absence of a well-organized domestic market and dependence of single species. Also, aquaculture in the district is highly vulnerable to climate change as the farms are located on low lying land and susceptible to frequent flooding. The implantation strategies presented in the chapter is based on the analysis carried out using RS and GIS resource mapping, coupled with the field level investigation on issues, problems and requirements, survey and focus group discussion with farmers, other resource users, and Government officials aiming at sustainability.

Approaches for increasing production and productivity

Expansion of aquaculture - In addition to the existing area, aquaculture can be expanded in 1871 ha of suitable area derived from this study. Land lease policy needs to be standardized to make use of the wastelands for livelihood development. Majority were small farmers before 2009, but only 19% of them carry out *P. vannamei* farming. Hence, there is a need to promote the alternative indigenous species culture such as *P. indicus* or fish culture with less investment. The presence of multiple creeks and canals with suitable water quality in the source water bodies, appropriate soil characteristics in the potential areas are the advantages for further aquaculture growth.

Better management practices for increasing productivity - The shrimp productivity levels in the district need to be improved by adopting better management practices (BMPs), biosecurity measures, quality inputs and group approach/cluster farming. BMPs such as use of SPF seed, good pond preparation without black soil, proper lime application, quality seed selection, water quality management, adequate aeration, better feed management, farm fencing, reservoir for water intake, provisions for bird scares/bird netting, management of biosecurity protocol with well-trained employees, wastewater treatment system adhering to prescribed wastewater standards will help not only to prevent disease occurrence but also increasing operational efficiency. Aqua business companies (feed), field level aqua-consultants, progressive farm leaders can be key technical information source/advisors to promote group approach to shrimp aquaculture.

Desilting and de-weeding waterbodies - The silt deposited in the irrigation canals and drainage canal block the free flow of water. Hence farms located in the tail end suffers without quality water. Desilting will ensure the water availability to tail end farms at right time.

Optimum and efficient resource use - The higher stocking density and feeding rates of intensive shrimp culture systems require supplemental aeration to maintain adequate dissolved oxygen levels. With high energy prices, energy efficiency is becoming much more important when comparing aeration techniques and devices. The survey carried out in the district indicated that high aeration is being used to maintain culture. Adequate energy use will reduce the production cost by Rs.5/kg.

Diversification of species - Dependence of single species, *P. vannamei* is a major challenge faced by the aquaculture in the country. Diversification into different finfish and shellfish species are very much needed to provide sustainable standard income to the small scale farmers. As *P. vannamei* culture is the high investment and risk-oriented, identification of suitable alternative indigenous species will help to improve the marginalized coastal population. As of now among finfishes, standardized seed production technology is available only for Asian seabass. As an alternative species, few farmers have taken up Asian seabass culture in trial mode at Sirkali Taluk of Nagapattinam District, and the possible production was 2.5-3 t/h. CIBA and RGCA also supplied seabass seed for cage culture and the production was 10 t/ha. Though the seabass culture is profitable, the absence of proper marketing channel is the major constraint for its growth.

Capacity building - Technical consultancy from the qualified persons will result in a successful culture. As shrimp farming is a fast growing enterprise, the entry of qualified consultants will help to adopt sustainable shrimp farming technologies. Capacity building at the taluk level for adopting better management practices, the impacts of climate change in the culture environment and their effective management will help to promote modern shrimp farming. Farmer field school approach which encourages experimenting and experiential learning could be the suitable methodology for capacity building of farming community.

Structural measures for sustainability

Structural measures with standard engineering practices are suggested to withstand heavy wind forces and also to prevent the floodwaters from entering the aquaculture farms.

Monitoring canals – In addition to desilting and de-weeding canals, regular monitoring and maintenance of embankments of rivers, canals, distributors, before the monsoon will enable the free flow of water.

Construction of buffer /barrier - Barriers and buffers along the coasts can be a useful risk reduction measure against gushing waters in case of tsunami/storm surge during cyclones and also keep water away from the floodplains in hatchery and farm locations.

Providing bio-shield - Reforestation programme and improvement of the vegetation cover will increase water infiltration capacity of the soil and act as a bio-shield against natural calamities.

Avoiding flooded areas - Liable to be flooded areas to be avoided or removed from planning for aquaculture. A well-designed proper farm significantly reduces the cost of construction and safeguards the farm in case of extreme events with the smooth and trouble-free operation for the production activities.

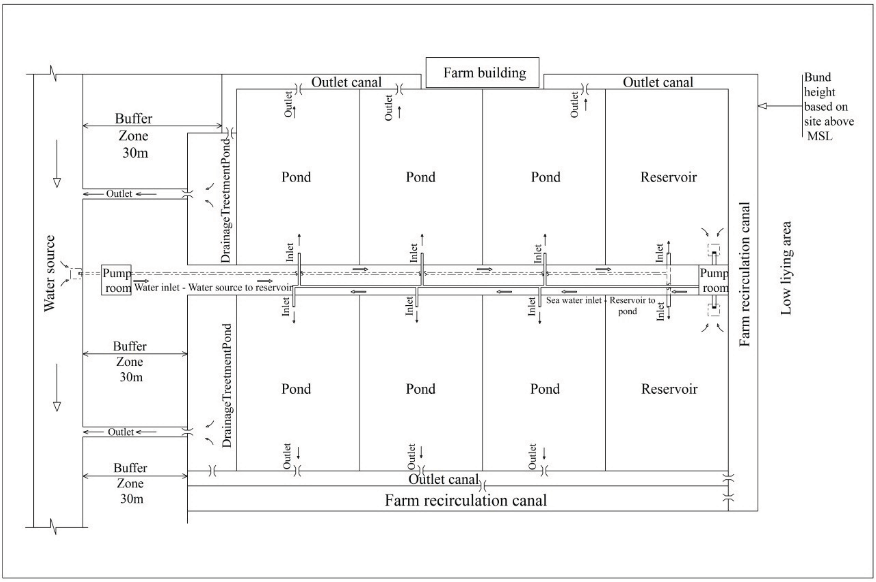

Fig.10.1 Recirculating canal shrimp farm design for flood-prone regions

Flood-prone farm design - Aquaculture farmers can efficiently manage extreme events to an extent by modifying the farm design and adapting resilient measures. Much improvement in adapting climate change could be achieved by incorporating requirements based on the lessons derived from the history of climate extremes management needs into farm design. Recirculation canals in addition to the reservoir, special design of periphery dikes, location-specific designs based on site elevation, community participation in preparatory measures; desilting source water bodies can aid in tackling the climate variability. Thus, greater effort should be devoted to developing better farm designs and community-based strategies for managing extreme weather events (Jayanthi et al., 2018).

Improved farm design with integration of recirculation canals around the farm (Fig. 10.1) in vulnerable coastal areas will help the farmers to prevent the flooding and also make use of the recirculated water without depending on water from the outside environment. This will prevent the loss of aquaculture stock and facilities, disease introduction, overtopping of water and reduced maintenance cost.

Modified scientific farm design increases the stability of the farm, protects the farm from extreme events /heavy rains, prevents floodwater entry to farm, safeguards the farm from a disease outbreak, ensures farm operations independent of outside environment, helps to cope up with climate variability, reduces the maintenance cost and supports maintaining good water quality. Majority of the farmers in the district are small farmers, constructed the farm ponds with basic requirements for farming without proper design for the location of the site or consideration on growing climatic variability.

Fig.10.2 recirculation canl around the shrimp farm

Many farms are located with the same elevation of MSL. Reservoir capacity of 25% of the farm area and recirculation canals with a width minimum of 3 m will serve the farm to hold the water as closed-loop.

Fig.10.3 Outer periphery shrimp farm dyke in flood prone low lying regions

The farm recirculation canal around the ponds (Fig. 10.2) with an elevation below the ground level will help to hold the water for farming and also as water harvesting during heavy rains. The height of outer bund of farm recirculation canal is to be designed based on site elevation above mean sea level and records of flood frequency and intensity, inundation occurred in the particular area. The height of the dike needs to be increased on the side of the open exposed, vulnerable area (Fig. 10.3). The optimum water depth requirement for *P. vannamei* culture ponds is 1.2 -1.4 m as it is column dwelling species and increasing the depth of water will help in increasing the stocking density. Provision of a central drainage system will help to remove the sludge from the pond bottom.

Cluster reservoir facilities - Small farmers, may not be able to culture *P. vannamei* as they cannot afford reservoir pond. Efforts need to be made to make the community-based reservoir formation, that will benefit the small scale *P. monodon* farmers to get *P. vannamei* license.

Farm electrification - Frequent power cut and no electricity subsidy for aquaculture adversely affect the small farmers as high cost involved in diesel increases the input cost. Hence making additional facilities for undisturbed supply of electricity and also to extend the electricity in identified areas of expansion will help the farmers to save energy cost.

Cold storage facilities - Cold storage facilities of 20000 T will support the district to keep the products for longer days to get a better price. There were no local processors as such, only agents are working for the seafood exporting companies functioning in the district. Hence the processing unit will help the farmers to a great extent.

Policy measures for developing aquaculture

Greater attention is required from policymakers on the part of policy formulation. The following are the policy measures to be considered for shrimp aquaculture by Department of Fisheries, Government of Tamil Nadu.

Licensing of farms - Majority of the farms are yet to get the licenses, and many farm owners are not traceable. Awareness needs to be created and needs to be dealt very seriously by the state department to ensure all farms are registered for shrimp farming before the operation.

Banking assistance and Insurance scheme - Non-availability of bank loans and insurance coverage for shrimp farming was the major problem during the planning stage and also at the time of extreme climate events such as flooding. Hence mechanism should be drawn to provide the banking assistance and insurance to the crop and infrastructure.

Expansion in identified areas - The suitable areas identified for aquaculture development should be used for future expansion in a phased manner. Zoning coastal areas for multiple users is one of the widely accepted methods that can avoid possible conflicts arising out of competition in resources use between aquaculture and others.

Fixing minimum price - There is no standardized rate for different counts of shrimp produce. Monopoly in price fixation affects the farmers adversely. Hence setting a minimum price for different counts will help the farmers to get the standard price of their products.

Extreme climate contingency plan - Damages to aquaculture has to be included as one of the subjects like agriculture to make on the spot assessment of damages caused by the calamity with justifiable relief.

Adaptations to manage climate change

Autonomous adaptation - measures need to be taken up at the farmers level and the planned adaptations to be taken up by the planners, development departments and research institutions.

Seasonal variations - To manage the problems due to seasonal and temperature changes, aquafarmers need to modify the water exchange regimes, the use of probiotics and minerals to improve the water quality, stock SPF shrimp seed, better aeration during night, increase the depth of water column, tree planting on bunds, postponing of seed stocking for a month and culture of alternative species.

Changing crop calendar - Changing the cropping season to advance the harvest before the monsoon, netting around the bund and increase the bund height were the adaptive measures suggested to deal with extreme events like heavy rain, flood, and cyclone.

Farmer level adaptations - Advanced harvest, Increase the height of the bunds, compacting the bunds with grass, Plantations on the bunds, Netting around the bund, Pre-emptive harvest can be practiced by the farmers to manage the changing climate

Planned adaptations - Advanced early warning systems (before 48 hrs); Opening of bar mouth, Dredging of canals, including aquaculture for natural calamity relief, insurance, and institutional credit are suggested measured from the Government departments. The study suggested that there is a need to strive for developing an alternative shrimp/fish species culture, adoption of strategies for effective implementation of climate change impacts.

Farmers first - The concept of "Farmer First" should be adopted while developing climate resilient adaptive measures incorporating the indigenous knowledge, wisdom, and experience of the farmers which ensures that the adaptation simple, cost-effective and voluntary adoption.

Shrimp aquaculture is moderately vulnerable to climatic variations but highly vulnerable to extreme events. Planned adaptive measures are either at the rudimentary level or non-existence. Hence policy initiatives are required to formulate planned adaptive measures to enhance the adaptive capacity of the farmers. Participatory approach with a strategy of inter-departmental coordination is essential to deal with climate change impacts and minimize the vulnerability of shrimp aquaculture sector.

Conclusions and Future Needs

Increasing developmental undertakings in the coastal resources have generated multifaceted conflicts between different stakeholders competing for space and conservation. Though aquaculture development can play a vital role for self-reliant food security and the economic growth of the country by using waste and unproductive lands, global attention was drawn not only due to the economic success but also because of the environmental issues raised over the unplanned, unregulated and unsustainable development, affecting ecologically important coastal habitats. Adverse environmental impacts related to shrimp aquaculture have been widely reported and raised questions about the sustainability of the sector. In addition to competing resource use, changing climate and extremes bring tremendous stress on resource use pattern in coastal regions. Spatially-referenced data, GIS based spatial analytical tools, and MCDSS provide numerous ways to manage and allocate resources.

Geospatial planning (GSP) process will be crucial for aquaculture development as it minimizes the risk of demands, makes the sector more environmentally safe and reduces the conflicts. A district has been choosen as the extent of study area, as decentralized planning in each state occurs at the district level in the country. The Nagapattinam District of Tamil Nadu was chosen for the model study as the region is well known for the vulnerability to extreme climatic events with low-lying topography, which can serve as a model for many climate hazardous district plans. The present effort on district level planning for aquaculture incorporates resource availability and quality, the status of and issues in farming, future expansion possibilities, existing infrastructure facilities, multiple stakeholders, climate extremes, the impacts of climate change on resource availability, and the present environmental regulations laid down by the Government of India.

The availability of space plays a major role in deciding the possibility of meeting the future food demand from aquaculture, however the GSP will play a primary role to ensure the allocation of space for aquaculture for the required area extent. Successful GSP, including the co-location of compatible activities, depend on the preparedness of the relevant stakeholder's participation, as it does on tools and techniques for finding suitable areas. The integration of suitable sectors is an intricate and controversial issue, which depends on a multitude of aspects, including comprehensiveness, transparency of the procedure and of decision-making, control, trustworthiness of the data and science and timing and neutral facilitation. Finally, GSP needs to be updated and flexible enough in the aquaculture sector to respond to varying circumstances, changes in ecological conditions, societal demand, growth expectations and policy.

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ICAR- Central Institute of Brackishwater Aquaculture
(Indian Council of Agriculural Research)
#75, Santhome High Road, MRC Nagar,
Chennai , Tamil Nadu, 600028.
Web : www.ciba.res.in