Political Ecology of Brackishwater Aquaculture in Purba Medinipur Coastal Plain, India

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by

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Under the supervision of

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Dedicated to my son

MIKU

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CERTIFICATE FROM THE SUPERVISOR

This is to certify that the thesis entitled "**Political ecology of brackishwater aquaculture in Purba Medinipur coastal plain, India**", submitted by Smt. **Mrinmoyee Naskar** (Index No. 20/20/Geo./26), who got her name registered on 7th October, 2020 for the award of Ph. D. (Science) Degree of Jadavpur University, is a bona fide research and absolutely based upon her own work under my supervision and that neither this thesis nor any part of it has been submitted for either any degree/ diploma or any other academic award anywhere before.

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Date: 12/03/2025

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The researcher was born in Burdwan, West Bengal, India on 19th March, 1984. She attended Rammohan College, Kolkata from 2002 to 2005, and graduated with a Bachelor of Arts in Geography. She obtained her Masters of Arts in Geography with specialization in Environmental Geography from Calcutta University in 2008. She is serving as Assistant Professor of Department of Geography at Baruipur College Since 2017. She qualified UGC-NET examination in June 2012. She joined the Department of Geography, Faculty of Science, Jadavpur University on 10th October, 2020 and started her doctoral research on *Political Ecology of Brackish Water Aquaculture in Purba Medinipur Coastal Plain, India*. Her research interests include political ecology, GIS based landscape modelling, and agricultural sustainability assessment with special reference to climate change. She has published several research papers and chapters in peer reviewed journals and edited book volumes.

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In Journal:

Naskar, M., Neogy, S., Roy, A. K., & Datta, D. (2024). A landscape in turmoil: characterizing the multi-decadal growth trajectory of brackishwater aquaculture in Medinipur Coastal Plain, India. *Ecological Questions*, 35(3), 1-28.

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In Seminars and Conference:

Presented a paper titled ‘Political Ecology of CBA in Purba Medinipur Coastal Plain of West Bengal’ in 59th Annual Meeting of the Association for Tropical Biology and Conservation, Coinbatore, India, 2nd July, 2023.

Presented a poster titled ‘Impacts of commercial brackish water aquaculture on the coastal habitat and biodiversity of West Bengal, India: an assessment applying remote sensing data and perception study’ in 59th Annual Meeting of the Association for Tropical Biology and Conservation, Coinbatore, India, 2nd July, 2023

Presented a paper titled ‘Assessment of environmental impacts of commercial brackishwater aquaculture in Medinipur Coastal Plain of Eastern India’ in IRALE Conference, Murti, West Bengal, 21st – 23rd February, 2024.

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Abstract

Exponential growth of export-oriented coastal brackishwater aquaculture (CBA) has become a research concern in academic and policy discussions on account of its diverse social and environmental consequences. Political ecology provides a multi-dimensional perspective of this global activity and explores the resultant dynamic interactions between man and environmental processes associated with it. In India, CBA expanded across multiple states causing massive alternation of coastal landscape and impacting the regional coastal ecology. Besides, it has triggered a number of environmental as well as social problems. CBA proliferation in the coastal C.D. Blocks of Purba Medinipur district of West Bengal has largely impacted the environmental, socio-economic, and political landscapes; which need to be investigated following a comprehensive as well as nuanced approach like political ecology. In this backdrop, the present research primarily focussed on the identification of the spatio-temporal patterns of growth of CBA in the study region, its effects on the coastal environment, and its subsequent impacts on the socio-political environment. Furthermore, the research also sought to formulate a number of implementable guidelines towards sustainable management of the coastal agro-ecosystems. For this purpose, remote sensing based satellite image analysis, water and soil samples collection and analysis, and schedule based questionnaire survey and FGDs were conducted. Data derived from various sources were statistically analysed and various maps were generated for better understanding of the scenarios. The results indicated that the area under CBA was continuously growing throughout the entire region in the last three decades at the cost of erstwhile croplands, waterbodies, and vegetation patches including coastal mangroves. However, a reversal of this trend could be noticed since 2021, wherein the land under CBA has reduced substantially and a notable portion of the aquaculture farms became abandoned. Besides, the unscientific farm management practice alarmingly impaired regional soil and water quality. In general, introduction of commercial shrimp farming has largely affected traditional livelihoods and altered the existing social and economic structure in a way that has triggered numerous social problems and distress among the local coastal community. The recent plunge of Indian shrimp market and the resultant abandonment of huge amount of shrimp farms has worsened the situation. In this context, a number of realistic guidelines were formulated for policy-level interventions towards the sustainable management of the coastal agroecosystems.

Keywords: Abandoned shrimp-farm, Coastal ecology, Environmental degradation, Landscape modification, Shrimp aquaculture, Socio-economic vulnerability

Content

List of Abbreviations

AHP	Analytic Hierarchy Process
AGEPS	Average Gender Equity Problem Score of a Particular Site
ALI	Asset Level Index
ALOI	Agricultural Land Ownership Index
APCS	Average Payment Compensation Score
ASCS	Average Social Conflict Score
ASPS	Average Social Problem Score
BAP	Best Aquaculture Practices Standards
BOD	Biochemical Oxygen Demand
C	Carbon
C&I	Criteria And Indicator
C.D. Block	Community Development Block
$Ca(OH)_2$	Calcium Hydroxide
CA-ANN	Cellular Automata and Artificial Neural Networks
$CaCO_3$	Calcium Carbonate
CaO	Calcium Oxide
CBA	Coastal Brackishwater Aquaculture
CBAIRVI	CBA-Induced Regional Vulnerability Index
CBCP	Central Pollution Control Board
CEI	Composite Educational Index
CIBA	Central Institute of Brackishwater Aquaculture
CIFRI	Central Inland Fisheries Research Institute
CIN	Climate-Information-Networking
Cl	Chlorides
Cl_2	Chlorine
COD	Chemical Oxygen Demand
CPEVI	Composite Perceptual Ecological Vulnerability Index
CRZ	Coastal Regulation Zones
CSII	Composite Social Impact Index
CSIR-NIO	Council Of Scientific & Industrial Research-National Institute of Oceanography
DEM	Digital Elevation Model
DO	Dissolved Oxygen
EC	Electrical Conductivity
EDF	Environmental Defense Fund
EHP	Enterocytozoon Hepatopenaei
EJF	Environmental Justice Foundation
EWM	The Entropy Weighing Method
FAO	Food And Agriculture Organization
FGD	Focus Group Discussions
FSI	Food Security Index
GAA	Global Aquaculture Alliance
GCP	Ground Control Point
GIS	Geographical Information System

HALS	Household Agricultural Landholding Score
HALS	Household Asset Level Score
HES	Household Education Score
HFSS	Household Agricultural Landholding Score
HIS	Household Income Score
HLDS	Household Livelihood Diversity Score
HLHS	Household Landholding Score
HTI	House Type Index
HTS	House Type Score
II	Income Index
IMNV	Infectious Myonecrosis Virus
ISA Net	Industrial Shrimp Action Network
K	Potassium
KCl	Potassium Chloride
LDI	Livelihood Diversity Index
LOI	Land Ownership Index
LULC	Land Use/ Land Cover
MAP	Mangrove Action Project
MCDA	Multi-Criteria Decision Analysis
MCDM	Multi-Criteria Decision-Making
MCP	Medinipur Coastal Plain
MFI	Micro Finance Institutions
$MgCl_2$	Magnesium Chloride
MOLUSCE	Modules Of Landuse Change Evaluation
MPEDA	Marine Products Export Development Authority
N	Nitrogen
NaCl	Sodium Chloride
NGO	Non-Governmental Organization
NH_3-N	Free Ammonia
NIS	Negative-Ideal Solution
NRDC	Natural Resources Defense Council
OC	Organic Carbon
OLI	Operational Land Imager
P	Phosphorus
PIS	Positive-Ideal Solution
RGEPS	Gender Equity Problem Score Assigned by Each Respondent
RMSE	Root Mean Square Error
RPCS	Response Score of The Respondents Regarding Payment of Compensation
RS	Remote Sensing
RSCS	Response Score of The Respondents Regarding Level of Social Conflict
RSPS	Social Problem Score Assigned by Each Respondent
TDS	Total Dissolved Solids
TIRS	Thermal Infrared Sensor
TK	Total Potassium
TM	Thematic Mapper
TN	Total Nitrogen
TOC	Total Organic Carbon

TOPSIS	Technique For Order of Preference By Similarity To Ideal Solution
TP	Total Phosphorus
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WFS	White Feces Syndrome
WHO	World Health Organization
WSSV	White Spot Syndrome Virus
WWF	World Wildlife Fund

List of Symbols

Gi	Getis-Ord Gi
A_b	Best alternatives
A_w	Worst alternatives
d_j	Degree of variation of vital information for the j^{th} indicator
Ed_b^+	Euclidean distance of the i^{th} target alternative from the best alternative
Ed_w^-	Euclidean distance of the i^{th} target alternative from the worst alternative
e_j	Entropy of j^{th} indicator
J_-	Positive impact
J_+	Negative impact
Mv	Total number of verifiers
r	Response
r_{ij}	Normalized score of j^{th} indicator for i^{th} CBA pond
s	Assigned scores to the responses
w	Assigned weightage to the livelihood options
$w_{ij}(d)$	Elements of the contiguity matrix for distance d
w_j	Final entropy weight for each indicator
WS_{ij}	Final normalized weighted score of an indicator
$\overline{x}$	Arithmetic Mean
x_{ij}	Standardized score of the j^{th} indicator for the i^{th} CBA pond

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Chapter I:

Introduction

1.1 Background of the study

Aquaculture is considered to be a reliable source of foreign exchange for nations and a source of income for marginalized communities inhabiting coastal floodplains in the third world (Stonich & Bailey, 2000). From 1980s, brackishwater aquaculture, especially shrimp farming, rapidly pervaded throughout the coastal zones of tropical countries in Asia, Latin America, and Africa (Stonich & Bailey, 2000; Hall, 2003) largely replacing traditional livelihoods and significantly transforming the natural habitat over widespread areas (Cruz-Torres, 2000; Pradhan & Flaherty, 2007).

In India, coastal brackishwater aquaculture (CBA) expanded across the coastal states of West Bengal, Orissa, Andhra Pradesh and Tamil Nadu, in response to the massive demand for shellfish in the global market (Pattanaik & Prasad, 2011). Consequently, vast tracts of lands along the coastal plain with higher soil salinity and low productivity of rice were rapidly converted into CBA farms, leading to substantial land use transformations (Dutta et al., 2016). Even though the growth of brackishwater aquaculture generated considerable livelihood opportunities and foreign revenue, it triggered a number of environmental and social problems (Hein, 2000; Rajitha et al., 2007; Pattanaik & Prasad, 2011). These problems were particularly common in the coastal districts of West Bengal, especially Purba Medinipur, which experienced rapid growth of brackish water aquaculture (Bhattacharya, 2012; Dutta et al., 2016).

The boom in export-oriented shrimp aquaculture has become a popular topic in academic and policy discussions on account of its diverse social and environmental consequences (Pokrant, 2009). It has also become a significant issue in political economy, which explains the impact of economic as well as political structures on commercial shrimp aquaculture (Hall, 2003). However, this approach suffers from several limitations such as insufficient focus on the ecological aspect and overemphasis on economic drivers (Lemke & Lingenfelter, 2017). Instead, a political ecology approach has been considered to be an effective tool to analyse the interactions between socio-economic, environmental, and political issues associated with the intensification of aquaculture, which considerably impact the socio-economy, policies and the production landscape (Cruz-Torres, 2000; Zinzani, 2018). However, more comprehensive research is required to completely understand the complexities between social, ecological, and political issues to identify the drivers of change that primarily exacerbate conflicts over resource allocation, equitable access to resources, and economic benefits (Bush & Marschke, 2017).

Against this backdrop, the present study aimed to examine and analyse various aspects of brackishwater aquaculture including its patterns of growth, ecological impacts, and socio-political implications using a political ecology approach. The stud primarily focussed on selected coastal blocks of Purba Medinipur district, West Bengal.

1.2 Brackishwater aquaculture and coastal environmental changes

The rapid growth of brackishwater aquaculture, especially, commercial shrimp farming. has massively transformed the coastal landscape in tropical regions. It has been responsible for large-scale environmental degradation including the destruction of coastal mangroves in many countries. Moreover, it has vastly altered ecologically sensitive wetlands and crop lands (Vandergeest et al., 1999; Hossain & Hassan, 2017). The destruction of coastal mangroves is one of the most detrimental effects of the growth of brackishwater aquaculture, particularly shrimp farms. Alterations in hydrological regimes due to the construction of canals and roads, and spread of diseases to the indigenous shrimp species are additional adverse impacts (Gowing et al., 2006). Worldwide, about one-third of the mangrove vegetation was destroyed in recent decades, with coastal shrimp farming being responsible for 50 percent of the total loss (Kuenzer et, al., 2011). Other environmental degradations include coastal erosion, intrusion of saline water in the crop lands, destruction of wild shrimp postlarvae and indigenous mud crabs, as well as a decrease in soil pH (Gowing et al., 2006). For instance, in Bangladesh, approximately 1.6 percent of the total mangrove forest cover in Bangladesh was transformed to shrimp farms. Moreover, leaching from the brackishwater shrimp ponds increased the salinity level of the adjacent crop lands and resulted in the loss of soil fertility. Additionally, the conversion of natural creeks into shrimp farms adversely affected the migration of fish communities and obstructed the free flow of water (Hossain & Hassan, 2017). Similar trends were observed in Philippiness, Thailand, Vietnam, Ecuador, Malaysia, Indonesia, and China where shrimp farming led to considerable mangrove destruction, water pollution, and widespread environmental degradation (Ahn et al., 2010; Dierberg & Kiattismkul, 1996; Gowing et al., 2006; Lebel et al., 2002; Rajitha, 2007; Ren et al., 2019; Shahid & Islam, 2002).

In India, the rapid growth of commercial shrimp farms has been one of the major causes of destruction of mangroves and alteration of coastal wetlands. Between 1975 and 2005, about 12 percent of the coastal mangroves were destroyed due to the growth of shrimp farms. A LISS III image-based study in 1999 revealed that about 80 percent of mangrove forest was destroyed for construction of shrimp farms (Rajitha et al., 2007). Approximately 2381 ha of mangrove forest was destroyed in the Mahanadi delta, directly due to the construction of shrimp ponds (Pattanaik & Prasad, 2011). Also, in the Godavari Delta of Andhra Pradesh, 14 percent of the shrimp farms were constructed by destroying coastal mangroves (Hein, 2000).

1.3 Coastal brackishwater aquaculture in South and East Asia

The conducive physical environment of tropical and sub-tropical areas in South and East Asia encouraged the exponential growth of brackishwater shrimp farming, especially along the coastal areas (Hossain et al., 2013). More than 50 countries produce shrimp commercially. However, most of the production comes from the third world countries, especially those in South and East Asia including China, India, Thailand, Viet Nam, Indonesia and Bangladesh (Hossain & Hassan, 2017). Dating back to the 1400s, brackishwater aquaculture began as a traditional economic practice in the coastal districts of Indonesia. However, the sector started to expand at rapid pace from the mid-1980s with assistance from both private and public sectors, becoming a promising source of foreign exchange (Armitage, 2002). Hall (2003) noted that export-oriented shrimp aquaculture pervaded along wide stretches of coastal areas of Southeast Asia, thriving under the support provided by both government and private agencies from early 1980s.

Japan started producing shrimps from 1980s, and after meeting the internal demand, it began exporting shrimp to Europe and United States from 1990s (Hall, 2003). Similarly, in Bangladesh, traditional brackishwater aquaculture, especially shrimp farming, has had a long history, especially along low-lying the coastal areas. The expansion of shrimp farms in Bangladesh began after its independence in the 1970s. The rapid growth of demand in the global market and price hike motivated the farmers of coastal Bangladesh to convert the low-lying areas along the tidal rivers as well as agricultural lands in the more inland parts into shrimp farms during the late 1970s and early 1980s. Presently, shrimp farming is an important source of foreign exchange in Bangladesh. Commercial shrimp farming started there in 1980s and rapidly spread across the south-western coastal parts in the following decades (Pokrant, 2009; Hossain et al., 2013; Hoque et al., 2017; Hossain & Hasan, 2017; Afroz et al., 2018).

Commercial shrimp farming flourished from 1980s in Philippines, replacing the cultivation of *Chanos Chanos* (Primavera, 1995). In Vietnam, it started during the late

1990s in response to the global demand for the product, and the country became one of the largest shrimp exporters within a short span of time (Anh et al., 2010).

In India, traditional brackishwater aquaculture was widely practiced along the East coast, especially in Tamil Nadu, Andhra Pradesh, Odisha, and West Bengal for ages. However, from 1990s, aquaculture in India shifted from its traditional form and became largely an export oriented commercial activity, the area under which grew incessantly. Most of the brackishwater aqua farms cultivated shrimp which contributed considerably in earning foreign exchange as well as generating livelihood opportunities. (Rajitha et al., 2005; Pradhan & Flaherty, 2007; Pattanaik & Prasad, 2011; Ojha & Chakrabarty, 2018). From 1980s, India became one of the leading shrimp exporters in the global market (Galappaththi & Nayak, 2017). *Penaeus monodon* and *Penaeus vannamei* were the two major types of shrimp cultivated in India (Ghoshal et al., 2014). Besides shrimp, various salt water fishes, such as grey mullet (*Mugil cephalus*), Asian seabass (*Lates calcarifer*), milkfish (*Chanos chanos*), and parlspot (*Etroplus suratensis*) were cultivated in the brackishwater aquaculture farms. Although tiger shrimp dominated the brackishwater aquaculture in India since the initiation of the scientific farming, since 2009, the white-leg shrimp started to become the dominant cultured variety (Ghoshal et al.,2019).

1.4 Need of comprehensive assessment of CBA dynamics and impacts

It has been found that most of the researches on aquaculture concentrated either on the technical or land related changes that have taken place or on the policy issues pertaining to the industry. A number of theoretical and empirical researches encompassing the economic, social, and ecological aspects were also found. However, these studies, especially in the case of India, failed to explore complex topics like political interests, inconsistencies in policy, legal framework, property rights, and inequity in resource and power distribution in the context of the burgeoning brackishwater aquaculture (Naskar, et al., 2024).

In the field of political ecology, despite ample theoretical development, empirical works to comprehend social and ecological factors affecting vulnerability issues and the subsequent effects on the society are rare. While most of the political ecological studies concentrated on global policy intricacies and related power dynamics, the approach still lacks in the empirical study of human-ecology nexus at micro scale.

Although, a number of current studies in various countries have resorted to the political ecology approach to analyse ecological and socio-economic implications of brackishwater aquaculture, such works are rarely found in case of India. Moreover, they are almost absent in the case of Purba Medinipur. Most of the published literature on the brackishwater aquaculture of the study area concentrated either on its economic aspects or on related land-use change dynamics. Thus, a comprehensive study was imperative to interlink the changing dynamics of CBA with the socio-political and ecological changes shaped by the lopsided growth of brackishwater aquaculture in the coastal tracts of the study area.

The present study relied upon the political ecology approach for a comprehensive analysis of the CBA dynamics and its impacts on ecological, socio-political, economic environment of the study area.

1.5 Contextualizing CBA through political ecology approach

Political ecology explores the dynamic interactions between man and environmental processes (Young et al., 2019). Garry Peterson (2000) demarcated political ecology as an approach that interrelated ecological aspects with political economy to capture the dynamic nature of stress between the changes in environment and human society as well as between different groups within the society. Political ecology also explained how the impacts of environmental changes are unequally distributed among different groups (Rodríguez-Labajos & Martínez-Alier, 2015). Bryant (1991) strongly advocated that the study of ecological transformation and sustainable development should incorporate political attributes for a comprehensive understanding of man-environment interplay. According to him, political ecology helped in recognizing the role of multifarious social and political attributes in environmental transformation. In 1992, Bryant had advocated for the application of the political ecology approach in understanding the uneven distribution of environmental impacts on different social groups, which he considered inevitable for a sustainable policy framework (Bryant, 1992).

According to several researchers, the export oriented brackishwater aquaculture, especially shrimp farming, in Southern Hemisphere, had been rife with controversies from its inception (Stonich & Bailey, 2000). Although, the massive growth of the industry brought with it a bunch of economic and social benefits to the host country, massive ecological destruction often generated social injustice, engendering conflicts and creating a conundrum in optimizing the benefits (Hossain & Hasan, 2017). Thus, CBA attracted the attention of a wide number of researchers, who attempted to analyse multiple aspects pertinent to shrimp farming such as trend of growth, market relations, its social and ecological impacts, as well as controversies and conflicts (Belton, 2016). A considerable number of these researchers have followed the political ecology approach to establish the inter-connectedness between the local, national and international processes around aquaculture and their reflection on ecology and common people (Stonich & Bailey, 2000). Vandergreest et al., (1999) relied upon the political ecology approach to comprehend the drivers of shrimp farming in Thailand. To them, political ecology offered a ground to understand various facets of shrimp farming. They found that the local issues associated with commercial shrimp farming transcended the local and regional level and reached national and global level. Cruz-Torres in 2000 analysed how the government policies promoting commercial shrimp culture had altered the livelihood practices of the common people of Sinola, Mexico and incorporated them into global market-based economy. Hall, (2003) proclaimed that, at the international level, the antagonistic movements against commercial shrimp farming largely concentrated on environmental issues such as massive destruction of mangroves and loss of other habitat and biodiversity, whereas the local issues such as increasing salinization, contamination of water and soil, loss of land productivity, and conflicts of interest encompassing access to land and resources got less importance. The political ecology concept had been adopted to explain how the unequal distribution of financial and political power among the shrimp producers broadly governed their access to the inputs and knowledge. Some of the studies focused on replacement of too much international control over shrimp farming system by local governance to ensure more involvement of local people in decision making (Pokrant, 2009).

Thus, several studies followed the political ecology approach to elucidate myriad social and environmental issues associated with shrimp farming. In the present study, the researcher attempted to interweave the changes wrought by the rampant growth of CBA at the landscape level, as well as on the socio-political environment and economy of the studied region. For this purpose, the researcher relied upon the comprehensive approach of political ecology.

1.6 Rationale of the study

The growth of brackishwater aquaculture in tropical coasts has been a much debatable issue worldwide as well as in India. Although the growth of CBA, especially shrimp farming, has brought economic benefits to the people living in tropical coastal areas, becoming a major source of foreign exchange for third world countries, the rampant growth of the CBA has been had various adverse ecological and social implications (Pradhan & Flaherty, 2007; Penmetsa et al., 2013; Hossain & Hasan, 2017). For instance, the Environmental Justice Foundation (EJF, 2014) reported that commercial shrimp farming was associated with major environmental impairment including massive conversion of sensitive coastal mangroves, wetland and farmlands (Hossain & Hasan, 2017). A number of studies also reported that commercial shrimp farms caused both water and soil contamination in the surrounding areas due to excessive use of artificial and poor quality fish feed, chemical pesticides, and fertilizers for sustaining high stocking density. Highly eutrophicated effluents released from the aquaculture farms also caused high pollutant and silt load in the estuaries causing severe damage to the ecosystems (Barraclough & Finger-Stich, 1996; Dewalt et al., 1996; Hall, 2003; Pokrant, 2009; Hossain et al., 2013).

Beside ecological impacts, commercial shrimp farming has engendered a number of social adversities. In fact, many researchers have advocated that the social and economic harms caused by the trade-oriented shrimp farming has eclipsed its economic benefits (Hossain & Hasan, 2017). A large number of researchers also found that commercialization of aquaculture and promotion of high-value, market-oriented species, especially shrimp, ensured the profits of input suppliers and producers as well as national income from export, but neglected rural employment generation, strengthening of the rural economy, and augmenting food security. Notably, the shrimp cultured in the Third World countries were primarily exported to the developed world, thus failing to address the issue of food security of the native dwellers (Barraclough & Finger-Stich, 1996; Stonich & Bailey, 2000; Hossain et al., 2013; Bush & Marschke, 2017).

In India, growth of brackishwater aquaculture has been responsible for considerable environmental degradation as already mentioned in the preceding sections. (Bhatta & Bhat, 1998; Kagoo & Rajalakshni, 2002; Mishra et al., 2008). Major social impacts included loss of crop lands and reduction of crop productivity, loss of food security and self-reliance, and exploitation of local farmers (Kagoo & Rajalakshni, 2002; Rajitha et al., 2005; Pradhan & Flaherty, 2007; Galappaththi & Nayak, 2017). Notably, the shrimp farms were mostly owned by the urban elites with strong political affiliations, often generating incidences of forceful capture of the lands from the marginal farmers. (Hossain et al., 2013; Roy, 2013; Galappaththi & Nayak, 2017).

While several studies throughout the world addressed the ecological and social implications of CBA, very few used a comprehensive approach to assess the ecological, socio-political, and economic implications of the CBA dynamics. Unfortunately, such studies were found to be almost absent in India. Moreover, there was sheer dearth of empirical research regarding the recent growth trajectory of CBA and its implications at the landscape level as well as its impact on the ecological and socio-political environment. Thus, the growth of brackishwater aquaculture and its ecological, economic, and socio-political implications needed to be analysed with a universal approach like political ecology.

1.7 Objectives of the research

The following objectives were outlined along the principles of political ecology on the basis of evidences obtained from published works on brackishwater aquaculture and the research gaps identified from a critical review of existing literature:

a. Identification of the spatio-temporal patterns of growth of coastal brackishwater aquaculture in the selected C.D. Blocks of Purba Medinipur.

b. Assessment of the effects of growth of brackishwater aquaculture on the coastal environment.

c. Evaluation of the socio-political consequences of the growth of brackishwater aquaculture in the study area.

d. Formulation of implementable guidelines towards sustainable management of the coastal agro-ecosystems.

1.8 Research design

The detailed review of literature including published research articles, books, book chapters, reports, and web documents related to brackishwater aquaculture enabled the researcher to identify the prevailing research gaps in the study relating to the impacts of brackishwater aquaculture growth on the ecology, economy, and socio-political scenario of the study area. Information pertaining to the growth of commercial brackishwater aquaculture in the last few decades and review of works on political ecology helped the researcher to develop the research objectives.

The study area was selected on the basis of the existing literature wherein it was found that there was growth of brackishwater aquaculture, especially commercial shrimp farming in the coastal districts of West Bengal in general and in Purba Medinipur in particular. The study area was then delineated on the basis of the consistency of the growth of brackishwater aquaculture in last three decades. Three coastal Community Development (C.D.) Blocks of Purba Medinipur district of West Bengal were selected as the study area because CBA had consistently thrived there from the last three decades. A pilot survey with a semi-structured questionnaire and Focus Group Discussions (FGD) were conducted to validate the observations. The present study aimed to comprehensively analyse the impact of the CBA on landscape, ecology, and the socio-political scenario of the study area. For this purpose, the research work was designed in four interconnected stages (Fig. 1.1).

Stage I: Identification of the spatio-temporal patterns of growth of coastal brackishwater aquaculture

Spatio-temporal transformation of selected wetlands was carried out using six orthorectified, cloud-free multi-temporal satellite images of pre-monsoon months covering the study area. These images were acquired from the open-source collection of the United States Geological Survey (USGS) Glovis (http://glovis.usgs.gov) website. The satellite data included four images of Landsat 5 Thematic, one image of Landsat 8 Operational Land Imager (OLI), and one Landsat 9 Operational Land Imager 2 (OLI–2), Thermal Infrared Sensor 2 (TIRS–2). Five LULC classification maps were prepared analysing the satellite images of 1991, 2001, 2011, 2021, and 2023. Based on the raster maps, the LULC transformation matrices showing the class-wise LULC change dynamics of the study region were prepared. FGDs with the local knowledge persons and major stakeholders were also conducted to understand the CBA growth dynamics in the area and LULC patterns and validate RS and GIS-based LULC transformation.

Stage II: Assessment of the effects of growth of brackishwater aquaculture on the coastal environment.

The study took into account both field-based sampling of the soil and water for assessing the impact of brackishwater aquaculture on the edaphic conditions of the areas adjacent to the brackishwater aquaculture ponds and the aquatic condition of the brackishwater aquaculture ponds. In order to select the sampling sites, the village-wise percentage of aquaculture area was derived from the LULC map of 2021 (Fig 4.4). Based on the percentage of aquaculture area, villages of the study area were divided into three equal classes, i.e., high density zone, medium density zone, and low-density zone. From each C.D. Block (i.e. Ramnagar-II, Contai-I, and Deshapran) considered under this study, three sites were selected randomly from each of the density zones. In this manner, 27 sampling sites were identified in the whole study area. Water samples were collected from 27 brackishwater aquaculture ponds and 27 soil samples were collected from the surrounding areas of those aquaculture ponds (Figure 5.1). Besides, a perception study was conducted among various stakeholders. At each site, two aquaculture owners, three aquaculture labourers, and five farmers having farmland adjacent to the aquaculture ponds were interviewed. Additionally, one focus group discussion (FGD) was conducted at each site where six to eight participants actively participated. The soil and water samples collected from the field were analysed in the laboratory and inputs from the perception study were analysed through various cartographic techniques.

Stage III: Evaluation of the socio-political consequences of the growth of brackishwater aquaculture

For this purpose, in-depth semi-structured interviews with the brackishwater farm owners, farm workers, and farmers of the surrounding areas at each of the 27 selected sited sites were conducted. At each site, two aquaculture owners, three aquaculture labours, and five farmers having farmland adjacent to the aquaculture ponds were interviewed. Also, one focus group discussion (FGD) was conducted at each site with six to eight active participants. Responses obtained from the interviews were analysed statistically and represented cartographically for better understanding.

Stage IV: Formulation of implementable guidelines towards sustainable management of the coastal agro-ecosystems.

For this purpose, a comprehensive CBA-induced regional vulnerability index (CBAIRVI) was developed based on the selected indicators. The CBAIRVI helped to identify the level of vulnerability of various zones. Based on these observations, site-specific recommendations for sustainable management of the coastal agro-ecosystems and best practice guidelines were prepared.

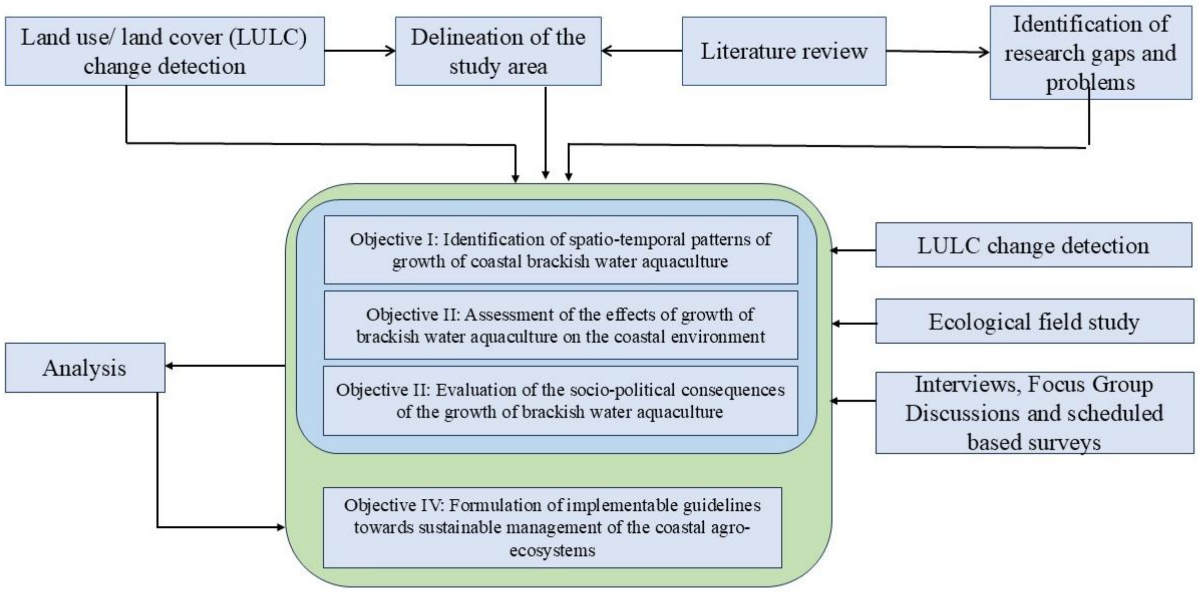

Figure 1.1: Design of the present research.

1.9 Research questions

Each objective of the given research was sub-divided into a number of research questions so that the researcher could attain them smoothly.

To identify the spatio-temporal patterns of growth of coastal brackishwater aquaculture in the selected C.D. Blocks of Purba Medinipur, the research questions that had been framed were as following:

a. What are the thriving zones of brackishwater aquaculture?
b. How has the land use/ land cover (LULC) of the studied area changed due to the growth of brackishwater aquaculture?
c. What is the pattern of growth of brackishwater aquaculture in the study area?

The assessment of the effects of growth of brackishwater aquaculture on the coastal environment was based on the following research questions:

a. What are the different ecological problems introduced in the study area after the growth of brackishwater aquaculture?
b. How are the surface water and soil of the region impacted by the growth of brackishwater aquaculture in the study area?

Evaluation of the socio-political consequences of the growth of brackishwater aquaculture in the study area was accomplished on the basis of the following research questions:

a. What are the major social and political drivers of the brackishwater aquaculture in the region?
b. How has the growth of brackishwater aquaculture impacted the social and political scenario of the region?
c. How has the growth of brackishwater aquaculture impacted different social groups?

Broad implementable guidelines towards sustainable management of the coastal agro-ecosystems were formulated on the basis of the following research question:

a. How has the growth of brackishwater aquaculture impacted different social groups?

1.10 Study area

For the purpose of the present study, three coastal Community Development (C.D.) Blocks of the Purba Medinipur district of West Bengal, lying within the Medinipur Coastal Plain, namely Ramnagar-II, Contai-I, and Deshopran were considered. Geographically, the district of Purba Medinipur lies between 22057’10” N to 21036’35” N and 88012’40” E to 86033’50” E, covering an area of 4713 sq. Km. The district is bounded by the distinct coastline of the Bay of Bengal in the south and south-east. While the district of Paschim Medinipur in West Bengal surrounds its western and northern parts, the Baleswar district of Odisha lies in the south-west. The eastern margin is defined by the Hugli estuary. The sites of the present study- the three coastal C.D. Blocks of Purba Medinipur, lie in the south-western part of the district, together covering an area that extends from 21° 39' 0" North latitude to 21° 54' 43.2" North latitude and 87° 31' 4.8" East longitude to 87° 54' 3.6" East longitude. The southern boundary of the study area is marked by the coastline of the Bay of Bengal. The other three sides of the study area are bounded by the C.D. Blocks of Ramnagar-I, Egra-I, Egra-II, Contai-III, Khejuri-I, and Khajuri-II. The congenial physiographic and demographic environment of the study area was found to have created favourable conditions for CBA to develop there as a dominant economic practice and leave its imprints on the dynamic landuse and land cover (LULC) pattern, local economy, and socio-political environment (Fig. 3.1).

1.11 Scope and limitations of the study

The present research attempted a comprehensive analysis of the impact of CBA on landscape, ecology, and socio-political scenario of the study area. For this purpose, a detailed and comprehensive review of literature was undertaken which enhanced the existing knowledge base on the development of brackishwater aquaculture, its social, economic, and political consequences across the globe and in India. Additionally, an exhaustive analysis of works based on the political ecological framework was undertaken during the review of literature since it formed the basic framework of the current research. This was considered to be a sincere attempt towards the enrichment of prevailing literature on the field of political ecology. Moreover, the present study is a pioneering work in India since the impacts of growth of CBA in the country have rarely been studied from the political ecology viewpoint.

The study sought to identify the thriving zones of the brackishwater aquaculture in the study area. It attempted to unveil the causes of clustering of the aquaculture ponds in specific areas based on localised physical and social environment. It also aimed to identify the pattern of growth of brackishwater aquaculture in the study area. For this purpose, analysis was carried out for all the assessment years which helped to detect the changing pattern of clustering of the aquaculture farms. The study assessed how the LULC pattern of the study area changed due to the growth of brackishwater aquaculture. It also identified the factors of growth and recent trends of development of brackishwater aquaculture in the studied region. To detect the growth trajectory of CBA, the percentage of Census Village-wise aquaculture area was calculated for the assessment years, i.e., 1991, 2001, 2011, 2021, and 2023, and was predicted for the year 2025. This approach was a novel attempt in this field. The study also undertook field sample-based assessment of the edaphic condition of the lands adjacent to the brackishwater aquaculture fields and aquatic condition of the brackishwater ponds, enhancing its accuracy. Furthermore, it took into account the primary survey-based data to analyse the socio-political consequences of the growth of brackishwater aquaculture which made the study authentic. Lastly, the development of comprehensive CBA-induced regional vulnerability index (CBAIRVI) and its mapping enabled the researcher to formulate site specific guidelines towards sustainable management of the coastal agro-ecosystems which might be further applied for the policy framework. Such vulnerability indexing with required modification can be applied for assessing the vulnerability of the brackishwater aquaculture throughout the globe. Altogether, the study will be able to abridge the existing knowledge gap which is required for local as well as regional policy formulation.

As far as limitations of this study were concerned, data scarcity and accessibility were the most important problems faced in course of the entire research. Since the study was a pioneering work in the region, the researcher faced an utter dearth of secondary data. As a result, the researcher had to rely mainly upon primary data. Besides, few questions regarding the political aspects were very sensitive and therefore, the field-surveys had to be carried out with utmost caution. The collection of soil and water sample was also quite difficult and time taking due to the typical physical terrain criss-crossed by numerous creeks and canals. Moreover, satellite images that were analysed belonged to pre-monsoon season to get cloud free data. Thus, the choices of satellite images was also limited. Lastly, as a major part of the study was conducted during the COVID-19 pandemic period, the researcher faced various struggles, especially while conducting the questionnaire-based survey.

1.12 Definition of key terms

Aquaculture is the breeding, rearing, and harvesting of fish, shellfish, algae, and other organisms in all types of water environments.

Brackishwater aquaculture is an activity to produce fish, shellfish, seaweed etc. in the areas adjoining coastal waters by making suitable impoundments or enclosures.

Intensive shrimp aquaculture is characterised by high stocking density in small ponds with average size of 0.1 to 0.5 ha. It is also input-intensive and largely relies on artificial fish feed, chemical fertilizers, pesticides, and farm machinery for frequent recycle of water and aeration facilities. Average yield ranges from 5,000 to 20,000 kg per hectare (Barraclough & Finger-Stich, 1996; Hall, 2003; Bhattacharya, 2009).

Salinization of soil is an excessive accumulation of water-soluble salts.

Eutrophication is the process in which a water body becomes overly enriched with nutrients, leading to the plentiful growth of simple plant life.

Common property refers to the type of property rights that are collectively owned and administered.

Conflict is an active disagreement between people with opposing opinions or principles

Hot Spot Analysis calculates the Getis-Ord Gi* (Gi) statistic for features in a weighted set of features. Given a set of weighted data points, the Gi statistic identifies the clusters of points with values higher in magnitude and tells whether features with high values or features with low values tend to cluster in a study area. In Gi statistics, if a feature's value is high, and the values for all its neighbouring features are also high, it is part of a hot spot (Anselin, 1995).

Focus group discussions are often used as a qualitative approach for a deeper understanding of socio-economic, ecological, and environmental issues. The technique involves obtaining information on a specific ecological or environmental issue from a particular group of purposefully selected individuals who have some knowledge regarding that problem.

Criteria and Indicators are sets of measures and conditions which are integrative and holistic, clearly defined, easy to measure and record, and acceptable to all stakeholders. C&I has been used here to monitor the wetland's ecological health and address the amount of degradation already incurred to achieve wetland ecosystem sustainability and human well-being.

MCDA*,* also known as Multi-Criteria Decision-Making (MCDM), is about making decisions when multiple criteria (or objectives) need to be considered together.

The entropy weighing method (EWM) is a frequently used weighing method that assigns weights according to the discriminating power of indicators. The biggest advantage of EWM is to create reliable weights for both qualitative and quantitative indicators and ensure the objectivity of evaluation results by avoiding the interference of human factors in weight determination (Lotfi & Fallahnejad, 2010; Zhu et al., 2020).

Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is a multi-criteria decision-making (MCDM) method. It is based on the principle that the preferred alternative has the least geometric distance from the positive ideal solution and the most from the negative ideal solution.

The positive ideal solution maximizes the benefit criteria and minimizes the cost criteria.

The negative ideal solution maximizes the cost criteria and minimizes the benefit criteria.

1.13 Outline of the study

The present study attempted to reveal the impacts of the rapid growth of coastal brackishwater aquaculture on the landscape, coastal ecology, and socio-political dynamics of the three coastal C.D. Blocks of Purba Medinipur district of West Bengal. To accomplish these objectives, the thesis was divided into eight chapters as given below:

The first chapter was an introduction to the research in general which presented its background, theoretical orientation as well as the rationale behind it. The objectives of the study were enlisted here along with details on the basic methodological framework or the research design.

The second chapter contained detailed reviews of research works relating to the various aspects of brackishwater aquaculture. It reconstructed the history of brackishwater aquaculture and the present distribution of the same worldwide. It also unveiled the factors that played a crucial role in the growth of brackishwater aquaculture, especially in the global south. Moreover, the detailed literature review explored the various ecological and social impacts of brackishwater aquaculture at global, national, and regional scale. Special emphasis was given to the field of political ecology with a detailed discourse on its origin, and evolution. The importance of political ecology as a separate field of inquiry as well as a tool in studying socio-ecological phenomena was examined through an in-depth assessment of various research works across the globe and India. Finally, the studies dealing with the various aspects of brackishwater aquaculture from political ecology viewpoint were reviewed.

In the third chapter, a nuanced description of the geography, climate, edaphic condition, biotic condition, demography, and socio-economic profile of the selected study area was provided. Besides, the environmental condition favourable for CBA growth in the Medinipur Coastal Plain and the rationale behind selecting three C.D. Blocks of Purba Medinipur as study sites was described.

Chapter four dealt with the spatio-temporal growth of CBA in the studied region. In this chapter, patterns of LULC transformation were analysed through five LULC maps and corresponding LULC transformation matrix. A prediction map of 2025 was also prepared. Census village-wise growth pattern was analysed and clustering pattern was analysed based on the hot spot maps. The drivers of the growth and growth pattern were discussed in detail.

In chapter five, the physico-chemical effects of CBA growth on the coastal environment of the study area were analysed. For this purpose, the results acquired from the analysis of soil and water samples were analysed. To understand the spatial variation of various edaphic and aquatic indicators, spatial maps were also prepared. Also, the findings of the perception-based study regarding the environmental problems were assessed and represented cartographically.

Chapter six dealt with the evaluation of the socio-political consequences of the growth of CBA in the study area. For this purpose, the data gathered from the semi-structured questionnaire surveys and FGDs were analysed. Moreover, the history of growth of brackishwater aquaculture in the study area was reconstructed. Various indexes were prepared to assess the socio-economic status of various stakeholders to portray the inequity that existed within the society. An economic vulnerability index was prepared to reveal the existing economic vulnerability of the brackishwater aquaculture farm owners. Also, a social impact index was prepared to depict the social impacts of the brackishwater aquaculture in the study area. Lastly, the drivers and nature of the conflicts between various social groups around the issue of brackishwater aquaculture growth were analysed.

In chapter seven, a comprehensive assessment was done to understand the CBA induced regional vulnerability using multiple criteria decision analysis (MCDA). Entropy Weighting Method (EWM) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) was applied to develop a comprehensive CBA-induced regional vulnerability index (CBAIRVI). The result was mapped using spline interpolation, which clearly showed the zones with various levels of vulnerability.

The last chapter enumerated several recommendations which could be of assistance for sustainable management of the coastal agro-ecosystems, especially brackishwater aquaculture. The recommendations included site specific recommendation for sustainable management of CBA, proposed best practices, and restorative aquaculture principles.

Chapter II:

Review of literature

2.1 Understanding brackishwater aquaculture

Aquaculture can be described as the production of fish in constructed or natural water bodies through alterations in the natural setup with the aim of larger production to meet increasing protein demands (Anyanwu et al., 2007). The cultivation of tiger shrimp, white-leg shrimp, and various salt water fishers, such as milk fish, mullets, catfish, seabass, milkfish etc. are common in brackishwater aquaculture. However, shrimp farming has been considered as the most profitable and thus is cultivated commercially in many countries of the world. Brackishwater aquaculture, especially shrimp farming, has been considered to be a reliable source of foreign exchange for nations globally as well as income opportunity for the marginalized communities inhabiting coastal floodplains in the third world (Barraclough & Finger-Stich, 1996; Stonich & Bailey, 2000). Consequently, it rapidly pervaded throughout the coastal zones of the tropical countries of Asia, Latin America, and Africa (Barraclough & Finger-Stich, 1996; Stonich & Bailey, 2000; Hall, 2003) since 1990s, largely replacing traditional livelihoods and transforming the natural habitat over widespread areas (Cruz-Torres, 2000; Pradhan & Flaherty, 2007).

Brackishwater shrimp farming is generally classified into four groups, namely, traditional, extensive, semi-intensive, and intensive. This categorization is primarily based on the nature of stocking density, intensity, and source of inputs used (Hossain et al., 2013; Ghoshal et al., 2019). However, some researchers have classified it into five categories namely, extensive, improved-extensive, semi-intensive, intensive, and super-intensive (Raux & Bailly, 2002; Bhattacharya, 2009). The average pond size ranges between 2 ha to 5 ha (Bhattacharya, 2009). Traditional shrimp aquaculture is practiced in wide parts of Southeast Asia, especially in Philippines and Indonesia for ages in conventional milkfish ponds.

Conventional aquaculture is an extensive farming practice that was established largely in the low-land areas along the coasts and rivers which depended on tidal movement for both food and shrimp fry supply. The average yields ranged from 50 to 500 kg per hectare (Hall, 2003; Bhattacharya, 2009; Ghoshal et al., 2019). This extensive method is almost similar to the traditional method but for the use of fertilizers and manures to produce feed. In this system, the average pond size ranges between 2 ha to 5 ha (Bhattacharya, 2009). Some seeds are stocked from hatcheries. The average production ranges between 1500 kg ha^{-1} and 1700 kg ha^{-1} in Indian Sundarbans (Ghoshal et al., 2019). The semi-intensive tiger shrimp (*Penaeus monodon*) aquaculture in Asia began with techniques developed in

Japan and Taiwan between the 1930s and 1970s. This method is more capital, technology, and labour-intensive than traditional farming, relying heavily on artificial feed and hatchery-reared shrimp fry. Stocking densities are much higher compared to traditional systems, with yields ranging from 50 to 5,000 kg ha^{-1} (Hall, 2003; Bhattacharya, 2009), and pond sizes typically vary from 0.25 to 4 ha (Bhattacharya, 2009). The high stocking densities and heavy use of external feed often led to increased vulnerability to disease outbreaks (Ghoshal et al., 2019). Intensive shrimp farming is characterized by very high stocking densities in small ponds, usually between 0.1 and 0.5 ha. This system is input-heavy, relying on artificial fish feed, chemical fertilizers, pesticides, and farm machinery for frequent water recycling and aeration. Yields range from 5,000 to 20,000 kg ha^{-1} (Barraclough & Finger-Stich, 1996; Hall, 2003; Bhattacharya, 2009). In some regions, shrimp farming alternates with paddy cultivation, as seen in Kerala, India, where paddy is grown from June to September, followed by shrimp farming from November to April (Gupta et al., 2001).

2.2 Present global distribution of CBA

The conducive physical environment of tropical and subtropical regions has prompted the rapid growth of brackishwater shrimp farming there, particularly in the coastal areas (Hossain et al., 2013). The lucrative economic returns from commercial shrimp farming have led global agencies and national governments to enthusiastically promote its expansion in coastal regions of South America, Africa, and Asia. Traditional shrimp farming began hundreds of years ago in Southeast Asia's coastal areas. Semi-intensive shrimp farms emerged in Latin America between the late 1970s and early 1980s, while intensive farming gained traction in Africa, particularly in Tanzania, during the 1990s. The majority of farm-raised shrimp is produced in Asia and Latin America. Thailand, followed by India, Indonesia, and the Philippines, leads production in Asia. The other globally important producers are China, Ecuador, Mexico, Colombia, Vietnam, Brazil, Bangladesh, and Honduras (Barraclough & Finger-Stich, 1996; Stonich & Bailey, 2000; Pokrant, 2009).

2.3 Growth trajectory of CBA

At present, commercial shrimp farming is extensively practiced in more than fifty countries worldwide, primarily in developing tropical regions. The ever-increasing demand from developed nations, primarily for crustaceans, has stimulated the rapid expansion of this agro-industry, thereby generating substantial environmental concerns in the economically disadvantaged producer nations of the tropical region, in general (Hossain & Hasan, 2017; Roy et al., 2021b).

2.3.1 Global scenario

Traditional shrimp aquaculture has been practiced for centuries across large parts of Southeast Asia, particularly in the Philippines and Indonesia, often within conventional milkfish ponds (Hall, 2003). With declining marine fish stocks and the rising global demand for fish protein, aquaculture has surged, surpassing all other forms of animal husbandry in growth (Dewalt et al., 1996; Pradhan & Flaherty, 2007). Among aquaculture products, shrimp has experienced the most remarkable growth. Stonich and Bailey (2000) noted that shrimp production from farms skyrocketed between 1975 and 1995, increasing by 300% from 1975 to 1985 and by another 250% from 1985 to 1995. Global shrimp production increased by 34% between 2002 and 2008 (Hossain et al., 2013).

Brackishwater aquaculture in Indonesia dates back to the 1400s, where it began as a traditional economic activity in coastal districts. However, the industry experienced rapid expansion starting in the mid-1980s, driven by both private and public sector support, becoming a major source of foreign exchange (Armitage, 2002). In Honduras, aquaculture boomed in the early 1980s, soon establishing itself as one of the largest shrimp producers in the Western Hemisphere. By 1993, about 11,500 ha of semi-intensive shrimp farms, focused on exports, had sprung up along southern Honduras' estuaries, aided by foreign loans and technical assistance (Dewalt et al., 1996). Similarly, export-driven shrimp aquaculture proliferated along vast stretches of Southeast Asia’s coastlines from the early 1980s, bolstered by government and private sector support (Hall, 2003).

Japan began shrimp farming in the 1980s, meeting domestic demand before expanding exports to Europe and the United States in the 1990s (Hall, 2003). In Bangladesh, traditional brackishwater aquaculture, particularly shrimp farming, has a long history, especially in the low-lying coastal regions. After gaining independence, shrimp farming expanded significantly in the 1970s. The rising global demand and price hikes during the late 1970s and early 1980s encouraged farmers to convert low-lying tidal areas and even inland agricultural lands into shrimp farms, making the industry a key part of the national economy. This rapid growth, often referred to as the "Blue Revolution" in Bangladesh, was supported by noteworthy financial and infrastructural assistance from both the national government and international donors (Pokrant, 2009; Hossain et al., 2013;

Hoque et al., 2017; Hossain & Hasan, 2017; Afroz et al., 2018). In Vietnam, commercial shrimp farming began in the late 1990s in response to the rising global demand and quickly positioned the country as one of the largest shrimp exporting countries worldwide (Anh et al., 2010).

2.3.2 National scenario

Several studies have documented that traditional brackishwater aquaculture in India has long been practiced along the eastern coast, particularly in Tamil Nadu, Andhra Pradesh, Odisha, and West Bengal (Rajitha et al., 2005). However, since the 1990s, India's aquaculture industry has transitioned from its traditional form to a more export-oriented commercial activity, leading to continuous expansion. The majority of brackishwater aquaculture farms cultivate shrimp, contributing significantly to foreign exchange earnings and creating livelihood opportunities (Pradhan & Flaherty, 2007; Pattanaik & Prasad, 2011; Ojha & Chakrabarty, 2018). By the 1980s, India had emerged as a major shrimp exporter in the global market (Galappaththi & Nayak, 2017). The primary shrimp species farmed in India are *Penaeus monodon* and *Penaeus vannamei* (Ghoshal et al., 2014). In addition to shrimp, various saltwater fish species are also farmed in these brackishwater systems, including grey mullet (*Mugil cephalus*), catfish, Asian seabass (*Lates calcarifer*), milkfish (*Chanos chanos*), and Pearl Spot (*Etroplus suratensis*). While tiger shrimp cultivation dominated India's brackishwater aquaculture for many years. Since 2009, the white-leg shrimp has become the dominant species (Ghoshal et al., 2019).

India’s cultured shrimp production surged from 25,401.20 metric tons in 1988 to 130,949.55 metric tons in 2006 (Ghoshal et al., 2019). Substantial investments were made in the industry during this period, with semi-intensive and intensive shrimp farms emerging through the conversion of paddy fields in coastal areas (Hein, 2000). A geospatial investigation by Prasad et al. (2019) identified five major coastal aquaculture zones in India; namely the Gangetic Delta of West Bengal, the Eluru area of Andhra Pradesh, the Vedaranyam region of Tamil Nadu, the Cambay region of Gujarat, and the Kutch region of Gujarat. The study found over 408,000 aquaculture ponds, each averaging less than one hectare in size, covering a total area of 3,200 km^2, with the majority concentrated along the eastern coast, particularly in the Krishna-Godavari Delta of Andhra Pradesh and the Gangetic Delta of West Bengal (Prasad et al., 2019).

Commercial shrimp farms began thriving along Karnataka's coast in the 1990s as private investors recognized the profitability of the sector. To facilitate this growth, the state government amended land reform laws, enabling the easy conversion of agricultural land into shrimp farms (Bhatta & Bhatt, 1998). A study by Pradhan and Flaherty (2007) in the Bhadrak district of Odisha revealed that shrimp farming generated nearly 60 times more income than rice farming, prompting many farmers to switch from paddy to shrimp cultivation. However, only a few obtained the proper authorization to do so (Pradhan & Flaherty, 2007).

2.3.3 Regional scenario

Brackishwater aquaculture, done in '*bheries*', is an age-old practice in the coastal districts of West Bengal. However, export-oriented semi-intensive tiger shrimp production started in the late 1980s and grew exponentially until 1995, when production halted due to a massive disease incursion (Ghoshal et al., 2014). West Bengal contributed a major share of India's total brackishwater fish and shrimp production. The state also exported a notable amount of shrimp and crab. Tiger shrimp was the dominant cultured species in brackishwater aquaculture in West Bengal. However, since 2009, the production of white-legged shrimp has dominated (Ghoshal et al., 2019). Brackishwater aquaculture in West Bengal is primarily practiced in Purba Medinipur, South 24 Parganas, and North 24 Parganas (Roy, 2013). According to Ojha & Chakrabarty (2018), the area under brackishwater shrimp farms has been increasing continuously, particularly in some coastal areas of West Bengal. The lucrative profit margin provided the initial impetus for local farmers to adopt commercial shrimp farming over traditional paddy cultivation.

2.4 Factors of growth and dominance of CBA

2.4.1 Food security

Aquaculture has been considered to have the potential to supplement the protein demand of the growing human population amid the decline in marine supply (Hossain & Hasan, 2017; Stonich & Bailey, 2000). For countries like India, where food security has always been a significant challenge, especially amid shrinking agricultural lands, aquaculture presents an enormous opportunity to bridge the widening gap between protein demand and supply (Hossain & Hasan, 2017; Ghoshal et al., 2019). Aquatic food is rich in nutritional value and is one of the most extensively exported food products globally. It accounts for more than fifteen percent of the animal protein consumed by people, particularly those in developing countries, and the rate of consumption continues to rise (FAO, 2012).

2.4.2 Economic promotion

The exponential demand for shrimp in the global market, especially in the USA, Japan, and the European Union, along with the consequent high market prices and scope for reliable export earnings, has encouraged the booming of commercial shrimp farming in tropical coastal areas (Barraclough & Finger-Stich, 1996; Hossain et al., 2013; Galappaththi & Nayak, 2017). Aquaculture is considered as a reliable source of income and protein supply for marginalized communities inhabiting coastal floodplains of the tropical and sub-tropical countries (Barraclough & Finger-Stich, 1996; Stonich & Bailey, 2000). Shrimp farming has emerged as one of the most profitable livelihood options for farmers in otherwise lesser fertile coastal lands with high salinity (Hossain et al., 2013). Being a potential source of foreign exchange, the growth of shrimp farming in the coastal areas of developing countries received significant impetus from both national and international investors (Barraclough & Finger-Stich, 1996; Béné, 2005). In Bangladesh, for example, shrimp contributes 81% of the total export-oriented national earnings from frozen foods. Shrimp farming also plays a major role in employment generation (Pokrant, 2009; Hossain et al., 2013). The growth of the shrimp industry has also spurred the development of several ancillary industries (Pokrant, 2009; Hoque et al., 2017).

Both national and various state governments in India have promoted the aquaculture industry as part of the 'blue revolution' (Naganathan et al., 1995; Bhatta & Bhat, 1998). To mobilize the growth of the industry and meet land demand, state land-use policies were altered to enable the conversion of estuarine land (Bhatta & Bhat, 1998). To amplify export earnings, the Indian government began promoting the growth of brackishwater aquaculture in the late 1980s through various initiatives, including liberalizing export policies, formulating fisheries schemes under Five-Year Plans, encouraging more investments in aquaculture, developing infrastructure, and creating provisions for loans, among others. The government's initiatives were also backed by financial and technical support from international investors. Due to high profitability, shrimp farming became the most important and widely cultured activity in this sector, attracting substantial investments from private companies. Between 1995 and 2004, shrimp production increased from 635,030.07 metric tons to 160,594.33 metric tons (Pradhan & Flaherty, 2007). The unviability of paddy cultivation in coastal areas with high salinization and the potential for high economic returns from brackishwater aquaculture prompted the rapid growth of aquaculture farms along extensive stretches of coastal areas in India (Dutta et al., 2016). Brackishwater aquaculture plays a vital role in national foreign exchange earnings and offers sustainable livelihood opportunities to a vast number of marginal coastal communities (Rao, 1981; Silas, 1983; Hein, 2000; Gupta et al., 2001; Pattanaik & Prasad, 2011).

Both traditional and semi-intensive scientific shrimp cultures are practiced in West Bengal (De Jong, 2017). The conducive environment and impetus from the national government have fostered the prolific growth of brackishwater aquaculture in the coastal tracts of the Purba Medinipur district and the Sundarbans of West Bengal (Dutta et al., 2016). Naskar et al. (2024), based on their study in the Contai-I, Ramnagar-II and Deshapran Blocks of Purba Medinipur district, proclaimed that brackishwater aquaculture has become a more reliable source of income for farmers than low-yielding rice cultivation. Moreover, the introduction of brackishwater aquaculture has made the saline-infested coastal tracts, which were otherwise unfavourable for crop production, suitable for livelihood generation (Naskar et al., 2024). Brackishwater aquaculture has become a lucrative source of income for the people of the Sundarbans living adjacent to the saline estuaries, where lands were otherwise mostly infertile (Burman, 2015).

2.4.3 Globalization

Globalization has been an important factor in integrating and networking global service providers and producers in the agro-food sector and promoting global collaborative ventures involving South American, Asian, European, and U.S.-based agencies and governments (Stonich & Bailey, 2000). Many global agencies, including the World Bank, the Food and Agriculture Organization of the United Nations (FAO), and the Asian Development Bank, are actively involved in the process, which gives continuous technical and financial support to augment the industry in developing countries (Hossain & Hasan, 2017).

2.5 Ecological impacts of CBA

A wide number of empirical as well as theoretical research works have illustrated the multifarious ecological and social impacts that have emerged from commercial shrimp farming (Kagoo & Rajalakshni, 2002; Pradhan & Flaherty, 2007; Hossain et al., 2013; Pokrant, 2009; Galappaththi & Nayak, 2017). In spite of its commendable contribution to social and economic well-being, the development of brackishwater aquaculture in the coastal areas of the tropics has remained fraught with controversies owing to the perpetual degradation it has wrought on the environment (Béné, 2005; Anh et al., 2010; Hossain &

Hasan, 2017; Kagoo & Rajalakshni, 2002; Pradhan & Flaherty, 2007; Hossain et al., 2013; Pokrant, 2009; Galappaththi & Nayak, 2017).

2.5.1 Global scenario

The Environmental Justice Foundation (EJF) reported that commercial shrimp farming is linked to significant environmental degradation, including the large-scale conversion of sensitive coastal mangroves, wetlands, and farmlands (Hossain & Hasan, 2017). Since the 1970s, aquaculture in general, and shrimp farming in particular, has expanded rapidly, leading to considerable ecological and social impacts (Galappaththi & Berkes, 2015). Commercial shrimp farming has caused environmental degradation in various ways, including the destruction of mangroves, soil and groundwater pollution, salinization, and outbreaks of diseases (Barraclough & Finger-Stich, 1996; Vandergreest et al., 1999; Cruz-Torres, 2000; Stonich & Bailey, 2000; Hossain et al., 2013; Galappaththi & Nayak, 2017; Hossain & Hasan, 2017). Several studies have indicated that commercial shrimp farms contribute to water and soil contamination in surrounding areas due to the excessive use of artificial fish feed, chemical pesticides, and fertilizers necessary to sustain high stocking densities. The highly eutrophic effluents released from these farms increase pollutant and silt loads in estuaries, causing severe damage to ecosystems (Barraclough & Finger-Stich, 1996; Dewalt et al., 1996; Hall, 2003; Pokrant, 2009; Hossain et al., 2013). Poor management practices, such as high stocking densities and the overuse of chemical fertilizers, pesticides, and antibiotics, have made commercial shrimp farming vulnerable to frequent disease outbreaks, posing a significant challenge to the industry in recent decades (Barraclough & Finger-Stich, 1996; Stonich & Bailey, 2000; Hall, 2003; Hossain et al., 2013; Hossain & Hasan, 2017). Vandergreest et al. (1999) reported that a disease outbreak devastated Thailand's shrimp industry in 1996, while excessive nitrogen contamination caused bacterial and fungal diseases that collapsed Taiwan's production system in 1988 (Barraclough & Finger-Stich, 1996).

The extensive destruction of mangrove forests in the Philippines, Thailand, and Indonesia during the latter half of the 20^{th} Century is attributed to the expansion of shrimp farming (Pokrant, 2009; Hossain et al., 2013). Vayda and Walte (1999) documented the substantial clearing of coastal mangrove forests for aquaculture between the 1940s and 1970s in Bais Bay and Banacon Island, Philippines. Dewalt et al. (1996) noted that the growth of shrimp farms along the estuarine areas in Honduras led to the extermination of large proportions of mangrove forests, alterations to the hydrological regime due to the construction of roads and dykes, and significant damage to estuarine biodiversity. Their study indicated that shrimp aquaculture directly destroyed one-third of the mangrove forests along the Gulf of Fonseca through construction activities and indirectly impaired the hydrological system. Furthermore, the collection of wild shrimp fry from estuarine areas led to significant loss of both estuarine and marine biodiversity (Dewalt et al., 1996). Here, the increasing number of fishermen has also placed greater pressure on land and fishing resources (Dewalt et al., 1996). Similar issues have been reported in the Sinaloa region of coastal Mexico, where pollutant-laden water from semi-intensive shrimp farms has degraded lagoon ecosystems (Cruz-Torres, 2000). The expansion of shrimp farms has posed serious threats to other natural resources, including mangroves and estuarine biodiversity, particularly wild shrimp populations. The expansion of coastal aquaculture has also led to significant damage to Indonesia's mangrove forests. For instance, in the Banawa district, 69% of the pristine mangrove forest was destroyed over fifteen years (Armitage, 2002).

The expansion of brackishwater shrimp farming has resulted in the destruction of approximately 6,500 ha of mangroves along Bangladesh's coastal areas. The collection of wild shrimp fry and the destruction of large amounts of by-catch have caused significant loss of estuarine and marine biodiversity in the Sundarbans (Pokrant, 2009; Hossain et al., 2013; Islam & Yasmin, 2017). Moreover, the unplanned development of shrimp farms has led to waterlogging and inundation of adjacent croplands, significantly increasing soil salinity and impairing soil fertility, while also deteriorating both surface and groundwater quality. Additionally, the overuse of fertilizers and chemicals in fish farms has harmed the biodiversity of surrounding areas (Datta et al., 2010; Hossain & Hasan, 2017; Afroz et al., 2018). The monoculture of shrimp has reduced local finfish and shellfish diversity, while also leading to the loss of croplands, diminished floral biodiversity, and a crisis in fuel, fodder, and grazing land for local communities. Due to the massive and unplanned growth of shrimp farms in Bangladesh, the floodplain has undergone significant landscape changes, with natural wetland areas being heavily impacted. Most natural canals have been converted into shrimp farms, hindering the migration routes of indigenous fishes and threatening the overall biodiversity of local waters. The construction of embankments within these canals has blocked natural drainage systems, often leading to waterlogging and inundation of adjacent crop fields (Hossain & Hasan, 2017).

The impoundment of saline water in lowlands for shrimp farming has increased salinity in surrounding areas, causing major damage to agriculture and reducing the availability of potable water (Hossain et al., 2013; Islam & Yasmin, 2017). Furthermore, the excessive extraction of groundwater has lowered the water table and led to salinization, rendering existing agricultural lands unviable for crop production (Hall, 2003; Hossain et al., 2013; Hoque et al., 2017). Hoque et al. (2017) reported that the expansion of brackishwater shrimp aquaculture since the 1970s has contributed to rising soil and water salinity in coastal Bangladesh. Islam and Yasmin (2017) noted that numerous scholars have reported various adverse environmental effects caused by the chemical fertilizers and pesticides used in shrimp farms. The haphazard expansion of shrimp farms has also led to the extermination of wetlands and drainage congestion (Haque, 2015). Vandergreest et al. (1999) indicated that salt intrusion from shrimp ponds near agricultural lands was responsible for the devastation of rice and sugar palm production in Thailand. Pollutants released from these ponds have also destroyed near-shore fisheries in the region (Vandergreest et al., 1999). In response to global shrimp demand, the Vietnamese government began promoting shrimp culture in the early 1990s, resulting in a transformation from extensive to intensive production systems, which has had significant implications for sensitive coastal ecosystems (Anh et al., 2010). According to Anh et al. (2010), intensive shrimp farms in Can Gio district of Vietnam generate considerable amounts of pollutants that increase with the age of the ponds due to inadequate management practices, leading to surface water pollution in surrounding areas. Hossain and Hasan (2017) argued that the value chain of commercial shrimp farming also has a high emission footprint, with the production process and transportation for international marketing requiring significant fuel consumption.

2.5.2 National scenario

Shrimp farming in India has been embroiled in various controversies from the outset, primarily regarding its social and environmental impacts (Hein, 2000). Multiple studies have highlighted the environmental hazards associated with the rise of commercial brackishwater aquaculture in India's coastal regions. These threats include the destruction of mangrove forests and vital coastal ecosystems, reduced agricultural productivity due to soil and groundwater salinization, and increased soil and water pollution, largely attributed to inadequate farm management practices (Hein, 2000; Rajitha et al., 2007; Pradhan & Flaherty, 2007; Pattanaik & Prasad, 2011; Dutta et al., 2016; Rajesh et al., 2016).

Pattanaik and Prasad (2011) identified significant adverse effects stemming from the rapid growth of commercial aquaculture, despite its economic contributions. Their research revealed extensive degradation of coastal ecosystems, particularly mangroves and wetlands, along with the mass conversion of agricultural land and heightened water pollution and soil salinization. Analysing satellite imageries from 1973 to 2006, the authors noted that most land conversion occurred post-1980, with substantial areas of mangrove forests, croplands, and water bodies being transformed into brackishwater farms in the Mahanadi Delta of Orissa. The study also pointed out the excessive use of chemicals, medicines, and artificial feeds in these shrimp farms, which contributed to various environmental issues (Pattanaik & Prasad, 2011).

In the Bhitarkanika region of Odisha, shrimp aquaculture ponds utilized saline water from the Brahmani-Baitarani River system, discharging pollutant-laden water back into the environment (Mishra et al., 2008). Mishra et al. (2008) found that this polluted effluent posed a significant threat to coastal ecosystems. The expansion of shrimp farming along India's east coast has led to marked declines in existing mangrove forests. A remote sensing study in the Godavari Delta indicated that approximately 14% of aquaculture farms were established by clearing mangrove areas (Hein, 2000). Satapathy et al. (2007) reported considerable mangrove loss due to aquaculture expansion from 1992 to 2004, with increased sediment and pollutant loads in the estuarine system from aquaculture effluent. Penmetsa et al. (2013) documented that the rapid growth of intensive brackishwater farms from 2001 to 2013 had severely degraded the soil and water quality in surrounding areas. Furthermore, extensive mudflats in Kerala have been converted into brackishwater farms (Gupta et al., 2001).

Coastal regions of India that became unsuitable for paddy cultivation due to salinization were rapidly transformed into brackishwater aquaculture sites. The promise of high economic returns from aquaculture incentivized the conversion of rice fields and mangrove areas at an alarming rate (Dutta et al., 2016). Rajesh et al. (2016) noted that the rapid expansion of brackishwater aquaculture since 2000 has significantly altered land use patterns in the coastal areas of Nagapattinam, Southeast India. Their study, utilizing remote sensing and GIS, illustrated the exponential growth of aquaculture in this region, resulting in the conversion of large areas of mudflats, coastal swamps, and cropland, thereby reducing crop land, water bodies, and vegetation cover. Field observations indicated considerable negative environmental impacts, including degradation of soil and water quality (Rajesh et al., 2016).

Bhatta and Bhat (1998) reported that over 65% of productive cropland in Karnataka had been converted to commercial fisheries since the 1990s. Once these lands were transformed, they became unsuitable for agriculture, rendering restoration economically unviable and technically impossible (Bhatta & Bhat, 1998). Similar findings were reported by Pradhan and Flaherty (2007) in Bhadrak district, Odisha. Hossain and Hasan (2017) highlighted that rampant shrimp farm expansion in Andhra Pradesh has led to mangrove destruction and salt intrusion into paddy fields.

Research has also indicated that shrimp production in India encountered significant challenges in the mid-1990s due to the outbreak of white spot disease (Hein, 2000; Rajitha et al., 2007; Jayanthi, 2011). Kagoo and Rajalakshni (2002) emphasized the need for environmentally sustainable practices in aquaculture, highlighting the various environmental repercussions associated with the industry. Their empirical findings suggested that agricultural areas and human settlements within a 3 km radius of aquaculture farms were particularly vulnerable to salinity and pollution (Kagoo & Rajalakshni, 2002). Rajarshi and Santra (2011) noted that saline water seepage from brackishwater aquaculture was a significant contributor to increased soil salinity around aquaculture farms near Bhitarkanika National Park. The growth of prawn aquaculture in Chilika since the 1980s has resulted in detrimental ecological consequences for Chilika Lake and its surrounding areas, significantly altering its hydrological and biochemical dynamics (Dujovny & Mohanty, 2007; Dujovny, 2009).

2.5.3 Regional scenario

Dutta et al. (2016) reported that land use and land cover in the coastal regions of West Bengal are undergoing rapid changes due to the extensive expansion of aquaculture. A remote sensing and GIS-based study in two coastal blocks of East Medinipur revealed that many aquaculture farms were established illegally, leading to significant conversion of croplands, water bodies, and fallow lands. Between 2006 and 2011, approximately 1194 ha of land were converted for brackishwater aquaculture. This swift conversion, coupled with poor management practices, has resulted in adverse social and environmental consequences, including reduced food crop production, loss of biodiversity, and increased soil and water salinity.

Using remote sensing techniques, Ojha and Chakrabarty (2018) found that shrimp farming expanded significantly at the expense of fertile croplands, particularly paddy fields, in the coastal C.D. Blocks of Purba Medinipur district, West Bengal. Their study documented an increase of 1,661.26 ha in brackishwater aquaculture between 2008 and 2016. In contrast, the same period saw a loss of approximately 1,945.31 hectares of cropland, along with substantial areas of fallow land, vegetation, and natural water bodies. This unchecked growth of aquaculture has caused considerable damage to natural resources and has negatively impacted the surrounding ecological balance. The authors also noted a significant rise in soil salinity and pH levels in areas surrounding brackishwater fish ponds, which has severely affected rice productivity (Ojha & Chakrabarty, 2018). Roy et al. (2021) based on the analysis of the satellite images, reported that between 1998 and 2008 and between 2008 to 2018 there was 7.76% and 24.85% increase in brackishwater aquaculture respectively in the coastal tracts of Medinipur mainly at the cost of crop lands. They have also found that, the incessant growth of coastal brackishwater aquaculture has considerable environmental implications including increase in ground water salinity and pH which has adversely impacted the crop yield in the region (Roy et al., 2021b). Dey et al. (2024) based on their empirical study in the Medinipur coastal plain found that, the amount of blue carbon sequestration in the areas covered by coastal brackishwater aquaculture ponds was much less in comparison to the amount of blue carbon sequestered in the covered by other LULC classes (Dey et al., 2024).

2.6 Socio-political impacts of brackishwater aquaculture

2.6.1 Global scenario

Although a group of researchers strongly advocated that the growth of aquaculture has strengthened the rural economy by generating livelihood opportunities, exalting the scope of higher income, and thereby augmenting the rural standard of living (Pradhan & Flaherty, 2007; Galappaththi & Nayak, 2017), a notable number of studies have endeavoured to identify the trade-offs that largely nullified the benefits generated from the sector (Barraclough & Finger-Stich, 1996; Cruz-Torres, 2000; Pradhan & Flaherty, 2007). Besides ecological and economic impacts, commercial shrimp farming has introduced a number of social adversities. Many researchers have advocated that the social and economic harms caused by trade-oriented shrimp farming have eclipsed the economic benefits (Hossain & Hasan, 2017). A large number of researchers have found that the commercialization of aquaculture and the promotion of high-value, market-oriented species, especially shrimp, have ensured the profits of input suppliers and producers as well as national income from exports, hindering the scope of ameliorating rural employment, strengthening the rural economy, and augmenting food security. Moreover, the shrimp cultured in developing countries were aimed to be exported to the developed world, thus were broadly unable to address the food security issue of the native dwellers (Barraclough & Finger-Stich, 1996; Stonich & Bailey, 2000; Hossain et al., 2013; Bush & Marschke, 2017). Also, most of the revenue that was earned from the farms was ultimately added to the urban capital, utterly depriving the rural areas (Bush & Marschke, 2017). The profit from intensive shrimp production is mainly garnered by the large feed and medicine-producing companies and shrimp processing companies (Barraclough & Finger-Stich, 1996). In addition to this, the growing use of low-priced fish for the production of fish feed has challenged the available protein supply for the poor (Stonich & Bailey, 2000).

To encourage the growth of shrimp farming, in many countries, the land use policy has been changed. This has been, in many cases, influenced by the politically influential actors for reaping their own benefits. For instance, in Malaysia, the Land Acquisition Act was altered in 1991 for encouraging the development of shrimp farms. This has caused massive landscape changes and deprived the local people of access to the land, water, and other natural resources traditionally used by them to support their livelihoods (Barraclough & Finger-Stich, 1996).

Stonich and Bailey (2000), after reviewing a wide number of works, have proclaimed that the degradation of coastal ecosystems, especially the destruction of mangroves due to an increase in brackishwater shrimp farming, has challenged the availability of natural resources for the local community. The dependence of the native dwellers on mangroves for their daily needs of food, fuel, and shelter has been utterly challenged in many cases, which has ultimately impaired their overall well-being. The destruction of natural resources due to the spread of shrimp farming has often instigated further complex social consequences such as resource crises, social injustice and inequality, and loss of livelihood, which in many cases have impoverished the small producers, etc. (Stonich & Bailey, 2000). In coastal Mexico, semi-intensive shrimp farms grew at a rapid rate as the government encouraged more private investments in the sector. This had led to the weakening of the native fishing cooperatives and the gradual marginalization of the indigenous fishing communities and their common property rights on lagoon resources. Although the growth of commercial shrimp farming promised livelihood opportunities, only a few local people could reap the actual benefits from the industry, for the fact that employment opportunities offered to the native people were very much seasonal and sporadic in nature (Cruz-Torres, 2000). In Bangladesh, the capturing of the creeks by the shrimp growers, which were common property resources for the rural community to collect fish, wild plants for food, and fodder for the cattle, has challenged the lives of the common populace (Hossain & Hasan, 2017). The growth of commercial shrimp culture in most cases promoted the rural affluent class along with absentee investors, who had systematically exploited the native peasants for their profit maximization (Galappaththi & Nayak, 2017). For instance, in Bangladesh, the government started leasing the lands and introduced the licensing system, which were mostly grabbed by the economically affluent and politically connected class, largely depriving the native populace (Hossain & Hasan, 2017). Even in the community-based shrimp culture in Sri Lanka, politicians were engaged in the appropriation of wetlands, applying their power (Galappaththi & Berkes, 2015). An empirical study in the Banawa coastal area of Indonesia documented a similar scenario where most of the owners of the aquaculture farms belonged to people from the well-off class, bureaucrats, and investors from outside. The introduction of capital- and technology-intensive aquaculture amplified ethnic divisions and discontent (Armitage, 2002). The study found that while the products and benefits generated from coastal aquaculture were largely hogged by the well-off class, the local marginal landholders by and large had to rely on the dwindling common property resources (Armitage, 2002).

Dewalt et al. (1996), based on their empirical work in Honduras, showed that since the onset of commercial shrimp farming, the farms were under the control of a few large producers, ignoring the involvement of marginalized communities. Moreover, the government promoted the growth of shrimp farms in the coastal areas, which largely challenged access to natural resources as well as traditional livelihoods of the local people. Contention propagated between the large companies and local people, encompassing a multifarious conflict of interest ranging from the process of land allocation for shrimp farming to access to natural resources. Unrest in many cases took violent forms, ranging from road blockades to torching company establishments (Dewalt et al., 1996). Hall (2003), in his work, ascertained that in many parts of Asia, shrimp farms were established on government-owned lands that were largely occupied by native dwellers, and the spread of shrimp farms expelled common property rights in many cases, which has triggered social unrest (Hall, 2003).

Based on the empirical studies in coastal Bangladesh, Hoque et al. (2017) showed that with the booming of brackishwater shrimp aquaculture in coastal Bangladesh, there has been exponential growth in demand for land, which led to an immediate crisis for land. This yawning gap between demand and supply instigated social problems like forceful land expropriation, fraudulent dealing, etc. Economically rich people, using their political network, often managed to coerce the native peasants (Hoque et al., 2017). The financially affluent community, often hailing from outside, gradually took hold of the production system, alienating the native farmers (Haque, 2015). Hossain and Hasan in 2017 and Afroz et al. in 2018 reported that the introduction of commercial shrimp farming gave rise to a new affluent class, and the land that was owned by the rural farmers was grabbed by a small section of rural well-offs and urban elites. Especially in the southwest coastal areas of Bangladesh, the wake of commercial shrimp farming has massively altered the land ownership structure, where more politically and economically powerful groups forced the enticed and sometimes coerced the small peasants to sell their lands at compromised prices. There were also instances of forceful capture of the lands from marginal farmers. This has disrupted the whole social hierarchy in the affected villages (Hossain & Hasan, 2017; Afroz et al., 2018). Asymmetries in the distribution of political and economic power aggravated the situation and gave way to more inequity in land and resource distribution (Hossain et al., 2013; Hoque et al., 2017).

Massive alterations in land ownership and the resultant imbalance caused an increase in the number of landless farmers, declining rice productivity, as well as forced withdrawal from common property rights. Shrimp farming introduced monoculture in coastal Bangladesh, which largely replaced labour-intensive traditional rice cultivation. Enticed by immediate financial profit, smallholders compromised rice cultivation and age-old supplementary livelihoods. Lack of capacity to safeguard against market fluctuations and outbreaks of diseases often caused major financial disruptions. These have often compelled marginal peasants to migrate outside in search of livelihoods (Pokrant, 2009; Hossain et al., 2013; Hoque et al., 2017). The introduction of shrimp farming encouraged investors from outside to invade the village economy, which threatened the traditional social structure (Pokrant, 2009; Hossain et al., 2013; Hoque et al., 2017). The effects of disruption of customary production relations and the invasion of outsiders in the system were often manifested in the violation of human rights.

Conflicts of interest between supporters of brackishwater shrimp farming and their antagonists, in most cases rice farmers, had intensified, which often took violent forms in Bangladesh (Datta et al., 2010b; Pokrant, 2009; Hossain et al., 2013; Hoque et al., 2017). Due to the rampant conversion of rice fields into shrimp farms, a huge number of sharecroppers and agricultural labourers lost their livelihoods. This created massive resentment among the larger native populace against the affluent shrimp farmers, who, in most cases, were urban elites, which often took violent forms. Between 1990 and 2010, more than 150 people were killed and thousands were injured due to such violent conflicts (Datta et al., 2010b). Altogether, the superimposition of market-oriented shrimp farming on the traditional rice farming-based village society has economically altered social and economic relationships, production systems, and traditional village hierarchy and triggered social conflicts of various scales (Pokrant, 2009; Hoque et al., 2017).

Hossain et al. (2015) found that the growth of modern technology-based commercial shrimp farming has caused notable changes in rural societies of the coastal villages and caused abrogation of traditional livelihoods, loss of land and food security, social strife, and marginalization of rural farmers. The conversion of cropland, most of which were under a multiple cropping system, was converted to shrimp farms. As a result, there was tremendous pressure on the existing cropland. To adapt to this situation, the farmers adopted high-yielding varieties and stopped cultivating traditional rice varieties (Ali, 2006). The authors found that in Bangladesh, the rapid conversion of paddy fields to shrimp farms, intake of labour in the shrimp farms, and rapid reduction of crop production due to a considerable increase in soil salinity have caused excess labour and forced agricultural labourers and landless farmers to migrate to urban areas in search of livelihoods. The wake of commercial shrimp farming triggered notable inequity within society, as the benefits were not equally shared among the various social classes, as it has largely failed to generate employment and engendered poverty and marginalization. This has instigated social conflicts and fierce clashes between the shrimp growers and traditional farmers.water aquaculture in Southeast Asia is mostly run by individual small farmers (Galappaththi & Berkes, 2015). Vandergreest et al. (1999), in their study, noted that the environmental pollution propagated by the shrimp farms undermined the inland fisheries, an important traditional livelihood based on common property. Accelerating concern among the native farmers regarding the shrimp farming-induced threats to traditional livelihoods has often instigated discontent against the propagation of shrimp farms in the villages of Thailand (Vandergreest et al., 1999). The rampant growth of CBA has caused massive alterations to traditional livelihoods, including paddy farming, and amplified food insecurity among the marginal community, leaving them with the threat of a lack of alternative livelihoods (Hossain & Hasan, 2017).

2.6.2 National scenario

Brackishwater aquaculture played an important role in stimulating livelihood opportunities and augmenting the scope of ready cash income for coastal communities. With the advent of commercial aquaculture, the poor farmers of the salt-infested coastal areas started acquiring better wages. Income generated from shrimp cultivation was far more promising than income from traditional rice cultivation (Batta & Bhat, 1998; Kagoo & Rajalakshni, 2002; Rajitha et al., 2007; Dutta et al., 2016). However, the benefits of commercial aquaculture were not reflected in the overall well-being of the native people, particularly due to the wide range of environmental and social challenges that stemmed from the lack of monitoring and management practices. Major social impacts included loss of cropland and reduction of crop productivity, loss of food security and self-reliance, and estrangement and exploitation of local farmers (Kagoo & Rajalakshni, 2002; Rajitha et al., 2007). The introduction of commercial shrimp farming undermined the labour market, as the requirement for labour in highly mechanized shrimp farms was much less than that of traditional rice farms. This further hindered livelihood opportunities (Batta & Bhat, 1998).

Batta and Bhat (1998), in their research in coastal Karnataka, portrayed the debilitating impacts of commercial shrimp farming on the rural economy. They argued that the impacts were multifaceted and community-specific. Besides challenging the livelihood opportunities of traditional farmers, the industry adversely affected the shrimp farmers as well (Batta & Bhat, 1998). In the mid-1990s, shrimp farmers experienced the worst shock due to the dual threat caused by disease outbreaks and the lowering of shrimp prices in the global market, which led to the closure of many shrimp farms (Batta & Bhat, 1998; Bhattacharya, 2009). A number of studies have pointed out that thriving commercial shrimp farming encouraged elite people from rural areas as well as from far-flung urban areas to invest in the industry. These investors, by virtue of their political affinities, often managed to take hold of the total production system, dispossessing the local peasants. This largely estranged the native peasants and disrupted the traditional rural economy (Roy, 2013; Galappaththi & Nayak, 2017). Galappaththi and Nayak (2017) cited a case study from the Chilika Lagoon, where the endorsement of commercial aquaculture by the State Government led to the marginalization of traditional fisheries. This resulted in overt protest movements against the state government policy by traditional fishers, which ultimately compelled the Odisha State High Court to impose a ban on non-traditional shrimp culture in the lagoon area in 1993. However, due to laxity in vigilance, unauthorized shrimp farming grew at a phenomenal rate (Galappaththi & Nayak, 2017). Based on a study in Bhadrak district, Odisha, Pradhan and Flaherty (2007) found that, despite promises to ameliorate the well-being of the local populace, in reality, the growth of shrimp culture brought only a meagre amount of fortune. The collapse of traditional rice farming and over-dependence on technology in shrimp farms generated an excess of labour, which was attributed to be the primary cause of low wage rates in shrimp farms. Additionally, the authors noted that the introduction of shrimp farming and the waning of rice farming had reduced livelihood opportunities for women. Besides, the stark difference in access to financial support, technology, and scientific knowledge between wealthy and poor farmers had spurred social inequality (Pradhan & Flaherty, 2007).

Numerous studies from India have noted that the burgeoning shrimp culture in coastal areas gradually usurped the common property rights of the native populace and threatened their well-being (Batta & Bhat, 1998; Pradhan & Flaherty, 2007). Pradhan and Flaherty (2007), in their study based on coastal Odisha, reported that the development of shrimp farms restricted women's access to the adjacent mangrove forests for collecting fish, fodder, and firewood (Pradhan & Flaherty, 2007). Some studies have acknowledged that shrimp culture in India has largely manifested as a commercial activity, which has, in many cases, brought about considerable changes in land leasing and tenure schemes (Bhattacharya, 2012). The rapid growth of shrimp farms along the coastal areas of Tamil Nadu and Andhra Pradesh, without regard for the implications on local inhabitants, has led to the erosion of common property rights, instigating class conflicts in many instances. Hossain and Hasan (2017) found that the growth of modern, technology-oriented commercial shrimp farming in Andhra Pradesh has led to notable unemployment in coastal rural villages. Kagoo and Rajalakshni (2002) described one such conflict between traditional fishers and shrimp farmers in the Nagapattinam and Kandleru creek areas of Andhra Pradesh.

2.6.3 Regional scenario

Bhattacharya (2009), while comparing the economic aspects of traditional and intensive shrimp farming, recognized that, in addition to considering the economic benefits derived from farming, it is essential to account for the costs of damages incurred. The author asserted that the extent of environmental damage caused by aquaculture largely depends on the intensity of the farming practice. In her study based on three districts of West Bengal, she demonstrated that the opportunity cost for intensive shrimp farming was greater than that for traditional shrimp farming. This is primarily due to the fact that the environmental damage caused by intensive shrimp farming and its contribution to the reduction of rice productivity in the region were significantly higher than those associated with traditional methods. Moreover, the cost of reclaiming lands used for intensive shrimp culture was also much higher. The author noted that the variability and magnitude of economic risks also increase with farming intensity. She concluded that although intensive shrimp farming may appear highly profitable in the short term, considering the burdens of opportunity costs and compensations associated with this method, it becomes economically unviable, especially for small landholders in West Bengal in the long run, where crop insurance and risk resilience opportunities are almost non-existent (Bhattacharya, 2009). Based on an empirical study in the Sundarbans of West Bengal, De Roy (2013) depicted that only affluent households (2.9%) possessed 8.9% of the total land of the village and 69.6% of the operational area under aquaculture in 2005-2006. In contrast, 46.9% of the total households, who belonged to the poor class, possessed only 9.6% of the total land of the village and only 4.3% of the operational area under aquaculture. Thus, the author claimed that the inequity in land distribution was exceedingly high, caused by the introduction of brackishwater aquaculture in the area. He also mentioned that the transfer of agricultural lands to aquaculture ponds was done by surpassing the existing government regulations (Roy, 2013).

2.7 Understanding the Political Ecology approach

2.7.1 Origin of Political Ecology

The term "Political Ecology" was first introduced in an academic setting by Frank Thone in 1935, though the social anarchism theory of Peter Kropotkin (1896), which is often regarded as its foundational basis (Robbins, 2011). It emerged as a response to the concept of ‘environmental determinism’, which largely influenced academic research throughout the 19th Century (Forsyth, 2004; Judkins et al., 2008; Robbins, 2011; Sengupta & Datta, 2020; Vayda & Walters, 1999). Prominent thinkers such as Alexander von Humboldt, Alfred Russel Wallace, Elisee Reclus, and Mary Fairfax Somerville played significant roles in shaping the evolution of this discipline (Khan, 2013; Sengupta & Datta, 2020). Europe and North America experienced similar progress in the 19th as well as 20th Centuries, which significantly contributed to the development of modern political ecology (Robbins, 2011). Political ecology gained its current significance later, particularly in the second half of the twentieth century (Leff, 2012; Robbins, 2011).

Thinkers such as Murray Bookchin (1962), Eric Wolf (1972), and Andre Gorz (1975) brought attention to the concept of political ecology amidst a critical environmental crisis in the 1960s and 70s (Biersack & Greenberg, 2006). It also became popular as a criticism of Cultural ecology, a concept that inadequately focused on the historical, structural, and social dimensions of power. While initially predisposed towards Marxist perspectives, contemporary political ecological theory is largely rooted in modifications of traditional 'Dependency Theory' and 'World System Theory,' allowing for a more thorough analysis of power dynamics compared to cultural ecology. Additionally, it served as a response to the excessive focus on productivism, growth, and consumerism, drawing on ideologies of civil disobedience, environmental conservation, feminism, and human rights (Biersack & Greenberg, 2006; Blaikie & Brookfield, 1987; Leff, 2015; Paulson, 2003; Robbins, 2011; Sengupta & Datta, 2020; Walker, 2005, Watts, 2017).

Bookchin was among the early pioneers of the political ecology concept, presenting his ideas in Our Synthetic Environments, his book authored in 1962, which explored the connections between social processes and environmental risks. Interestingly, he never explicitly used the term "political ecology" in his writings (Biersack & Greenberg, 2006; Leff, 2012). The term was first introduced by Eric Wolf in his work Ownership and Political Ecology in 1972. His version of political ecology was rooted in neo-Marxism, emphasizing the role of power relations in shaping human-nature interactions (Biersack & Greenberg, 2006; Leff, 2015; Zimmerer, 1994).

2.7.2 Definition of Political Ecology

The coexistence of a wide gamut of theories and principles contributed by several scholars throughout the long genealogy of political ecology made it a very difficult task to synthesize its eclectic field into a single definition (Ingalls & Stenman, 2016). Various authors attempted to define the term "ecology" in 'political ecology' through different perspectives. Some proponents believed that political ecology primarily addressed ecological problems. However, authors like Atkinson (1991) argued that political ecology was mainly concerned with environmental movements. In contrast, political ecologists like Russett (1967) claimed that the core focus of political ecology was to explain the interconnections between political relationships and their impact on the environment (Forsyth, 2004). Bryant (1992) stated that political ecology examined the ecological effects of various drivers, the changes they caused, and the implications for society, the economy, and political relationships. Political ecology also evaluated the political foundations of environmental issues and laws, defining itself as the ‘politics of ecology’ (Forsyth, 2004).

Political ecology developed as a multidisciplinary approach combining natural and social sciences to analyse human-environment interactions (Peterson, 2000; Paulson, 2003). Components of political economy, such as production relations and community access to resources, were used to understand environmental issues and develop sustainable alternatives (Paulson, 2003). It explored the dynamic interconnections between human and environmental processes (Young et al., 2019). The central idea was that environmental changes and conflicts were rooted in social relationships at various scales (Greiner & Sakdapolrak, 2016). It became a major research field in Geography, examining human-nature relationships. Political ecologists like Turner (1999) and Zimmerman (1994) integrated biophysical and social processes in their empirical studies, and from its outset, political ecology also focused on hazard management (Walker, 2005).

Political ecology examined marginality, plurality, and production pressures on the environment. Researchers in the mid-20th Century included power dynamics, inequality, and conflict within society, addressing them in the context of global issues such as colonialism (Paulson, 2003; Walker, 2005). Mayer (1996) suggested that political ecology was the best approach for understanding human-environment interactions from local to global scales by analysing resource use patterns.

Atkinson (1991) emphasized the importance of a historical perspective in the study of human-environment relationships, arguing that these relationships took time to manifest in landscape and environmental changes. He also noted that human actors, such as state governments and international agencies, directly influenced decisions regarding environmental change (Kalipeni & Oppong, 1998). Blaikie and Brookfield (1987) defined political ecology from a Marxist viewpoint, exploring the connections between ecosystems, political economies, and local communities. From this perspective, political ecology focused on materialism, equality, and environmental issues, aiming for a fair distribution of and access to resources (Lipietz, 2000).

Murray Brooklin (1962) and Andre Gorz (1975) introduced a neo-Marxist discourse of political ecology that questioned the nature of human-environment relationships. According to Erzersberger, environmental crises were closely tied to capitalism (Leff, 2015). In this view, capitalism was seen as the primary cause of environmental destruction (Forsyth, 2004). Later, other dimensions such as Third-World and feminist political ecology emerged (Peterson, 2000). Peterson (2000) described political ecology as an approach linking ecological aspects with political economy to examine tensions between environmental and social changes, as well as conflicts within different societal groups. This approach was widely used to connect local ecological issues with global political economies, helping researchers understand the interplay between environmental and political forces on various scales (Stonich & Bailey, 2000).

Vandergreest et al. (1999) argued that political ecology served as a platform to understand how the environment had been politicized. They noted that political ecologists merged human ecology with political economy to explore the links between identity and resource politics (Vandergreest et al., 1999). Political ecology explained how the effects of environmental changes were distributed unequally among different groups (Rodríguez-Labajos & Martínez-Alier, 2015). Political ecologists viewed societal struggles as a result of unequal resource and power distribution (Forsyth, 2004; Young, 2019). Numerous studies focused on power disparities that led to resource appropriation and environmental degradation (Bryant, 1998). Bryant and Bailey (1997) argued that political ecology viewed the environment as a competitive space where social groups vied for access and control of natural resources. Wolf (1972) saw power dynamics that led to environmental degradation as a central theme in political ecology (Sovacool, 2018). The political economy approach was widely used to study how power dynamics, resource allocation, and social linkages contributed to societal change (Belton, 2016). Political ecology continually examined how power dynamics shaped human-environment interactions (Ingalls & Stenman, 2016). Lukes (1973) identified three dimensions of political power: overt, covert, and structural. Peterson (2000) incorporated these dimensions into political ecology, adding the concept of scale. Alier (2002) defined political ecology as addressing "ecological distribution conflicts," including disputes over resource access and distribution (Escobar, 2006).

Bryant (1998) argued that politics should be a priority in political ecology, which he saw as focused on the human-environment interaction driving environmental degradation. He advocated for incorporating political factors into studies of ecological transformation and sustainable development to better understand these interactions. In 1992, Bryant outlined three areas of political ecology: identifying drivers of ecological change, examining the resulting conflicts, and analysing their unequal impacts on people. He stressed that addressing the uneven distribution of environmental impacts across social groups was essential for developing sustainable policies. The rise of “Third-World political ecology” in the 1970s, which focused on resource-related conflicts in developing countries, emerged as a critique of cultural ecology and was closely aligned with radical geography and neo-Marxist thought (Bryant, 1998).

Political ecology was also used to study gender issues, such as the unequal distribution of economic benefits between men and women and the lack of female participation in decision-making (Bryant, 1998). Turner (1999), in his research in West Africa, explored how power dynamics between male and female livestock owners influenced species composition. Richard Schroeder (1999) showed how changes in community politics regarding agroforestry in Gambia undermined women's empowerment by reducing their access to income-generating resources (Walker, 2005).

Turner (2014) suggested that political ecology had connections with human ecology, which it initially emerged to challenge. He also explored the conceptual links between resilience theory and political ecology, recommending that both approaches be used together to better understand the impacts of environmental changes on society and the sources of conflict.

However, political ecology also faced significant criticism. Early works were criticized for vagueness and insufficient attention to politics, while recent research had been criticized for overemphasizing political dominance over resources (Paulson, 2003). Walker (2005) noted that political ecology shifted towards the study of "environmental politics." Contemporary studies had been criticized for narrowing the field to resource politics while neglecting broader environmental issues (Vayda & Walters, 1999). Peterson (2000) criticized modern political ecology for portraying ecosystems as passive, failing to account for the dynamic nature of ecosystems and their role in driving community conflicts over resources. He advocated incorporating concepts such as resilience, adaptive cycles, and multilateral approaches to better understand human-ecology interactions. Vayda and Walters (1999) argued that political ecology should focus on specific environmental changes and trace their causes and effects. Forsyth (2004) criticized political ecology for overemphasizing resource struggles and described it as an extension of cultural ecology that examined local environmental issues from an anthropological perspective.

2.7.3 Conceptual framework and its development

Political ecology eventually became a popular multidisciplinary approach that combined local ecological issues with the global political economy. It helped researchers to understand the interplay between environmental and political forces and the resulting changes in society and the environment from local to global levels (Stonich & Bailey, 2000). Vandergreest et al. (1999) asserted that political ecology served as a platform for scholarly discourse to comprehend how the environment had been politicized. They also noted that political ecologists intertwined human ecology with political economy to understand the connections between identity politics and resource politics (Vandergreest et al., 1999). The political economy approach was widely applied to investigate the role of power dynamics, resource allocation, and social linkages in the course of social change (Belton, 2016).

Hoque et al. (2017) demonstrated in their study that social and ecological factors modifying vulnerability issues, along with their effects on society, could be efficiently explained by integrating the concepts of political ecology, resilience, and well-being. The resilience approach could elucidate the state of changes, while the political ecology perspective could explain the role of various stakeholders regarding their power within the system and their involvement in resource dynamics. An unequal distribution of social power played a crucial role in the course of social change, as the needs of certain groups were prioritized over others, leading to inequities in resource allocation (Hoque et al., 2017).

Ingalls and Stenman (2016) explored the interconnectedness between the resilience approach and political ecology, concluding that as both shared overlapping areas of interest, objectives, and frameworks to theorize social and ecological issues, synthesizing these approaches would be convenient and effective in comprehensively understanding human-nature interactions. They suggested drawing insights from political ecology to expand the understanding of power dynamics within resilience frameworks. However, they also criticized political ecology for being overly theoretical and focusing too much on politics at the expense of ecology. They argued that incorporating the resilience approach could help political ecology better understand ecological processes and contribute to decision-making and policy development (Ingalls & Stenman, 2016).

Several studies in political ecology examined how the privatization of public services affected citizens. Bakker (2003) analyzed how political ecology can explain the impact of government decisions on people and the environment, using the example of water supply privatization in OECD countries, where governments privatized domestic water supply to address water scarcity and environmental protection. Bakker pointed out that many private agencies were increasingly dominating the water supply market. With the privatization of public water services, public policies changed significantly as control shifted from the public to the private sector. Privatization introduced commercialization, transforming essential services like water supply, which is a basic human right, into commodities to be purchased based on one's ability to pay. Thus, political ecology could identify the "winners" and "losers" when a system underwent such changes (Bakker, 2003).

Political ecology was also employed to explain the global and local forces and historical spread of various diseases (Kalipeni & Oppong, 1998). They used the political ecology approach to analyze the refugee crisis and associated health impacts and conflicts in Africa. They demonstrated how people were forced to flee their land in search of safety, crossing borders and suffering from infectious diseases due to the lack of healthcare in refugee camps. According to Newman (1995), large-scale migration, often caused by overpopulation, natural disasters, disease, or ethnic conflicts, had a long history. Kalipeni and Oppong (1998) claimed that over 5.4 million people were displaced in 1993 due to ethnic conflicts in Africa, based on data from the United Nations High Commissioner for Refugees. They argued that political ecology offered insight into the root causes of the ongoing refugee crisis, which extended beyond ethnic conflict to global issues such as colonialism and decolonization. For instance, "ethnic favouritism" was a key factor in violent ethnic conflicts. Additionally, ecological and economic factors like natural disasters and famine contributed to creating economic and climate refugees. The authors further contended that the refugee problem was directly linked to health issues, such as the spread of famine, malnutrition, and diseases resulting from livelihood crises and reduced agricultural output. The disruption of healthcare during conflicts and the poor conditions in overcrowded refugee camps also contributed to disease spread (Kalipeni & Oppong, 1998; Newman, 1995).

The relationship between migration, environment, and climate migration was also studied through the lens of political ecology. Political ecologists consistently addressed the issue of forced migration due to hazards, famine, drought, and other environmental challenges. Political ecology asserted that economically disadvantaged groups were more vulnerable to environmental hazards (Greiner & Sakdapolrak, 2016). Greiner and Sakdapolrak (2016) argued that political ecology was the most suitable approach for understanding the causes and processes of environmental migration.

2.8 Political Ecology in understanding the man-environment nexus

Escobar (2006) explored the implications of 'neo-liberal globalization' on the environment and society by applying a political ecology approach. He ascertained that globalization instigated inequality, and as an inextricable result, struggles and strife for natural resources ramped up worldwide. It engulfed the indigenous cultures of many societies and endorsed the economic practices that underpinned the interests of the affluent class, which furthered environmental degradation and the marginalization of the underprivileged sections. Peterson (2000) resorted to the political ecology approach to explicate how human interventions like the construction of dams, land-use changes, and fishing substantially altered the salmon habitat of the Columbia River Basin, USA, at different scales and how different scales of political power influenced the decisions and behavior of various groups. He also argued that the dynamic nature of inter- and intra-group conflicts of interest formed a nested hierarchy, which significantly influenced human-ecology interactions.

Vaccaro et al. (2013) correlated political ecology with conservation approaches. He advocated that conservation policy decisions, such as defining the boundaries of protected areas, were often related to power dynamics within society. According to him, these conservation policies were frequently implemented by politically powerful groups, resulting in the suffering of the weaker sections of society due to these decisions. Several researchers adopted theories and concepts of political ecology to assess the costs and benefits that emerged from particular policies, as well as the distributional patterns of those benefits and costs among various ethnic groups within a community. One such study on the conservation of mangrove forests in the coastal zone of southern Banawa, Indonesia, conducted by Armitage (2002), explained how the economic, social, and ecological dynamics of Banawa faced brisk transformation when pristine coastal mangrove cover was destroyed by the rapid expansion of brackishwater aquaculture, which the national government deliberately promoted to ensure foreign exchange. Using the political ecology approach, the author explained that specific administrative interests, such as the promotion of commercial aquaculture, were reflected in policy narratives that endorsed the interests of a particular section of actors while largely ignoring the rights of the commons.

Conflicts and movements encompassing water-related issues were discussed through a political ecological lens by Rodríguez-Labajos and Martínez-Alier in 2015. The authors claimed that changes in the hydrological regime were closely associated with social and cultural perspectives and that the impacts were differentially encountered by various groups within the community. The authors admitted that political ecology could trace the possession of power that largely determined access to water resources. LaVanchy et al. (2017) identified access to potable water as a major issue of social discontent globally.

The political ecology framework was widely applied by scholars to investigate the implications of government climate adaptation policies, especially concerning local people and the environment. Sovacool et al. (2015) applied the approaches of political ecology and political economy to 'climate change adaptation'. Following the political ecology perspective, Sovacool (2018) evaluated the multi-dimensional and multi-scalar implications of climate adaptation policies. Citing examples from Bangladesh, the author explained how the pernicious interconnections among the four dimensions of political ecology—namely "enclosure, exclusion, encroachment, and entrenchment"—could potentially hinder climate change adaptation endeavours. The policies provided ample opportunities for the privileged classes of both rural and urban areas to garner more resources by exploiting the weaker sections of society through their political and financial power. Furthermore, these policies broadly denied the participation of native people, marginalized sections, and women in policy frameworks and implementation, thus failing to address the needs of a larger group. Over time, these policies enabled elite outsiders to systematically exploit resource-poor native dwellers by expropriating their land and restricting their customary rights to access resources. These factors gradually altered social structures, perpetuated inequality, and instigated conflict within society. Additionally, in many instances, erroneous adaptation projects not only imposed potential threats to existing resources but also deterred existing resource conservation measures and exposed marginalized sections to a multitude of vulnerabilities. He identified the implementation of 'shrimp zone rules' by the Bangladesh government in 1992, aimed at amplifying shrimp production, as a significant threat to the existing mangrove ecosystem. Vázquez (2017) judged the climate adaptation initiative endorsed by the Mexican government through the political ecology framework. Based on his study in Tabasco, he explored how government policies failed to address the needs and comprehend the perspectives of local communities, thereby triggering social discontent.

Some environmental issues in India were also analyzed from a political ecology perspective. From this viewpoint, Dujovny (2009) explored the implications of the government's decision to 'dredge a new sea mouth' in Chilika Lake, India, in 2002. He illustrated how the government's attempts to contend with frequent floods, protect croplands, and promote shrimp farming through a bureaucratic and techno-savvy method inadvertently failed to recognize the benefits of floods and the adverse ecological effects of brackishwater aquaculture on the indigenous fishing community.

Thompson (2018) resorted to the political ecology approach to explore how the interplay between institutions and stakeholders, along with asymmetries in power distribution among stakeholders at different levels, determined the success and failures of 'mangrove restoration' initiatives. He identified conflicts of interest between various institutions and between communities and institutions, as well as a lack of coordination and promiscuity in power distribution among various 'actors' as factors that might lead to the failure of otherwise promising management policies. Consequently, he advocated for a nuanced understanding of the interconnectedness among social, economic, and political drivers as imperative for any successful management policy.

2.9 CBA through the Political Ecology lens

Many researchers have noted that export-oriented brackishwater aquaculture, particularly shrimp farming in the Southern Hemisphere, has been rife with controversies since its inception (Stonich & Bailey, 2000). Although the industry's massive growth brought several economic and social benefits to host countries, it has also led to significant ecological destruction, which often propagated social injustices and conflicts, creating obstacles in optimizing these benefits (Hossain & Hasan, 2017). Consequently, commercial brackishwater aquaculture has drawn the attention of numerous researchers who have attempted to analyze various aspects of shrimp farming, including its growth trends, market relations, social and ecological impacts, and the related controversies and conflicts (Belton, 2016). Thus, several researchers have adopted a political ecology approach to explore the interconnectedness between local, national, and international processes surrounding aquaculture and their impact on ecology and communities (Stonich & Bailey, 2000).

Vandergeest et al. (1999) employed this approach to understand the drivers of shrimp farming in Thailand. They argued that this approach offered a framework for understanding the various facets of shrimp farming, including the interplay between the physical environment and social dynamics. For instance, in shrimp farming, landscapes were politicized based on their value in the international and urban markets. The authors asserted that research in political ecology often illustrates how large commercial enterprises tend to dominate the shrimp production system, systematically displacing smaller owners. These enterprises could afford to implement self-regulatory mechanisms to mitigate the industry's environmental and social damages. In contrast, small and medium-scale farmers, though more numerous, lacked the capacity and cohesion to maintain ecological sustainability. Using the political ecology lens, the authors also highlighted how the government was compelled to impose stringent regulatory measures to address these negative impacts (Vandergeest et al., 1999). Various national governments, including those of Honduras, Thailand, India, and Bangladesh, have imposed restrictions on commercial shrimp farming to mitigate its adverse effects. These measures included the demarcation of cultivation zones and prohibitions on shrimp farming in ecologically fragile areas (Hossain et al., 2015).

The local issues associated with commercial shrimp farming have often transcended regional boundaries to become national and global concerns. Researchers have used political ecology to analyze these developments, highlighting that the exponential growth of commercial shrimp farming has faced significant criticism for its environmental, social, and economic consequences. Conflicts between conservationists (including various NGOs) and industrial groups promoting shrimp farming have escalated from local to global levels. Several international organizations, such as the World Wildlife Fund (WWF), Greenpeace, Natural Resources Defense Council (NRDC), Environmental Defense Fund (EDF), Rockefeller Brothers Fund, MacArthur Foundation, and Mangrove Action Project (MAP), collaborated in 1997 to form the Industrial Shrimp Action Network (ISA Net) to oppose the expansion of shrimp farming. In response, industrial groups, their governments, and some academic institutions established the Global Aquaculture Alliance (GAA) to support shrimp farming. The united protests by local communities and NGOs against industrial shrimp farming gradually received international support, leading to global coalitions advocating for environmental protection and the rights of affected communities (Stonich & Bailey, 2000; Béné, 2005).

There have been instances where these coalitions effectively influenced national governments to make decisions in favor of environmental protection and local communities' needs. For example, in 1996, the Honduran government temporarily halted the expansion of the shrimp industry along the Pacific coast, and India's Supreme Court decided to abolish non-traditional shrimp farms within Coastal Regulation Zones (CRZ) through the CRZ Notification of 1991 (Stonich & Bailey, 2000; Béné, 2005). Despite organized efforts from pro-industry groups to counter these movements, the controversies and debates over shrimp farming's impact have continued (Hein, 2000).

Differences in opinions and a lack of communication between NGOs and environmentalists from the Global North and South regarding sustainability standards have often weakened the protest movements against commercial shrimp farming (Stonich & Bailey, 2000). Cruz-Torres (2000) analyzed how government policies promoting commercial shrimp culture in Sinaloa, Mexico, altered local livelihoods and integrated communities into a global market-based economy, leading to resource-centred conflicts and the violation of traditional resource rights (Cruz-Torres, 2000). Similarly, Armitage (2002) described how the Indonesian government's push for commercial aquaculture between 2001 and 2005 led to mangrove forest destruction and challenges related to common property rights (Armitage, 2002).

Hall (2003) noted that international movements against commercial shrimp farming predominantly focused on environmental issues like mangrove destruction, while local concerns such as salinization, soil contamination, and conflicts over land and resource access received less attention. Countries like Honduras, Bangladesh, and India experienced intense social conflicts and violence over industrial shrimp farming, in contrast to relatively limited opposition in Indonesia, the Philippines, and Thailand. Despite these issues, shrimp farming continued to thrive in coastal Asia, often outpacing local disputes and regulatory restrictions. However, the industry's most significant threat often came from within, particularly the risk of disease outbreaks (Hall, 2003).

The political ecology concept has been utilized to explain how disparities in financial and political power among shrimp producers shape their access to resources and knowledge. Some studies suggest that replacing excessive international control with local governance could increase community involvement in decision-making processes related to shrimp farming (Pokrant, 2009). Goss et al. (2001) revealed that in Thailand, shrimp culture evolved from large-scale extensive farming to small-scale intensive farming in the 1990s, leading to significant social changes, increased labour demand, and a rise in the number of ‘have-nots’. Access to modern technology in shrimp farming was uneven and often influenced by social relations and control by select government and financial agencies (Goss et al., 2001).

Beitl (2012) examined the effects of changing government policies in Ecuador from promoting shrimp aquaculture to traditional fishing, aiming to protect indigenous livelihoods. The study highlighted that while policies intended to support local communities, the benefits were primarily captured by organized and empowered groups, marginalizing less powerful members of society (Beitl, 2012). Belton (2016) linked the political economy and social well-being approaches to analyze how shrimp farming in Southwest Bangladesh affected local farming systems and farmers' well-being. He noted that despite higher cash incomes from shrimp farming, its impact on traditional agrarian livelihoods challenged farmers' sense of self-sufficiency and overall well-being (Belton, 2016). Haque (2015) identified policy gaps that allowed wealthy investors to exploit small farmers, further contributing to environmental degradation and social inequality (Haque, 2015).

Studies in regions like the Mekong Delta, Vietnam, and Karnataka, India, illustrate how commercial aquaculture led to social and ecological challenges, often exacerbated by unequal resource distribution and political dynamics (Bhatta & Bhat, 1998; Zinzani, 2018). Political and legal interventions, such as the Supreme Court of India's ban on illegal shrimp farms in 1996, aimed to protect traditional livelihoods but faced resistance from pro-industry groups.

Bhattacharya (2012) highlighted changes in land leasing practices in West Bengal due to shrimp farming, where small landholders, fearing risks, leased out their lands and missed the economic opportunities provided by shrimp farming. Social and economic status significantly influenced these leasing decisions, perpetuating inequality in benefits from the industry (Bhattacharya, 2012).

2.10 Identified research gaps

The detailed literature review regarding various aspects of political ecology and impacts of growth of CBA in general, and the development of CBA in the Medinipur coastal plain in particular revealed that there exist prominent research gaps. It was found that, in spite of glaring presence of social and ecological implications of CBA, most researches on CBA focused on the technical or land-related changes and policy issues concerning the industry (Pokrant, 2009). However, the growth of CBA and its obvious implications need to be studied from more comprehensive approach to include its implications in landscape, socio-economy, environment, and political scenario. Thus, these need to be analyzed from a comprehensive approach like political ecology. Nevertheless, a number of works in this respect have been done in various countries of the tropical world, there is dearth of empirical research which have been done covering multi-faceted aspects of growth dynamics of CBA. Moreover, very few researches were found in India in general and in the studied region in particular which comprehensively addressed the implications of CBA growth emphasizing on man-environment nexus.

There was utter lack of empirical researches which addressed recent growth trajectory of CBA in the studied region. Moreover, there was sheer dearth of research regarding the implications of growth of CBA at the landscape level as well as its impact on the ecological and socio-political environment. Accordingly, empirical study of growth dynamics of CBA and its implications on the landscape, ecology, scocio-political environment of the studied region through political ecology approach got crucial importance and occurred as the fundamental basis of the present research.

Chapter III:

Study area

3.1 A geographical account of the Medinipur Coastal Plain

The Indian state of West Bengal has a considerably long coastline of approximately 180 km which is endowed with rich floral and faunal diversity, multifarious geomorphic features, and anthropogenic interferences. The coastal stretch of West Bengal is morphologically divided into two broad divisions. On the western side, lies the mesotidal Chenier delta of Subarnarekha River, while the microtidal Ganga-Brahmaputra delta lies to the east. The western section is also called the Medinipur Coastal Plain (MCP) (Bandyopadhyay et. al., 2009; Das & Dandapath, 2014).

This coastal stretch was formed during the time of Holocene transgression (Bandyopadhyay et. al., 2009). The morphology of the area is highly impacted by the dynamic nature of shoreline in the geological time. Multiple parallel ridges of coastal dunes, interdunal wetlands, estuaries, mud flats, sand beaches, and salt pans are the most distinct geomorphic features of this region (Das & Dandapath, 2014). The area is covered by coastal alluvium of both recent and older deposition, which consists of sandy and sandy loam soil (Purkait, 2017).

Environmental perils, such as coastal erosion, coastal flood, penetration of saline water in the crop lands, degradation of sand dunes, and massive land use transformation, adversely affected the socio-economic development of the area (Debnath & Roy, 2015; Purkait, 2017). Among these, coastal flooding induced by storm surges and intrusion of salt water are the major geomorphic hazards that disrupt the lives and livelihoods of the local populace, primarily threatening the agricultural sector, which is the backbone of the regional economy (Purkait, 2017).

Due to the prevalence of saline creeks, irrigation is a major limiting factor for agriculture. As a result, the area is dominated by a single crop with low productivity (Bauri & Upadhyay, 2016). Consequently, a vast area has been transformed into commercial coastal brackishwater aquaculture (CBA), especially shrimp farming (Bauri & Upadhyay, 2016).

3.1.1 Geographical location

The MCP is located at the southern part of West Bengal along the Bay of Bengal coast, with a length of almost 59.79 km. It extends from the Baleswar district of Odisha in the east to the Junput sector in Purba Medinipur district of West Bengal (Chakrabarti, 1995; Dey et. al., 2005; Chakrabarti & Nag 2015; Roy & Datta 2018; Roy et. al., 2020). The region is bounded by the Subarnalekha estuary in the west and the Rasulpur estuary in the east (Bandyopadhyay et. al., 2009). The northern boundary of the MCP is marked by the ancient dune complex and, in the south, it extends up to the Bay of Bengal coast. This coastal stretch extends from 21°38'13.126"N to 21°42'30"N and from 87°35'7.718"E to 87°46'14.29"E (Das & Dandapath, 2014). For the purpose of the present research, three coastal Community Development (C.D.) Blocks of the Purba Medinipur district of West Bengal, lying within MCP; namely Ramnagar-II, Contai-I, and Deshapran were considered.

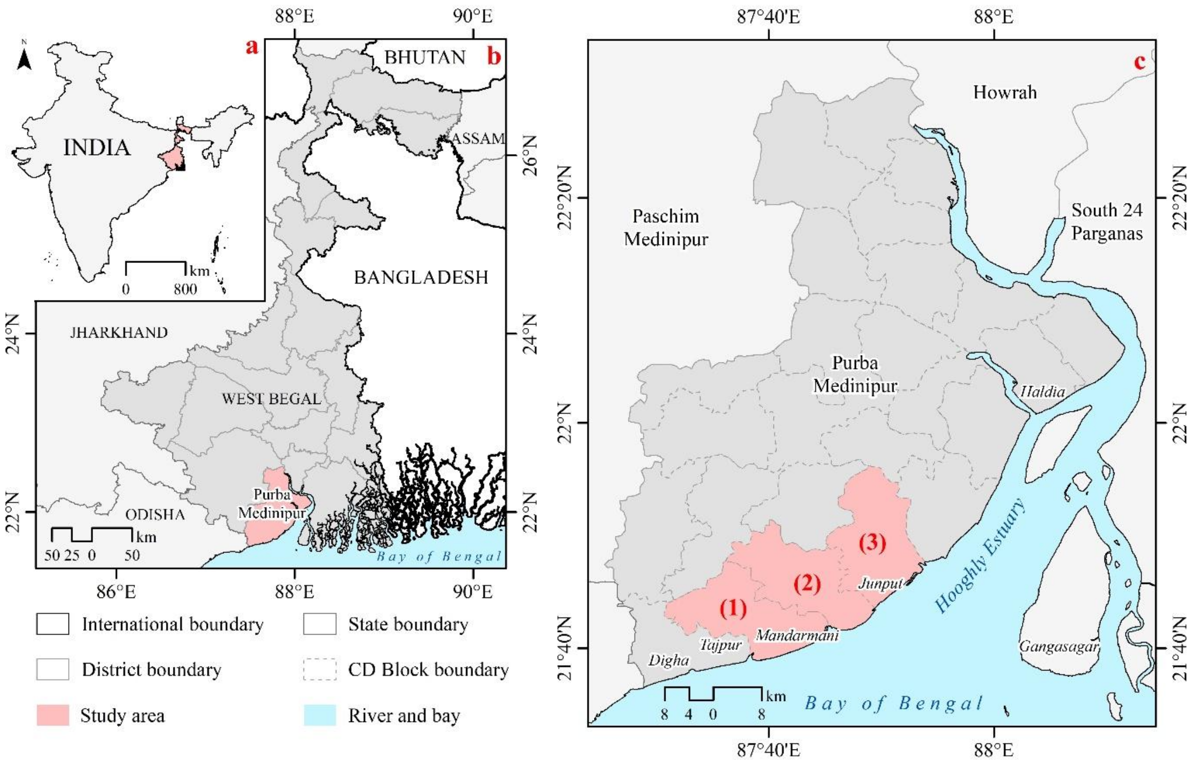

Figure 3.1: Location map of the selected study sites. Numeric digits in parenthesis indicate the selected C.D. Blocks of Purba Medinipur district, viz. (1): Ramnagar-II; (2): Contai-I; and (3): Deshapran.

These three C.D. Blocks lie in the south-west part of the district, and together, they cover an area that extends from 21° 39' 0" North latitude to 21° 54' 43.2" North latitude and 87° 31' 4.8" East longitude to 87° 54' 3.6" East longitude. The southern boundary of the study area is marked by the coastline of the Bay of Bengal. The congenial physiographic and demographic environment of the study area was found to have created favourable conditions for CBA to develop there as a dominant economic practice and leave its imprints on the dynamic landuse and land cover (LULC) pattern, local economy, and socio-political environment (Fig. 3.1).

3.1.2 Physical environment

The physical environment of the study area must be studied thoroughly in an apriori manner to understand the conducive physical condition that played an important role in the development of CBA in the region.

3.1.2.1 Geological and geomorphological setups

The MCP is located at the eastern margin of the Subarnarekha delta situated along the south-western coast of West Bengal. The area is covered with unconsolidated sediments from the Holocene age to the present time at the surface, carried and deposited by the Subarnarekha and Ganges rivers which are underlined by unconsolidated sediments of Pleistocene age (Niyogi, 1975; Dey et. al., 2005; Debnath & Roy, 2015; Mondal & Mondal, 2015). The general relief is almost flat with a gentle slope (<10°) towards the coast lying in the southern part. Besides, the western part is higher than the eastern part due to the presence of dunes there. (Mandal, 2013; Debnath & Roy, 2015). The average elevation of the region hovers around 0-6 m from the mean sea level (Purkait, 2017). The typical landscape of the region is the outcome of a complex interaction between aeolian, fluvial, and marine processes (Debnath & Roy, 2015; Kamila et. al., 2020).

The present landform is influenced by multiple phases of transgression and regression of the sea level and controlled by the depositional history of the region (Dey et. al., 2005; Bandyopadhyay et. al., 2009; Das & Dandapath, 2014). The sea level of the Bay of Bengal rose considerably about 6000 years ago which was followed by the regression of the sea level causing a shift in the shoreline towards the south. Again, a fall in the sea level has been noticed in the last 500 years. 6000 years ago, the position of the shoreline was 5-15 km landward from the position of the shoreline at present. The shoreline shifted further southward and was positioned about 2-5 km away from its present position 3000 years ago. At present, erosion and accretion are taking place simultaneously along this coastal region. However, the shifting of shoreline towards the inland and coastal erosion induced by sea level rise has now become a characteristic environmental phenomenon of the region (Dey et. al., 2005; Sahoo et. al., 2014).

The topography of MCP is dominated by the presence of coastal dunes, interdunal wetlands, mudflats, major river estuaries, and a complex network of tidal inlets and creeks (Dey et. al., 2005; Kamila et. al., 2020). From east to west, Pichabani, Jhalda, Shankarpur, and Jatramala are the four major tidal creeks of the region, which have divided the shoreline into five beach zones (Bandyopadhyay et. al., 2009). Elongated ridges of coastal dunes with heights as much as 11 to 12 m, lying almost parallel to the coastline of the Bay of Bengal, are the most prominent geomorphic features of the region. The dune ridges are interspaced by wetlands and are truncated by marine erosion as well as anthropogenic interferences (Kamila et. al., 2020; Mandal et al., 2013). At least four dune ridges more or less parallel to the coastline were formed in the last 6000 years representing the southward shifting of the shoreline during the regression of the sea. These dune ridges are features of the coastal aeolian process, formed by the interaction of transported sand from the sea beach with coastal vegetation (Dey et. al., 2005). Recently, the inland shift of the coast in many places and the erosion of dunes have become the major local geomorphic events (Sahoo et. al., 2014; Purkait, 2017). It is necessary to mention here that the typical geomorphological setup, especially the presence of multiple tidal rivers, inlets, and creeks, that become the sources of saline water, make the environment of the study area fit for the growth of CBA.

3.1.2.2 Climatic condition

The climate of the MCP is characterised by the subtropical humid climate with three disparate seasons, namely Pre-Monsoon (prevailing between March and June), Monsoon (between July and October), and Post-Monsoon (between November and February) (Dey et. al., 2005; Bauri & Upadhyay, 2016). The maximum temperature of the region ranges between 29 °C to 36.8 °C while the minimum temperature varies from 5.7 °C to 24.7 °C. The average annual rainfall and the relative humidity range between 1192 mm and 1956 mm and 60% and 90% respectively. As the area is dominated by the monsoon climate, the wind direction in the summer and rainy season is normally from S-SSW, which reverses in the winter season and becomes NNE in direction. The climate has a distinct impact on the morphology of the coastal tract. While the multiple cyclonic depressions formed under the influence of the southwest monsoon, mainly during the pre-monsoon and post-monsoon season cause storm surge-induced coastal flooding, and marine erosion, the dry northeast winter monsoon accelerates the aeolian processes (Dey et. al., 2005; Gayen et. al., 2022).

3.1.2.3 Edaphic condition

The MCP is mainly composed of unconsolidated marine sediments and some alluvial, and aeolian deposits comprising sand, silt, and clay (Debnath & Roy, 2015). The nature of the soil in this region is determined by the action of tidal rivers and marine influences

(Mandal et. al., 2013). The soil of the region is grouped into three major categories, viz. saline soil, alluvial soil, and sandy soil (Mandal et. al., 2013). The soil texture of the major portion of the region is dominated by clay, which is deposited by the rivers Rupnarayan and Haldi. As a result, the soil is less permeable and poorly drained, which causes water logging during the monsoon season (Directorate of Census Operations, WB, 2011; Mondal, 2012). The clay and silt content are very low in the coastal regions and increases towards the inland. Concurrently, the proportion of nitrogen, phosphorus, and organic matter content in the soil is also low in the regions near the coast and increases towards the inland part (Debnath & Roy, 2015).

The available land varies based on the soil fertility, rainfall, presence of irrigation water, terrain, vegetation covers etc. (Mondal & Mondal, 2015). The northern portion of the region is composed mainly of alluvial soil which is sufficiently fertile for the growth of various crops. However, the soils in the dune ridge areas and regions near the shoreline have high proportions of sand and lack organic matter. Also, near the shoreline and along the tidal creeks where the soil is under the influence of saline water, the soil salinity is high and the soil fertility is notably low (Mandal et. al., 2013). It is pertinent to mention here that, in the study area, the high salinity of the soil and frequent water logging rendered the lands less productive, and consequently they were converted into brackishwater aquaculture farms over the past few decades (Directorate of Census Operations, West Bengal, 2011).

3.1.2.4 Biotic condition

The biotic environment of the entire region is highly impacted by its typical geomorphic condition, especially marine influence. In the Purba Medinipur district, the coastal tract between the Hugli estuary and the Junput sector has high ecological diversity, harbouring as many as 57 mangrove species which include *Avicennia officinalis, Avicennia Alba, Exococaria agallocha, Acanthus ilicifolius, Sueda maritima, Salicornia brachiate, Rizophora mucronata, Ipomea pescaprae.* Besides, 8 species of algae, 8 species of phytoplankton, and numerus mangrove associated plant varieties are also found in the region. *Spinifex littoreus,* a grass species, is the dominant vegetation in the beachfront areas which act as sand binder and plays an important role in dune stabilization (Datta et al., 2021a; Datta et al., 2021b). *Ipomoea pescaprae*, a highly salt tolerant species, is found in the mobile dune areas and also act as a sand binder. The proliferation of Casuarina species is found in the more stabilized dune areas. Shrubs and bushes, especially, *Pandanus tectorius* species is also found abundantly in this part (Roy et al., 2020). *Anacardium occidentale*, the sturdy evergreen tree species that grow copiously in the coastal areas and is also a commercially important species. *Cyperus corymbosus*, which grows luxuriantly in the swamps, marshy lands, and in the water-logged areas, is also an economically important species. Thus, the floral species found in the study region play not only an important role in stabilizing the dunes and protecting the sensitive coastline, but also have their salutary effect on the socio-economy of the region (Directorate of Census Operations, West Bengal, 2011; IISWBM, 2020).

Rapid expansion of human population has caused substantial habitat loss of the fauna in the region. However, the coastal regions still house a number of faunal species including twelve types of crabs, forty eight types of Mollusca, thirteen types of prawns, twenty one types of shrimps, horseshoe crabs, oysters, starfish, sea-urchins, sea animones, sea-pen etc. (Datta et al., 2024). Moreover, rabbits, rats, and snakes of various types are also found throughout the region. Additionally, almost fifty one types of fish varieties are found in the region (Directorate of Census Operations, West Bengal, 2011; IISWBM, 2020). However, the unbridled growth of commercial shrimp monoculture, which has caused rampant land use transformation and habitat loss, poses a severe threat to the biodiversity of the region (Debnath & Roy, 2015; Mondal & Mondal, 2015).

3.1.3 Human environment

The human environment consists of the demographic profile and socio-economic scenario of the study region.

3.1.3.1 Demographic profile

The district of Purba Medinipur in West Bengal came into existence in 2002 when the erstwhile Medinipur district was divided into two separate units- Purba Medinipur and Paschim Medinipur (Mondal & Mondal, 2015). The Purba Medinipur district covers an area of 4093.94 km^2 with four subdivisions, viz. Tamluk, Haldia, Egra, and Contai. It consists of twenty-five C.D. Blocks, five Municipalities, and 2949 census villages. According to the 2011 Census, the total population of Purba Medinipur was 5095875 with a population density of 1076 persons per km^2. The district had a comparatively low percentage of scheduled caste and scheduled tribe population (Table 3.1). The male and female populations of the district were 26,29,834 and 24,66,041, respectively. With a sex ratio of 938, it ranked 18th out of the 19 districts of West Bengal. Moreover, it ranked first in literacy in the state of West Bengal with a literacy rate of 87.66%. However, the gender-wise distribution of literacy rate was found to be uneven. In 2011, while the male literacy rate was 92.3%, the female literacy rate was considerably lower at 81.4%. Notably, the district had a high percentage of rural population (i.e. 88.37%). However, while the rural population currently exhibits a decreasing trend, the urban population has been registering a continuous increase. Similarly, the decadal growth rate is declining in the rural areas and increasing in the urban ones. The total decadal growth rate between 2001 and 2011 was 15.4%. Religion-wise, the district is dominated by people belonging to the Hindu community (85.2%), followed by the Muslims (14.6%) (Directorate of Census Operations, West Bengal, 2011).

Table 3.1: Major demographic attributes of the study region, 2011.

Demographic attribute	Ramnagar II	Contai I	Deshapran	District total
Total population	156054	170894	176393	5095875
Decadal growth of population	13.60%	12.65%,	15.24%	15.4
Rural population (%)	100%	100%	96.91%	88.37%
Sex ratio	942	940	940	938
Scheduled caste population (%)	12.41%	13.79%	10.04%	14.62%
Scheduled tribe population (%)	0.44%	0.05%	0.06%	0.54%
Literacy rate	89.38%	89.32%	88.33%	87.66%
Male literacy rate	95.02%	94.57%	93.53%	92.3%
Female literacy rate	83.37%	83.73%	83.41%	81.4%

Source: Directorate of Census Operations, West Bengal, 2011

The C.D. Blocks considered in the present study belong to the Contai Sub-division. The total populations of Ramnagar-II, Contai-I, and Deshapran were 156054, 170894, and 176393 respectively in 2011 with a decadal growth of 13.60%, 12.65%, and 15.24%, respectively. Of the three C.D. Blocks, Ramnagar-II and Contai-I were completely rural in character but there were few sporadic patches of urban population in the Deshopran Block. The sex ratio in each of the three C.D. Blocks was higher than the district average. Conversely, the percentages of scheduled caste and scheduled tribe population in the selected C.D. Blocks were lower than that of the district as a whole. Moreover, the literacy rate in Ramnagar-II, Contai-I, and Deshapran in 2011 were also slightly higher than the district literacy rate (Table 3.1) (Directorate of Census Operations, West Bengal, 2011).

3.1.3.2 Socio-economic profile

Agriculture is the backbone of the economy of the Purba Medinipur district and as much as 86.49% of the total reported area is under cultivation, especially food crops, of which paddy is the most dominant (table 3.2) (Directorate of Census Operations, West Bengal, 2011; Mondal, 2012).

Table 3.2: Land utilization classification statistics of Purba Medinipur district, 2011.

Sl. No.	Landuse type	Area in thousand ha
1	Forest	0.90
2	Area under non-agricultural use	102.24
3	Barren and unculturable land	0.69
4	Permanent pasture and other grazing land	0.18
5	Land under various tree groves	2.15
6	Culturable waste land	0.29
7	Fallow land other than current fallow	0,24
8	Current fallow	1.85
9	Net area sown	288.05

Source: Directorate of Census Operations, West Bengal, 2011

Table 3.3: Area under major crops in Purba Medinipur district, 2011.

Sl.no.	Major crop	Area in thousand ha
1	Rice	449.5
2	Wheat	0.5
3	Pulses	6.9
4	Mustard	6.4
5	Other oil seeds	15.9
6	Jute	0.7
7	Potato	4.9
8	Chillies (dry)	3.4
9	Ginger	1.2

Source: Directorate of Census Operations, West Bengal, 2011

Other major crops which are grown in the region includes rice, potato, pulses, oil seeds, jute, betel vine etc. (Table 3.3). The average size of agricultural land holdings is 0.53 ha. 60.14% of the land holdings are of marginal size (i.e. < 1.0 ha.), followed by 26.77% of small sized land holding (i.e. 1.0 ha to 2.0 ha) and only 0.23% of large holding (i.e. > 10 ha. (Directorate of Census Operations, West Bengal, 2011).

Purba Medinipur is endowed with a large proportion of area under various waterbodies including river, creeks, canals, and tanks. Consequently, fishery has become a distinct economic practice of the local inhabitants. In the last three decades, the state government has taken a number of initiatives to exhort seed production and commercial fish production. Floriculture and horticulture are also distinct economic practices there. However, animal husbandry is underdeveloped, primarily due to the lack of pasture areas and fodder production. Besides agriculture, production of various handicrafts is a traditional livelihood activity of the local populace. Furthermore, recently, Micro, Small and Medium enterprises (MSME) have developed considerably through various governmental initiatives. The district is in a leading position with respect to large industries because of the Haldia Petro Chemical Complex in Haldia and the Kolaghat Thermal Power Station in Kolaghat. However, out of all the economic activities, the most striking one is the hefty growth of CBA, especially shrimp, which has left its imprints on the landscape, causing brisk LULC transformation, especially in the coastal C.D. Blocks (Directorate of Census Operations, WB, 2011).

The total, male, and female work participation rate of the district was 37.5%, 38.1%, and 32.8% which were all lower than the state work participation rate. The percentage of main worker to total worker reduced from 24.1% in 2001 to 22.1% in 2011 and it was also lower than the state percentage. Regarding the percentage of main worker, a wide gap was observed between the share of male and female workers, which denoted the presence of notable gender discrepancies. While the percentage of main worker to total population was 38.0% for the males in 2011, it was only 5.2% for the females. It was also much lower than the state percentage and showed a declining trend in last three decades (Directorate of Census Operations, West Bengal, 2011).

In the three C.D Blocks taken into consideration in the present study, i.e. Ramnagar II, Contai I, and Deshapran, the percentage of workers in 2011 were 36.37%, 36.10%, and 37.65% respectively. Similar to the district level, there existed a wide gap between the male and female workers in these C.D. Blocks (Table 3.5). Following the trend of the district, most of the workers were engaged in agricultural activities in the selected C.D. Blocks (Table 3.6). In consonance with the district scenario, the percentage of cultivable area to total area was very high in the studied C.D. Blocks (table 3.4) (Directorate of Census Operations, West Bengal, 2011).

Table 3.4: Percentage of area under cultivation in the study area, 2011.

	Ramnagar II	Contai I	Deshapran	Purba Medinipur
Percentage of cultivable area	77.26	87.49	86.38	86.49

Source: Directorate of Census Operations, West Bengal, 2011

Table 3.5: Percentage of total, main and marginal workers, 2011.

Percentage of worker	Ramnagar II	Contai I	Deshapran	Purba Medinipur
Percentage of total worker	36.37	36.10	37.65	37.49
Percentage of male total worker	59.57	58.05	57.71	57.65
Percentage of female total worker	11.73	12.75	16.31	15.99
Percentage of main worker	21.14	21.97	19.82	22.12
Percentage of male main worker	37.87	38.58	34.19	38.03
Percentage of female main worker	3.37	4.29	4.53	5.15
Percentage of marginal worker	15.22	14.13	17.83	15.37
Percentage of male marginal worker	21.70	19.47	23.52	19.62
Percentage of female marginal worker	8.35	8.45	11.78	10.83

Source: Directorate of Census Operations, West Bengal, 2011

Table 3.6: Distribution of workers in various categories of economic activities, 2011.

Percentage of worker	Ramnagar II	Contai I	Deshapran	Purba Medinipur
Percentage of cultivator	20.04	14.97	16.45	18.07
Percentage of agricultural labour	45.44	37.59	36.73	36.76
Percentage of household industry workers	2.05	4.48	4.67	6.22

Source: Directorate of Census Operations, West Bengal, 2011

3.2 Environmental conditions favourable for CBA growth

Perusal of scientific studies show that the conducive physical settings such as wet-tropical climate, presence of wide flat coastal tract with gentle slope, easy access of saline water through various rivers, creeks and canals, natural salinity of soil etc. provided impetus for the expansion of CBA in the coastal areas of MCP in general and in the study area in particular. Besides, the land quality of the district is not uniform. In most of the coastal C.D. Blocks, except Ramnagar-I and Contai-I, the land quality is medium to low. The main limiting factor is low soil fertility due to high salinity (Mondal & Mondal, 2015). Accordingly, low productivity of paddy and vegetables due to high soil salinity, insufficient drainage, frequent incidence of flood, and invasion of tidal water have resulted in poor economic conditions, prompting the marginal communities inhabiting the study area to adopt brackishwater aquaculture as a lucrative source of income. In addition, both the state and the central governments have provided continuous support to the local populace for adopting CBA as an alternative livelihood option that could also be a reliable source of foreign revenue for the nation (Dutta et al. 2016; Ojha & Chakrabarty, 2018).

3.3 Justification of selecting three C.D. Blocks as study sites

CBA is practiced in the coastal C.D. Blocks of Purba Medinipur district, which includes Ramnagar-I, Ramnagar-II, Contai-I, Contai-III, Deshapran, Khejuri-II, and Nandigram-I. Brackishwater aquaculture in '*bheries*' is an age-old practice in these coastal Blocks. However, export-oriented semi-intensive to intensive shrimp production started in these parts from 1980s and flourished exponentially in 1990s (Dutta et al., 2016; Ojha & Chakrabarty, 2018; Mandal et. al., 2021). The spatial growth evolved considerably from 1990s to present. Between 1990 and 2000, CBA concentrated in the Ramnagar-II Block and spread across the western part of Ramnagar-I and the eastern part of Contai-I. It expanded further westward between 2000 and 2010. During this time, the highest concentration was found in Deshapran and Khajuri-II Block while it dwindled in the Ranmagar-I Block due to a surge in tourism activities. Nevertheless, CBA activities were still substantial in Ramnagar-II, and Contai-I Block. Between 2010 and 2020, the highest concentration zone of CBA was located in the Khejuri-II Block and dispersed to Ranmagar-II, Contai-I, and Deshapran in the west and Nandigram-I in the East (Mandal et. al., 2021).

The present study sought to assess the impacts of the hefty growth of CBA on land use transformation, coastal environment, and on the socio-political landscape of the Purba Medinipur district in the last three decades. Consequently, the study only took into account those coastal C.D. Blocks where CBA had grown over the last three decades. In Khejuri-II and Nandigram-I Blocks, CBA was a more recent development and, therefore, not considered in the present research. In Ramnagar-I, although CBA grew over more than three decades, tourism has become the dominant commercial activity of late, especially in the coastal areas while CBA is dwindling. Hence, the present research also did not incorporate Ramnagar I in its purview. The research, thus, took into account the Ranmagar-II, Contai-I, and Deshapran Blocks of Purba Medinipur district because of the fact that, these were the only three coastal C.D. Blocks where CBA had grown consistently during the last three decades and is still considered as a dominant commercial activity.

Chapter IV: Spatio-temporal patterns of CBA growth

4.1 Introduction

CBA in West Bengal is mostly practiced in Purba Medinipur, South 24 Parganas, and North 24 Parganas (Datta et al., 2010b; Roy, 2013; Datta & Ghosh, 2015; Ojha & Chakrabarty, 2018). Exponential growth of CBA has occurred in the coastal C.D. Blocks of the Purba Medinipur district, replacing the landscape to a great extent and triggering a multitude of environmental as well as social problems (Datta & Ghosh, 2015; Roy et al., 2021b).

4.2 Methodological framework

4.2.1 Data used

Six orthorectified, cloud-free multi-temporal satellite images of pre-monsoon months covering the study area were acquired from the open-source repository of the United States Geological Survey (USGS) Glovis (http://glovis.usgs.gov) for the present study (Table 1) (Roy & Datta, 2018). These images, having Universal Transverse Mercator (UTM) projection and World Geodetic System 84 datum, included data of Landsat 5 Thematic Mapper (TM) (Path 139, Row 45; dated February 9, 1991, March 6, 1991, April 25, 2001, and February 16, 2011), Landsat 8 Operational Land Imager (OLI) (Path 139, Row 45; dated March 15, 2021), and Landsat 9 Operational Land Imager 2 (OLI–2), Thermal Infrared Sensor 2 (TIRS–2) (Path 139, Row 45; dated April 14, 2023) (Roy et al., 2021b). Since the pre-monsoon months were universally regarded as the prime season for aquaculture cultivation, these were deliberately chosen for analysis. Besides, a total of 200 ground control points (GCPs) were collected from different parts of the study area covering all the land use/ land cover (LULC) classes through GPS-based surveys (Handheld Garmin 12 channel device) (Fig. 4.1.).

Table 4.1: Details of satellite images used for LULC classification.

<table>
<tr><th>Date of Acquisition</th><th>Sensor</th><th>Path/
Row</th><th>Spatial resolution
(m)</th></tr>
<tr><td>9th February 1991
6th March 1991
25th April 2001
16th February 2011</td><td>Landsat 5 Thematic Mapper (TM)</td><td rowspan="3">139/45</td><td rowspan="3">30</td></tr>
<tr><td>15th March 2021</td><td>Landsat 8 Operational Land Imagery (OLI)</td></tr>
<tr><td>14th April 2023</td><td>Landsat 9 Operational Land Imager 2 (OLI–2)</td></tr>
</table>

4.2.2 Image processing and classification

Radiometric correction and atmospheric corrections were performed using ERDAS Imagine 2014 software to obtain improved accuracy of the satellite data for the image classifications (Roy & Datta, 2018). Afterward, the image of 2023 was geocoded with the help of GCPs collected from the field, and the other images were successively geo-referenced using the image-to-image georeferencing method. For the georeferencing of the successive images, a third-order polynomial geometrical model was selected and the root mean square error (RMSE) was retained less than 0.5 pixels (Bhattacharjee et al., 2022). The area of interest indicating the study area was clipped from the images using the same software.

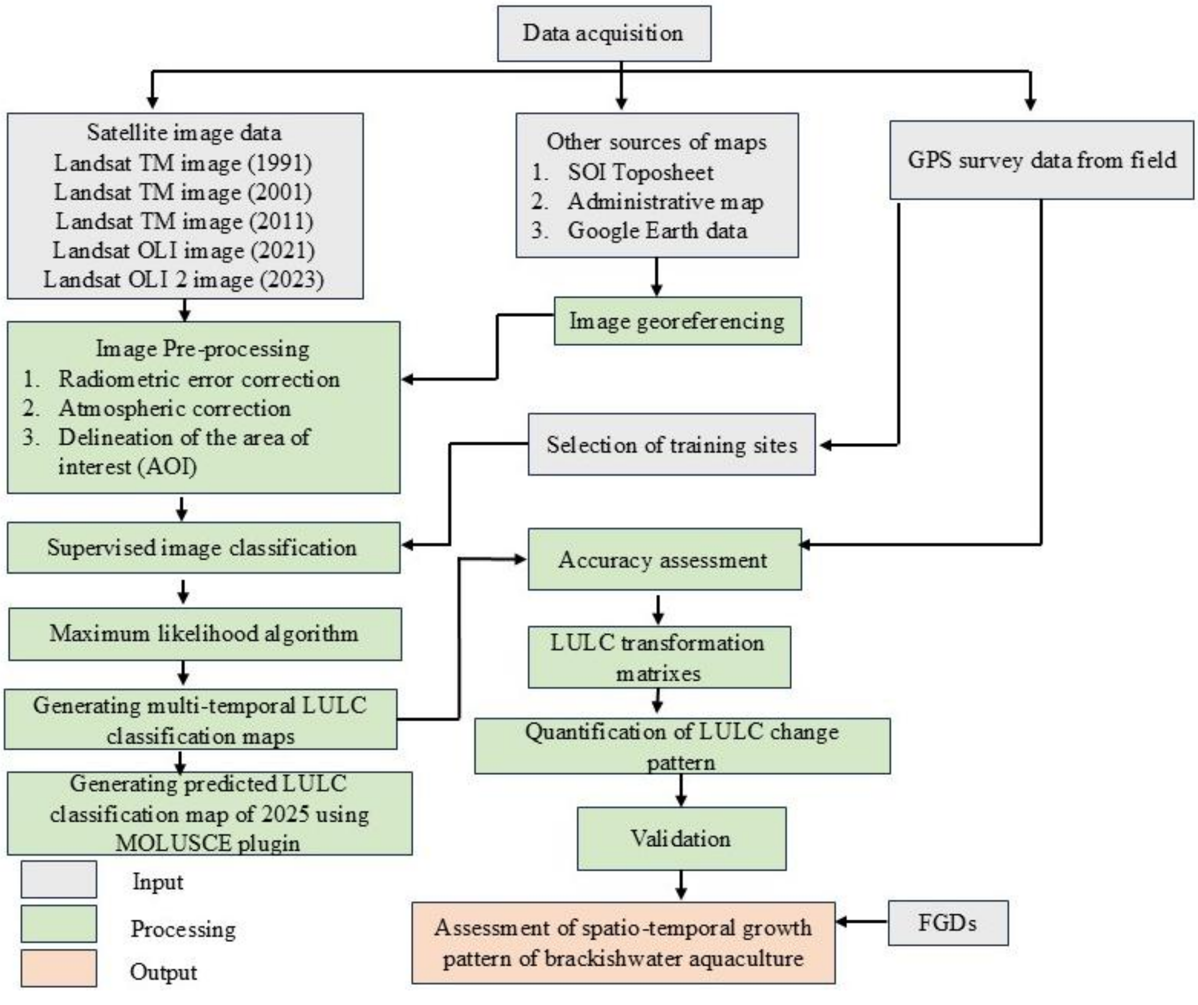

Figure 4.1: Methodological framework for identification of the spatio-temporal patterns of growth of CBA in the study area.

Supervised image classification of the five images was carried out using the maximum likelihood parametric decision rule (Lillesand et al., 2008; Li et al., 2014). A total of eight LULC classes were taken into consideration for the image classification relying on the authors' a-priori knowledge regarding the present study area. The LULC classes were aquaculture, abandoned aquaculture, other waterbody, cropland, mangrove vegetation, other vegetation, built-up, and bare land and sand, respectively (Datta & Deb, 2012). Notably, the aquaculture class in this study denoted the CBA areas. To identify this class distinctly, CBA farms were located during the field surveys, the records of which were maintained meticulously. These were later used during the LULC classification. Besides, the spectral signature of the pixels, along with tones, patterns, shapes, and textures were taken into consideration to distinguish between CBA and other waterbodies (Mazumder et al., 2021). It is necessary to mention that other vegetation also included the under-canopy rural settlements. Accuracy assessment was performed for all five classified images with the help of 200 GCPs collected from all eight LULC classes during the ground truth survey. Alongside, overall accuracy and Kappa Coefficient were generated to validate the accuracy level. Following the image classification, LULC transformation matrices were generated to assess the inter-class LULC changes within the assessment period (Mazumder et al., 2021; Roy et al., 2021a).

4.2.3 Geo-statistical analysis

To detect the growth trajectory of CBA, the percentage of Census Village-wise aquaculture area was calculated for the assessment years, i.e., 1991, 2001, 2011, 2021, and 2023, and was predicted for the year 2025. Additionally, a hotspot analysis was carried out for similar years. Anselin (1995) stated that spatial data analysis techniques could identify spatial association and autocorrelation in ortho-referenced images. One such measure of spatial autocorrelation is Moran's I (Moran, 1950). The Local Influence of Spatial Autocorrelation (LISA) method was found to be useful in identifying the existence of local spatial clustering or ‘hot spots’ and, accordingly, was applied here (McCullagh, 2006; Pérez-Peña et al., 2009; Ratcliffe, 2010; Yunus et al., 2015). The Hotspot Analysis calculates the Getis-Ord Gi* (Gi) statistic for features in a weighted set of features. Given a set of weighted data points, the Gi statistic identifies the clusters of points with values higher in magnitude and tells whether features with high values or features with low values tend to cluster in a study area. In Gi statistics, if a feature's value is high, and the values for all its neighbouring features are also high, it is part of a hot spot. The Getis-Ord Gi* is defined as (Eq. 4.1):

$$Gi^* = \sum_j w_{ij}(d)x_j \div \sum_j x_j \quad \text{(Eq. 4.1)}$$

where, $w_{ij}(d)$ are the elements of the contiguity matrix for distance d. For every pair of points, this matrix assigns a spatial weight and a binary classification based on whether the point is within a distance d of I (Pérez-Peña, 2009). The resultant Gi statistic is in the form of a statistically significant as well as standardized Z score. The larger the Z score is, the more intense the clustering of high values. These statistical analyses were taken into account since they were proportionate to the global indicator of spatial correlation and depicted the degree of significant geographical clustering of comparable values around the specific observation (Anselin, 1995).

4.2.4 Analysis of patch dynamics of CBA

Several extensively recognized spatial metrics were computed to assess the growth trajectory of CBA during 1991-2023 from the LULC raster datasets, using the spatial pattern analysis program, FRAGSTATS version 4.2 software (University of Massachusetts, Amherst, USA) (McGarigal, 1995; Tolessa et al., 2016; Nandi et al., 2020; Roy, et al., 2021b). Patch area (AREA), patch perimeter (PERIM), and shape index (SHAPE) were chosen for analysis at the patch level after construing pertinent research related to relevant spatial metrics (Li et al., 2004; Matsushita et al., 2006). Furthermore, ten traditional landscape metrics were selected at the class level, covering three aspects of patch complexity, namely, area, shape, and degree of agglomeration.

(1) Area metrics: In this study, class area (CA) was chosen as a measure of landscape composition; specifically, to identify how much of the landscape comprised a particular patch type (Li et al., 2004; Jia et al., 2019). To measure the proportional abundance of each patch type in the landscape, the percentage of the landscape (PLAND) was chosen. The number of patches (NP) of a particular patch type is a simple measure of the extent of subdivision or fragmentation of the patch type, thereby representing the class consisting of a single patch. The mean patch area (AREA_MN) measured the statistical distribution of land area. In addition, the largest patch index (LPI), a measure of dominance, that depicted the degree of landscape fragmentation, was selected to measure the proportion of the total area taken up by the largest patch in the study area (Lausch & Herzog, 2002; Li et al., 2004; Su et al., 2011).

(2) Shape metrics: In this study, the mean perimeter-area ratio (PARA_MN) and the mean fractal dimension index (FRAC_MN) were used as two shape indices under a particular class (Southworth et al., 2004; Su et al., 2011). Between the two, PARA_MN was the simpler measure of patch shape. When the shape of a patch remains constant, PARA_MN changes with the patch area. FRAC_MN circumvents PARA_MN's primary

shortcoming in gauging shape complexity, with a greater FRAC_MN indicating a more irregular shape.

(3) Degree of agglomeration metrics: The degree of spatial agglomeration or separation of patches in a landscape is represented by agglomeration indices. The degree of agglomeration is low when a landscape is made up of numerous small, discrete patches; it is high when a landscape is made up of a few large patches or if the patches belonging to the same category are sufficiently connected. In this study, the indices assessing the degree of agglomeration were patch density (PD), landscape shape index (LSI), and percentage of similar adjacency (PLADJ). PD represents the degree of fragmentation in a landscape. Landscape patch indices, LSI and PLADJ, both quantify the degree of class aggregation in terms of shape complexity (Southworth et al., 2004; Datta et al., 2021).

4.2.5 Projecting future CBA growth trajectory

After the preparation of LULC maps of 2011, 2021, and 2023, prediction for the year 2025 was done using a machine learning-based modelling approach, i.e., Cellular Automata and Artificial Neural Networks (CA-ANN) model under the MOLUSCE (Modules of Landuse Change Evaluation) plugin in the open-source QGIS software (Version 2.18.23). Several spatial variables, namely, digital elevation model (DEM), slope, rainfall, temperature, population density, and distance from roads and canals were considered as driving factors to run the projection. In this CA-ANN model, a hidden layer of 10, an iteration of 1000, a momentum value of 0.06, and a learning rate of 0.001 were used (Perović et al., 2018; El-Tantawi et al., 2019). Area change and transition probability matrices were generated using the 2011 and 2021 LULC maps. Initially, the LULC scenario of 2023 was simulated using LULC data for the years 2011 and 2021. Further, it was validated with reference to the actual LULC map of 2023 as a measure of calibration and fine tuning. Finally, the LULC map for the year 2025 was developed by the calibrated system (by calculating the overall Kappa coefficient), using the actual classified maps of 2021 and 2023, respectively.

4.3 Results

4.3.1 Patterns of LULC transformation

During the span of the assessment period of 33 years (i.e., from 1991 to 2023), the landscape of the study area was observed to have experienced a notable transformation of the landscape where the major noticeable aspect was the pattern of successive growth and decay of aquaculture in the region (Fig. 4.2.). The classification accuracy for all the five LULC maps was generated in this regard. Here, the overall Kappa coefficient values were 0.75, 0.78, 0.77, 0.80, and 0.84 and overall classification accuracies were 79.50%, 81.31%, 80.90%, 83.33%, and 86.36 % for the years 1991, 2001, 2011, 2021, and 2023, respectively (Table 4.2.).

In 1991, the area under CBA was 24.28 km^2 which increased by 73.35% in 2001, covering an area of 42.09 km^2 (Table 4.3A.). 10.44 km^2 of land under agriculture was converted to CBA. Besides, 3.06 km^2 of other waterbody and 2.75 km^2 of other vegetation also got converted to CBA. Between 1991 and 2001, cropland had marginally increased from 266.09 km^2 to 270.81 km^2 whereas land under other vegetation decreased from 208.67 km^2 to 189.35 km^2. Noticeably, the patch of coastal mangroves had also reduced in area, a considerable part of which got converted to CBA.

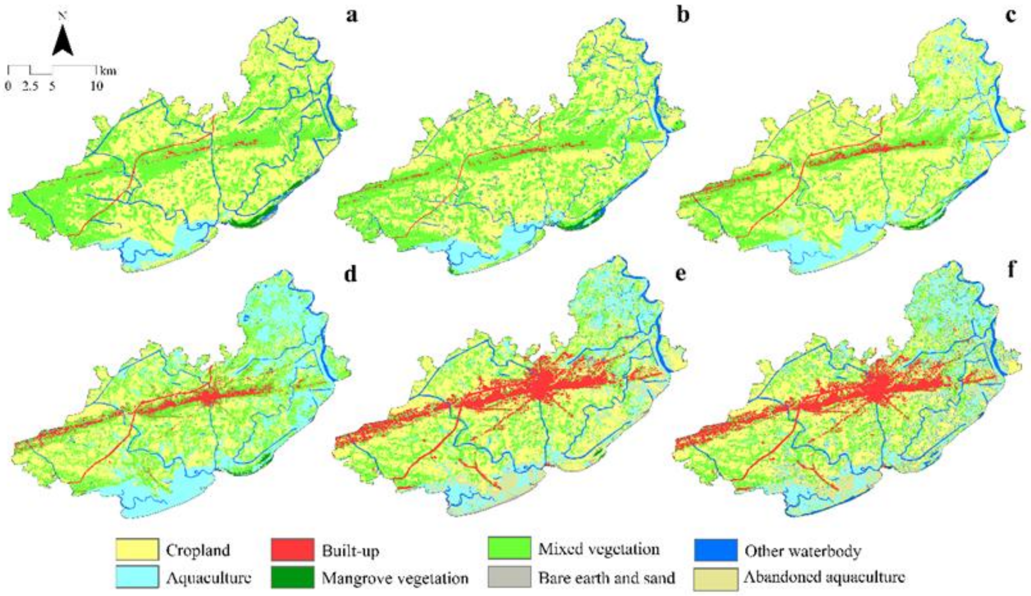

Figure 4.2: Spatial distribution of different LULCs for the year (a) 1991, (b) 2001, (c) 2011, (d) 2021, (e) 2023, and predicted for the year (f) 2025.

Following the trend of the previous decade, the land under CBA increased by 74.54% between 2001 and 2011, and a total of 73.47 km^2 area came under CBA (Table 4.3B.). Specifically, 22.88 km^2, 5.72 km^2, and 2.57 km^2 of area under cropland, other waterbodies, and other vegetation respectively got converted to CBA. The patch of coastal mangroves was further reduced from 2.51 km^2 to 1.45 km^2, of which 0.77 km^2 was converted to CBA.

Between 2011 and 2021, the total area under CBA registered a massive increase from 73.97 km^2 to 155.97 km^2, indicating 110.87% of growth (Table 4.3C.). A considerable amount (i.e. 70.78 km^2) of cropland was converted to CBA. As a result, cropland was reduced from 284.41 km^2 to 217.17 km^2 between 2011 and 2021. Other vegetation had also reduced from 149.92 km^2 to 122 km^2, of which 8.63 km^2 was converted to CBA. Furthermore, to compensate for the conversion of cropland to CBA, 33.30 km^2 of other vegetation had been converted to croplands. Coastal mangrove covers were further reduced from 1.45 km^2 to 1.06 km^2, and 0.33 km^2 of mangrove was converted to CBA.

A drastic change in the landscape scenario was observed in 2023, especially in the case of CBA (Table 4.3D.). Although, from 1991 to 2021, CBA increased incessantly, a sudden fall in land under CBA was observed in 2023 when it reduced from 155.97 km^2 to 96.94 km^2 in just two years and 36.76 km^2 of land under CBA had become abandoned. Some amount of land under CBA also got converted to cropland, other vegetation, other water bodies, and barren land.

Photograph 4.1: Traditional paddy field.

Photograph 4.2: Conversion of paddy field to shrimp farm.

Photograph 4.3: Typical shrimp farm.

Photograph 4.4: Abundant shrimp farm.

Table 4.2: Accuracy assessment report of classified images.

Year	Overall accuracy (%)	Overall Kappa (K^)
1991	79.50	0.76
2001	81.31	0.78
2011	80.90	0.77

Year	Overall accuracy (%)	Overall Kappa (K^)
2021	83.33	0.80
2023	86.36	0.84

4.3.2 Census Village-wise growth pattern of CBA

In the study area, it was observed that, at the initial phase, i.e. during 1991, CBA had developed almost at all the coastal Census Villages of Ramnagar-II and the southwestern part of Contai-I C.D. Blocks, respectively (Fig. 4.3.). In the following decades, CBA spread in the other Census Villages located along the coast as well as in more inland parts, mainly along the tidal rivers and canals. In 2001, CBA was initiated in those areas that were located away from the coastal region and had grown along the tidal rivers and canals. In 2011, the area under CBA grew in the Census Villages where CBA had already been established. Also, CBA grew in adjacent Census Villages and spread in the more inland parts with the highest spread in the Deshapran Block, where CBA got initiated in almost all Census Villages located along the Rasulpur river and had even spread further westward. The massive growth of aquaculture had taken place between 2011 and 2021, and CBA had grown in all the Census Villages located along the coast. Following the trend of the previous decade, the areal growth was highest in the villages of Deshapran Block, where CBA had extended into the western side in the inland part. CBA had also spread in the extreme northern part of the study area. A notable change in the scenario was found in 2023 when the land under CBA had been considerably reduced and a considerable portion of CBA farms became abandoned. The concentration of CBA had reduced in almost all villages. In 2023, a high concentration of CBA was mainly found in the villages along the coast and a few villages in the inland part. Coastal villages in the Contai-I and Deshapran Blocks still had higher concentrations of CBA, though the percentage of land under CBA in these villages had reduced than those of 2021 (Fig. 4.3).

Table 4.3A: LULC transformation matrix from 1991-2001.

LULC class	Area in 2001 (km^2)								
	Abandoned aquaculture	Cropland	Aquaculture	Bare earth and sand	Built-up	Mangrove vegetation	Other vegetation	Other waterbody	Total area (1991)
Area in 1991 (km^2)									
Abandoned aquaculture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cropland	0.00	207.93	10.44	0.32	1.73	0.01	40.86	4.80	266.09
Aquaculture	0.00	0.01	24.21	0.03	0.00	0.01	0.01	0.01	24.28
Bare earth and sand	0.00	0.16	0.64	0.29	0.53	0.02	0.10	0.37	2.11
Built-up	0.00	0.00	0.01	0.01	4.32	0.00	0.01	0.01	4.36
Mangrove vegetation	0.00	0.16	0.98	0.08	0.00	2.31	0.27	0.40	4.20
Other vegetation	0.00	55.73	2.75	0.17	2.44	0.08	143.35	4.15	208.67
Other waterbody	0.00	6.82	3.06	0.08	0.23	0.08	4.75	17.78	32.80
Total area (2001)	0.00	270.81	42.09	0.98	9.25	2.51	189.35	27.52	542.51

Table 4.3B: LULC transformation matrix from 2001-2011.

LULC class	Area in 2011 (km^2)								
	Abandoned aquaculture	Cropland	Aquaculture	Bare earth and sand	Built-up	Mangrove vegetation	Other vegetation	Other waterbody	Total area (2001)
Area in 2001 (km^2)									
Abandoned aquaculture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cropland	0.00	219.97	22.88	0.02	1.46	0.01	23.83	2.64	270.81
Aquaculture	0.00	0.22	41.81	0.02	0.01	0.00	0.01	0.02	42.09
Bare earth and sand	0.00	0.35	0.20	0.20	0.01	0.05	0.06	0.11	0.98
Built-up	0.00	0.01	0.02	0.01	9.17	0.00	0.01	0.03	9.25
Mangrove vegetation	0.00	0.15	0.77	0.20	0.00	1.30	0.06	0.03	2.51
Other vegetation	0.00	56.11	2.57	0.07	6.37	0.05	122.75	1.43	189.35
Other waterbody	0.00	7.60	5.72	0.11	0.08	0.04	3.20	10.77	27.52
Total area (2011)	0.00	284.41	73.97	0.63	17.10	1.45	149.92	15.03	542.51

Table 4.3C: LULC transformation matrix from 2011-2021.

LULC class	Area in 2021 (km^2)								
	Abandoned aquaculture	Cropland	Aquaculture	Bare earth and sand	Built-up	Mangrove vegetation	Other vegetation	Other waterbody	Total area (2011)
Area in 2011 (km^2)									
Abandoned aquaculture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cropland	0.00	183.44	70.78	0.02	4.61	0.02	22.23	3.31	284.41
Aquaculture	0.03	0.02	73.49	0.07	0.03	0.04	0.05	0.24	73.97
Bare earth and sand	0.00	0.01	0.40	0.18	0.01	0.00	0.02	0.01	0.63
Built-up	0.00	0.02	0.01	0.00	17.02	0.00	0.03	0.02	17.10
Mangrove vegetation	0.00	0.09	0.33	0.00	0.00	0.98	0.03	0.02	1.45
Other vegetation	0.00	33.30	8.63	0.00	7.38	0..02	99.62	0.99	149.92
Other waterbody	0.00	0.29	2.33	0.07	0.10	0.02	0.02	12.20	15.03
Total area (2021)	0.03	217.17	155.97	0.34	29.15	1.06	122.00	16.79	542.51

Table 4.3D: LULC transformation matrix from 2021-2023.

LULC class	Area in 2023 (km^2)								
	Abandoned aquaculture	Cropland	Aquaculture	Bare earth and sand	Built-up	Mangrove vegetation	Other vegetation	Other waterbody	Total area (2021)
Area in 2021 (km^2)									
Abandoned aquaculture	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Cropland	3.18	151.01	10.32	2.02	15.01	0.00	31.12	4.51	217.17
Aquaculture	36.76	13.79	84.82	2.43	1.23	0.01	11.79	5.14	155.97
Bare earth and sand	0.01	0.01	0.01	0.31	0.00	0.00	0.00	0.00	0.34
Built-up	0.00	0.04	0.00	0.00	29.09	0.00	0.01	0.01	29.15
Mangrove vegetation	0.01	0.48	0.01	0.02	0.00	0.51	0.02	0.01	1.06
Other vegetation	0.05	41.16	1.48	0.06	10.39	0.03	66.42	2.41	122.00
Other waterbody	0.01	1.50	0.30	0.05	0.00	0.00	0.58	14.35	16.79
Total area (2023)	40.04	208.00	96.94	4.89	55.72	0.55	109.94	26.43	542.51

Table 4.3E: Projected LULC transformation matrix from 2023-2025.

LULC class	Area in 2025 (km^2)								
	Abandoned aquaculture	Cropland	Aquaculture	Bare earth and sand	Built-up	Mangrove vegetation	Other vegetation	Other waterbody	Total area (2023)
Area in 2023 (km^2)									
Abandoned aquaculture	37.76	0.41	0.40	0.01	0.01	0.00	0.90	0.55	40.04
Cropland	1.42	194.14	0.80	0.01	2.16	0.00	1.01	8.46	208.00
Aquaculture	20.17	0.74	73.34	0.01	0.03	0.00	1.49	1.16	96.94
Bare earth and sand	0.03	0.02	0.01	3.80	0.00	0.00	0.05	0.98	4.89
Built-up	0.00	0.00	0.00	0.00	55.72	0.00	0.00	0.00	55.72
Mangrove vegetation	0.00	0.01	0.00	0.00	0.00	0.07	0.01	0.46	0.55
Other vegetation	0.20	2.00	0.50	0.40	0.03	0.00	105.56	1.25	109.94
Other waterbody	1.14	0.03	0.15	0.00	0.02	0.00	0.03	25.06	26.43
Total area (2025)	60.72	197.35	75.20	4.23	57.97	0.07	109.05	37.92	542.51

The hot spot analysis revealed the pattern of significant clustering of villages with higher concentrations of CBA. In 1991, hot spots (with 99% Confidence Interval) were mainly found in all the coastal villages and a few near-coastal villages of Ramnagar-II, and in the coastal villages located at the southwestern part of the Contai-I Block. In 2001, hot spots propagated along the coast and in most of the near-coastal villages in these two C.D. Blocks. Hot spots emerged in the eastern part of Deshapran Block mainly along the Rasulpur river and existing canals in 2011. Along with this, significant clustering of villages with low CBA, i.e., cold spots, were found in the middle portion of the study area where the amount of built-up was higher, which was developed over the dune ridges. In 2021, hot spots had spread across more villages, and the highest spread was found in the Deshapran Block. However, a more significant clustering of cold spots appeared in the middle portion of the study area. In 2023, the concentration of CBA reduced, and hot spots were found mainly in the coastal and near-coastal villages (Fig. 4.4). It is necessary to mention here that the Z score values were 11.20, 17.17, 23.44, and 27.97 for the years 1991, 2001, 2011, and 2021 respectively, which denoted that CBA continued to cluster more intensely up to 2021. However, the Z score value for the year 2023 decreased to 20.20 denoting a decrease in the clustering of CBA. Nonetheless, the *p* values for all the cases were statistically significant ($p < 0.05$) and Z scores were positive. This indicated more significant spatial clustering and fewer chances of spatial randomness (Badlowski et al., 2021).

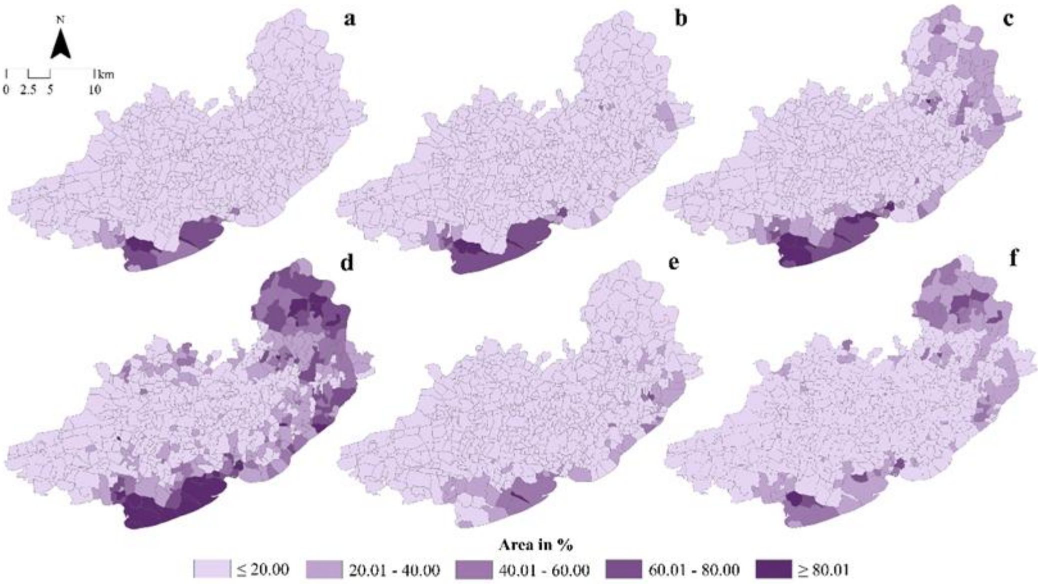

Figure 4.3: Census Village-wise percentage of area under aquaculture for the year (a) 1991, (b) 2001, (c) 2011, (d) 2021, (e) 2023, and predicted for the year (f) 2025.

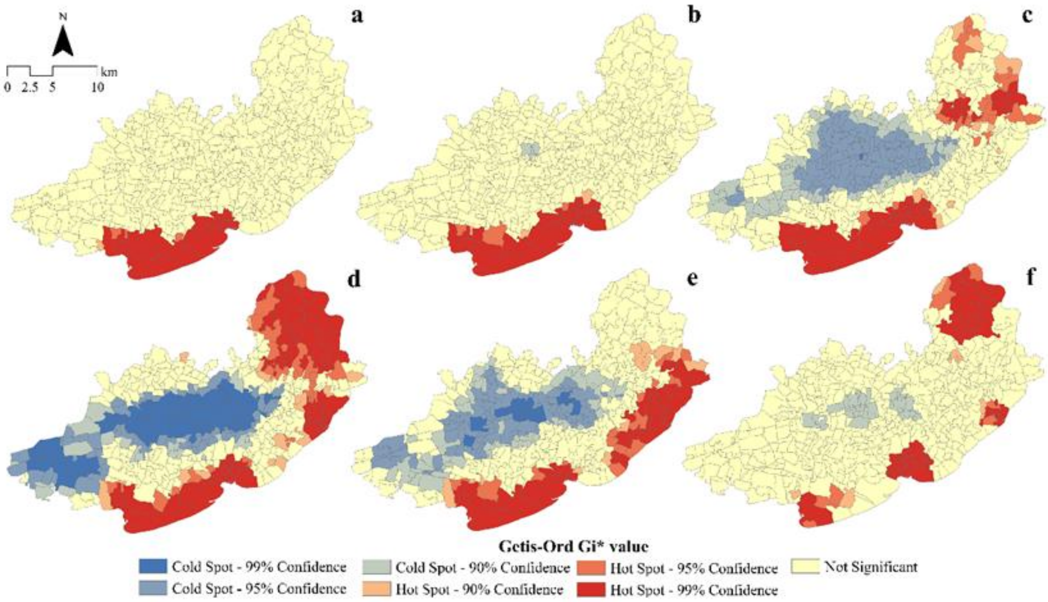

Figure 4.4: Spatial distribution of aquaculture hotspots for the year (a) 1991, (b) 2001, (c) 2011, (d) 2021, (e) 2023, and predicted for the year (f) 2025.

4.3.3 Patch dynamics of CBA

To assess the growth pattern of CBA, the output of patch level and class level spatial metrics of the three C.D. Blocks of the study site had been intensively analysed. At the patch level, the mean AREA metric of Contai-I had decreased from 5.25 ha to 1.65 ha and it had again increased to 2.97 ha in 2023. Similarly, the largest patch AREA value (332.55 ha) came down to 40.05 ha in a span of only two years. The same trend can be noticed regarding maximum PERIM values, where there had been a constant increase (from 15060 m to 42600 m), followed by a huge fall to 8580 m. The mean values of the SHAPE metric depicted a drop in the first four decades (1.33 to 1.20), followed by a rise (1.30) in 2023. The same trend can be observed with regard to the SHAPE metric in Ramnagar-II. However, a steady notable rise in the SHAPE metric (1.16 to 1.40) can be noticed in Deshapran. Here, the mean AREA metric had constantly increased from 0.33 ha in 1991 to 4.68 ha in 2021, thereafter falling to 3.10 ha in 2023. The maximum PERIM values rose from 3660 m to 527820 m, thereby dropping to 397080 m. However, the mean PERIM values depicted a notable rise from 267.50 m to 1141.16 m. In Ramnagar-II, the mean AREA metric had sharply declined from 13.48 ha to 3.75 ha (Table 4.5A.). Similarly, the largest patch AREA value (3708.45 ha) came down to 435.15 ha only. The mean PERIM values depicted a declining pattern (1082.71 m to 79537 m) followed by an upsurge (1052.62 m). In this C.D. Block, the maximum PERIM values increased gradually between 1991 and 2021 (112440 m to 151920 m) and then fell to 108720 m in 2023.

Regarding the class level metrics, results revealed that from 1991 to 2021, the changing patterns of the CBA in the study region was consistent, as the landscape became more fragmented and dispersed. However, the scenario got reversed during the year 2023. The absolute values of CA for CBA increased rapidly suggesting an increased area and lesser landscape heterogeneity up until the year 2023 (from 236.07 ha to 2741.49 ha in Contai-I; from 31.23 ha to 7622.10 ha in Deshapran; from 2235.96 ha to 4313.25 ha in Ramnagar-II), when it fell to 1336.50 ha, 4657.21 ha, and 2102.40 ha respectively in 2023. (Table 4.5B.). From 1991 to 2021, large areal chunks of CBA have appeared, evident in the increasing PLAND for all the C.D. Blocks. After 2021, the metric reduced notably, reaching 6.80% in Contai-I, 25.32% in Deshapran, and 12.95% in Ramnagar-II. Both NP and PD values (per 100 ha) recorded a steep rise since 1991 in Contai-I and Deshapran, thereby indicating an augmented area and landscape heterogeneity. However, both the values for these two C.D. Blocks fell sharply in the year 2023 (NP: 813 and 1503; PD: 4.14 and 8.17, respectively. LPI values have constantly increased over time (1991-2021), pointing towards the development of larger and combined patches in all the C.D. Blocks, i.e., the CBA patches were broken first and then aggregated and again broke in 2023. However, AREA_MN in Deshapran has continuously increased since 1991, suggesting that although large areas of CBA patches are fragmented, they have not disappeared. An opposite condition has been noticed in the other two C.D. Blocks with a steady fall in CBA patches since 2001. FRAC_MN values have depicted a very minute growth which could possibly lead to the development of shape complexity over time.

The patch complexity has also been analysed with the PARA_MN metric and it showcased diminishing values for the three C.D. Blocks from 1991-2023, demonstrating the presence of less dispersive patches. Regarding the metrics of agglomeration, LSI statistics depicted the emergence of amorphous patches from 2001 to 2023 in Deshapran and Ramnagar-II. In the case of Contai-I, disaggregation was initiated in 1991 (7.17) and continued up to 2021 (41.13), post which there was a direction towards aggregation with values falling to 36.39 in 2023. High PLADJ values revealed maximum agglomeration. However, decreasing values in Contai-I (85.93 in 1991 to 70.10 in 2023) and Ramnagar-II (92.77 in 1991 to 78.93 in 2023) revealed a discontinuous pattern of CBA development. Nevertheless, ever-increasing values in the last 30 years (1991-2021) from 38.33 to 83.73 indicated continuous CBA patches with the commencement of relative disaggregation in

2023. Overall, the changing trend of landscape indices mirrored the loss of landscape diversity, as the fragmented, and complicated nature of CBA dominated across the study area.

4.3.4 Modelled CBA spread pattern in 2025

The probable LULC scenario of the study region in 2025 has been predicted using a multi-parameter-based model (Fig. 2f). The simulations had directed towards a steady growth in all the LULC classes barring aquaculture, cropland, and bare earth and sand. A notable loss of area in CBA was projected at 75.20 km^2, representing a reduction of 4.01% (~ loss of 21.74 km^2 area) from the 2023 context (Table 4.3E). The greatest decline had been observed in the southern section of Ramnagar-II followed by the northeastern portion of Deshapran. This loss could be attributed to the predicted rise of abandoned aquacultural lands by 3.81% and other water bodies by 2.12% (Table 4.4). Furthermore, the model denoted that there would have been a maximum conversion of CBA to abandoned aquaculture.

Table 4.4: LULC statistics for the predicted scenario of 2025.

LULC class	Area (km^2)	Area (%)
Abandoned aquaculture	60.72	11.19
Cropland	197.14	36.38
Aquaculture	75.20	13.86
Bare earth and sand	4.23	0.78
Built-up	57.97	10.69
Mangrove vegetation	0.07	0.01
Other vegetation	109.05	20.10
Other waterbody	37.92	6.99

Table 4.5A: Comparison of landscape metrics at patch level from 1991 to 2023.

CD Block	Year	Patch metric								
		Area (ha)			PERIM (m)			SHAPE		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Contai-I	1991	0.09	162.99	5.25	120	15060	984	1.00	5.19	1.33
	2001	0.09	202.23	2.22	120	20100	524.88	1.00	3.53	1.21
	2011	0.09	271.53	1.45	120	26340	430.79	1.00	3.99	1.17
	2021	0.09	332.55	1.65	120	42600	519.64	1.00	5.82	1.20
	2023	0.09	40.05	2.97	120	8580	840.00	1.00	3.33	1.30
Deshapran	1991	0.09	8.46	0.33	120	3660	267.50	1.00	3.05	1.16
	2001	0.09	99.99	1.47	120	22680	505.40	1.00	8.04	1.19
	2011	0.09	205.11	1.59	120	44520	570.76	1.00	8.73	1.24
	2021	0.09	3517.83	4.68	120	527820	1015.69	1.00	22.21	1.24
	2023	0.09	1528.29	3.10	120	397080	1141.16	1.00	25.36	1.40
Ramnagar-II	1991	0.09	1854.72	11.24	120	112440	1082.71	1.00	6.51	1.23
	2001	0.09	2522.43	13.48	120	139980	1056.31	1.00	6.96	1.21
	2011	0.09	2936.97	8.79	120	146100	870.53	1.00	6.73	1.26
	2021	0.09	3708.45	8.91	120	151920	795.37	1.00	6.24	1.19
	2023	0.09	435.15	3.75	120	108720	1052.62	1.00	12.76	1.34

AREA: patch area; PERIM: patch perimeter; SHAPE: shape index

Table 4.5B: Comparison of landscape metrics at class level from 1991 to 2023.

CD Block	Year	Class metric									
		CA	PLAND	NP	AREA_MN	LPI	FRAC_MN	PARA_MN	PD	LSI	PLADJ
Contai-I	1991	236.07	1.20	45.00	5.25	0.83	1.05	1045.72	0.23	7.17	85.93
	2001	536.04	2.73	242.00	2.22	1.03	1.04	1060.91	1.23	13.66	82.23
	2011	1021.23	5.19	706.00	1.45	1.38	1.04	1039.64	3.59	23.69	77.66
	2021	2741.49	13.94	1662.00	1.65	1.69	1.04	976.78	8.45	41.13	76.37
	2023	1336.50	6.80	813.00	1.64	1.00	1.05	941.70	4.14	36.39	70.10
Deshapran	1991	31.23	0.17	96.00	0.33	0.05	1.03	1166.14	0.52	11.26	38.33
	2001	928.08	5.04	633.00	1.47	0.54	1.04	1021.38	3.44	26.14	74.15
	2011	2893.95	15.73	1818.00	1.59	1.11	1.04	990.03	9.88	48.17	73.11
	2021	7622.10	41.43	1628.00	4.68	19.12	1.04	1021.22	8.85	47.27	83.73
	2023	4659.21	25.32	1503.00	3.10	8.31	1.06	996.88	8.17	62.69	72.39
Ramnagar-II	1991	2235.96	13.78	199.00	11.24	11.43	1.04	1105.12	1.23	11.36	92.77
	2001	2628.09	16.19	195.00	13.48	15.54	1.04	1030.89	1.20	10.04	94.12
	2011	3278.79	20.20	373.00	8.79	18.09	1.04	1014.73	2.30	14.17	92.57
	2021	4313.25	26.57	484.00	8.91	22.84	1.04	965.50	2.98	14.65	93.31
	2023	2102.40	12.95	561.00	3.75	2.79	1.05	981.84	3.46	32.16	78.93

CA: total class area; PLAND: percentage of landscape; NP: number of patches; AREA_MN: mean patch area; LPI: largest patch index; FRAC_MN: mean fractal dimension index; PARA_MN: mean perimeter-area ratio; PD: patch density; LSI: landscape shape index; PLADJ: percentage of similar adjacency

4.4 Discussion

4.4.1 Drivers of CBA growth

With the diminution in the marine fish catch and to supplement the ever increasing demand of fish-protein in the world market, aquaculture increased exponentially exceeding all the other types of animal husbandry (Dewalt et al, 1996; Pradhan & Flaherty, 2007). Exponential demand of shrimp in global market, especially in USA, Japan, and European Union and consequent high market price as well as scope of reliable export earning persuaded booming of CBA in tropical coastal areas (Hossain et al., 2013; Galappaththi & Nayak, 2017). Thus, among all the aquaculture products, shrimp recorded the extraordinary growth (Stonich & Bailey, 2000). Global production of cultured shrimp increased 34% between 2002 and 2008 (Hossain et al, 2013). CBA emerged as one of the most profitable livelihoods for the marginal farmers in the otherwise infertile coastal lands having high salinity (Hossain et al., 2013; Salunke et al, 2020). Being a potential source of foreign exchange, the growth of CBA in the coastal areas of the developing countries received potential impetus from both the national and international investors (Béné, 2005).

In India traditional brackishwater aquaculture had been widely practiced along the East coast, especially in Tamil Nadu, Andhra Pradesh, Orissa, and West Bengal for ages. However, since 1990s aquaculture in India shifted from its traditional form and largely became export oriented commercial activity, the area under which grew incessantly. Most of the CBA farms cultivated shrimp which contributed considerably in earning foreign exchange as well as generate livelihood opportunities (Rajitha et al., 2005; Pradhan & Flaherty, 2007; Pattanaik & Prasad, 2011; Ojha & Chakrabarty, 2018). To amplify the export earning, Indian Government started promoting growth of brackishwater aquaculture since late 1980s through various initiatives including liberalizing export policies, formulating various fisheries schemes under Five-Year Plans, encouraging more investments in aquaculture, developing infrastructures, creating provisions for loan etc. The government initiatives were also backed by financial and technical supports from international investors. (Pradhan & Flaherty, 2007; Salunke et al, 2020). As a consequence, since 1980's India became one of the major shrimp exporters in the global market (Galappaththi & Nayak, 2017). Between 1995 and 2004, shrimp production increased from 70,000 tonnes to 117,500 tonnes (Pradhan & Flaherty, 2007). Penaeus monodon and Litopenaeus vannamei are the two major types of shrimp cultivated in India (Ghoshal et al, 2017). Besides shrimp, the brackishwater aquaculture farms also cultivated various salt water fishers, such as grey mullet (Mugil cephalus), catfish, Asian seabass (Lates calcarifer), milkfish (Chanos chanos), and parlspot (Etroplus suratensis). Though tiger shrimp dominated the brackishwater aquaculture in India since the initiation of the scientific farming, since 2009, the white-leg shrimp started to become the dominant cultured variety (Ghoshal et al, 2019).

Brackishwater aquaculture ‘bheries’ was an age old practice in the coastal districts of West Bengal. However, export oriented semi intensive tiger shrimp production started in late 1980s and grew exponentially until 1995 when the production came into halt due to massive disease incursion (Ghoshal et al, 2017). Tiger shrimp cultivation continued up to 2009, which was then replaced by the exotic species *Litopenaeus vannamei*, commonly known as white-leg shrimp, which was promoted for its fast growth potential and more intensive cultivation opportunity. In the following years, West Bengal became a major contributor in India’s total brackishwater fish and shrimp production (Boyd et al., 2018; Ghoshal et al, 2019). CBA in West Bengal is mostly practiced in Purba Medinipur, South 24 Parganas, and North 24 Parganas, where CBA farms had been increasing unabatedly, especially in few coastal C.D. Blocks (Roy, 2013; Ojha & Chakrabarty, 2018). Conducive environment and impetus from national government persuaded the proliferous growth of CBA in the coastal tracts of East Medinipur district of West Bengal which includes Ramnagar II, Contai I, and Deshapran block. Besides, unviability of paddy cultivation in these coastal areas having high salinity and scope of high economic return from brackishwater aquaculture provided the initial impetus for the local farmers to adopt the CBA over the traditional paddy culture. Moreover, introduction of CBA made the saline infested coastal tracts of the study area, which were otherwise unfavorable for crop production, suitable for livelihood generation (Dutta et al. 2016). Accordingly, CBA grew incessantly in the study area, especially after the introduction Litopenaeus vannamei production after 2009 and it continued to ramp till 2021. Nevertheless, since 2022 there has been a sharp decline in the area and production of shrimp at national level in general and at the study area in particular mainly due to various reasons which included frequent disease attack, increasing cost of production, and sharp fall in market rate since 2022 (Aqua Culture Asia Pacific, 2023).

4.4.2 Consequences of CBA growth

Between 1991 and 2021 the area under CBA grew constantly as the areas with low agricultural productivity gradually converted to CBA. The establishment of commercial brackishwater shrimp ponds amidst the croplands caused increase in salinity of the surrounding areas resulting in considerable decrease in agricultural productivity (Ojha & Chakrabarty, 2018; Roy et al., 2020), further provoking the crop farmers to either convert their lands to CBA farms or to lease out their lands to the CBA farmers. Furthermore, the area under waterbody and other vegetation also got converted into CBA as the marginal farmers of the region found commercial shrimp farming more lucrative source of income. One of the major reasons behind this growth was the increasing global demand for shrimp, especially in the USA, Japan, and the EU, has led to a surge in cultured shrimp aquaculture in tropical coastal areas (Stonich & Bailey, 2000; Hossain et al., 2013; Galappaththi & Nayak, 2017; Salunke et al, 2020). It was also found that, the growth of CBA had direct impact on annihilation of coastal mangroves, as in the assessment period there was constant encroachment of CBA into the coastal mangrove patches.

4.4.3 Recent trend of decline in CBA practice

Between 2021 and 2023, the area under CBA reduced drastically and wide amount of land became abandoned in the study area. The factors behind this scenario ranged from local to global. This had happened due to multiple causes including climate vagaries eliciting multiple virus infestations like white spot syndrome virus (WSSV), Enterocytozoon hepatopenaei (EHP), white feces syndrome (WFS), infectious myonecrosis virus (IMNV), etc., the increasing cost of production, and a sharp decline in market rate in 2022 (Aqua Culture Asia Pacific, 2023; Chu Se Pepper, 2022; Jory, 2023; Murali, 2023; White, 2023; World Aquaculture Society, 2023b), due to lower demand from the United States, and European Union as well as China which were the three major shrimp exporting countries of India. Furthermore, Ecuador has become a major competitor for India in China's shrimp import market which has flooded the international market with shrimp at a much cheaper rate than India. Thus, India's seafood export market has been facing a dual crisis of a 20-30 % decline in international market demand and a 20-25% fall in global price rate. Additionally, global inflation and multiple economic aftermaths of the Russia-Ukraine war including a sharp increase in energy prices has triggered an increase in production costs and a decrease in market price (Dao, 2022; Pijl, 2022; Rajani & Balasubramanian, 2022). The study has predicted that more area under CBA will get converted to abandoned land due to a multitude of reasons, including recurrent bouts of diseases, swelling production costs, and a sharp drop-in market rate.

4.5 Major findings

It was found that the area under CBA was continuously growing throughout the entire region in the last three decades. However, an extreme alteration in the scenario could be noticed in the present year, wherein the land under CBA was reduced substantially and a notable portion of CBA farms became abandoned. The prediction model denoted that more shrimp ponds will become abandoned in the recent future. Significant clusters with greater CBA concentrations along shorelines gradually shifted to built-up areas, demonstrating the havoc landscape modification caused by farm fragmentation. The mammoth conversion of the CBA farms to abandoned aquaculture farms has led to an upsurge of unproductive land. Owing to the already existing high saline conditions, these lands can also not be converted to croplands, thereby affecting the food security of the local populace. In this context, it was apprehended that realistic paths need to be explored to make CBA farming both ecologically sustainable and economically feasible.

Chapter V:

Physico-chemical effects of CBA growth on coastal environment

5.1 Introduction

The intensive commercial CBA, especially shrimp farming, has become a lucrative source of foreign currency for many tropical coastal countries throughout the globe since the 1980s. From the very beginning, the CBA practice, especially intensive, monoculture-based, modern technology-oriented shrimp farming has raised various controversial issues owing to its considerable environmental and social impacts despite playing a key role in export earnings and livelihood generation (Hall, 2003; Béné, 2005; Anh et al., 2010; Galappaththi & Berkes, 2015). Commercial shrimp culture has engendered environmental degradations in many ways including mangrove destruction, deterioration of soil and water quality through pollution and salinization, disease outbreaks, etc. (Hossain et al., 2013; Galappaththi & Nayak, 2017; Roy et al., 2021b). Several studies also reported that commercial shrimp farms caused both water and soil contamination in the surrounding areas due to huge stocking density, excessive use of chemical fertilizers, and pesticides, and poor quality of feed. Effluents released from the aquaculture farms also caused high pollutant and silt load in the estuaries causing severe damage to the ecosystems (Hall, 2003; Pokrant, 2009; Hossain et al., 2013; Roy et al., 2021b).

In India, CBA, especially shrimp farming, has expanded at a rapid pace since the 1980s, especially along the eastern coastal states including West Bengal, Odisha, Andhra Pradesh, and Tamil Nadu (Pattanaik & Prasad, 2011). Along with the introduction of intensive shrimp farming, multifarious environmental threats have also been propagated which included the destruction of mangrove forests and other invaluable coastal and estuarine ecosystems; a decrease in crop productivity due to salinization of soil and groundwater; an increase in soil and water pollution etc. owing to the lack of farm management in shrimp farms (Rajitha et al., 2007; Pradhan & Flaherty, 2007; Pattanaik & Prasad, 2011; Dutta et al., 2016; Rajesh et al., 2016; Roy et al., 2021b; Datta et al., 2023). In Purba Medinipur district of West Bengal, the brisk growth of commercial shrimp culture has brought about considerable damage to the environment of the surrounding region, particularly, increased salinity of the surrounding region and notable water pollution (Ojha & Chakrabarty, 2018; Roy et al., 2021b).

5.2 Methodological framework

To assess the environmental impacts, both ecological field sampling and stakeholders' perception survey were conducted. For ecological sampling, both surface water from the brackishwater aquaculture ponds and soil samples were collected (Fig. 5.1).

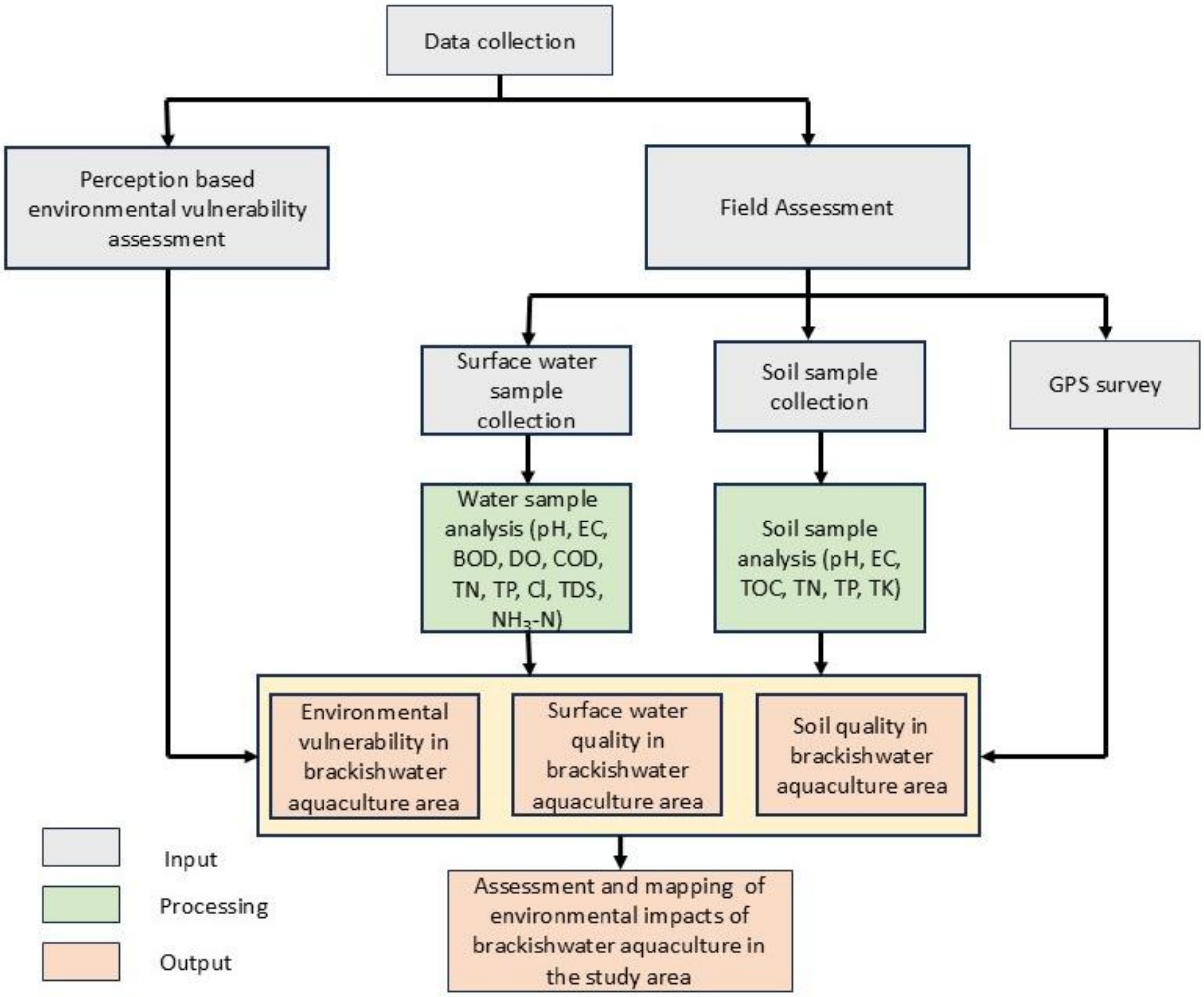

Figure 5.1: Methodological framework to assess physico-chemical effects of CBA growth on coastal environment.

5.2.1 Selection of relevant environmental indicators

Maintaining the quality of water is not only inevitable for shrimp farming but also imperative for sustaining the environmental quality of the surrounding areas. However, unscientific practices including the use of a high amount of food additives, use of various chemicals, and high stocking density cause notable water pollution. Water pollution not only accelerates the mortality rate and lowers production of shrimps but also pollutes the rivers and creeks where untreated wastewater is released. In addition, water from the shrimp ponds that have a high Electrical Conductivity (EC) infiltrate into the surrounding crop fields and cause considerable crop damage (Anh et al., 2010; Didar-Ul Islam & Bhuiyan, 2016; Hossain & Hasan, 2017). Thus, for the environmental impact assessment of the CBA, analysing the water quality of the shrimp ponds and soil quality of the surrounding areas become vital. In this regard, relevant environmental indicators were selected to assess the impact of CBA on the surrounding environment. Indicators were selected based on an in-depth review of relevant published literature (Hossain & Hasan, 2017).

Electrical Conductivity (EC) is the prime influential factor for water quality assessment. EC of the water is generated due to the ionization of the dissolved inorganic solid matters and it determines the total dissolved solids in it. It also determines the salt quantity in water and is the primary quality indicator for all types of water (Rajesh et al., 2016). Besides EC, the amount of Chlorides (Cl) was also estimated from the collected water sample for a better understanding of the salinity level (Penmetsa et al., 2013). The permissible limit of pH in the water as prescribed by WHO is 6.5 to 8.5 (Rajesh et al., 2016). Also, lime in the form of $CaCO_3$, $Ca(OH)_2$, or CaO is used in the shrimp ponds to reduce the acidity of the water at different phases. This often pushes the alkalinity above the permissible limit. Furthermore, a high amount of organic and inorganic fertilizers and feed additives are used for the rapid growth of shrimp. The over-use of fertilizers like ammonium phosphates and di-ammonium phosphate raises the nitrogen (N), phosphorus (P), and potassium (K) contents in the water which often leads to water pollution. With the growth of shrimps, more feed is added and a greater amount of waste is generated. As a result, with time, the amount of Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Total Dissolved Solids (TDS) increase, and at the penultimate stage, water often gets severely polluted, leading to the violation of the Global Aquaculture Alliance's Best Aquaculture Practices Standards (BAP) (Anh et al., 2010). Therefore, in addition to these parameters, the amount of Dissolved Oxygen (DO) and NH_3-N were also analysed to assess the water quality regime (Penmetsa et al., 2013).

Seepage of saline water from the earthen embankments of the shrimp ponds is one of the major reasons behind the increase of soil salinity in the immediate surrounding areas of the aquaculture ponds. Thus, soil EC was estimated from the samples collected from the crop lands present at the immediate surroundings (1 m) of the shrimp ponds (Rajarshi & Santra, 2011). To understand the soil quality of the croplands located in the surrounding areas of the shrimp farms, soil pH, Total Nitrogen (TN), Total Phosphorus (TP), Total Potassium (TK), and Total Organic Carbon (TOC) were measured (Mishra et al, 2008; Penmetsa et al., 2013; Rao et al., 2019).

5.2.2 Measuring procedures of environmental indicators

5.2.2.1 Edaphic indicators

Brackishwater aquaculture has obvious impacts on soil quality, especially on soil salinization in the surrounding areas through seepage, which impacts the agricultural productivity of the adjacent crop fields (Rajarshi & Santra, 2011; Roy et al., 2021b). Hence, the soil quality assessment of all these areas of commercial brackishwater aquaculture was crucial in the study for assessing the environmental impacts comprehensively. In this regard, soil samples were collected from the nearest agricultural areas (1 m distance from the shrimp farm) to the brackishwater aquaculture ponds. Soil samples of agricultural lands were collected from 15 cm depth after removing the top organic layer and accrued dust (Rajarshi and Santra, 2011) from the sites immediately adjacent to the aquaculture ponds. Soil samples collected from the agricultural fields were analyzed for deriving amounts of various soil quality parameters such as pH, EC, Total Organic Carbon (TOC), Total Nitrogen (TN), Total Phosphorus (TP), and total potassium (TK) (Olsen et al., 1954; Subbiah & Asija, 1956; Datta et al., 2010a; Rajarshi & Santra, 2011; Penmetsa et al., 2013; Datta & Deb, 2017; Gayen & Datta, 2023) (Table 5.1).

5.2.2.2 Aquatic indicators

For the assessment of the pollution load of the water released from the brackishwater aquaculture ponds, water quality was assessed based on samples collected from several selected ponds. Samples were collected in the post-monsoonal months, i.e. at the end of second crop cycle. Polythene bottles, each with a capacity of one litre were used for collecting samples from approximately 10 cm beneath the surface of the water. For the assessment of DO, glass bottles (Winkler bottles) were used. Water samples were collected from the outlet points of the shrimp ponds (Penmetsa et al., 2013). Water pH and EC were measured using the EUTECH pH Meter (pH 700) and HANNA EC/ TDS Meter (HI-2300) respectively at the sampling site (Datta et al., 2010). The collected samples were also analyzed at the laboratory to derive the amounts of various water quality parameters including Biochemical Oxygen Demand (BOD), Dissolved Oxygen (DO), Chemical Oxygen Demand (COD), Total Nitrogen (TN), Total Phosphorus (TP), Chloride (Cl), Total Dissolved Solids (TDS), and Free Ammonia (NH_3-N) following the standard protocols (Basak, 2006; Mishra et al., 2008; Penmetsa et al., 2013; Rajesh et al., 2016; APHA, 2017; Ojha & Chakraborty, 2018; Rao et al., 2019; Enayathali, 2021; Hendriani & Samadi, 2022; Tiwari et al., 2022; Gayen & Datta, 2023) (Table 5.1).

Table 5.1: Status of soil and water quality parameters in sampled brackishwater aquaculture ponds located in the study area.

Environmental Component	Parameter	Unit	Maximum Value	Minimum Value	(Mean±SD)	Measuring Method	Reference
Soil quality	pH	0-14	8.02	5.30	6.73±0.81	EUTECH pH Meter (pH 700)	Datta & Deb, 2017
	EC	µmhos cm^{-1}	4960	161	1624.59±1154.83	HANNA EC/ TDS Meter (HI-2300)	Datta et al., 2010
	TN	mg kg^{-1}	1212.50	247.20	408.01±194.06	Alkaline potassium permanganate method	Subbiah & Asija, 1956
	TOC	%	1.04	0.28	0.47±0.17	Modified wet oxidation method	Jackson, 1967
	TP	mg kg^{-1}	3733.80	165.80	1205.63±636.50	Olsen et al. (1954)	Olsen et al., 1954
	TK	mg kg^{-1}	6791	328.4	3756.14±1390.39	Flame Photometer (Model No. Systronics 128)	Jackson, 1967
Water quality	pH	0-14	9.70	7.37	8.08±0.68	EUTECH pH Meter (pH 700)	Datta et al., 2010
	EC	µmhos cm^{-1}	11650	338	7385.93±3868.28	HANNA EC/ TDS Meter (HI-2300)	Datta et al., 2010
	TDS	mg L^{-1}	7540	192	4650±2638	IS 3025 (part 16)-1984	Enayathali, 2021
	BOD	mg L^{-1}	22	2	8.44±4.16	IS 3025 (Part-44) 1993 Reaffirmed, 2019	Tiwari et al., 2022
	DO	mg L^{-1}	8.54	3.30	6.36±1.38	APHA 23rd Edition	Roy et al., 2020
	COD	mg L^{-1}	115	12	41.50±20.20	APHA 23rd Edition, 2017 – 5220 B	Tiwari et al., 2022
	Cl	mg L^{-1}	7957	27	3062.89±2011.81	IS 3025 (part 32)-1988	Enayathali, 2021
	TN	mg L^{-1}	7.42	2	3.3±1.49	APHA 23rd Edition 4500	Enayathali, 2021
	TP	mg L^{-1}	26.90	0.05	2.40±5.94	IS 3025 (part 45)-1993	Enayathali, 2021
	NH3-N	mg L^{-1}	0.29	0.01	0.07±0.07	APHA 23rd Edition, 4500-NH3 F, 2017	Hendriani and Samadi, 2022

*SD=Standard deviation

Photograph 5.1: Collection of soil sample from 15 cm depth.

Photograph 5.2: Preserving the soil samples in plastic zipped pouch bags.

Photograph 5.3: Collection of water sample from 10 cm depth.

Photograph 5.4: Preserving the water samples in plastic sampling bottles.

Photograph 5.5: Collection of water sample for DO from 10 cm depth in Winkler bottle.

Photograph 5.6: Fixing the water samples in Winkler bottle by adding chemicals for DO analysis.

5.2.3 Sampling design

For the selection of the 27 sampling sites, a stratified random sampling method was adopted. For this purpose, the village-wise percentage of aquaculture area was derived from the LULC map of 2021 (Fig 4.4). Based on the percentage of aquaculture area, villages of the study area were divided into three equal classes, i.e., high density zone, medium density zone, and low-density zone. From each C.D. Block (i.e. Ramnagar-II, Contai-I, and Deshapran) considered in this study, three sites were selected randomly from each of the density zones. In this manner, 27 sampling sites were identified in the whole study region. Water samples were collected from 27 brackishwater aquaculture ponds and 27 soil samples were collected from the surrounding areas of those aquaculture ponds (Fig. 5.2.). Besides, a perception study was conducted among various stakeholders. At each site, two aquaculture owners, three aquaculture labourers, and five farmers having farmland adjacent to the aquaculture ponds were interviewed. Along with this, one focus group discussion (FGD) was conducted at each site where six to eight participants actively participated.

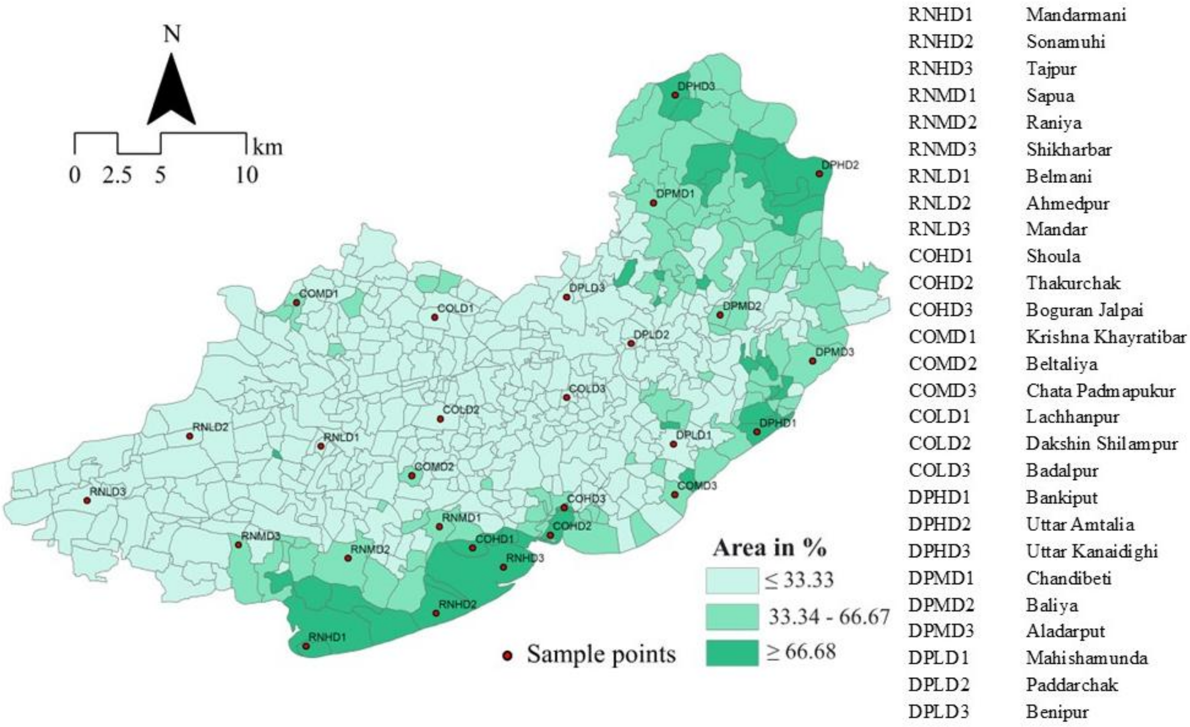

Figure 5.2: Location of the sample points.

5.2.4 Spatial zonation mapping

To depict the parameter-wise spatial concentration of the tested surface water of the aquaculture ponds and soil samples, regularised spline interpolation was conducted using ArcGIS® Pro 2.3 software. The spline tool uses a mathematical function to interpolate known values while minimizing the total surface curvature by yielding a smooth surface that precisely passes the input points (Childs, 2004; Datta et al., 2022). This method generates a model that exhibits gently varying surfaces such as pollution concentration (Kazemi et al., 2017).

5.2.5 Participatory appraisal on environmental impacts of CBA

An individual-based perception study as well as a FGD were conducted at each selected site to understand the perception among various stakeholders regarding the existing ecological problems induced by the growth of CBA. For this purpose, a structured questionnaire was prepared, on the basis of which aquaculture owners, aquaculture workers, and the farmers having croplands adjacent to the aquaculture ponds were interviewed. The study also tried to prepare an ecological vulnerability index based on the perception of various actors. Thus, the questionnaire was detailed which took into account questions regarding the presence and intensity of the ecological problems. The responses were analysed using some statistical and cartographic methods to understand the scenario. FGDs were also conducted at each site to verify the results obtained from the remote sensing-based study, field-based ecological study, and questionnaire-based perception study.

5.2.6 Statistical analysis

The quantitative data obtained from the questionnaire survey were analysed and represented through various cartographic techniques. Besides, to explicate the physico-chemical effects of CBA growth on coastal environment in the region, a composite index was prepared. Seven verifiers were taken into consideration for preparing the composite perceptual ecological vulnerability index (CPEVI) of the brackishwater aquaculture farms, which included amount of fuel consumed by the commercial shrimp farms (v.1.a), use of organic fertilizers and insecticides (v.1.b), number of medicines used (v.1.c), status of water treatment before discharge of water (v.1.d), level of awareness regarding environmental impacts of brackisgwater aquaculture (v.1.e), environmental problems existed in the region (v.1.f), and type of land use conversion (v.1.g) (Table 5.2.). Since the study took into account various verifiers of multiple dimensions, various types of scoring methods were thus used. Here, high vulnerability got more score and vice versa. For fuel consumption, the farms using 400 L or less fuel got the lowest vulnerability score of 1 and the farms consumed 700 L or more fuel got the highest vulnerability score of 5. Shrimp pond, which used at least some organic fertilizers and insecticides were considered less ecologically vulnerable, and thus got score 1 and the pond that entirely relied upon chemical fertilizers and insecticides was more ecologically vulnerable, and thus got a score of 5. Likewise, if the shrimp farms had water treatment system before releasing the effluent water, got the vulnerability score 1; and the farms without any water treatment system got vulnerability score of 5. Regarding the level of awareness among the shrimp farm owners regarding the environmental impacts of CBA, the same 5-point scoring scale was used and lowest score of 1 was assigned to the farms having owners highly concerned about environmental impacts and highest score of 5 was assigned to the farms having owners totally indifferent about environmental impacts. Furthermore, various environmental problems engendered by the introduction of CBA in the region were listed in the region under v.1.f. To calculate the score of v.1.f, firstly, various environmental problems existed in the area were listed. Followed by this, each problem was assigned with weightage value based on the intensity and nature of problem. Then, all the weightage values of the problems identified by each respondent was summed up to get the score of environmental problems identified by each respondents using the following equation (Eq. 5.1):

$$\sum r * w \qquad \text{(Eq. 5.1)}$$

Where, r = Response; w = Assigned weightage to the environmental problems.

Similarly, various other LULCs got converted to CBA in the region were listed under v.1.g. To calculate the score of v.1.g, firstly, various environmental problems existed in the area were listed. Followed by this, type of LULC assigned with weightage value based on the type of LULC. Then, all the weightage values were summed up to get the score of LULC conversion problems identified by each respondents using the following equation (Eq. 5.2):

$$\sum r * w \qquad \text{(Eq. 5.2)}$$

Where, r = Response; w = Assigned weightage to the environmental problems.

Finally, the CPEVI was calculated using the following equation (Eq. 5.3), where to get the ecological vulnerability index value of a particular shrimp farm, all the scores of the verifiers were summed up and then was divided by the number of verifiers.

$$\text{CPEVI} = \frac{\sum V.1.a + V.1.b + V.1.c + V.1.d + V.1.e + V.1.f + V.1.g}{Nv} \qquad \text{(Eq. 5.3)}$$

Where, Nv = Number of verifiers.

Table 5.2: Scoring guide for composite perceptual ecological vulnerability index (CPEVI) of the brackishwater aquaculture farms.

Number	Verifier	Related question	Score
V.1.a	Fuel consumption	How much diesel is consumed in your farm in one season to raise shrimps from 1000 sq. m pond area?	• <400 L (1) • 400-500 L (2) • 500-600 L (3) • 600-700 L (4) • >700 L (5)
V.1.b	Use of organic fertilizers and insecticides	Do you use organic fertilizers and insecticides in your aquaculture ponds?	• Yes (1) • No (5)
V.1.c	Number of medicines used	How many medicines do you use in your brackishwater aquafarm?	• < 2 (1) • 4-6 (2) • 7-9 (3) • 10-12 (4) • > 12 (5)
V.1.d	Water treatment before discharge of water	Do you treat the water before discharging it from the aquaculture ponds?	• Yes (1) • No (5)
V.1.e	Level of awareness regarding environmental impacts of brackishwater aquaculture	Are you aware of the environmental degradations caused by brackishwater aquaculture practice in the area?	• Highly concerned (1) • Highly aware (2) • Moderately aware (3) • Not aware (4) • Totally indifferent (5)
V.1.f	Environmental problems	What are the environmental negative impacts of brackishwater aquaculture practice in the area?	Weightage assigned to each environmental problem: • Mangrove destruction (2) • Salt water intrusion (.5) • Soil and water pollution (.75) • Loss of biodiversity (1.5) • Obstruction to the environmental water flow (.25)
V.1.g	Land use conversion	What was this land use before the establishment of the brackish water aquaculture farm?	Weightage assigned to each land use change: • Mangrove forest (2) • Waterbody (1.5) • Other vegetation (.75) • Crop land (.5) • Fallow land (.25)

5.3 Results

5.3.1 Spatial zonation pattern of edaphic indicators

5.3.1.1 pH

According to the Central Pollution Control Board (CPCB), India, the prescribed pH level for the 'D' category of water (i.e. Propagation of wild-life and fisheries), is 6.5 (CPCB, 2019). However, in the present study area, all the brackishwater aquaculture ponds were observed to have pH higher than the prescribed limit. Soil pH varied between 5.30 and 8.02 with higher values being concentrated in the southern areas of Ramnagar-II, Contai-I, and in the northern tip of Deshapran C.D. Block. The mean value of soil pH was 6.73 ± 0.81 (Table 5.1). It was observed that the pH values were higher in the areas with high brackishwater concentration zones (Fig. 5.3).

5.3.1.2 Electrical Conductivity (EC)

Soil EC depicted almost similar patterns for the entire region. Highest EC 4960 µmhos cm^{-1} was found in Uttar Amtalia located at the north eastern part along the Rasulpur River (Table 5.1). EC was also high in Tajpur, Mandarnami, Sonamihi, Shikharbar, Soula, Thakurchak, Baguran Jalpai which were located along the coastal area. EC values of the brackishwater aquacultural ponds were found to be high in the areas located along the coast and the Rasulpur River where the density of aquaculture was also high. The mean value of soil EC was 1624.59 ± 1154.83 µmhos cm^{-1} (Fig. 5.3).

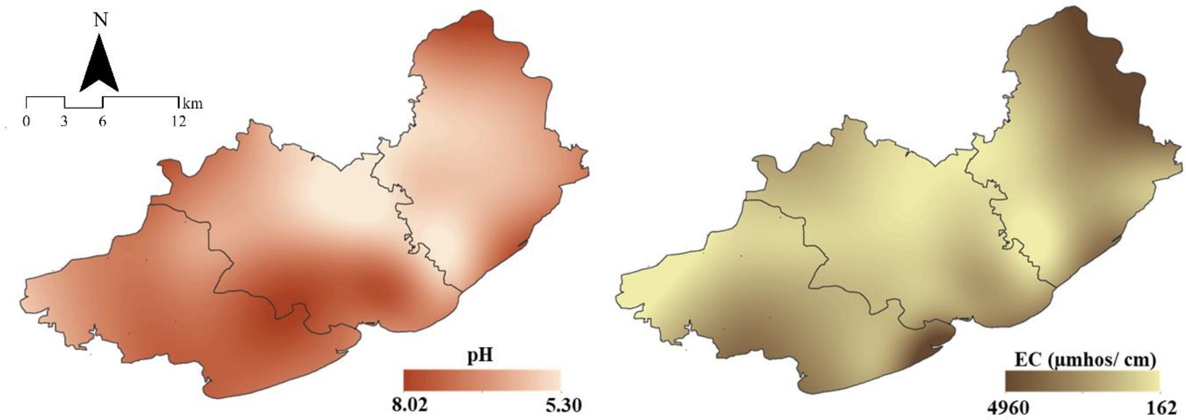

Figure 5.3: Spatial distribution of soil pH and soil EC status.

5.3.1.3 Total Organic Carbon (TOC)

An almost reverse condition was found for the case of TOC in comparison with pH and EC. Highest TOC of 1.04% was found in Mahishamunda followed by Benipur (0.73%), Lachhanpur (0.71%), Badalpur (0.68%), and Mandar (0.66%) where the density of brackishwater aquaculture was less. On the contrary, lower TOC values were registered in areas where the density of brackishwater aquaculture was high. For example, the lowest value of 0.28% was found in Uttar Kanaigighi followed by Soula (0.29%) (Fig. 5.4.). The mean value of soil EC was 0.47±0.17 mg kg^{-1} (Table 5.1.).

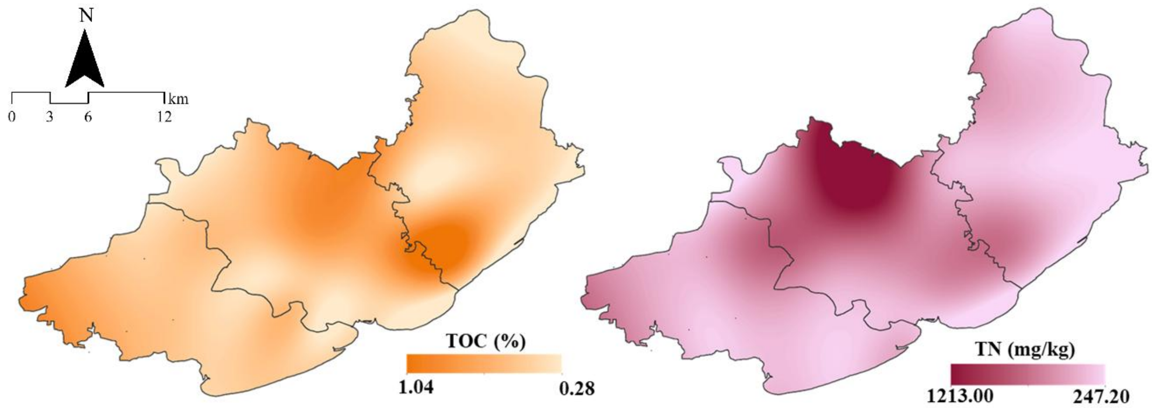

Figure 5.4: Spatial distribution of soil TOC and soil TN status.

5.3.1.4 Total Nitrogen (TN)

Soil N almost followed the trend of TOC. Soil TN was densely concentrated in the extreme northern parts in Lachhanpur (1213 mg/kg), followed by Belmani (657 mg kg^{-1}), Dakshin Shilampur (629 mg kg^{-1}), Mahishamunda (567 mg kg^{-1}), and Badalpur (519 mg kg^{-1}). In all these areas, concentration of brackishwater aquaculture was low. However, the lowest level of soil TN was found in Aldarput (247 mg kg^{-1}) followed by Uttar Kanaidighi (252 mg kg^{-1}), Chata Padmapukur (267 mg kg^{-1}) and Uttar Amtalia (268 mg kg^{-1}) where the concentration of brackishwater aquaculture was moderate to high (Fig. 5.4). The mean value of soil EC was 408.01±194.06 mg kg^{-1} (Table 5.1).

5.3.1.5 Total Phosphorus (TP)

Concentration of soil TP was also high in the areas with low concentration of brackishwater aquaculture. The highest concentration of soil TP (3734 mg/kg) was found in Mandar, located at the extreme western part of the study area where the concentration of brackishwater aquaculture was also very low. The soil TP level was also high in Benipur, Mahishamunda, Lachhanpur, and Dakshin Shilanpur. On the contrary, a low soil P was found in the areas with a high concentration of brackishwater aquaculture. For instance, the lowest level of soil TP (166 mg kg^{-1}) was registered in Thakurchak, located at the southern part of the study area along the coast (Fig. 5.5). The mean value of soil EC was 1205.63±636.50 mg kg^{-1} (Table 5.1).

5.3.1.6 Total Potassium (TK)

The maximum soil TK value (6791 mg kg^{-1}) was recorded at Mandar, located at the western part of the study area followed by Lachhanpur (5158 mg kg^{-1}), Mahishamunda

(5086 mg kg^{-1}), and Belmani (5074 mg kg^{-1}), where the concentration of brackishwater aquaculture was low. The minimum value of 328.40 mg kg^{-1} soil TK was found in Uttar Kanaidighi where the concentration of brackishwater aquaculture was very high (Fig. 5.5). The mean value of soil TK was 3756.14±1390.39 mg kg^{-1} (Table 5.1).

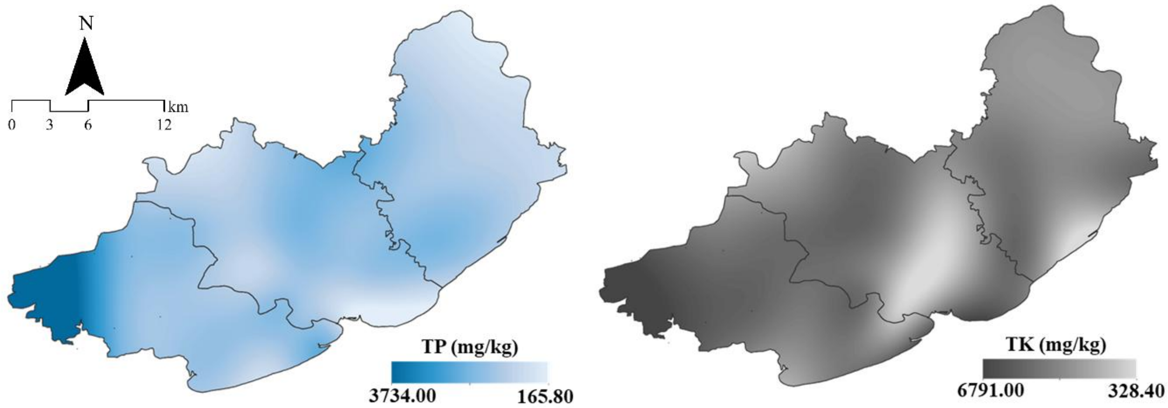

Figure 5.5: Spatial distribution of soil TP and soil TK status.

5.3.2 Spatial zonation pattern of aquatic indicators

5.3.2.1 pH

The study site recorded a water pH value between 7.37 and 9.7 with a mean value of 8.08 ± 0.68 indicating moderate alkalinity (Table 5.1). Higher pH could be found in the coastal tracts and along the Rasulpur River where the concentration of brackishwater aquaculture was also found to be high. The highest pH value was found in Mandarmani, followed by Sonamuhi, Tajpur, Sapua, Raniya, Shikharbar; located at the southern section of Ramnagar-II C.D. Block. In Contai-I C.D. Block; Shoula, Thakurckak, and Boguran Jalpai recorded high pH values. Uttar Amtaliya and Uttar Kanaidighi located in the Deshapran C.D. Block also had high pH value. In all these areas, the concentration of brackishwater aquaculture was high. Lower pH values were seen in the central positions of all three Blocks, where the concentration of brackishwater aquaculture was also found to be low (Fig. 5.6).

5.3.2.2 Electrical Conductivity (EC)

With respect to water EC, values as high as 11,650 μmhos cm^{-1} were observed in Mandarmani, located in close proximity to the coast and having high density of CBA. EC more than 10,000 μmhos cm^{-1} was also found in the areas with high concentration of CBA such as Shoula, Thakurchak, Boguran Jalpai, and Chata Padmapukur in Contai-I C.D. Block, and Uttar Kanaidighi, Uttar Amtalia, Bankiput, and Aladarput in Deshapran

C.D. Block. EC values were observed to decrease along the north-western part of Ramnagar-II and the north-eastern sections of Contai-I depicting values as low as 338 µmhos cm^{-1} (Fig. 5.6.). The mean value of EC was 7385.93 ± 3868.28 µmhos cm^{-1}, which depicted the overall high salinity of the region (Table 5.1).

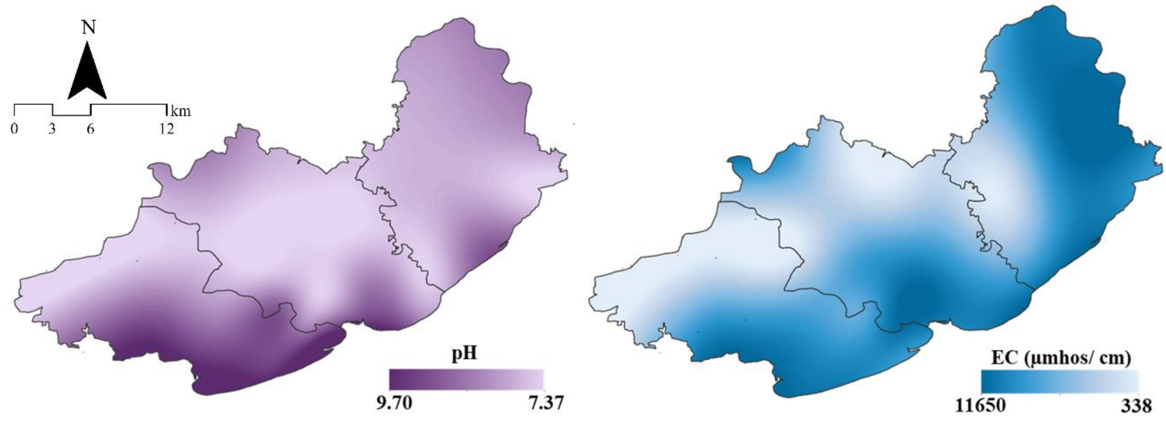

Figure 5.6: Spatial distribution of water pH and water EC status.

5.3.2.3 Biochemical Oxygen Demand (BOD)

Similar patterns were showcased by water BOD, where high circular concentration could be observed entirely in the southern portion of Contai-I as highest BOD value (22 mg L^{-1}) was found in Boguran Jalpai followed by Thakurchak and Shoula. BOD of the aquaculture ponds was also high in Mandarmani, Sonamuhi, Tajpur, Sapua, and Raniya located in the near-coastal areas of Ramnagar-II. BOD reduced in an outward radiating manner towards the northern and north-western areas of all the C.D. Blocks (Fig. 5.7). For BOD, the mean value of 8.44 ± 4.16 mg L^{-1} indicated a high concentration in the brackishwater aquaculture farms (Table 5.1).

5.3.2.4 Dissolved Oxygen (DO)

For BOD, the mean value of 6.36±1.38 mg L^{-1} indicated moderate DO in the CBA farms (Table 5.1). Highest do of 8.54 mg L^{-1} was found in Mandar, located in Ramnagar-II C.D. Block. In Mandar, the concentration of brackishwater aquaculture was very low. However, the lowest DO of 3.3 mg L^{-1} was found in Boguran Jalpai, followed by Thakurchak, and Shoula in Contai-I and Uttar Kanaidighi and Chandibeti in Deshapran C.D. Blocks. The lower amount of DO was found in the areas with a high concentration of CBA (Fig. 5.7).

5.3.2.5 Chemical Oxygen Demand (COD)

Similar to BOD, COD was also high in the CBA ponds with a mean value of 41.50 ± 20.20 mg L^{-1} (Table 5.1). The highest COD of 115 mg L^{-1} was observed in Thakurchak followed by Boguran Jalpai (69 L^{-1}) in Contai-I C.D. Block. COD was also very high in Mandarmani (68 L^{-1}), Sonamuhi (55 L^{-1}), Tajpur (53 L^{-1}), Raniya (51 L^{-1}), Shikharbar (52 L^{-1}) of Ramnagar-II and Bankiput (56 L^{-1}) of Deshapran C.D. Blocks (Fig. 5.8).

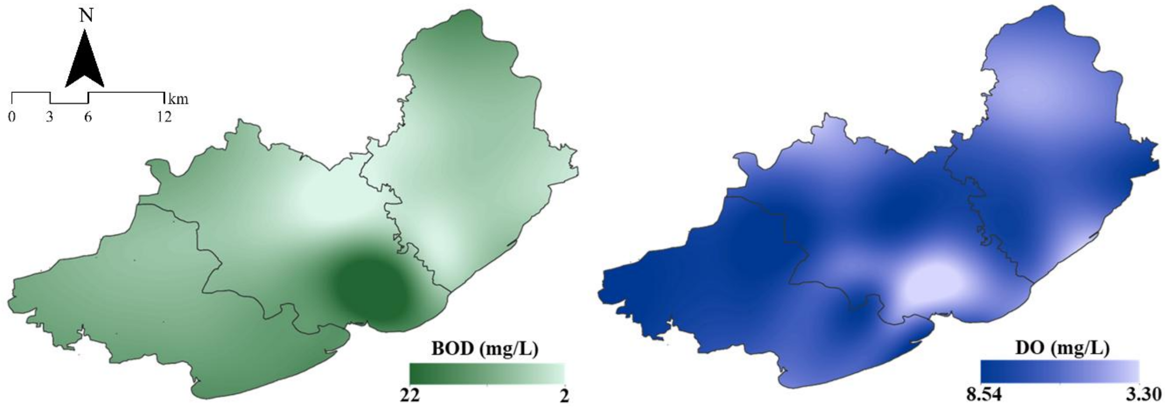

Figure 5.7: Spatial distribution of water BOD and water DO status.

5.3.2.6 Total Nitrogen (TN)

The amount of TN found in the CBA ponds was high, with a mean value of 3.3±1.49 mg L^{-1} (Table 5.1). The highest values of TN were recorded in Shoula, in the near-coastal area of Contai-I, followed by Thakurchak and Boguran Jalpai. TN values of more than 5 mg L^{-1} were also found in Sonamuhi in Ramnagar-II and Bankiput in Deshapran C.D. Blocks. TN values were high in areas with a high concentration of brackish water aquaculture and vice versa. The lowest amount of TN (2 mg L^{-1}) was found in Ahmedpur, Lachhanpur, Dakshin Shilampur, Badalpur, Mahishamunds, Poddarchak, and Benipur, where the concentration of CBA was very low (Fig. 5.8).

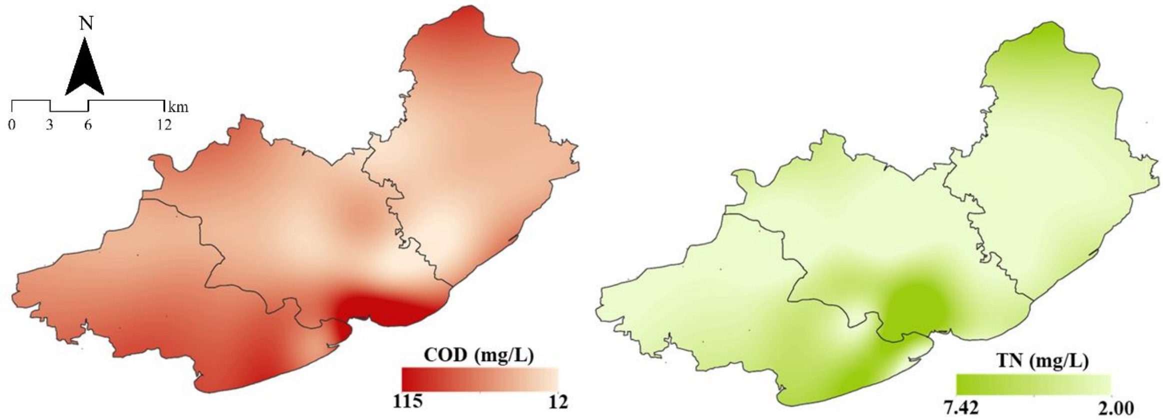

Figure 5.8: Spatial distribution of water COD and water TN status.

5.3.2.7 Total Phosphorus (TP)

TP in the whole region varied widely, with a maximum value of 26.90 mg L^{-1} found in Mandarmani, followed by Tajpur (17.4 L^{-1}) in the Ramnagar-II C.D. Block, and a minimum value of 0.05 mg L^{-1} in Dakshin Shilampur in the Contai-I C.D. Block. The mean value was 2.40 ± 5.94 mg L^{-1} (Table 5.1). In general, higher TP values were found in areas with high CBA concentration and vice versa (Fig. 5.9).

5.3.2.8 Chlorides

The same trend was observed in water Cl, where the highest value (7957 mg L^{-1}) was recorded at Tajpur, followed by Mandarmani (5625 L^{-1}) and Sohamuhi (5305 L^{-1}) in the Ramnagar-II C.D. Block. Cl values exceeding 4000 mg L^{-1} were also found in Shoula (6988 L^{-1}), Thakurchak (6558 L^{-1}), and Boguran Jalpai (6962 L^{-1}) in Contai-I C.D. Block, as well as in Uttar Kanaidighi (4768 L^{-1}) and Uttar Amtalia (4808 L^{-1}) in Deshapran C.D. Block. A decreasing trend was noted towards the mid-eastern and western sections of the study area, where the concentration of brackish water aquaculture was low (Fig. 5.9). The mean value of Cl was 3062.89 ± 2011.81 mg L^{-1} (Table 5.1).

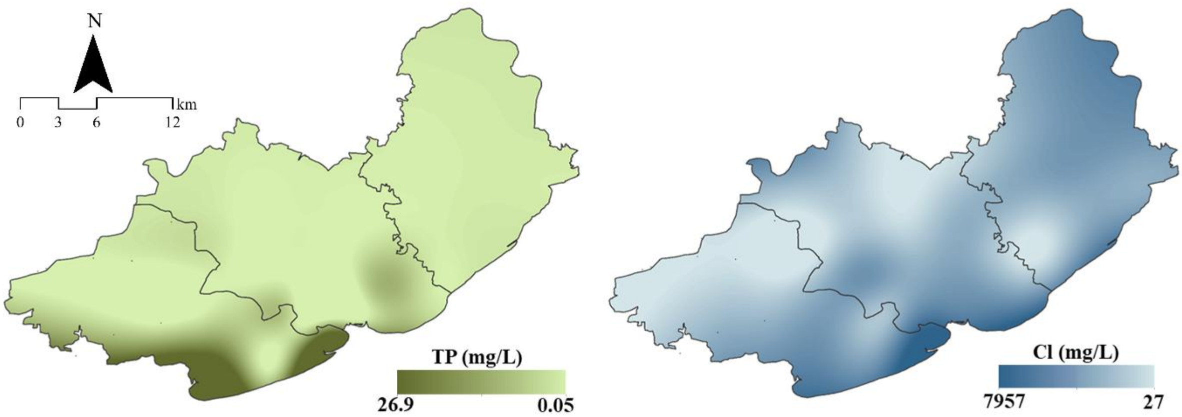

Figure 5.9: Spatial distribution of water TP and water Cl status.

5.3.2.9 Total Dissolved Solids (TDS)

Conversely, water TDS had been found to spread almost evenly with moderate values in the upper portions and had densely concentrated in the southern portions of the study region. However, a mean TDS value (4650 ± 2638 mg L^{-1}) denoted a higher concentration of the CBA ponds in general (Table 5.1). The highest TDS was recorded in Mandarmani (7540 L^{-1}) followed by Sonamuhi (7355 L^{-1}) and Tajpur (6894 L^{-1}) in Ramnagar II. A TDS of more than 6500 mg L^{-1} was found in Shoula, Thakurchak, and Boguran Jalpai in Contai-I alongside Uttar Kanaidighi, Uttar Amtaliya, and Bankiput in Deshapran. All these areas had high concentration of CBA. The lowest amount of TDS was observed in Lachhanpur (192 mg L^{-1}) and Mahishamunda (312 L^{-1}), where the concentration of CBA was very low (Fig. 5.10).

5.3.2.10 Free Ammonia as N

Free ammonia as N (NH_3-N) as prescribed by the CBCP (2019) is 1.2 mg L^{-1} or less. Notably, it occurred in amounts less than the standard limit with mean value of 0.07±0.07 mg L^{-1} in every brackishwater aquaculture pond of the study region (Table 5.1). However, the amount of free ammonia as N was relatively higher in the areas with high concentration of CBA (Fig. 5.10).

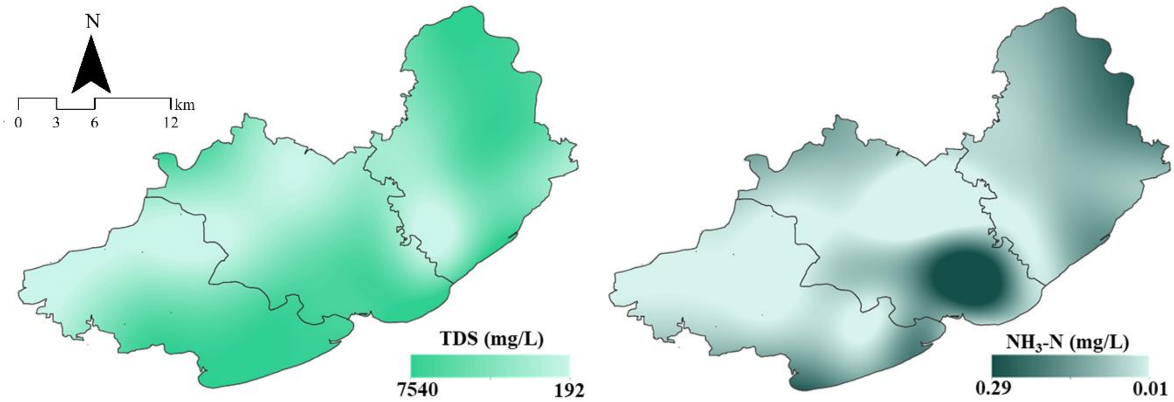

Figure 5.10: Spatial distribution of water TDS and water NH_3-N status.

5.3.3 Peoples' perception on ecological impacts of CBA

From the perception study, it was observed that the owners and workers of the brackish water aquaculture operations primarily came from outside the area. Consequently, they were less aware of the environmental degradation caused by the extensive expansion of CBA (Fig. 5.11). Conversely, local villagers were more cognizant of the ecological issues arising from this rapid growth, including the destruction of coastal mangroves, saltwater intrusion into croplands, loss of soil fertility, loss of biodiversity, and waterlogging due to the construction of shirmp farms amidst paddy fields. Additionally, most respondents agreed that the large-scale conversion of croplands to CBA had led to local food insecurity and that the conversion of land previously covered by vegetation had resulted in the habitat loss of many animal species (Fig. 5.12).

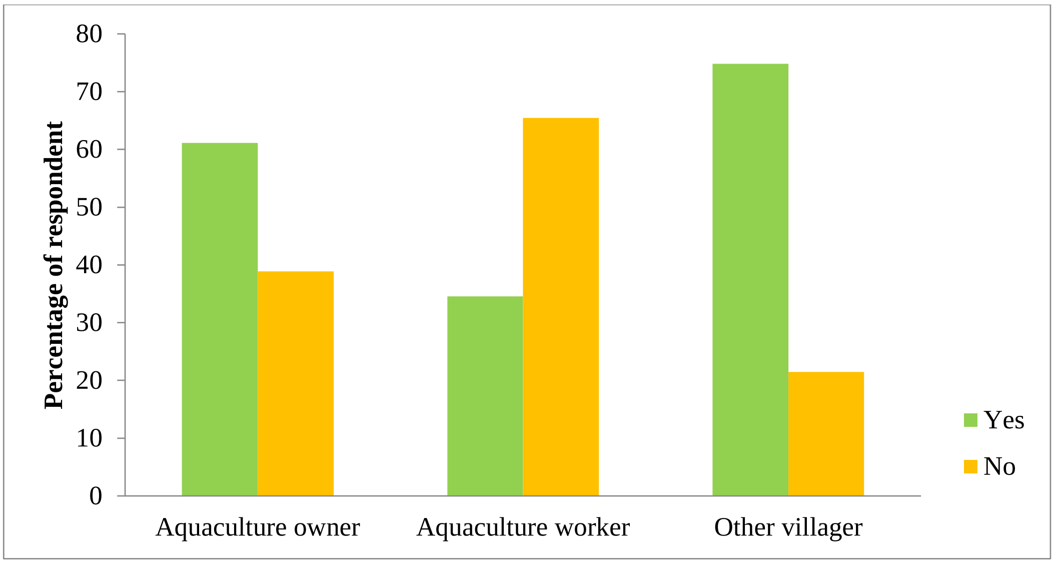

Figure 5.11: Perception level of various stakeholders (n = 370) regarding environmental problems.

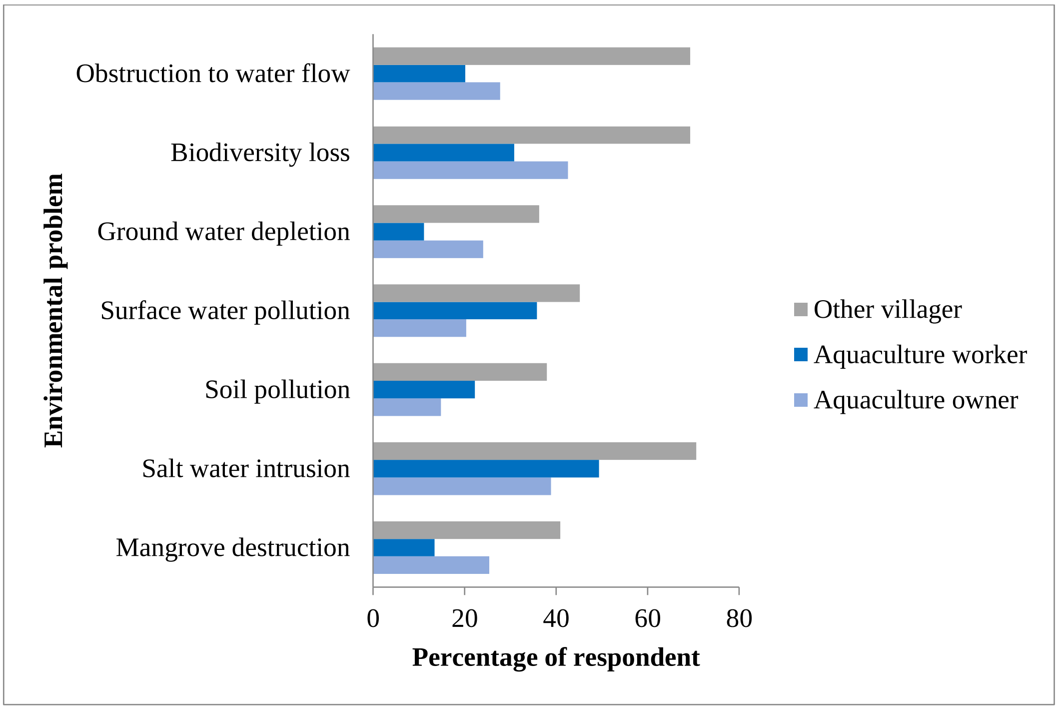

Figure 5.12: Perception level of various stakeholders (n = 270) regarding various environmental problems induced by CBA.

A composite perceptual ecological vulnerability index (CPEVI) of the brackishwater aquaculture farms was computed taking into consideration various factors which included amount of fuel consumed by the commercial shrimp farms, use of organic fertilizers and insecticides, number of medicines used, status of water treatment before discharge of water, level of awareness regarding environmental impacts of brackishwater aquaculture, environmental problems existed in the region, and type of land use conversion. The result revealed that there was high consumption of diesel to operate the machineries of the aquafarms. Over 20% of the shrimp farms used more than 700 L of fuel in one season, which definitely caused air pollution. Moreover, almost all shrimp farms used high amount artificial feed and quite a good number of medicines, the residues of which created high pollutant loads. Furthermore, only a very few farms (5.40%) treat water before releasing it into the creeks, tidal rivers and ocean. Regarding the awareness level of the shrimp farm owners, it was found that most of them (70.37%) were not aware of the environmental consequences of the commercial brackishwater shrimp farming in the area and they were found to be very reluctant about the environmental issues. This might be due the cause that, most of them were not the native dwellers. However, some of the shrimp farm owners who were aware of the environmental degradations had reported that loss of habitat and utter decrease in biodiversity, loss of coastal mangrove, water logging, and increase in soil salinity were the major environmental problems engendered by the rampant growth of commercial shrimp farming. It was revealed during the interviews with the shrimp farm owners that most of the shrimp ponds (72.22%) came into existence by transforming crop lands. Also, in the near coastal areas, mangroves were destroyed to establish shrimp farms.

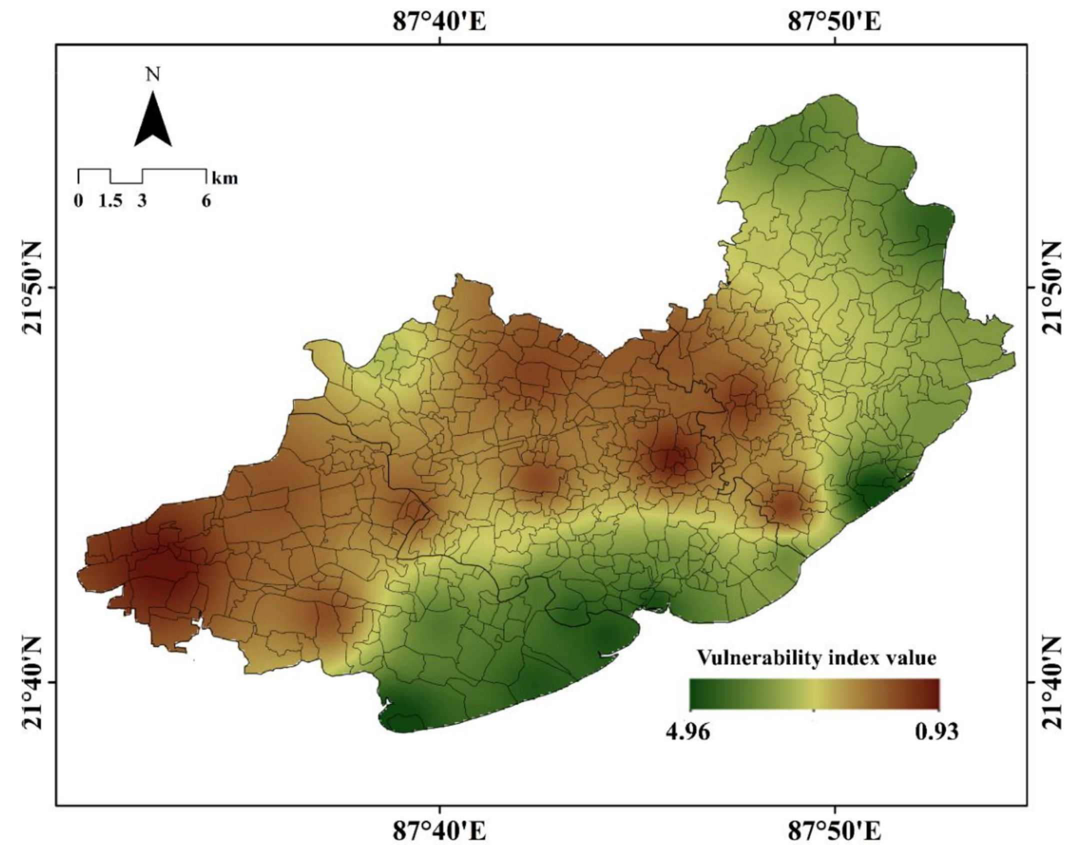

Figure 5.13: Spatial distribution of composite perceptual ecological vulnerability index (CPEVI) values over the study region.

The study found that there is variability in spatial distribution of ecological vulnerability of the shrimp farms. In general, it was found that the shrimp farms located along the coast in southern part of the study area and along Rasulpur River situated at the western part, were found to be more ecologically vulnerable. In these areas the density of CBA was also high. Highest vulnerability index value was found in Uttar Kanaidighi located at the south east part of the study area along the Bay of Bengal. Ulnerability index values were also high in Mandarmani, Sonamuhi, Tajpur, Soula, Thakurchak, and Uttar Amtaliya (Fig. 5.13).

5.4 Discussion

As brackish water aquaculture, particularly shrimp farming, became a lucrative source of economic gain and technology became more accessible, it experienced significant growth in the coastal C.D. Blocks of Purba Medinipur district in general, and the study area in particular. This expansion led to the conversion of extensive croplands. However, the unplanned expansion and unscientific farming practices introduced notable environmental threats to the surrounding areas, raising concerns about the sustainability of brackishwater aquaculture in the region (Ojha & Chakraborty, 2018; Roy et al., 2021).

According to the CPCB (2019), the water from brackishwater aquaculture is classified under 'propagation of Wildlife and Fisheries,' which is categorized as 'D' grade water. The CPCB water criteria stipulate that the pH should be between 6.5 and 8.5, dissolved oxygen (DO) should be 4 mg L^{-1} or higher, and free ammonia (as N) should be 1.2 mg L^{-1} or lower (CPCB, 2019). In most of the studied brackishwater aquaculture farms, the pH values were high but remained within the CPCB's prescribed limits. However, in some aquaculture sites, particularly in high-density areas, pH values significantly exceeded the recommended standards, indicating an alkaline nature of the water. This high pH value was likely due to excessive carbon dioxide consumption resulting from a high rate of phytoplankton, such as blue-green algae, in nutrient-rich water, a common occurrence in brackishwater aquaculture ponds (Penmetsa et al., 2013; Yokogawa, 2020). Free ammonia (NH_3-N) was within the CPCB limit across all studied sites but varied widely among the ponds. Low DO levels indicated a high pollutant load (Mishra et al., 2008; Penmetsa et al., 2013; Venkateswarlu et al., 2019). The lower DO values, especially in high-density zones with elevated stocking densities, were likely due to the overuse of food additives and nutrients.

The level of BOD serves as a major indicator of organic pollutants in the water, with high BOD reflecting a high pollutant load (Rao et al., 2019; Gayen & Datta, 2023). BOD was significantly higher in ponds situated in high-density aquaculture zones. For example, in Boguran Jalpai, BOD reached as high as 22 mg L^{-1}, and similarly high levels were observed in intensive farming ponds in Ramnagar-II and Deshapran C.D. Blocks. Similarly, COD was notably high in most aquaculture ponds, particularly in high and medium-density zones, likely due to the overuse of medicines and chemicals for controlling bacterial and parasitic diseases.

The high levels of Cl and EC also indicated water pollution. Their levels are generally elevated in the saline water used in brackishwater shrimp farms. Additionally, Cl were often added to the ponds to minimize bacterial and parasitic growth (Mishra et al., 2008; Penmetsa et al., 2013). The study revealed that Cl concentrations were much higher in ponds near the coast and tidal rivers, which were located in high and medium-density aquaculture zones. Conversely, ponds farther from coastal areas and tidal rivers, which practiced lower-intensity farming, had lower Cl levels. Similarly, EC levels were very high in high and medium-density zones, especially near coastal areas and tidal rivers where intensive shrimp farming was common.

The TN levels also served as a key indicator of water pollution (Mishra et al., 2008; Penmetsa et al., 2013). Elevated N levels were observed in regions with very intensive shrimp farming, likely due to excessive use of fish feed and its residues. TP content, indicative of organic load in the ponds, was excessively high in some aquaculture ponds, particularly in high-density zones with high stocking rates and P-rich fertilizers (Mishra et al., 2008; Senarath & Visvanathan, 2001). Elevated P levels may lead to increased eutrophication. Most shrimp farms in the study area had high TDS, reflecting significant sediment presence in the water, likely due to overuse of fertilizers, food additives, and fish excreta (Páez-Osuna, 2001; Mishra et al., 2008; Penmetsa et al., 2013). In high and medium-density zones, TDS often exceeded 5000 mg L^{-1} (Fig.5.10). Brackishwater shrimp farms generate two types of waste: sediment and wastewater (Senarath & Visvanathan, 2001), with pollutant loads increasing due to high stocking densities, overuse of feed additives, fertilizers, and other chemicals aimed at maximizing production (Páez-Osuna, 2001). Field surveys indicated that effluent water, with high pollutant loads, was discharged directly into natural water bodies (e.g., rivers, creeks, and inlets), damaging the surrounding ecology, particularly aquatic biodiversity and water-dependent fauna such as water birds (Gayen et al., 2020).

CBA also significantly impacted adjacent agricultural lands, particularly in terms of elevated soil pH and salinity (Ojha & Chakraborty, 2018; Mondal et al., 2023). The study found that soil pH and EC were higher in agricultural lands in high and moderate aquaculture density zones. Optimal soil pH for crop growth typically ranges between 6.0 and 7.5 (FAO, 2021). Although soil pH in the study area is generally moderately acidic to slightly acidic (Chesworth, 2008; Sahu, 2014; Oshunsanya, 2018), pH in high-density brackishwater zones was found to be considerably alkaline, reaching as high as 8.02 in Sapua. Conversely, soil pH in low-density aquaculture zones remained slightly acidic. Soil EC was also notably high in agricultural plots within high-density brackishwater zones due to saline water seepage from adjacent aquaculture ponds and inadequate farm management practices, such as failing to drain effluent water from nearby fields. Elevated soil pH typically leads to reduced soil nutrient levels, including organic C, N, P, and K, which impairs crop growth (Sirsat, 2017; Ojha & Chakraborty, 2018; Maiti et al., 2021; Mandal et al., 2021). Agricultural areas adjacent to ponds in high-density aquaculture zones had lower levels of TOC, TN, TP, and TK compared to areas in low-density zones, suggesting reduced crop productivity in high-density zones. It is noteworthy to mention here that, the shrimp farms, especially old and large farms located near the coastal areas and along Rasulpur River, were ecologically less sustainable due to the lack of farm management and scientific knowledge, poor infrastructure, high fuel consumption, over use of fish feed and medicines, and lack of environmental awareness.

5.5 Major Findings

This study aimed to assess the environmental impacts of brackishwater aquaculture by analysing various water quality parameters of aquaculture ponds and soil quality parameters of adjacent agricultural lands. The study area was divided into three brackishwater aquaculture density zones. It was found that brackishwater aquaculture density was highest in coastal areas and along the Rasulpur River due to higher salinity and easy access to saline water. In these regions, the clustering of brackishwater shrimp farms was also high, with poorer water quality and increased pollution loads. Furthermore, most farms in these areas employed semi-intensive to highly intensive farming methods that did not address water pollution control. Consequently, water quality was poor, especially in densely clustered farms. Alarmingly, these farms released untreated effluent water into adjacent rivers, creeks, and canals, which were then reused as sources of saline water for the farms. This unscientific farm management practice impaired regional water quality, posing significant threats to aquatic biodiversity and water-dependent fauna, such as water birds. The release of untreated effluent water into source waters increased the risk of contamination and disease, raising concerns about the sustainability of brackishwater aquaculture. Additionally, the growth of CBA, often at the expense of croplands, and unscientific farm practices, such as saline water leakage into adjacent croplands, increased soil pH and salinity, which negatively affected soil fertility and crop productivity, thus threatening regional food security. It can be concluded that while the rapid expansion and clustering of brackishwater aquaculture, particularly shrimp monoculture, may have brought economic benefits to the region, unscientific farm management practices driven by profit maximization and lax government oversight have resulted in severe long-term environmental impacts. Government intervention is crucial to implement eco-friendly farm management practices and promote widespread awareness in the region.

Chapter VI:

Socio-political consequences of the growth of CBA

6.1 Introduction

Extensive brackishwater aquaculture including shrimp farming has been a traditional practice in most of the coastal parts of Southeast Asia including India (Hall, 2003; Rajitha et al., 2007; Pradhan & Flaherty, 2007; Pattanaik & Prasad, 2011; Ojha & Chakrabarty, 2018). In India, despite the fact that the development of commercial brackishwater shrimp farming generated livelihood opportunities for many people through various ancillary industries, most of the economic benefits were reaped by a small group of individuals who were already economically well-off and politically powerful (Durai & Babuji, 2023). Commercially produced shrimp was mainly a high-value, market-oriented commodity that largely failed to improve the food and livelihood security of the general population. Instead, the profits were primarily gained by multinational fish-feed and medicine companies, as well as shrimp processing firms (Barraclough & Finger-Stich, 1996).

Since this type of farming is highly capital-intensive, local people were often unable to invest in commercial brackishwater shrimp farming, leaving the opportunity to be seized by urban elites. These elites became farm owners by expropriating croplands from local farmers (Galappaththi & Nayak, 2017; Hossain & Hasan, 2017; Swarnokar et al., 2020). These outsiders, along with some affluent locals, frequently benefited by appropriating common property rights, which debilitated traditional livelihoods, adversely impacted food security through the massive conversion of croplands, and ultimately marginalized the native population (Hossain & Hasan, 2017; Afroz et al., 2018). This situation, in many cases, altered existing social structures and relationships (Pokrant, 2009; Hossain et al., 2013; Hoque et al., 2017).

The rapid conversion of croplands and vested lands into commercial shrimp farms led to numerous problems, such as reduced crop productivity due to soil quality deterioration and saline water intrusion, increased landlessness among farmers, weakened livelihoods of agricultural labourers, and the appropriation of common property rights. These issues caused resentment among the local population, which often led to conflicts between shrimp farm owners and crop farmers (Vandergreest et al., 1999; Pradhan & Flaherty, 2007; Roy, 2013; Galappaththi & Nayak, 2017).

The present study area under investigation also experienced similar social, economic, and political impacts due to the rapid conversion of vested lands and croplands into commercial brackishwater shrimp farms (Dutta et al., 2016; Ojha & Chakrabarty, 2018).

Against this backdrop, this chapter aims to identify the major social and political drivers of CBA, explore the nature of its social and political consequences in the study area, and explicate the unequal distribution of its impacts on various social groups." It has been ensured in this chapter that the narrative remains in the past tense, except for the statements expressing universal truths or the chapter's purpose.

6.2 Methodological framework

6.2.1 Data sources

A systematic review of the literature enabled the researcher to gain in-depth knowledge to understand the development of CBA, particularly shrimp farming, in the study region. Additionally, in-depth interviews were conducted with various stakeholders, including shrimp farm owners, shrimp farm labourers, farmers who had rented out their lands, farmers from the surrounding areas, and local residents. These interviews aimed to reconstruct the historical development of commercial shrimp farming, conduct scenario analysis, and assess the socio-political impacts of CBA. Furthermore, focus group discussions (FGDs) were carried out to validate the responses obtained from the questionnaire surveys (Fig. 6.1). Secondary data regarding the year-wise area and production of brackishwater shrimp culture at the national level and the state level were retrieved from the MPDA website (MPDA, 2024).

6.2.2 Development of structured questionnaire

To explore the socio-political dynamics of the study region related to the CBA, a semi-structured questionnaire was developed for interviewing the aquaculture farm owners, farm labourers, farmers, and other villagers living in the surrounding areas of the CBA farms. The semi-structured questionnaire allowed the respondents to share their views in a comprehensive manner (Annexure I). It contained several sections to extract necessary information about the socio-economic conditions of the respondents such as the asset level of the respondents, various economic aspects of shrimp culture, nature of the farming system, various threats of commercial shrimp farming, and the perception of various stakeholders regarding different socio-economic impacts of commercial shrimp culture in the area. The respondents were also inquired about the various socio-political issues relating to the growth of CBA in the area. The questionnaire was developed in English and translated into lucid Bengali (vernacular language) for easy understanding. It contained both close and open-ended questions. In some questions, particularly those related to the perception of various impact assessments, respondents were asked to score the given options using a Likert scale, where 1 indicated minimum impact and 5 represented maximum impact. Pilot surveys were conducted in different parts of the study region, after which the questionnaire was improved and revised before the final launch of the survey. Interviews were conducted at different times of the year throughout the study period of 2021-2024 (Hoque, 2017; Ahsan & Brandt, 2015).

6.2.3 Focus group discussion

FGDs were conducted in various parts of the study area to gather qualitative data. The FGDs facilitated more intensive interaction with respondents, allowing for the collection of qualitative information regarding the social and economic impacts of the growth of CBA in the area. Both positive and negative impacts of CBA development were discussed. More detailed conversations regarding sensitive issues, such as political drivers and impacts related to the development of CBA, were carried out during the FGDs (Beitl, 2012; Abdullah et al., 2017). 5 to 7 participants from various social as well as gender groups constituted each focus group.

Photograph 6.1: Questionnaire survey conducted at the study area based on semi-structured questionnaire.

Photograph 6.2: FGD conducted at the study area to get qualitative data through intensive interaction.

6.2.4 Sampling design

Scheduled surveys and FGDs were conducted following a stratified random sampling method. Based on the LULC pattern of 2021 (Fig 4.4), the areal percentage of brackishwater aquaculture was derived. Villages in the study region were then divided into three equal classes based on the percentage of aquaculture area: high-density zone, medium-density zone, and low-density zone. For each C.D. Block (i.e., Ramnagar-II, Contai-I, and Deshapran) considered in this study, three sites were randomly selected from each density zone. In total, 27 sampling sites were identified across the entire study region (Fig. 5.1).

At each site, two aquaculture farm owners, three aquaculture labourers, and five villagers, including farmers, were interviewed. For the survey, commercial shrimp farms and households were randomly selected at each site. One FGD was conducted at each of the 27 sites, with 5–7 participants from various socio-economic groups attending each FGD session.

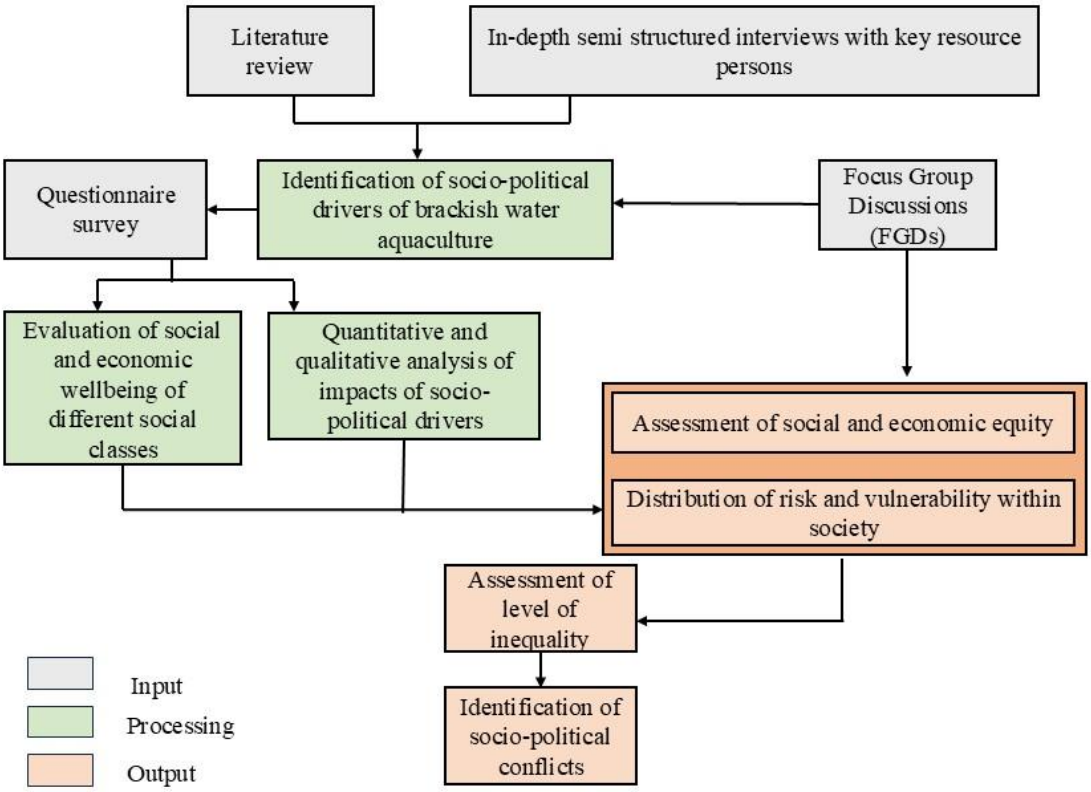

Figure 6.1: Methodological framework to assess socio-political consequences of the growth of CBA in the study region.

6.2.5 Statistical analysis

The quantitative data obtained from the questionnaire survey were analysed and represented using various cartographic techniques. Additionally, to elucidate the socio-economic status of various actors involved in commercial shrimp farming in the region, a socio-economic status index was developed. Three main social groups were selected for analysis: shrimp farm owners, shrimp farm labourers, and crop farmers in the surrounding areas of the shrimp farms. This composite index aimed to understand how the growth of CBA in the area differently impacted the socio-economic well-being of these groups.

Altogether, eight indicators were considered for preparing the composite index, which included the educational level of the family (v.2.a), livelihood diversity (v.2.b), monthly family income (v.2.c), amount of landholding (v.2.d), amount of agricultural land (v.2.e), house types (v.2.f), asset level (v.2.g), and food security (v.2.h) (Table 6.1). Index values were calculated from the scores received by each indicator to clearly understand how different aspects of social and economic well-being varied among the three social groups. Since the study incorporated various indicators across multiple dimensions, different scoring methods were utilized (Barraclough & Finger-Stich, 1996; Stonich & Bailey, 2000; Hossain et al., 2013; Bush & Marschke, 2017; Hoque, 2017).

*Composite Educational Index (CEI)***:** To calculate the CEI, education levels were divided into five classes, receiving scores from 1 to 5, where only 'literate' received a minimum score of 1 and 'graduate and above' received a maximum score of 5. The household education score (HES) was calculated as follows:

$$HES = \frac{\sum r * s}{n} \quad \text{(Eq. 6.1)}$$

Where, r = Response; s = Assigned scores to the responses; n = Total number of family members in a household. HES value ranged between 1 to 5 where 1 denoted low household education status and 5 denoted very high household education status.

Based on the HES values, CEI was calculated as follows:

$$CEI = \frac{\sum HES}{N} \quad \text{(Eq. 6.2)}$$

Where, N = Total number of all the surveyed households.

Livelihood diversity index (LDI): To calculate the LDI, various livelihood options were selected and assigned weights based on their economic viability. The first step in calculating the LDI was to determine the Household Livelihood Diversity Score (HLDS). Households with a greater number of economically sustainable livelihoods received higher scores. The maximum possible HLDS for a household was 5, which was calculated using the following formula:

$$HLDS = \sum r * w \quad \text{(Eq. 6.3)}$$

Where, r = Response; w = Assigned weightage to the livelihood options.

LDI was then calculated using the following equation:

$$LDI = \frac{\sum HLDS}{N} \quad \text{(Eq. 6.4)}$$

Where, N = Total number of all the surveyed households.

Income index (II): To calculate the II, monthly household income was categorized into five classes, each with an assigned score from 1 to 5. Households with an income below INR 10,000 received the minimum score of 1, while those with an income above INR 60,000 received the maximum score of 5. The II was then calculated using the following equation:

$$II = \frac{\sum HIS}{N} \qquad \text{(Eq. 6.5)}$$

Where, HIS = Household income score; N = Total number of all the surveyed households.

Land ownership index (LOI): To calculate the LOI, the amount of landholding was divided into five classes, with each class being assigned a score from 1 to 5. Households with landholdings below 0.5 hectares received the minimum score of 1, while those with landholdings above 2.0 hectares received the maximum score of 5. The LOI was then calculated using the following equation:

$$LOI = \frac{\sum HLHS}{N} \qquad \text{(Eq. 6.6)}$$

Where, HLHS = Household landholding score; N = Total number of all the surveyed households.

Agricultural land ownership index (ALOI): To calculate the ALOI, the amount of agricultural landholding was divided into five classes, with each class being assigned a score from 1 to 5. Households with agricultural landholdings below 0.5 hectares received the minimum score of 1, while those with agricultural landholdings above 2.0 hectares received the maximum score of 5. The ALOI was then calculated using the following equation:

$$ALOI = \frac{\sum HALS}{N} \qquad \text{(Eq. 6.7)}$$

Where, HALS = Household agricultural landholding score, N = Total number of all the surveyed households.

House type index (HTI): To calculate HTI the types of houses were divided into three classes where mud hoses got score 1, semi-concrete houses got score 3, and concrete houses got score 5. HTI was then calculated using the following equation:

$$HTI = \frac{\sum HTS}{N} \qquad \text{(Eq. 6.8)}$$

Where, HTS = House type score; N = Total number of all the surveyed households.

Asset level index (ALI): To calculate ALI various assets were listed and were given same. To calculate the ALI, first, the household asset level score (HALS) was calculated. The more numbers of assets a family had, the more score it obtained. A household at the maximum could have HALS of 5 which was calculated using the following formula:

$$HALS = \sum r * w \qquad \text{(Eq. 6.9)}$$

Where, r = Response; w = Assigned weightage to the livelihood options.

ALI was then calculated using the following equation:

$$ALI = \frac{\sum HALS}{N} \qquad \text{(Eq. 6.10)}$$

Where, N = Total number of all the surveyed households.

Food security index (FSI): To calculate the FSI, the types of food security were divided into five classes. These classes were scored from 1 to 5, where 'grown crop not at all sufficient/no crop land at all, so rice is purchased from the market' received the minimum score of 1, 'grown crop slightly less than the family consumption need' received a score of 2, 'grown crop just sufficient for the family consumption need' received a score of 3, 'grown crop slightly more than the family consumption need' received a score of 4, and 'grown crop more than sufficient for family need, with the surplus sold in the market' received a score of 5. The FSI was then calculated using the following equation:

$$FSI = \frac{\sum HFSS}{N} \qquad \text{(Eq. 6.11)}$$

Where, HFSS = Household agricultural landholding score; N = Total number of all the surveyed households.

Finally, the composite socio-economic status index (CSESI) was calculated using the following equation:

$$CSESI = \frac{\sum CEI + LDI + II + LOI + ALOI + HTI + ALI + FSI}{Mv} \qquad \text{(Eq. 6.12)}$$

Where, Mv = Total number of verifiers.

Table 6.1: Scoring guide for assessment of socio-economic status index of various social groups in the CBA farm area.

Number	Verifier	Related question	Scoring system
V.2.a	Educational level of the family	What are the levels of education of each member of your family?	• Literate (1) • Primary level (2) • Secondary level (3) • Higher Secondary level (4) • Graduate and above (5)
V.2.b	Livelihood diversity	What are the various livelihoods practiced by of the family members?	Weightage assigned to each livelihood practice: • Service holder (0.4) • Brackishwater aquaculture farm owner (0.3875) • Businessman (0.375) • Medium/ large scale industrial worker (0.3625) • Freshwater aquaculture farm owner (0.35) • Cultivator having own land (0.3375) • Brackishwater aquaculture farm worker (0.325)

Number	Verifier	Related question	Scoring system
			• Transporter (0.3125) • Small scale industrial worker (0.3125) • Freshwater aquaculture farm worker (0.3) • Labour (0.2875) • Share cropper (0.275) • Traditional fisher (0.2625) • Landless labour (0.25) • Stock farmer (0.2375) • Renter (0.225)
V.2.c	Monthly family income	How much is the total monthly income of your family?	• < 10, 000 INR (1) • 10,000-20,000 INR (2) • 20,000-40,000 INR (3) • 40,000-60,000 INR (4) • >60,000 INR (5)
V.2.d	Amount of land	How much land do you own?	• < .5 (ha) (1) • .5-1.0 (ha) (2) • 1.0-1.5 (ha) (3) • 1.5-2.0 (ha) (4) • >2.0 (ha) (5)
V.2.e	Amount of land	How much agricultural land do you own?	• < .5 (ha) (1) • .5-1.0 (ha) (2) • 1.0-1.5 (ha) (3) • 1.5-2.0 (ha) (4) • >2.0 (ha) (5)
V.2.f	House type	What is the type of your house?	• Concrete house (5) • Semi concrete house (3) • Mud house (1)
V.2.g	Asset level	Do you own the mentioned assets?	Weightage assigned to each asset: • Furniture (0.625) • Television (0.625) • Bicycle (0.625) • Motor cycle (0.625) • Mobile phone (0.625) • LPG (0.625) • Sanitation unit (0.625) • Livestock (0.625)
V.2.h	Food security	Does your family's annual consumption need of staple crop met by own cropland's production?	• Grown crop more than sufficient for family need and rest sold in the market (5) • Grown crop slightly more than the family consumption need (4) • Grown crop is just sufficient for the family consumption need (3) • Grown crop slightly less than the family consumption need (2) • Grown crop not at all sufficient/ no cropland at all so that rice is purchased from the market (1)

The Composite Economic Vulnerability Index (CEVI) was developed to assess the economic vulnerability of commercial shrimp farm owners. Seven different indicators were identified to measure the level of economic vulnerability: the number of brackishwater aquaculture ponds owned (v.3.a), aquaculture pond ownership type (v.3.b), source of investment (v.3.c), effect of market price fluctuation (v.3.d), crop failure (v.3.e), profit/loss status (v.3.f), and deviation from normal profit levels (v.3.g) (Table 6.2.). Since the study considered indicators across multiple dimensions, different scoring methods were applied, with higher vulnerability receiving a higher score.

For example, shrimp farm owners with a medium number of ponds (i.e., 12-14) received the maximum score of 5, while those with a very large number of ponds (i.e., 25 or more) or a very small number of ponds (i.e., 2 or less) received the lowest score of 1. Regarding pond ownership, the lowest vulnerability score of 1 was assigned to farmers who owned all the ponds themselves, while a score of 3 was given to those with a mix of owned and rented ponds. The highest vulnerability score of 5 was assigned to farm owners who rented all their ponds from villagers.

To calculate the vulnerability score for the source of investment in shrimp farms, different investment sources available in the area were listed and assigned weightage. The vulnerability score was derived by adding these weighted values. In the case of market price fluctuation, farm owners who experienced significant market fluctuations received a score of 5, while those who did not face any market fluctuation received a score of 1. The same scoring pattern was used for crop failure.

For profit/ loss status, the scoring was as follows: high profit received a score of 1, moderate profit a score of 2, marginal profit/marginal loss a score of 3, moderate loss a score of 4, and high loss a score of 5. The amount of profit or loss in INR was determined through interviews with the shrimp farm owners. This pattern was also applied when scoring the level of deviation from normal profit, where a high positive deviation received a score of 1, moderate positive deviation a score of 2, marginal positive/negative deviation a score of 3, moderate negative deviation a score of 4, and high negative deviation a score of 5.

Finally, the CEVI was calculated using the following equation: to determine the vulnerability index value of a particular shrimp farm owner, all the scores of the indicators were summed and then divided by the number of indicators. The equation is as follows:

$$\mathrm{CEVI} = \frac{\sum V.3.a + V.3.b + V.3.c + V.3.d + V.3.e + V.3.f + V.3.g}{Mv} \quad \text{(Eq. 6.13)}$$

Where, Mv = Total number of verifiers.

Table 6.2: Scoring guide for perceptual economic vulnerability index of the CBA farms.

Number	Verifier	Related question	Scoring system
V.3.a	Number of brackishwater aquaculture ponds	How many brackishwater aquaculture ponds do you have?	• ≥ 2 (5) • 3-5 (4) • 6-8 (3) • 9-11 (2) • 12-14 (1)

Number	Verifier	Related question	Scoring system
			• 15-18 (2) • 19-21 (3) • 22-24 (4) • ≤ 25 (5)
V.3.b	Aquaculture pond ownership type	Do you own the aquaculture ponds or it is rented?	• Mixed ownership (3) • Own (1) • Rented (5)
V.3.c	Source of investment	What are the sources of investment for the aquaculture farming?	• Own capital (.25) • National bank (.5) • Private bank (.75) • Local financers (1.5) • Fish feed agency (2)
V.3.d	Effect of market price fluctuation	Did market price fluctuation affect the income from CBA farming?	• No (5) • Yes (1)
V.3.e	Crop failure	Did you face crop failure?	• No (5) • Yes (1)
V.3.f	Profit/ loss status	What is the profit/loss status for the current production season?	• High profit (1) • Moderate profit (2) • Marginal profit/ marginal loss (3) • Moderate loss (4) • High loss (5)
V.3.g	Deviation of normal profit level	How much the current profit level deviated from normal profit level?	• High positive deviation (1) • Moderate positive deviation (2) • Marginal positive/ negative deviation (3) • Moderate negative deviation (4) • High negative deviation (5)

The Composite Social Impact Index (CSII) was calculated for each of the 27 selected sites, taking into consideration four different indicators: types of social problems (v.4.a), payment of compensation (v.4.b), level of social conflict (v.4.c), and gender equity (v.4.d) (Table 6.3). The study incorporated indicators across multiple dimensions, employing various scoring methods accordingly (Afroz et al., 2018; Galappaththi & Berkes, 2015; Galappaththi & Nayak, 2017; Hoque et al., 2017; Hossain & Hasan, 2017).

To calculate the score for the types of social problems (v.4.a), a list of social issues existing in the area was created. Each identified problem was then assigned a weighted value based on its intensity and nature. The total score for the social problems reported by each respondent was determined by adding the weighted values of the identified problems using the following equation:

$$RSPS = \sum r * w \qquad \text{(Eq. 6.14)}$$

Where, RSPS = Social problem score assigned by each respondent; r = Response; w = Assigned weightage to the social problem.

The average social problem score of a particular site (ASPS) was then calculated using the following equation:

$$ASPS = \frac{\sum RSPS}{n} \qquad \text{(Eq. 6.15)}$$

Where, n = Total number of persons interviewed.

Regarding payments of compensation, a score of 1 was assigned for a positive response, while a score of 5 was assigned for a negative response. All the responses were summed and then divided by the total number of individuals interviewed to obtain the average score for v.4.b using the following formula:

$$APCS = \frac{\sum RPCS}{n} \qquad \text{(Eq. 6.16)}$$

Where, RPCS = Response score of the respondents regarding payment of compensation; APCS = Average payment compensation score.

To obtain the score for v.4.c, the levels of social conflict were first classified into five groups, with very violent conflict receiving a score of 5 and no conflict receiving a score of 1. All the responses were then summed and divided by the total number of individuals interviewed to calculate the average score for v.4.c using the following formula:

$$ASCS = \frac{\sum RSCS}{n} \qquad \text{(Eq. 6.17)}$$

Where, RSCS = Response score of the respondents regarding level of social conflict; ASCS = Average social conflict score.

To calculate the score for v.4.d, various gender equity issues were first listed. Each identified problem was then assigned a weighted value based on its nature. The total score for the gender equity problems reported by each respondent was derived by adding the weighted values of the identified issues using the following equation:

$$RGEPS = \sum r * w \qquad \text{(Eq. 6.18)}$$

Where, RGEPS = Gender equity problem score assigned by each respondent; r = Response; w = Assigned weightage to the social problem.

The average gender equity problem score of a particular site (AGEPS) was then calculated using the following equation:

$$AGEPS = \frac{\sum RGEPS}{n} \qquad \text{(Eq. 6.19)}$$

Lastly CSII was calculated using the following equation:

$$CSII = \frac{\sum ASPS + APCS + ASCS + AGEPS}{Mv} \qquad \text{(Eq. 6.20)}$$

Where, Mv = Total number of verifiers.

Table 6.3: Scoring guide for construction of the social impact index of the CBA farms.

Number	Verifier	Related question	Scoring system
V.4.a	Social problems	What are the negative social impacts of	Weightage assigned to each social problem: • Decrease in paddy production (1)

Number	Verifier	Related question	Scoring system
		brackishwater aquaculture practice in the area?	• Conversion of croplands to aquaculture ponds (0.875) • Forceful land selling at cheap rate (0.75) • Increase in landless labour (0.625) • Increase in intersectionality in the social frame (0.5) • Unequal political power (0.5) • Loss of grazing land & common property resources (0.375) • Increase in out migration (0.25) • Deterioration of traditional livelihood (0.125)
V.4.b	Payment of compensation	Do you pay any compensation to the neighbouring farmers due to increase in soil salinity?	• Yes (1) • No (5)
V.4.c	Level of social conflict	What is the level of social conflict?	• Very violent (5) • Violent (4) • Moderately violent (3) • Less violent (2) • No conflict (1)
V.4.d	Gender equality	What is the level of gender equality?	Weightage assigned to each social problem: • Social abuse against women (2) • Loss of economic opportunity for women (1.5) • Absence of participation of women in business decision (.75) • Lack of scope for training and capacity building (.5) • Loss of social status of women (.25)

6.3 Results

6.3.1 Regional CBA evolution trajectory: a participatory reconstruction

6.3.1.1 Monodon era

The study attempted to reconstruct the history of CBA development based on a participatory appraisal. In-depth discussions in FGDs and interviews with commercial shrimp farm owners, shrimp farm labourers, farmers, and local villagers revealed the stage-wise development of CBA in the region.

The participatory appraisal indicated that, in the 1980s, the cultivation of tiger prawns (*Penaeus monodon*) began along the coastal areas. The government distributed vested lands among the local populace to enhance their socio-economic well-being and generate foreign exchange. However, modern technology-based commercial shrimp farming required significant initial investments. Consequently, local villagers could not afford to invest in shrimp farming and instead rented out these lands to urban elites and a few economically strong villagers, who overwhelmingly acquired the land at low rates and established shrimp farms. Between 1980 and 1990, tiger prawn cultivation continued to thrive in the coastal areas and along the tidal rivers, leading farm owners to reap considerable profits. Encouraged by this success, more individuals invested in the sector, resulting in the conversion of coastal mangroves, wetlands, and substantial amounts of cropland into commercial shrimp farms. Initially, when croplands began to be converted to shrimp farms amidst agricultural areas, there was some resistance from crop farmers, primarily due to concerns about saltwater intrusion into surrounding croplands.

In 1991, the Coastal Regulation Zone notification was enacted, and an environmental impact assessment of commercial shrimp farming was conducted, revealing the detrimental implications of the haphazard growth of intensive shrimp farming (Hein, 2000). Consequently, the Supreme Court of India imposed a ban on non-traditional brackishwater aquaculture in the CRZ areas in 1996 (Hein, 2000). In 1997, the representatives of the national aquaculture lobby filed a petition with the Supreme Court to review the judgment, leading to the implementation of the Aquaculture Bill of 1997. This Bill strictly prohibited further growth of commercial shrimp farming in CRZ areas, allowing existing intensive shrimp farms to continue, provided they underwent a licensing process. The Bill also stated that no new intensive shrimp farms would be developed (Hein, 2000). In 2005, the Coastal Aquaculture Authority (CAA) Act was enacted to monitor the development, ecological sustainability of the farms, and quality control, as well as to issue licenses to qualified shrimp farms (Durai & Babuji, 2023). However, in practice, there was a lack of enactment of the Bill and a complete absence of vigilance. As a result, intensive shrimp farms continued to proliferate in coastal areas, along tidal rivers and creeks, and further inland, significantly transforming existing rice-paddy fields. At this stage, crop farmers repeatedly protested the expansion of shrimp farms within rice-producing areas due to saltwater infiltration and reduced crop productivity.

In 2012, the commercial shrimp farming system in the studied region faced a major crisis due to outbreak of diseases, severely impacting tiger prawn cultivation. The immediate effects included significant economic losses and the closure of most shrimp farms. Furthermore, there was a substantial market loss and a sharp decline in shrimp prices as the United States ceased importing shrimp from India due to high antibiotic usage (Brooks, 2016) (Fig. 6.2).

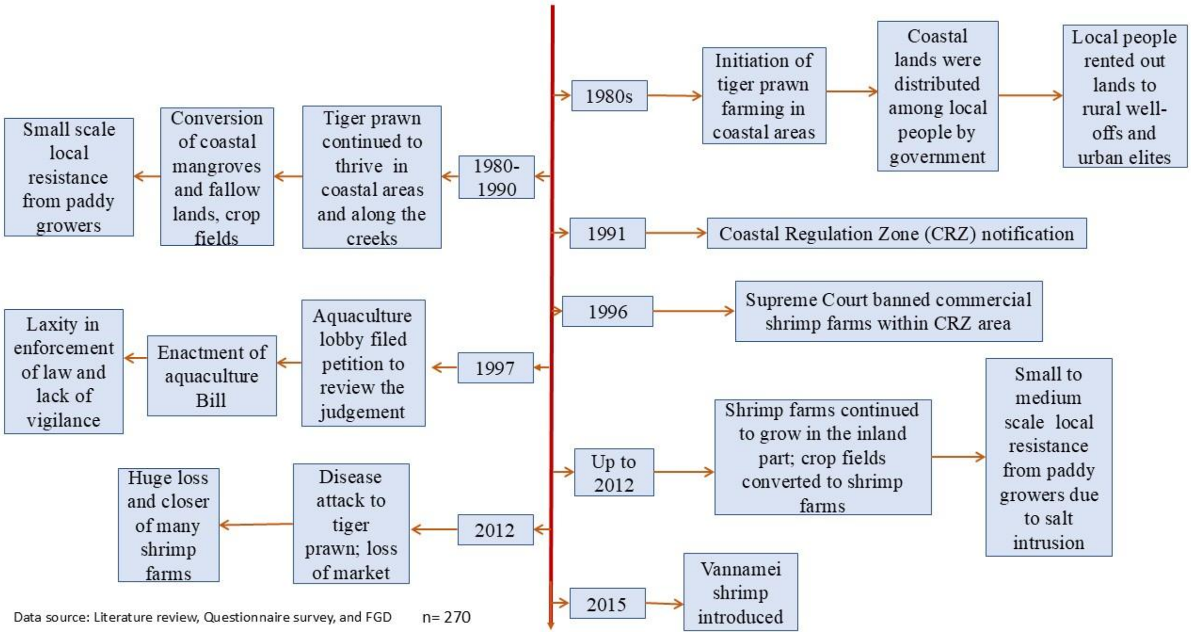

Figure 6.2: Evolution of CBA in the region (up to 2015).

6.3.1.2 Vannamei era

In 2015, a dramatic change occurred in the shrimp farming landscape, as tiger prawn cultivation was replaced globally by the farming of *Litopenaeus vannamei* (vannamei shrimp). Multinational fish feed and seed companies convinced shrimp farmers that vannamei was a more resilient species than tiger prawns, capable of being cultivated more intensively and thereby ensuring greater profits. Consequently, farm owners began farming vannamei with renewed enthusiasm. Between 2015 and 2019, production soared, and market rates were high. Lured by this success, many crop farmers started converting their rice-paddy fields into intensive shrimp farms, as earnings from commercial shrimp farming proved to be significantly more profitable than rice farming. This led to a substantial transformation of crop fields into shrimp ponds, even in the inland areas of the study region. Although rice farmers protested against the shrimp farms, their lack of coordinated action meant that the dispersed protests and conflicts failed to make a significant impact.

However, this favourable scenario did not last long. In 2019, intensive shrimp farming began to suffer intermittent economic losses due to outbreaks of White Spot Syndrome Virus (WSSV), highly fluctuating market conditions, and severe damage caused by cyclones. The situation worsened in 2020-21 when the global shrimp market experienced a significant downturn due to the pandemic. Additionally, India lost its major markets in

China and the European Union. Between 2021 and 2023, several viruses, including WSSV, *Enterocytozoon hepatopenaei* (EPH), White Faecal Syndrome (WFS), Running Mortality Syndrome (RMS), Black Gill Disease (BGD), Loose Shell Syndrome (LSS), and White Muscle Disease (WMD), infested shrimp farms (Teora, 2023). Concurrently, India faced stiff competition from Ecuador and China in the global market (The Shrimp Blog, 2022). As a result, shrimp farm owners incurred massive economic losses, with more than 50% of commercial brackishwater shrimp farms shutting down and lying abandoned. This crisis has left many farmers struggling with overwhelming debt, leading to instances of suicide due to the immense pressure caused by financial burdens (Fig. 6.3).

6.3.2 Socio-political dimensions of CBA growth

6.3.2.1 Changing pattern of political-economy

The introduction and rapid growth of commercial shrimp farming in coastal Purba Medinipur, particularly in the study region, has led to notable changes in the economic landscape. The economic transformations brought about by the emergence of commercial shrimp farming (CBA) in the region are multifaceted, yielding both positive and negative impacts. Prominent characteristics of CBA include capital-intensive farming, high economic risk, and highly fluctuating market conditions. Moreover, the shift towards

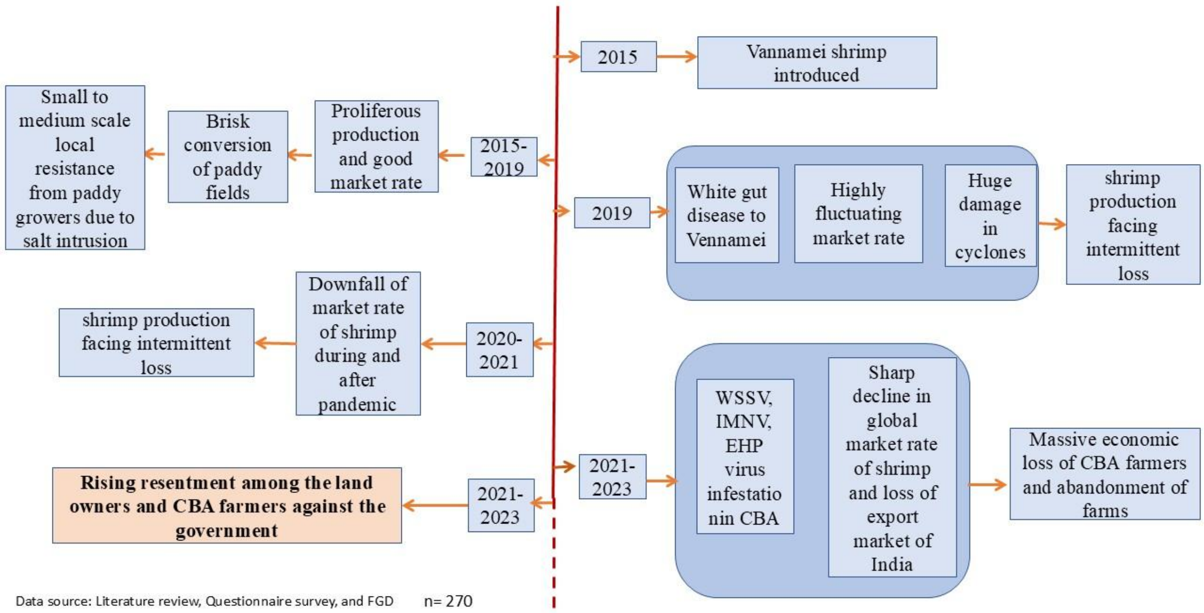

Figure 6.3: Evolution of brackishwater aquaculture in the region since 2015.

export-oriented, technology-based intensive shrimp farming has caused substantial alterations in traditional rural livelihood patterns and economic relations.

The perception-based study revealed that CBA in the study region began in the 1980s, driven by government promotion of commercial shrimp farming to generate foreign exchange and bolster livelihood opportunities for the local population. However, due to its capital-intensive nature, which requires significant initial investments and ongoing costs, economically disadvantaged rural residents were unable to directly participate in production. Initially, local people rented out their less productive or unproductive rice-paddy fields plagued with high salinity to rural and urban elites. This small group of economically better-off individuals became the owners of shrimp ponds and started producing tiger prawns.

With the onset of commercial shrimp production, ancillary industries such as ice production, shrimp storage, and processing facilities were established in the area, creating new business opportunities in shrimp feed, medicines, and seed production. The local farmers who rented out their lands relied on rental income for their livelihoods, with some taking jobs as labourers on shrimp farms at compromised wages. Additionally, some rural residents found work in the transport sector, ice-making industry, and shrimp processing facilities. Consequently, the introduction of commercial shrimp farming led to the emergence of new economic classes and altered economic relationships within the community.

As shrimp production increased and market prices surged due to high global demand, CBA in the study region expanded rapidly, attracting more investors, primarily from urban areas, eager to establish new shrimp farms. Consequently, land prices and rents began to rise. More than seventy percent of the respondents during the survey opined that land price increased after the introduction of commercial shrimp farming in the region. Enticed by these high values, more marginal farmers sold or rented out their lands to shrimp farm owners (Fig. 6.4). The commercial shrimp farms grew rapidly, initially concentrated in coastal areas and along tidal rivers, but eventually expanding into more inland regions and even within rice-paddy fields; converting croplands, water bodies, and areas under vegetation.

Two primary factors contributed to the rapid conversion of croplands into shrimp farms. Firstly, the promise of high profits from commercial shrimp farming led farmers to seek more land to expand their operations, pressuring surrounding farmers to sell or rent their lands, often at compromised rates. Secondly, the establishment of brackishwater shrimp farms near rice-paddy fields impaired rice production due to saline water intrusion, compelling rice farmers to sell or rent their lands, especially those adjacent to the shrimp farms. This situation altered the traditional land selling system, making it less transparent. Furthermore, as rice-paddy fields were heavily converted, the number of landless farmers increased, and many agricultural labourers lost their jobs.

Additionally, the highly mechanized nature of commercial shrimp farming required fewer labourers, leading to an oversupply of labour in the area. Consequently, wages for labourers decreased (Fig. 6.5). Furthermore, shrimp farm owners often perceived pond-based works as unsuitable for women, resulting in the loss of livelihood opportunities for women who had previously worked as agricultural labourers. Thus, the growth of CBA has profoundly altered the economic scenario of the region.

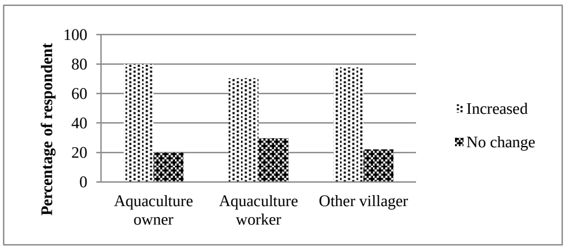

Figure 6.4: Perception regarding increase of land price after introduction of CBA (n = 270).

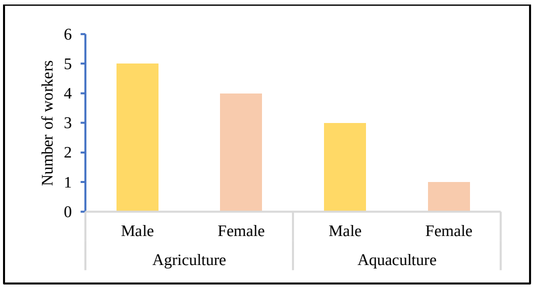

Figure 6.5: Number of labourers engaged in agriculture and shrimp farms.

The economic conditions of shrimp farm owners were found to be inconsistent, marked by significant risks and threats due to various factors inherent in the industry. Commercial shrimp farming is a highly capital-intensive enterprise, requiring substantial initial investments and ongoing operational costs. Given the absence of government schemes to facilitate loans for shrimp aquaculture, many farmers relied on personal capital or loans from private banks and agencies. From discussions with shrimp farm owners, it emerged that larger, more economically stable farmers were able to either invest their own capital or secure loans from private banks. In contrast, medium and small farmers, who were primarily former rice farmers, often found themselves unable to cover the costs from their own resources. These smaller farmers also harboured a lack of confidence in approaching banks for loans, primarily due to fears of incurring losses and becoming defaulters. The primary survey revealed that more than seventy percent of the shrimp farm owners invested their own capital. Consequently, medium and small farmers—who represented the majority—turned to local agents of fish feed and medicines for financial support (Fig. 6.6).

The shrimp farmers typically purchased fish feed and medicines on credit from these local agents, which resulted in them paying significantly higher prices than the market rate for these products. Additionally, they were often compelled to sell their shrimp to the same agents at prices lower than the prevailing market rate, leading to a cycle of economic exploitation. If farmers experienced crop loss or faced economic downturns due to low market prices, they often found themselves unable to repay their debts, plunging deeper into a vicious cycle of indebtedness. This situation forced them to continue purchasing fish feed and medicines on credit from the same agents and to sell their shrimp at a loss until their debts were cleared. As a result, many farmers became trapped in a relentless debt cycle.

The perception-based study also revealed that some farm owners, particularly large-scale operators, possessed government licenses, which allowed them to access sporadic benefits such as shrimp seeds and feeds. However, a significant number of small farmers lacked licenses and were therefore unable to secure government support. There was a notable apathy toward obtaining licenses among these farmers, as the benefits received from the government—relative to the licensing fees—were minimal. It was found that nearly eighty percent of the shrimp farm owners had no license (Fig. 6.7). Furthermore, the study indicated a general laxity in government enforcement of the mandatory licensing system, complicating the situation for smaller farmers seeking assistance.

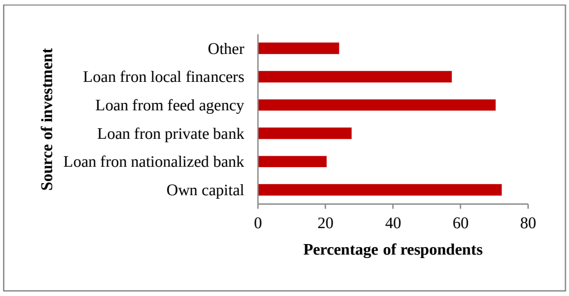

Figure 6.6: Different sources of investments of CBA owners (n = 54).

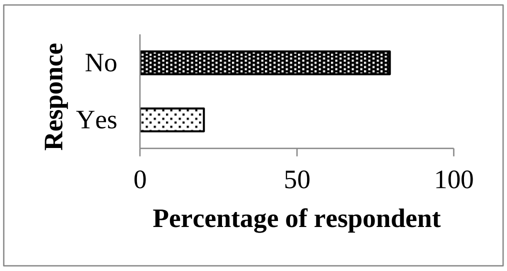

Figure 6.7: Status of having license of the CBA owners (n = 54).

The export-oriented commercial shrimp farming is fraught with various risk factors. During the survey, farm owners revealed that frequent market fluctuations (hundred percent shrimp farm owners), significant crop loss due to recurrent infestations of various viruses (nearly eighty percent shrimp farm owners), and natural calamities (more than ninety percent shrimp farm owners) were major threats to intensive commercial shrimp farming in the study area (Fig. 6.8). Drastic decline in shrimp exports from India has severely impacted the local economy. The COVID-19 pandemic induced low market demand, which was a major setback for the shrimp producers in the region. Most shrimp farm owners reported that the market had not returned to normal in the post-COVID period. They indicated that the market price for 20-30 full-grown or approximately 1 kg weighted shrimps dropped drastically from INR 380 to INR 250 at the beginning of 2022, resulting in massive losses. According to the perception study, the production cost for 1 kg of shrimps is INR 350, making the sharp drop in market price particularly detrimental. Furthermore, as exporters refused to purchase the produced shrimp due to the drastic decrease in shrimp exports, farmers struggled to sell their crops, often having to accept even lower prices. In addition, over the past three years, there has been a significant increase in the prices of shrimp feed, wages, and fuel, further raising production costs and reducing profit margins.

In the study area, *Enterocytozoon hepatopenaei* (EHP) and White Spot Syndrome Virus (WSSV) were found to be the primary causes of crop failures since 2017. Farmers also reported repeated outbreaks of other diseases like BGD, WFS, RMS, LSS, and WMD; which have caused substantial economic damage. These disease outbreaks were primarily attributed to unscientific farm management practices, such as the absence of water treatment before and after farming. The survey revealed that more than 70% of shrimp farmers in the region experienced crop loss due to disease infestations since 2017. The spread of EHP and WSSV worsened in 2022 and 2023, and, combined with low market demand, approximately 70% of shrimp farm owners were compelled to shut down their farms at the beginning of 2023.

The study found that about 50% of shrimp farm owners did not take the risk of starting a second crop in 2022, and approximately 70% of shrimp farms did not initiate their first crop at the beginning of 2023. As a result, most shrimp farms are currently lying abandoned. Consequently, farmers are facing a severe economic crisis, with a particularly dire situation for many small farmers who are burdened by substantial debt. The closure of most farms has also led to job losses for shrimp farm labourers. At present, a few farmers who are still cultivating shrimp have completely stopped growing shrimps of 20-30 pieces/ kg due to lack of market demand and have also ceased production of smaller shrimps of 50-70 pieces/ kg due to high production costs. Currently, only a few large farm owners are cultivating shrimps of medium size of 40-60 pieces/ kg, which still has some market demand.

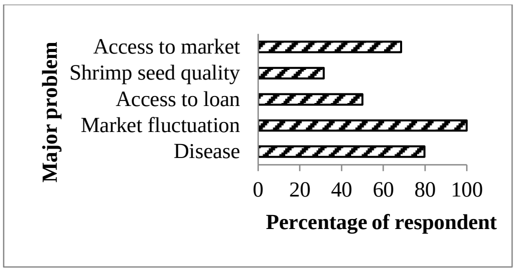

Figure 6.8: Various problems encountered by the CBA owners (n = 54).

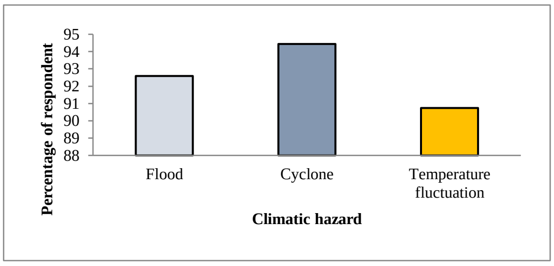

Figure 6.9: Various climatic hazards causing crop loss of CBA (n = 54).

Another major challenge faced by commercial shrimp farmers was natural calamities. A series of cyclones had hit the study region in the last ten years, devastating the shrimp farms and causing notable crop loss. According to the respondents, Cyclone Titli in 2018, Fani in 2019, Amphan in 2020, and Yaas in 2021 wreaked havoc in the shrimp farms of the study region. Cyclone Amphan caused the severest damage due to the inundation of many shrimp farms. In the aftermath of the cyclone, pollution levels increased, leading to major disease outbreaks. Many shrimp farms were flooded, resulting in the loss of nearly all shrimp overnight, which caused massive economic losses. Cyclone Yaas washed out vast areas of shrimp farms, particularly those situated near the coast. Other shrimp farms also suffered extensive damage due to flooding, as embankments were breached in several locations. Tidal waves as high as 2-4 m swept away large tracts of land. The three C.D. Blocks considered under the study, located along the coast, were severely affected, with losses particularly high at farms where the shrimp were nearly mature (Fig. 6.9).

The perception study revealed that both owners with a large number of ponds (≥ 25 ponds) and those with a smaller number (≥ 2 ponds) were economically vulnerable. Owners with many ponds indicated that, due to the rapid spread of viruses, all their ponds would be affected, leading to substantial economic loss. Conversely, owners with one or two ponds reported being more prone to falling into the debt cycle if they experienced crop loss or low market rates.

Regarding ownership type, 61.11% of owners had all their farms rented from crop farmers, while 27.77% owned their farms outright. Additionally, 11.11% of owners had some ponds of their own and some rented (Fig. 6.10). Among these groups, those with all rented ponds were the most economically vulnerable, as they were obligated to pay rent even when they faced losses. During interactions with shrimp farm owners, it was found that, because shrimp farming is highly capital-intensive and there is no support from the government, they relied on various sources of funding, including personal capital, national banks, private banks, local financiers, and fish feed agencies. The perception study found that 59.26% of farm owners depended financially on local fish feed agencies and were exploited by them. This dependency made them more economically vulnerable than farmers who relied solely on their own capital.

The shrimp farm owners indicated that the market had been highly volatile since 2020, and 74.07% of the shrimp farm owners reported that they could not earn a profit due to very low market rates. Furthermore, disease outbreaks have been frequent since 2019, with 81.48% of shrimp farm owners experiencing total crop loss in 2022 and 2023, forcing many to shut down their farms due to substantial economic losses. The perception study found that 68.51% of shrimp farmers could not garner any profit in 2022 and 2023, and 64.81% reported significant deviations from their normal profit levels during this period (Fig. 6.11).

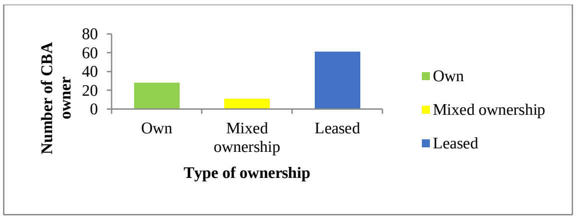

Figure 6.10: Nature of CBA farm ownership (n = 54).

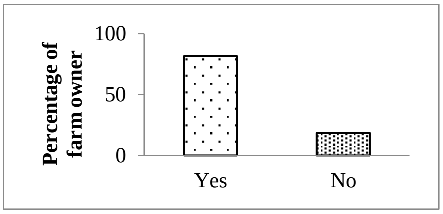

Figure 6.11: Intensity of crop failure (n = 54).

6.3.2.2 Perception-based composite economic vulnerability index

A perception-based composite economic vulnerability index (CEVI) for brackishwater aquaculture farms was developed to assess the economic vulnerability of the commercial shrimp farm owners in the study area. This index was based on seven economic drivers, including the number of brackishwater aquaculture ponds owned, aquaculture pond ownership type, source of investment, effects of market price fluctuations, crop failure, profit/ loss status, and deviation from the normal profit level (Table 6.12). The CEVI map revealed that the economic vulnerability of shrimp farms was high in several areas: the southern part of the study area near the coast, the western part along the Rasulpur River, and the extreme northern part, where the concentration of shrimp farms was also very high. The highest CEVI values were found in Sonamuhi, located in the southeast, and in Krishna Khayratibar, situated in the southern part of the study area along the Bay of Bengal. Additionally, vulnerability index values were notably high in Mandarmani, Sapua, Raniya, Soula, Baguran Jalpai, Chata Padmapukur, Uttar Amtaliya, Bankiput, Chandibeti, and Aladarput (Fig. 6.12).

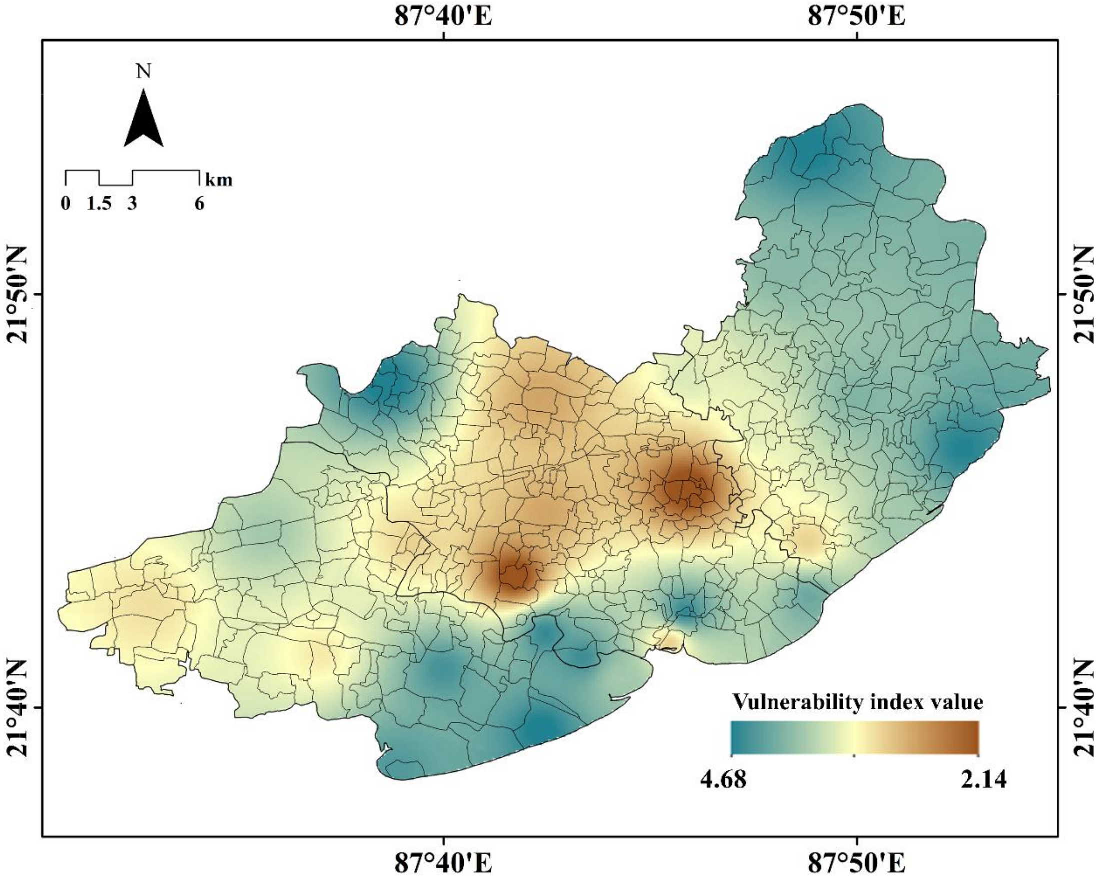

Figure 6.12: Spatial distribution of economic vulnerability of CBA farms, depicted by CEVI scores (n = 54).

6.3.2.3 Changing pattern of social-ecological scenarios

The introduction of CBA in the study region has led to the establishment of a global market-based commercial farming system, largely replacing traditional livelihoods. The rapid conversion of paddy and vegetable farms into commercial shrimp farms has exposed local communities to numerous threats, including forceful land appropriation, food insecurity, loss of traditional livelihoods, and rising indebtedness.

Before the initiation of commercial shrimp farming, the primary livelihoods for the local population included paddy and vegetable farming, as well as marine and riverine fishing. However, with the advent of shrimp farming, which offered significantly higher profit margins than paddy farming, fallow lands, ponds, and crop fields began to be converted into shrimp farms. Initially, due to the capital-intensive nature of this farming system, the local population could not participate effectively (Fig. 6.13). Many chose to sell or rent out their land at lucrative prices. Encouraged by early successes, a few economically better-off rural individuals also began converting their croplands into shrimp farms. The substantial economic returns from shrimp production created a clear divide in social classes.

Survey respondents reported ongoing conflicts between shrimp farm owners and traditional farmers and fishers, as the encroachment of shrimp farms into paddy-producing areas increased soil salinity (more than 4000 μmhos cm^{-1} at many places) and negatively impacted rice production. Compensation for damaged crops became a contentious issue. Despite the crop farmers' efforts to restrict the expansion of shrimp farms in agricultural sites, the economically and politically powerful shrimp owners effectively suppressed the voices of local communities.

In the second phase of growth, post-2015, when the culture of *Litopenaeus vannamei* gained traction, more crop farmers converted their lands to shrimp farms. Many paddy growers were compelled to do so as their crop production suffered due to saltwater intrusion. During the survey, several small shrimp farm owners expressed their dissatisfaction, noting that while they had appreciated the consistent but low income from paddy production, the introduction of saltwater shrimp farming drastically reduced their rice yields. Ultimately, they felt they had no choice but to convert their fields into shrimp ponds. Although shrimp farming could yield profits about ten times greater than paddy production, it came with substantial risks, exposing traditional rice farmers to the uncertainties of a fluctuating global market.

The rapid expansion of commercial shrimp farming disrupted the homogeneity of rural society and traditional social relations, creating divisions based on economic status and resource access. Large investors, primarily urban elites, significantly benefited from this shift. They expanded their shrimp farms by acquiring surrounding lands and adeptly navigated the market's ups and downs. Many of these large farm owners also ventured into shrimp feed and medicine supply businesses, allowing them to buffer occasional losses with alternative income sources. Moreover, these politically connected shrimp farmers often violated land conversion policies to convert fallow and agricultural lands into shrimp farms, with instances of forceful land acquisition by land-grabbing syndicates being prevalent in the study region. In some cases, these syndicates illegally altered land ownership using political connections to deceive original landowners.

Most large shrimp farm owners employed labourers from other districts, such as Paschim Medinipur and South 24 Parganas, who were willing to work for lower wages. The primary survey revealed that more than seventy percent of the shrimp farm workers migrated from various districts of West Bengal to the region (Fig. 6.14). Consequently, the growth of commercial shrimp culture failed to provide meaningful livelihood opportunities for the local population. As paddy fields transitioned into shrimp farms, agricultural labourers, particularly women, began to lose their jobs. Small and medium farmers frequently faced the threat of crop loss due to disease outbreaks and market fluctuations, leading them into a vicious cycle of debt. A third group in this scenario consisted of crop farmers who rented their land to large shrimp operators. Initially, these farmers received good rental income, but over time, shrimp owners negotiated for considerably lower rents. With no viable option to revert their land back to paddy production, they felt compelled to accept these reduced rates. While protest movements did arise, they lacked organization, allowing the more politically powerful shrimp owners to quash dissent. The fourth group comprised rice-paddy farmers who continued to cultivate their fields but suffered from the negative impacts of saltwater intrusion, which sharply reduced their crop productivity. Many of these farmers reported in interviews that despite repeated complaints to local authorities, they received minimal or no compensation from shrimp farm owners for their losses.

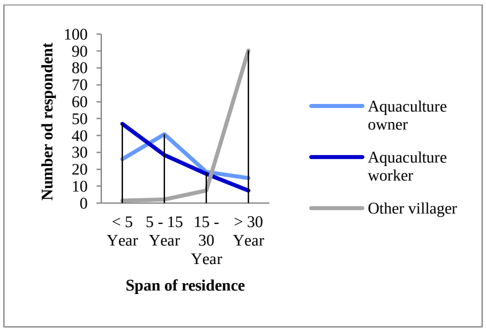

Figure 6.13: Composition of the farm owners and labourers based on origin (n = 135).

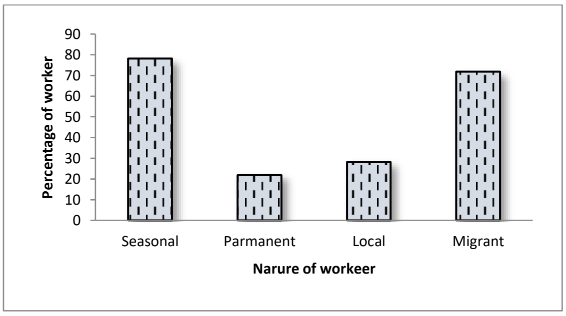

Figure 6.14: Composition of the CBA labourers based on employment tenure (n = 81).

The fifth group consists of common villagers, most of whom have expressed concerns about losing their traditional livelihoods due to the rampant growth of shrimp farms. They reported that they have lost their common property rights, including the collection of food and fodder from fallow lands that have been converted into shrimp ponds. Fishermen have complained that pollutant-laden effluents from shrimp ponds are directly discharged into rivers, creeks, and the ocean, reducing both the quantity and variety of fish available, which has severely impaired their traditional livelihoods. Additionally, the noteworthy conversion of rice-paddy fields into shrimp ponds has adversely affected food security for the local population (fig. 6.15). Widespread loss of grazing fields has further challenged the livelihoods of cattle growers.

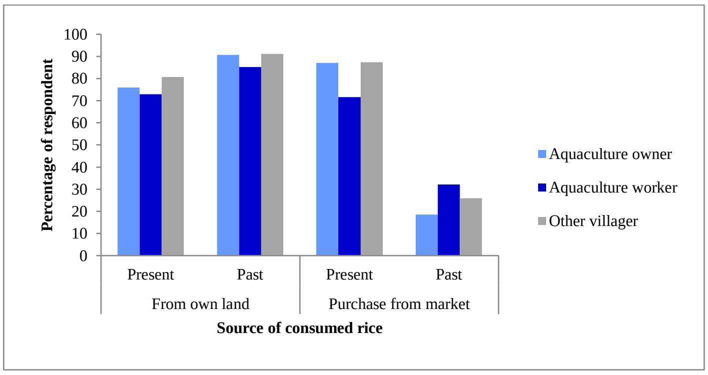

Figure 6.15: The impact of CBA on regional food security (n = 270).

The situation worsened when shrimp farming began to incur financial losses in 2022. Small and medium shrimp farmers struggled to absorb these losses and found themselves in significant economic crisis and debt. Paddy farmers who had rented their lands to shrimp growers reported that after 2022, as profits from shrimp farming sharply declined, many shrimp farmers ceased operations and abandoned the land without recovering it. Now, these lands lie vacant, as rice production is not feasible in the highly saline fields. Consequently, many individuals have lost their jobs and fertile land, compelling them to migrate to various parts of the country in search of work. Thus, the initiation, growth, and subsequent losses of the commercial shrimp industry have dramatically altered the social structure, creating a highly heterogeneous society and changing power dynamics and resource-based social relations.

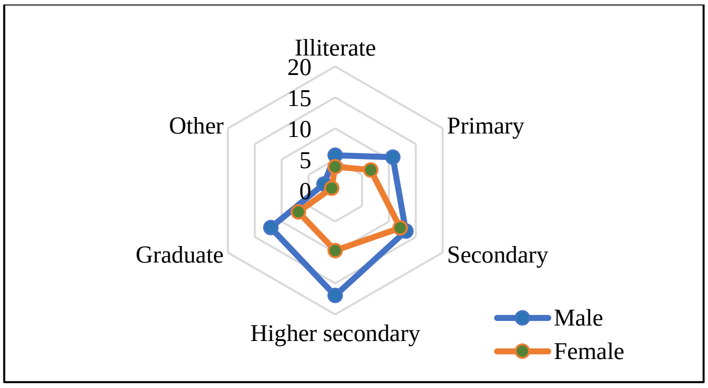

Figure 6.16: Education level of shrimp farm owner families (n = 54).

The perception study revealed that the introduction of commercial shrimp farming in the area has led to the emergence of three distinct social groups: shrimp farm owners, shrimp farm labourers, and common villagers. There is a stark disparity in socio-economic status among these three groups. Regarding literacy levels, families of shrimp farm owners were found to be in a much better position, with 25.26% of family members having completed secondary education, 26.65% achieving higher secondary education, and 18.92% holding a degree (Fig. 6.16). In contrast, among common villagers, 30.99% had completed secondary education, 12.46% had achieved higher secondary education, and only 6.67% had graduated (Fig. 6.18). Shrimp farm labourers were identified as the most educationally disadvantaged group, with 26.83% of family members being illiterate and 30.39% having only received primary education (Fig. 6.17).

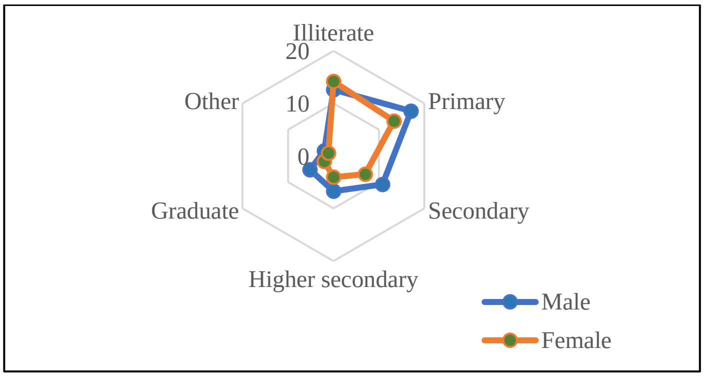

Figure 6.17: Education level of shrimp farm labour families (n = 81).

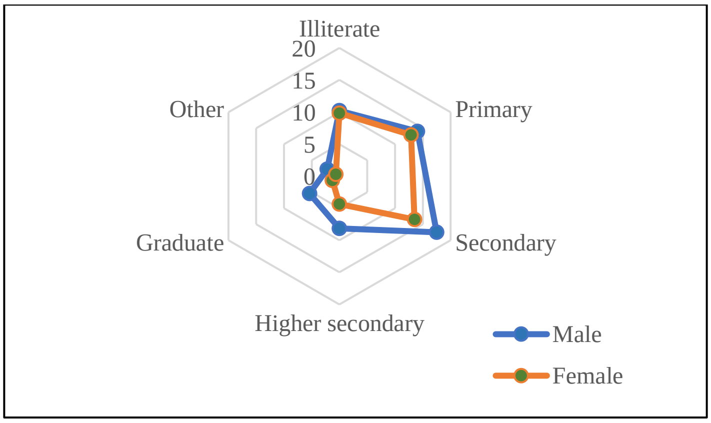

Figure 6.18: Education level of families of common villagers (n = 135).

Regarding livelihood diversification, the data revealed significant differences among the three groups studied. A substantial 77.77% of shrimp farm owners and 72.5% of common villagers had their own crop fields, whereas only 58.03% of shrimp farm labourers owned croplands (Figure 6.19). Many shrimp farm labourers were engaged as sharecroppers (20.99%) and agricultural labourers (11.11%), as they could not find consistent work at the shrimp farms throughout the year.

Notably, many common villagers pursued fishing (14.07%) and freshwater fish cultivation (38.52%) as secondary sources of livelihood. However, only 14.44% of common villagers found employment on shrimp farms, with the majority of labourers being outsiders. Additionally, 36.33% of common villagers' families and 20.98% of shrimp farm owners were categorized as marginal workers. Another income source for common villagers came from land rents (35.6%), as many rented their lands to shrimp farmers. Livestock ownership also differed across the groups: 53.33% of common villagers and 45.3% of shrimp farm owners had livestock, while only 37.14% of shrimp farm labour families reported having any livestock.

Moreover, a notable 40.74% of shrimp farm owners operated medium to large businesses, and 18.52% had family members employed in the service sector. In contrast, only 7.41% of shrimp farm workers' families had small businesses, and just 3.7% had members in the service sector. This disparity highlighted that shrimp farm owners were in a much better position regarding livelihood diversification and family income levels compared to the other two groups.

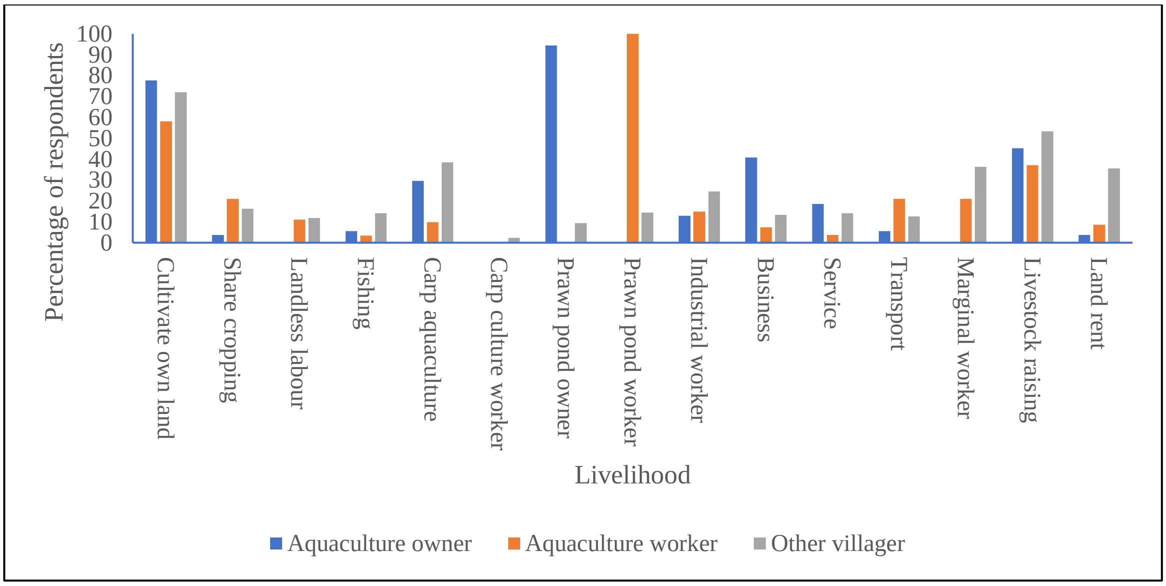

Figure 6.19: Livelihood diversities among the families of shrimp farm owners, shrimp farm labourers, and common villagers (n = 270).

The study revealed significant disparities in family income among the three groups. Specifically, 46.3% of shrimp farm owners reported a family income exceeding INR 60,000.00, while the majority of common villagers and shrimp farm labourers had family incomes ranging from INR 5,000.00 to INR 10,000.00 (Fig. 6.20).

In terms of land holdings, shrimp farm owners possessed more extensive land than both common villagers and labourers (Fig. 6.21). This disparity was also evident in asset levels, with shrimp farm owners having a much higher asset accumulation compared to the other two groups (Fig. 6.23). Notably, 74.07% of shrimp farm owners lived in concrete houses, whereas a substantial 60.79% of shrimp farm labourers resided in mud houses, highlighting the stark economic divide between the groups (Fig. 6.22).

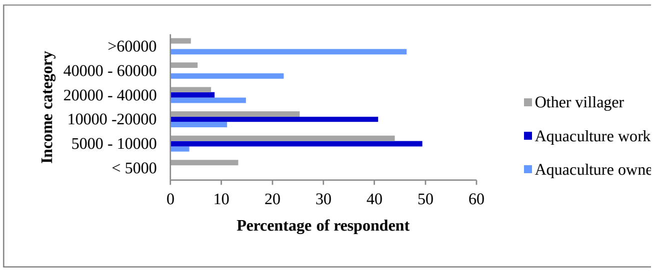

Figure 6.20: Level of family income among various socio-economic groups (n = 270).

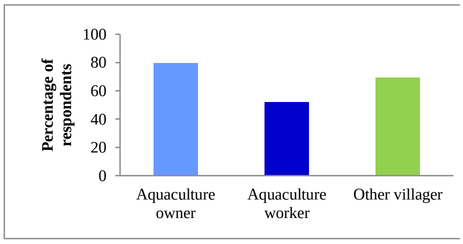

Figure 6.21: Status of cropland ownership of socio-economic groups (n = 270).

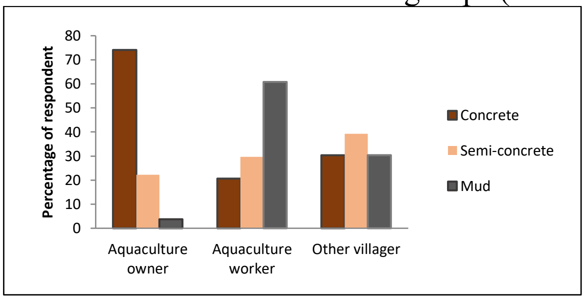

Figure 6.22: House types of various socio-economic groups (n = 270).

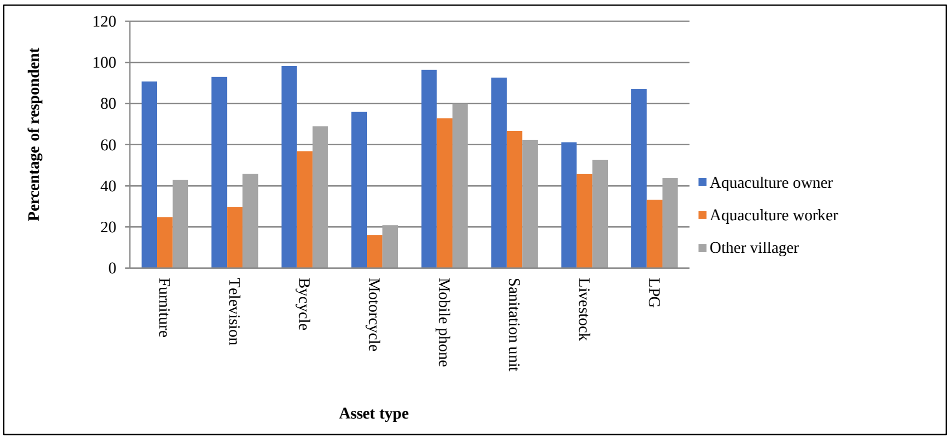

Figure 6.23: Types of assets in the households of various socio-economic groups (n = 270).

6.3.2.4 Composite socio-economic status

To assess the socio-economic status of the three socio-economic groups existing in the region, a socio-economic status index was prepared. Eight socio-economic factors were taken into consideration for preparing the composite index, which included the educational level of the family, monthly family income, livelihood diversity, house types, asset level, amount of landholding, amount of cropland, and food security (Fig. 6.24).

SOCIAL CATEGORY	EI	LDI	II	LOI	ALOI	HTI	ALI	FSI	COMPOSITE SOCIO-ECONOMIC STATUS INDEX
OWNER	3.35	1.60	4.09	2.13	2.04	4.41	4.35	2.04	3.00
WORKER	2.34	0.86	1.62	1.37	1.31	2.19	2.17	1.26	1.64
VILLAGER	2.87	1.08	1.79	1.46	1.36	3.00	2.61	1.44	1.95

High status 5 … 0 Low status

Figure 6.24: Composite socio-economic status of various groups (n = 270).

6.3.2.5 Composite social impact index

A composite social impact index (CSII) was calculated for each of the 27 selected sites, considering four different social drivers. These included types of social problems, payment of compensation, level of social conflict, and gender equity. The study found that the social impact of the growth of commercial shrimp farming in the area was diverse. A high CSII was identified in Mandarmani, Sonamuhi, Tajpur, Baguran Jalpvai, Krishna Kayratibar, Bankiput, Chandibeti, and Baliya, where the number of various social impacts was high. These impacts included a decrease in paddy production, conversion of croplands to aquaculture ponds, forceful land selling at cheap rates, an increase in landless labour, greater intersectionality in the social framework, unequal political power, loss of grazing land and common property resources, increased outmigration, and deterioration of traditional livelihoods.

In most areas, especially where commercial shrimp farming had been practiced for several years, crop farmers were not compensated for crop damage. Furthermore, the level of conflict between shrimp farm owners and villagers, particularly crop farmers, was high in Mandarmani, Tajpur, Sapua, Ranya, Krishna Kayratibar, Beltaliya, Chata Padmapukur, Badalpur, Bankiput, Chandibeti, Aladarput, and Poddarchak.

The primary gender issues in the shrimp farms included social abuse against women, loss of economic opportunities for women, absence of women's participation in business decisions, lack of training and capacity-building opportunities, and loss of women's social status. The social impact distribution map indicated that the social impact was highest in the north-eastern, northern, and south-western parts of the study region, where the number of various social consequences was high, resulting in a comparatively elevated level of conflict between shrimp farm owners and villagers, especially crop farmers.

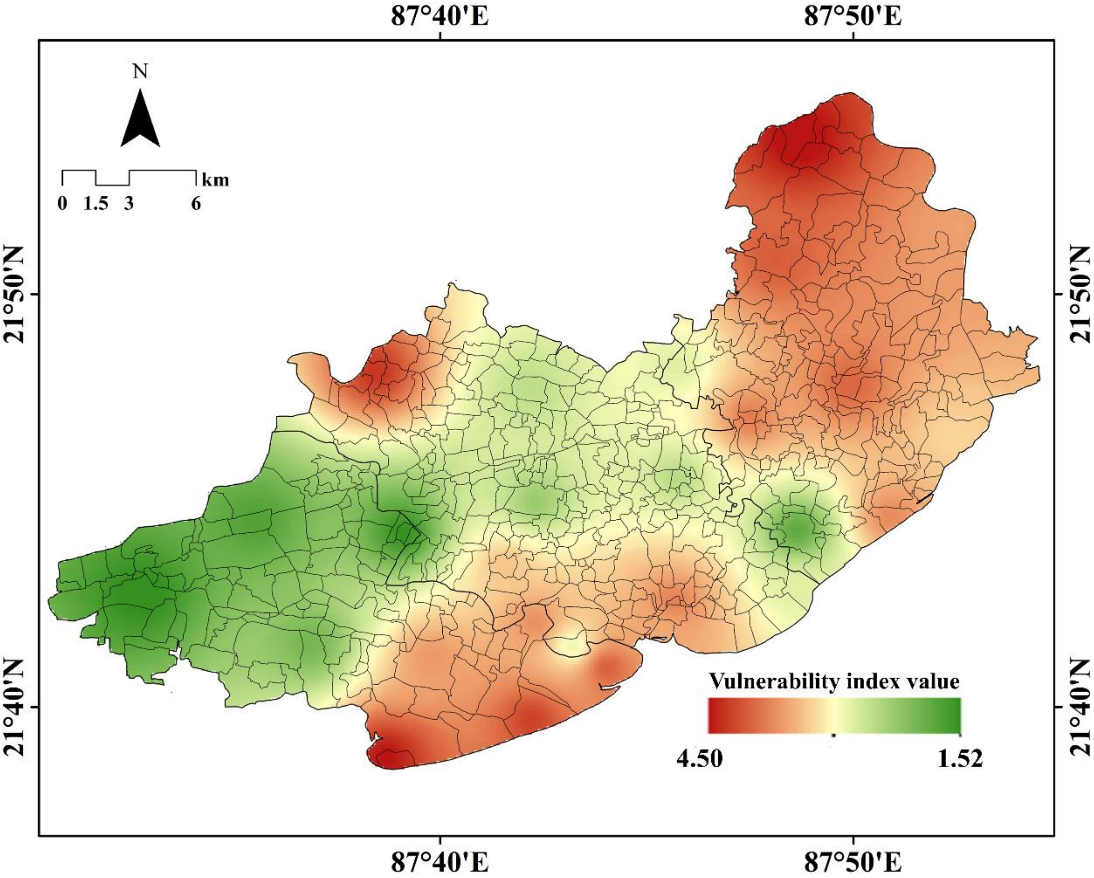

Figure 6.25: Spatial distribution of social impact (CSII values) of CBA farms (n = 270).

6.3.2.6 Contextualizing CBA evolution with regional socio-political conflicts

After the initiation of CBA, conflicts between various groups at different scales became a common phenomenon. Initially, when shrimp farming began to thrive in the region, conflicts arose between the local populace and shrimp farm owners, most of whom came from outside the area and reaped benefits without contributing to the local community. Initially, shrimp farming was established on fallow tracts and unfertile croplands near coastal areas and along tidal rivers. However, over time, it began to spread into more inland agricultural areas. As shrimp farm owners expanded their operations, the embankments between shrimp farms and rice-paddy fields narrowed, leading to the infiltration of saline water into the paddy fields. This significantly reduced paddy production, with paddy growers adjacent to shrimp farms being the worst affected. This situation became a pressing issue, and rice farmers throughout the area vehemently protested against the growth of shrimp farms in agricultural regions, demanding compensation. However, these protests were not well coordinated, allowing the politically stronger shrimp farm lobby to suppress dissent. Additionally, claims for compensation by rice farmers who suffered crop losses due to saline water infiltration went unfulfilled, aided by local political governance. Common villagers reported that the demand for land increased with the emergence of commercial shrimp farming, and shrimp farm owners, with the assistance of land mafias, forcibly appropriated lands. There was widespread resentment among the locals against shrimp farms due to the loss of traditional livelihoods and common property rights.

During the FGDs, it was revealed that the growth of commercial shrimp farming led to the emergence of several social groups, including large shrimp farmers, small shrimp farmers, those who rented out their lands to shrimp owners, rice-paddy farmers, traditional fishermen, and other common villagers. The conflict was multidimensional and complex, arising primarily from conflicts of interest among these groups regarding resource allocation and benefit sharing. Conflicts also emerged between large and small shrimp farm holders over resource usage. The most critical natural resource for shrimp farmers is water. Small farm holders complained that large, economically powerful shrimp farm owners, supported by political leaders, controlled water and land management without any established rules or governance. Meanwhile, rice growers expressed concerns about increasing salinity and declining productivity. Traditional fishers and common villagers also voiced grievances about the expropriation of common property resources and the destruction of traditional livelihoods. During the FGDs, respondents indicated that in many areas, rice farmers, fishers, and common people submitted joint petitions to local governmental bodies against shrimp farmers for various unjust activities. However, these efforts proved futile, as shrimp farmers were more politically influential.

6.4 Discussion

Although commercial shrimp farming has generated various economic and social benefits, particularly concerning national income, it is fraught with numerous social problems in India in general and in the study area in particular. Rampant and unplanned conversion of cropland, land expropriation, threats to traditional livelihoods, and the expropriation of common property rights are some of these issues. Commercial shrimp farming began in the 1990s in the study region, leading to a significant conversion of croplands, especially after the introduction of *L. vannamei* in the post-2012 period. Two major drivers behind this continuous land conversion were the growing demand for land to expand shrimp farms and crop farmers leasing their lands to shrimp farmers, which allowed them to earn more money than from paddy farming. Initially, non-agricultural lands were converted, but as the demand for land increased, croplands began to be converted as well. Paddy farms adjacent to shrimp farms experienced negative impacts, with productivity declining due to rising soil salinity (Acharya, 2014; Shee, 2020; Maiti et al., 2021; Das et al., 2024). Moreover, the industry has become economically unsustainable due to frequent outbreaks of diseases and natural disasters, particularly cyclones, sharp increases in the price of fish feed and other input costs, and a significant decline in global market demand, especially in the post-COVID period. As a result, shrimp farmers in India, particularly in the study area, are facing an economic crisis (The Shrimp Blog, 2022; Das et al., 2024).

Commercial shrimp farming is highly dependent on international markets. It is considered a high-value food commodity, with most production occurring in the coastal areas of the Global South and exported to first-world countries. For instance, India is a dominant shrimp exporter globally, with most exports going to the United States and the European Union (Patil et al., 2021). Shrimp exports play a pivotal role in India's national income, making India the second-largest producer of aquacultural products, accounting for 17.5% of the total shrimp produced globally (Geetha et al., 2019). However, the international market is highly volatile, impacting the production and economic sustainability of shrimp farming. A drop in shrimp prices in the world market can occur due to economic recession, low demand, low quality of shrimp, and high competition among various producing countries. The Indian government is continuously encouraging the growth of commercial shrimp farming. Accordingly, the Coastal Aquaculture Authority (Amendment) Bill was passed in August 2023 to boost production (Coastal Aquaculture Authority, 2024). However, the export scenario remained bleak in the same year. Due to the dual factors of low market prices for shrimp and rising costs of shrimp feed, many farmers either stopped farming in 2023 or reduced their stocking rates. The situation is worse in three leading states of India: Andhra Pradesh, West Bengal, and Gujarat (Gibson, 2023). For instance, India experienced a 12% decrease in shrimp production in 2022-23 due to low market demand.

Four main reasons contributed to this bleak scenario. Firstly, global market demand for shrimp dropped during the pandemic and post-pandemic periods. India's shrimp exports faced significant disruptions due to COVID-19-related shipment problems and the worldwide economic recession during the pandemic. The drastic reduction in shrimp imports from India by China adversely affected more than 600,000 shrimp farmers in West Bengal, especially in the Purba Medinipur district, leading to a reduction of $1.5 billion in the country's shrimp exports. Secondly, since 2022, India has lost its market share in the US, China, and the European Union. Thirdly, there has been heightened competition in the global market from Ecuador, which has flooded the market with shrimp at lower prices. In contrast to India, Ecuador's success in shrimp production can be attributed to cultivating more virus-resistant varieties suitable for local conditions and farming on large scales of 200 to 250 hectares. With reduced market demand, shrimp farmers have been compelled to sell at prices lower than production costs. Finally, climate vagaries, particularly unexpected heavy rainfall, have led to frequent outbreaks of WSSV, EHP, and WFS viruses. The situation has worsened as the prices of shrimp feed and medicines have risen excessively in the last three years (Sadafule et al., 2013; CIBA, 2020; ICSF, 2024; The Shrimp Blog, 2022; Aqua Culture Asia Pacific, 2023; Gibson, 2023; World Aquaculture Society, 2023; Arora, 2024; Singh, 2024).

Viral, bacterial, and fungal diseases have been recurrent threats to commercial shrimp farming throughout Asia, particularly in India. *Enterocytozoon hepatopenaei* (EHP) has posed a significant threat to *L. vannamei* shrimp culture since 2016, causing considerable crop losses. WSSV is another virus whose spread has resulted in substantial economic losses (World Aquaculture Society, 2023a; Patil et al., 2021). In West Bengal, 50% of farmers faced severe economic losses due to WSSV outbreaks (Mohan et al., 2004). Disease infestations lead to direct economic losses due to high mortality or total crop damage, as well as increased production costs for combating the spread of the virus. Indirectly, these outbreaks affect the livelihoods of those involved in the shrimp farming process (Patil et al., 2021).

Climate change poses a significant threat to the sustainability of commercial shrimp farming in India, particularly in the study area. Climate-induced factors, including rising temperatures, unexpected heavy rainfall, and prolonged dry spells, contribute to frequent disease outbreaks. Additionally, natural hazards such as cyclones, storm surges, coastal floods, and rising sea levels cause significant crop damage and economic loss (Pradhan & Dash, 2021; Bhanja et al., 2023; Custom Market Insights, 2024). Continuous rainfall reduces DO levels, oscillates salinity and pH levels, and fosters the emergence of various diseases. Conversely, prolonged high temperatures increase pH levels and salinity while reducing DO and water depth (Pradhan & Dash, 2021). For example, low production throughout India has been attributed to extended dry periods and lack of rain due to El

Niño, resulting in decreased water depth and higher pollutant accumulation, which has led to frequent outbreaks of non-viral EHP disease, WSSV virus, and Running Mortality Syndrome (RMS) (Brooks, 2016; Teora, 2023). Furthermore, severe cyclones have repeatedly caused extensive damage to shrimp farms. The frequency of severe cyclones has increased due to climate change induced by global warming (Pradhan & Dash, 2021). Historical evidence reveals that between 1970 and 2019, India experienced as many as 117 cyclones (Indian Meteorological Department, 2021). For instance, Cyclone Amphan caused widespread inundation of shrimp farms, resulting in enormous crop damage (Purkayastha, 2020). Similarly, Cyclone Yaas devastated vast areas of shrimp farms, leading to losses exceeding INR 9 billion in the shrimp farms of the Medinipur district (Dao, 2022; Mutter, 2021). Cyclone Yaas affected approximately 2,000 to 5,000 ha of shrimp ponds in West Bengal and Odisha, resulting in more than a 15% reduction in shrimp exports that season (Bhanja et al., 2023). The shrimp farms in the Purba Medinipur district were particularly impacted by strong winds and inundation due to storm surges during the two severe cyclones, Amphan and Yaas. Economic losses in the district's shrimp farms were estimated at about $130 million (Pradhan & Dash, 2021; Bhanja et al., 2023).

The growth of commercial shrimp farming has largely failed to bolster the local economy and has devastated traditional livelihoods. It has threatened the common property rights and the right to food and nutrition of traditional fishermen. Additionally, it has adversely affected the local populace by contaminating water, degrading soil quality, encroaching on croplands and grazing lands, limiting access to traditional fishing grounds, and disrupting socio-cultural harmony (FIAN International, 2024). More than 100,000 crop farmers, particularly in Purba Medinipur, have converted their paddy fields to commercial shrimp farms. Although this shift has brought instant wealth to a small group of people; many shrimp farmers, especially small and medium-sized farmers, face huge losses due to market fluctuations, disease outbreaks, and natural calamities. Currently, many of the paddy farmers, who converted their lands to shrimp farms, are again willing to return to paddy production. However, due to the high salinity of the land, reclaiming it has become costly and time-consuming (Singh, 2019; Chakraborty, 2024).

A similar scenario was observed in the study region, where commercial shrimp farming burgeoned up to 2021, resulting in the conversion of vast amounts of cropland, fallow lands, ponds, and coastal mangroves into commercial shrimp farms. Although shrimp farms initially started near coastal areas and along tidal rivers, where salinity was already high, the success of shrimp farming led to increased demand for land, subsequently engulfing rice farms in more inland areas. Due to inadequate farm management, saltwater intrusion into surrounding croplands became commonplace, impairing soil quality and crop production. As rice production significantly decreased, marginal farmers either sold or leased their lands to shrimp farm owners. However, conflicts between shrimp farm owners and crop farmers emerged over issues such as forced land expropriation, insufficient rent payments, and the unwillingness to compensate for crop damage. Additionally, conflicts arose among local villagers as grazing fields for livestock were either taken over by shrimp farmers or degraded due to saltwater intrusion. Traditional fishermen also experienced conflicts with shrimp farmers, as access to the ocean became challenging due to the development of shrimp farms along the coast, which were often protected by fencing. They have also complained about pollution caused by effluents released by shrimp farms, which has impaired fish biodiversity (Maiti, 2021).

Despite intermittent losses due to disease outbreaks, natural calamities, fluctuating markets, and occasional social unrest, shrimp farming was generally considered a profitable business. However, the scenario changed in the post-pandemic period when global demand for Indian shrimp drastically decreased, leading to significant losses for shrimp farmers. To exacerbate the situation, recurrent outbreaks of diseases such as WSSV, EHP, and WFS ravaged the crops. Consequently, shrimp farmers are now struggling with an economic crisis. Many have closed their farms and ceased paying rent for the lands they leased. With limited options for reclaiming the land for rice cultivation, the entire system has been disrupted.

6.5 Major findings

Aquaculture plays a pivotal role in the national income of the coastal states of the Global South and bolsters the livelihoods of numerous marginal communities living in these areas. India has experienced a drastic evolution in the aquaculture sector, particularly in shrimp farming, which has transformed from a traditional livelihood into a significant commercial practice and is now one of the most important sectors for earning foreign currency. Initially, the Government of India encouraged the growth of commercial shrimp farming on unproductive lands to increase export earnings and improve the livelihoods of marginalized populations in coastal regions. However, over time, the industry has become riddled with myriad economic and social problems. High establishment costs, increasing input costs, a highly fluctuating global market, crop losses due to frequent disease outbreaks, and the occurrence of natural calamities are some of the major economic hindrances. Meanwhile, rapid conversion of rice farms, appropriation of common property resources, destruction of traditional livelihoods, increasing salinity in surrounding areas, and resultant conflicts between shrimp farmers and crop growers are pressing social and political issues.

CBA is often considered a profitable industry; however, it comes with numerous risk factors. In the study region, many rice-paddy farmers converted their lands to shrimp farms, enticed by the significant profits gained by large farmers compared to the lower profits from rice farming, often ignoring the hidden risks. Farm owners frequently flouted necessary sustainable management practices. The lack of proper farm management, particularly the absence of adequate water treatment during both the intake of water and the discharge of pollutant-laden effluents, led to repeated outbreaks of various diseases, resulting in substantial economic losses. Fluctuating weather conditions, along with the frequent occurrence of severe cyclonic storms, storm surges, and floods, also ravaged shrimp farms across extensive areas, causing significant crop loss. As a capital-intensive farming system, commercial shrimp farming suffers from a lack of government credit schemes and subsidies. Consequently, most farmers have to rely on loans from local agencies, and repeated crop losses, particularly in recent years, have ensnared them in a cycle of debt.

The introduction of commercial shrimp farming has largely affected traditional livelihoods and altered the existing social and economic structure, widening the gap between the rich and the poor. The infiltration of saline water into surrounding crop fields has significantly reduced crop productivity, compelling marginal farmers to sell or rent their lands to shrimp farm owners at compromised rates. This shift has exposed rural communities to the volatile global market. Furthermore, the loss of cropland has left rice farmers, sharecroppers, and agricultural labourers jobless, with female agricultural labourers being the worst affected. As commercial shrimp farms often hire labourers at lower rates from outside the area, they have failed to absorb the unemployed locals, resulting in an oversaturated labour market and decreased wage rates. Consequently, there has been a high rate of outmigration in search of livelihoods. Thus, the boom in shrimp farming has brought little economic benefit to the common villagers.

The situation worsened when shrimp farming faced a major setback in the post-COVID period due to the loss of the Indian shrimp market and a sharp decrease in market prices. This has caused substantial economic losses, primarily impacting small shrimp farmers who find themselves trapped in a vicious cycle of debt. Moreover, in the study area, many shrimp farmers have closed their farms due to the economic losses caused by declining shrimp demand, frequent disease outbreaks, and the devastation caused by Cyclone Amphan and Cyclone Yaas. Thousands of ha of land now lie barren, and the people dependent on the industry have lost their livelihoods. With almost no chance of reclaiming the land for rice cultivation, marginalized individuals have no choice but to migrate to various parts of the country to become unskilled labourers.

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Chapter VII:

CBA induced regional vulnerability: A comprehensive assessment

7.1 Introduction

CBA has rapidly expanded across tropical regions in Asia, Latin America, and Africa since the 1990s (Barraclough & Finger-Stich, 1996; Stonich & Bailey, 2000; Hall, 2003). CBA, particularly commercial shrimp farming, has thrived in countries such as Thailand, India, China, Ecuador, Mexico, Colombia, Vietnam, Brazil, Bangladesh, Tanzania, and Honduras, primarily for generating foreign exchange and meeting the demand for protein (Barraclough & Finger-Stich, 1996; Hossain et al., 2013; Galappaththi & Nayak, 2017). Despite these benefits, the rapid expansion of CBA has sparked global debate due to its various negative effects on the environment, society, and local economies. In this context, a comprehensive assessment was crucial to address the regional vulnerabilities caused by the expansion of CBA in the study region. Such an assessment would have supported the formulation of sector-specific guidelines and policy interventions to mitigate these negative impacts. Unfortunately, despite the many issues caused by CBA, there was a significant lack of comprehensive vulnerability assessments and mapping of its impacts, in India in general and in the study area in particular. This chapter aimed to fill that gap by developing a comprehensive index, i.e. the CBA-induced regional vulnerability index (CBAIRVI).

7.2 Methodological framework

In previous chapters (Chapter 5 and Chapter 6), we discussed the ecological, economic, and social impacts of CBA in the study region and has developed various vulnerability indices. In this chapter, the identified vulnerability attributes were combined into a comprehensive regional vulnerability index and create a spatial model for the same.

7.2.1 Identification of vulnerability indicators

The vulnerability indicators largely depend on the characteristics of the study regio, the specific vulnerabilities of the region, and the research objectives (Gayen & Datta, 2023). The selected vulnerability indicators must be specific to the objectives of the study. To achieve this, we developed a Criteria and Indicator (C&I) framework to identify the ecological, economic, and social attributes s necessary for assessing the CBAIRVI. An in-depth review of published literature was conducted to identify these attributes. Subsequently, these indicators were cross-verified during FGDs held at each selected site. The attributes were then revised and modified to suitable indicators based on the feedback received from these FGDs. Initially, three distinct sets of C&I were developed to understand the vulnerabilities of aquaculture ponds (as discussed in Chapters 5 and 6). These sets included ecological, economic, and social vulnerabilities. In this chapter, we combined these three C&I sets to form the comprehensive CBAIRVI.

The criteria encompass both quantitative and qualitative indicators collected from ecological measurements and perception-based studies. These indicators address edaphic, aquatic, economic, and social components, with details about perception-based indicators already provided in Chapter 5 and Chapter 6. To calculate the final CBAIRVI, we also included field-based ecological measurement data related to edaphic and aquatic indicators. The edaphic indicators comprise soil pH, EC, TOC, TN, TP, and TK; while the aquatic indicators consist of water pH, EC, BOD, DO, COD, TN, TP, Cl, TDS, and NH_3-N.

7.2.2 Scoring system

The scoring system for economic, ecological, and social indicators was discussed in Chapter 5 (Section 5.3.6) and Chapter 6 (Section 6.2.5). To assign scores to edaphic and aquatic indicators, the arithmetic mean (μ) and the standard deviation (σ) of each indicator were first calculated. Subsequently, either direct or inverse scores were assigned, depending on whether the indicator had a positive or negative impact on vulnerability, respectively. Indicators were classified into five categories based on their impact, with a score of 5 indicating the highest vulnerability and a score of 1 representing the lowest.

For water pH, values outside the range of [$>(\mu+2\sigma)$] and [$<(\mu-2\sigma)$] received a score of 5, indicating the greatest vulnerability, while values within the optimal range of [$(\mu+0.5\sigma)$ to $(\mu-1.5\sigma)$] received a score of 1. For EC, BOD, COD, TN, TP, Cl, TDS, and NH_3-N, the following scoring system was employed: values greater than $(\mu+1.5\sigma)$ received a score of 5 (very high vulnerability); values in the range of [$(\mu+1.5\sigma)$ to $(\mu+0.5\sigma)$] received a score of 4 (high vulnerability); values in the range of [$(\mu+0.5\sigma)$ to $(\mu-0.5\sigma)$] received a score of 3 (moderate vulnerability); values in the range of [$(\mu-0.5\sigma)$ to $(\mu-1.5\sigma)$] received a score of 2 (low vulnerability); and values less than $(\mu-1.5\sigma)$ received a score of 1 (very low vulnerability). For DO, the scoring is reversed: lower values indicate higher vulnerability, with values less than $(\mu-1.5\sigma)$ receiving a very high vulnerability score of 5; values in the range of [$(\mu-0.5\sigma)$ to $(\mu-1.5\sigma)$] receiving a high vulnerability score of 4; values in the range of [$(\mu+0.5\sigma)$ to $(\mu-0.5\sigma)$] receiving a moderate vulnerability score of

3; values in the range of [(μ+1.5σ) to (μ+0.5σ)] receiving a low vulnerability score of 2; and values greater than (μ+1.5σ) receiving a very low vulnerability score of 1.

For soil pH, the scoring follows the same pattern as for water pH, where values closer to the optimal range indicated lower vulnerability. However, indicators such as TOC, TN, TP, and total potassium (TK) followed an inverse scoring pattern. It is important to note that indicators with a negative impact received direct scores, while those with positive impacts receive inverse scores, as the goal was to assess vulnerability. Thus, a score of 5 indicates the highest vulnerability, while a score of 1 indicates the lowest vulnerability (Table 7.1).

The scoring system for economic, ecological, and social indicators was thoroughly explained in Chapter 5 and Chapter 6. In this chapter, we integrated edaphic and aquatic indicators from field-based ecological sampling to calculate the final CBAIRVI.

Table 7.1: Scoring method of indicators having positive or negative impacts on CBA-induced vulnerability.

Scale	Direct scoring	Reverse scoring	Scale	Central optimum value
> $\bar{x}$+1.5SD	A = 5	E = 1	< $\bar{x}$- 2 SD	E = 1
($\bar{x}$+0.5 SD) to ($\bar{x}$+1.5SD)	B = 4	D = 2	< $\bar{x}$-1.5 SD to $\bar{x}$- 2 SD	D = 2
($\bar{x}$-0.5SD) to ($\bar{x}$+0.5 SD)	C = 3	C = 3	< $\bar{x}$-1 SD to $\bar{x}$-1.5 SD	C = 3
($\bar{x}$-1.5SD) to ($\bar{x}$-0.5SD)	D = 2	B = 4	< $\bar{x}$-0.5 SD to $\bar{x}$-1 SD	B = 4
< $\bar{x}$-1.5SD	E = 1	A = 5	$\bar{x}$+ 0.5 SD to $\bar{x}$- 0.5 SD	A = 5
			> $\bar{x}$+ 0.5 SD to $\bar{x}$+ 1 SD	B = 4
			> $\bar{x}$+ 1 SD to $\bar{x}$+ 1.5 SD	C = 3
			> $\bar{x}$+ 1.5 SD to $\bar{x}$+ 2 SD	D = 2
			> $\bar{x}$+ 2 SD	E = 1

7.2.3 Multi-criteria decision analysis for indicator grouping

The C&I approach has been widely recognized as a useful method under multi-criteria decision analysis (MCDA), where criteria and indicators/ verifiers are selected based on the specific research purpose (Datta et al., 2010a; Ding et al., 2017). MCDA enables researchers to make informed decisions when faced with numerous alternatives that often possess conflicting attributes (Lotfi and Fallahnejad, 2010; Monghasemi et al., 2015). For example, in this study, C&I were chosen to assess the vulnerability status of aquaculture ponds. Each indicator provided unique information, and the indicators carried different weights based on their impact on vulnerability. Consequently, one of the critical objectives of MCDA is to determine the appropriate weight for each indicator/ verifier (Taheriyoun et al., 2010; Lotfi and Fallahnejad, 2010).

There are various methods for assigning these weights, including both subjective and objective approaches. Subjective methods, such as the weighted least squares method

(Chu, 1979), the Analytic Hierarchy Process (AHP), and the Delphi method (Hwang et al., 2012), heavily rely on the preferences and perceptions of decision makers. In contrast, objective methods, such as multiple objective programming (Choo et al., 1985; Saaty, 1980) and principal component analysis (Fan, 1996), utilize mathematical models to calculate weights without considering the preferences of decision makers, thereby making the process more impartial (Lotfi and Fallahnejad, 2010). One of the most commonly used objective weighting methods is the Shannon's entropy concept, which has been applied in numerous scientific studies (Shannon, 1948; Lotfi and Fallahnejad, 2010). Originally used in information theory, the Shannon's entropy measures general uncertainty. In transportation models, for example, entropy is utilized as a measure of trip dispersal between origin and destination points (Islam & Roy, 2006), and in physics, it quantifies disorder and randomness (Islam & Roy, 2006). It has also been applied to measure fuzziness (Güneralpa et al., 2007).

In the entropy weighting method (EWM), a higher value of entropy for a specific attribute corresponds to a smaller weight assigned to that attribute, indicating that it possesses less discriminatory power in the decision-making system (Lotfi and Fallahnejad, 2010). Consequently, this method has gained widespread acceptance in scientific research for deriving weights objectively for MCDA problems, particularly in scenarios where decision makers find it challenging to identify clear preferences. In this study, the EWM was employed to assign relative weights to the selected indicators (Dehdasht et al., 2020).

In EWM, *m* alternatives (e.g., CBA ponds) and *n* indicators were considered to assess the value of x_{ij}, where x_{ij} represents the standardized score of the jth indicator for the ith CBA pond. The resulting decision matrix of these x_{ij} scores was further normalized using Eq. (7.1) to eliminate anomalies in data dimensions and convert different units and scales into common measurable units, facilitating comparisons between various indicators.

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \qquad \text{(Eq. 7.1)}$$

Where, r_{ij} = the normalized score of jth indicator for ith CBA pond; $i = 1, 2, 3, \ldots\ldots\ldots m;$ $j = 1, 2, 3, \ldots\ldots\ldots n.$ Then, entropy (e_j) for each indicator was computed as follows:

$$e_j = -\frac{1}{\ln(m)} \sum_{i=1}^{m} r_{ij} \ln r_{ij} \qquad \text{(Eq. 7.2)}$$

Where, $\ln r_{ij}$ is defined as 0, if $r_{ij} = 0$. Thereafter, the calculation of the degree of variation (d_j) for each criterion was done as:

$d_j = 1 - e_j$ (Eq. 7.3)

Where d_j measures the degree of variation of vital information for the j[th] indicator. Lastly, the calculation of the final entropy weight for each indicator (w_j) was as follows:

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \quad \text{(Eq. 7.4)}$$

7.2.4 Development of CBAIRVI using the TOPSIS method

The CBAIRVI was developed to assess the vulnerability statuses of CBA farms. The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is a MCDA method originally created by Ching-Lai Hwang and Yoon in 1981, which was later refined by Yoon in 1987 and Hwang et al.in 1993. TOPSIS is based on the idea that the best alternative should have the "shortest geometric distance from the positive-ideal solution (PIS) and longest geometric distance from the negative-ideal solution (NIS)" (Aslam, 2021). This method enables researchers compare alternatives by considering the weights of each indicator, their normalized scores, and the geometric distances between the alternatives for each criterion. In TOPSIS, data normalization is essential to convert the criteria measured in different units into a common unit for comparison (Dakos et al. 2015).

For the construction of CBAIRVI using TOPSIS, first an evaluation matrix (X) was prepared which can be defined as: $X = (x_{ij})_{m \times n} = \begin{bmatrix} x_{11}, & x_{12}, & x_{1n} \\ x_{21}, & x_{22}, & x_{2n} \\ x_{m1} & x_{m2} & x_{mn} \end{bmatrix}$ (Eq. 7.5)

Where, m represents the total number of CBA ponds within the complex (P). $P = \{P_i | i = 1, 2, \ldots., m\}$; n represents a total number of evaluation indicators under a criterion (C). $C = \{C_j | j = 1, 2, \ldots., n\}$. The normalization of the evaluation matrix and calculation of the normalized score (r_{ij}) was performed using the following equation:

Normalized matrix, $R = (r_{ij})_{m \times n} = \begin{bmatrix} r_{11}, & r_{12}, & r_{1n} \\ r_{21}, & r_{22}, & r_{2n} \\ r_{m1} & r_{m2} & r_{mn} \end{bmatrix}$ (Eq. 7.6)

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad \text{(Eq. 7.7)}$$

Thereafter, the final normalized weighted score (WS_{ij}) of an indicator was calculated as:

$WS_{ij} = r_{ij} \times w_j$ (Eq. 7.8)

Where, W_j = final entropy weight for each indicator obtained through Shannon's EWM. $W = \{W_j | j = 1, 2, \ldots., n\}$; $W_j > 0$ *and* $\sum_{j=1}^{n} W_j = 1$.

The determination of the best alternative (A_b) and the worst alternative (A_w) for each CBA pond (i[th]) was then assessed based on the impact of each indicator (positive or negative) interplayed upon the cumulative characteristics of the CBA ponds. In this case,

$A_b =$

$\{\langle \min (r_{ij}| \; i = 1,2,3, \ldots\ldots, m \mid j \in J_-\rangle, \langle \max(r_{ij}|i = 1,2,3, \ldots.., m|j \; \in J_+\rangle\} \equiv$

$\{r_{bj}|j = 1,2,3, \ldots.., n\}$ (Eq. 7.9)

$A_w =$

$\{\langle \max (r_{ij}| \; i = 1,2,3, \ldots\ldots, m \mid j \in J_-\rangle, \langle \min(r_{ij}|i = 1,2,3, \ldots.., m|j \; \in J_+\rangle\} \equiv$

$\{r_{wj}|j = 1,2,3, \ldots, n\}$ (Eq. 7.10)

where, $J_+ = \{j = 1,2,3, \ldots\ldots, n|j\}$ indicates indicator having a positive impact, and $J_- = \{j = 1,2,3, \ldots\ldots, n|j\}$ having a negative impact on overall vulnerability.

The Euclidean distance (Ed_b^+ *and* Ed_w^- respectively) of the *i[th]* target alternative from the best and worst alternatives is measured as follows:

$$Ed_b^+ = \left[\sum_{j=1}^{m}\left(V_{ij} - V_j^+\right)^2\right]^{0.5} \quad \text{(Eq. 7.11)}$$

$$Ed_w^- = \left[\sum_{j=1}^{m}\left(V_{ij} - V_j^-\right)^2\right]^{0.5} \quad \text{(Eq. 7.12)}$$

where, Ed_b^+ *and* Ed_w^- are two distances from the target alternative *i* to the PIS and NIS respectively.

The CBAIRVI of each CBA pond under each criterion is then computed:

$$CBAIRVI_i = \frac{Ed_w^-}{(Ed_w^- + Ed_b^+)} \quad \text{(Eq. 7.13)}$$

Where, $0 \leq Ed_{iw} \leq 1; i = 1,2,3, \ldots\ldots, m$; $CBAIRVI_i \leq 1$, only if the alternative has the most vulnerable condition, and $CBAIRVI_i \geq 0$, only if the alternative has the least vulnerable condition. Lastly, all CBA ponds were ranked in ascending order based on these $CBAIRVI_i$ values for each criterion (Gayen & Datta, 2023).

7.3 Results

7.3.1 Spatial vulnerability zonation pattern

For the purpose of assessing the vulnerability status of the CBA ponds selected from the study region, a comprehensive C&I framework was constructed. The C&I framework contained 5 criteria and 34 indicators. The 5 criteria taken into consideration in this study were edaphic condition, aquatic condition, perceptual economic vulnerability, perceptual ecological vulnerability, and perceptual social impact. Under the edaphic condition criteria, there were 6 indicators; under aquatic condition criteria, there were 10 indicators; under perceptual economic vulnerability, there were 7 indicators; under ecological vulnerability, there were 7 indicators; and under perceptual social impact, there were 4 indicators. For all these indicators, relative weights were calculated using the EWM method and were assigned accordingly (Table 7.2). Besides, the nature of relationships of the individual indicators in relation to the overall vulnerability of the CBA ponds. i.e., positive relationship and negative relationship were also assigned. It is noteworthy to mention here that, these relationships were specifically valid for the CBA ponds of the study region and may change in other CBA regions of the world.

Table 7.2: Set of C&I and indicator weights for assessment of comprehensive CBA vulnerability.

Evaluation criterion	Indicator	Relation with CBA vulnerability	Indicator weight
Edaphic condition	pH	-	0.007
	EC	+	0.004
	Total organic carbon (TOC)	-	0.003
	Total Nitrogen (TN)	-	0.002
	Total phosphorus (TP)	-	0.002
	Total potassium (TK)	-	0.004
Aquatic condition	pH	-	0.008
	EC	+	0.006
	Biochemical oxygen demand (BOD)	+	0.003
	Dissolved oxygen	-	0.004
	Chemical oxygen demand (COD)	+	0.003
	Total Nitrogen (TN)	+	0.004
	Total phosphorus (TP)	+	0.001
	Chloride (Cl)	+	0.003
	Total dissolved solids	+	0.830
	NH3-N	+	0.004
Economic vulnerability	Number of CBA ponds	-	0.003
	Aquaculture pond ownership type	-	0.005
	Source of investment	-	0.005
	Effect of market price fluctuation	+	0.006
	Crop failure	+	0.006
	Profit/ loss status	-	0.003
	Deviation of normal profit level	-	0.001
Ecological Vulnerability	Fuel consumption	+	0.013
	Use of organic fertilizers and insecticides	-	0.018
	Number of medicines used	+	0.011
	Water treatment before discharge of water	-	0.002
	Level of awareness regarding environmental impacts of CBA	-	0.007
	Environmental problems	+	0.003
	Land use conversion	+	0.004
Social impact	Social problems	+	0.006
	Payment of compensation	-	0.012
	Level of social conflict	+	0.006
	Gender equity	+	0.002

Following the TOPSIS method, performance score (Pi) for all the CBA ponds (27 ponds) were calculated and were ranked according to the performance score (Pi).

Thereafter, on the basis of the level of Pi score, they were divided into three equal divisions i.e. high (≤ 0.372), medium (0.373 – 0.683), and low (≥ 0.684). This has revealed that, CBA pond with highest vulnerability was found in Sapua and vulnerability was lowest in Belmani. Other than Sapua, level of vulnerability of CMA pond were also high in Uttar Kanaidighi (0.969), Thakurchak (0.969), Baguran Jalpai (0.966), Raniya (0.966), Sonamuhi (0.965), Tajpur (0.961), Uttar Amtalya (0.958), Mandarmani (0.957), Saula (0.956), and Bankiput (0.955). CBA ponds with moderate vulnerability were found in Badalpur (0.667), Dakshin Shilampur (0.666), Shikharbar (0.666), Chandibeti (0.666), Aldarput (0.666), Krishna Khayratibar (0.665), Beltaliya (0.665), Chata Padmapukur (0.665), and Baliya (0.665). However, CBA ponds with low level of vulnerability were found in Poddarchak (0.335), Benipur (0.335), Mahishamunda (0.045), Lachhanpur (0.044), Ahmedpur (0.043), Mandar (0.042), and Belmani (0.041) (Table 7.3).

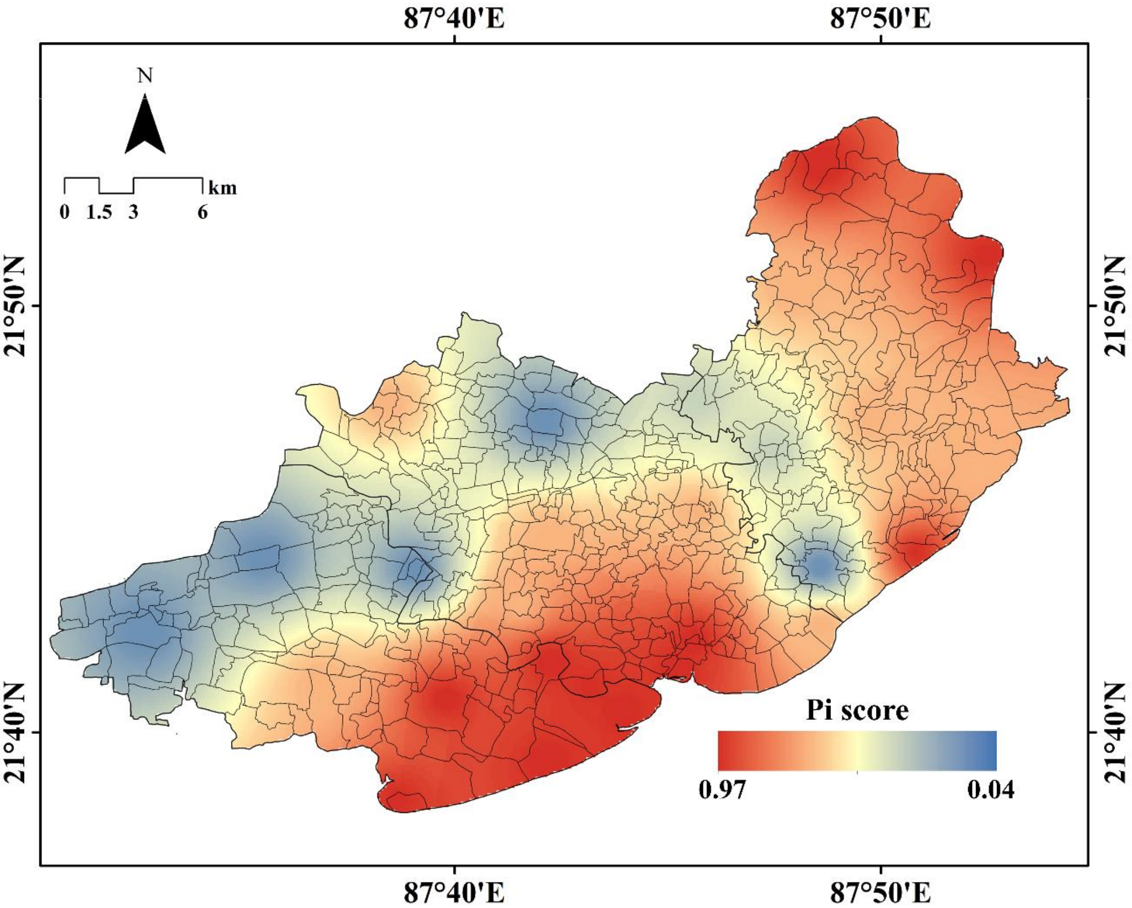
Table 7.3: Status of the comprehensive CBA induced regional vulnerability.

Location code	Location	Pi	Rank	Vulnerability class
RNHD1	Mandarmani	0.957	9	High
RNHD2	Sonamuhi	0.965	6	High
RNHD3	Tajpur	0.961	7	High
RNMD1	Sapua	0.974	1	High
RNMD2	Raniya	0.966	5	High
RNMD3	Shikharbar	0.666	14	Medium
RNLD1	Belmani	0.041	27	Low
RNLD2	Ahmedpur	0.043	25	Low
RNLD3	Mandar	0.042	26	Low
COHD1	Shoula	0.956	10	High
COHD2	Thakurchak	0.969	3	High
COHD3	Boguran Jalpai	0.966	4	High
COMD1	Krishna Khayratibar	0.665	17	Medium
COMD2	Beltaliya	0.665	18	Medium
COMD3	Chata Padmapukur	0.665	19	Medium
COLD1	Lachhanpur	0.044	24	Low
COLD2	Dakshin Shilampur	0.666	13	Medium
COLD3	Badalpur	0.667	12	Medium
DPHD1	Bankiput	0.955	11	High
DPHD2	Uttar Amtalia	0.958	8	High
DPHD3	Uttar Kanaidighi	0.969	2	High
DPMD1	Chandibeti	0.666	15	Medium
DPMD2	Baliya	0.665	20	Medium
DPMD3	Aladarput	0.666	16	Medium
DPLD1	Mahishamunda	0.045	23	Low
DPLD2	Poddarchak	0.335	21	Low
DPLD3	Benipur	0.335	22	Low

A spatial distribution model of CBA induced regional vulnerability was prepared on the basis of Pi scores which showed that the CBA ponds located near the coastal areas and along the tidal rivers were high. The map revealed that, CBA pond with highest vulnerability was found in Sapua followed by Uttar Kanaidighi, Thakurchak, Baguran

Jalpai, Raniya, Sonamuhi, Tajpur, Uttar Amtalia, Mandarmani, Saula, and Bankiput. CBA ponds with moderate vulnerability were found in the areas located away from the coast and tidal rivers which included Badalpur, Dakshin Shilampur, Shikharbar, Chandibeti, Aldarput, Krishna Khayratibar, Beltaliya, Chata Padmapukur, and Baliya. However, CBA ponds with low level of vulnerability were found in more inland parts which included Poddarchak, Benipur, Mahishamunda, Lachhanpur, Ahmedpur, Mandar, and Belmani (Fig. 7.1).

Figure 7.1: Spatial distribution of CBA induced regional vulnerability (CBAIRVI) scores in the study region.



7.4 Discussion

Evaluation of CBA-induced regional vulnerability was a challenging task especially because CBAIRVI values depended on the performance scores of the selected indicators with various dimensions. To assess the comprehensive regional vulnerability, the study took into account ecological field sampling based edaphic and aquatic indicators as well as perception based ecological, economic, and social indicators relevant to the CBA vulnerability of the region. As a result, various types of scoring methods had to be applied for the ecological field-based indicators and perception-based indicators. Naturally, the weight of all the indicators with respect to the overall vulnerability was not equal. To avoid the bias of assigning the relative weight for different indicators, an objective-based mathematical model. i.e., the entropy weighting method (EWM) was adopted (Lotfi and Fallahnejad, 2010; Dehdasht et al. 2020). It is noteworthy to mention here that the high variation in the vulnerability level of the CBA ponds were due to the high localized impact like variation of use of farm technologies, farm management practices, level of technological knowhow of the pond owners, their awareness and knowledge level etc.

Regarding the comprehensive vulnerability of the CBA ponds, it was found that Sapua had scored highest vulnerability followed by Uttar Kanaidighi, Thakurchak, Baguran Jalpai, Raniya, Sonamuhi, Tajpur, Uttar Amtalia, Mandarmani, Saula, and Bankiput. CBA ponds with moderate vulnerability were found in the areas located relatively away from the coast and tidal rivers which included Badalpur, Dakshin Shilampur, Shikharbar, Chandibeti, Aldarput, Krishna Khayratibar, Beltaliya, Chata Padmapukur, and Baliya. However, CBA ponds with low level of vulnerability were found in more inland parts which included Poddarchak, Benipur, Mahishamunda, Lachhanpur, Ahmedpur, Mandar, and Belmani. The indicator level assessment can unveil the actual reasons behind the scenario. It was found that the mean value of EC in the CBA ponds were 7385.93 ± 3868.28 µmhos cm^{-1} while the prescribed limit for *L. Vannamei* culture is 1057–1312 µS cm^{-1} (Chaikaew, 2019; Mariscal-Lagarda, 2010). EC value as high as 11650 µmhos cm^{-1} was found in Mandarmani located in close proximity to the coast and having high density of brackishwater aquaculture. EC more than 10,000 µmhos cm^{-1} was also found in the areas with high concentration of brackishwater aquaculture which includes Shoula, Thakurchak, Boguran Jalpai, and Chata Padmapukur in Contai I C.D. Block, and Uttar Kanaidighi, Uttar Amtalia, Bankiput, and Aladarput in Deshapran Block.The reason might be the direct intake of saline water from the ocean and the tidal river. EC decreased along the northwestern part of Ramnagar-II and the northeastern sections of Contai–I depicting values as low as 338 µmhos cm^{-1} at Lachhanpur. These regions were far away from the sea and these areas were devoid of tidal rivers. As a result, the salinity level was low.

According to the Central Pollution Control Board, India, the prescribed pH level for the 'D' category of water (i.e. Propagation of wild-life and fisheries), is 6.5 (CPCB, 2019). According to CIBA (2016) the pH level for *L. vannamei* must range between 7.5-8.5. However, the study site has recorded water pH between 7.37 and 9.7 with a mean value of 8.08 ± 0.68 indicating moderate alkalinity. This is because of application of lime during the pond preparation. Highest pH value was found in Mandarmani, followed by Sonamuhi, Tajpur, Sapua, Raniya, Shikharbar, located at the southern section of Ramnagar-II C.D. Block. In Contai-I C.D. Block Shoula, Thakurckak, and Boguran Jalpai recorded high pH values. Uttar Amtaliya and Uttar Kanaidighi located in the Deshapran C.D. Block also had high pH value. Whereas the pH level of some CBA ponds was lower as the pond owners used less amount of lime during the pond preparation. These ponds mainly located in the area where the CBA ponds flourished recently and have low density of ponds. Ahmedpur, Belmani, Mandar in Ramnagar II, Lachhanpur, Dakshin Shilampur, Badalpur in Contai I, and Mahishamunda, Poddarchak, and Benipur of Deshapran Block are some of them.

Regarding BOD level, the prescribed limit for aquaculture pond is 10 mg L^{-1} (Global Seafood Alliance, 2024). Highest BOD value was found in Baguran Jalpai (22 mg L^{-1}) followed by Thakurchak (15 mg L^{-1}). BOD of the aquaculture ponds was also high in Mandarmani, Sonamuhi, Tajpur, Sapua, Shoula and Raniya. A high amount of BOD represents level of microbes present in the water that consumes dissolved oxygen and makes the water polluted (Green & Ward, 2011). The high level of BOD might be due to the over use of feed additives due to faulty farm management practice. It was also found that BOD level was high in the ponds practicing very intensive shrimp culture. However, low BOD concentration was found in in the areas practicing less intensive culture such as in Ahmedpur, Belmani, Mandar in Ramnagar II, Lachhanpur, Dakshin Shilampur, Badalpur in Contai I, and Mahishamunda, Poddarchak, and Benipur of Deshapran Block. According to Central Pollution Control Board, India, the prescribed DO level for the 'D' category of water (i.e. Propagation of wild-life and fisheries), is 4 mg L^{-1} or more (CPCB, 2019). For *L. vannamei* culture, the prescribed DO level is should be more than 4 mg L^{-1}. A low amount of DO might be due to overstocking and excessive feeding rates. Besides high temperature can also reduce the DO level (CIBA, 2016; Skretting, 2024). It was surprisingly found that though the BOD level was high in most of the CBA ponds, DO level was also high in those ponds except for a few ponds. This is because of the fact that the CBA farmers use artificial aeration system to maintain the DO level to keep the shrimps to survive. However, BOD level was very high in Baguran Jaipai (22 mg L^{-1}) and DO level was very low (3.3 L^{-1}). This was completely due to a localized factor which includes lack of proper farm management. In Boguran Jalpai, the shrimp farmers used to practice very high intensity of farming with very high stocking density, where 90,000 to 1,00,000 post-larvae shrimps were released. As a result, more feed and fertilizers were also added in the growing period. The feed residues due to over use of feed additives and fertilizers might made the ponds overloaded with organic pollutants increasing the BOD level and decreasing the DO level. DO level was also low (3.86 L^{-1}) in Uttar Kanaidighi due to the same localized factors.

The standard maximum COD level for estuaries is 75 L^{-1} as prescribed by the Coastal Aquaculture Authority of India (Coastal Aquaculture Authority, 2024). COD level for For *L. Vannamei* culture, COD should not exceed 70 mg L^{-1} (MPEDA, 2003). High amount of COD was found in Thakurchak (115 mg L^{-1}), followed by Baguran Jalpai (69 mg L^{-1}). High amount of COD indicates high organic load in pond water, the normal range of which varies within 40 to 80 L^{-1}. COD in the shrimp ponds increases due to over application of fertilizers and food (Giao, 2021). The high concentration of COD in the shrimp ponds might also be due to the application of chlorides (Kahar, 2024).

According to Central Pollution Control Board, India, the prescribed free ammonia (NH_3) for the 'D' category of water (i.e. Propagation of wild-life and fisheries), is 1.2 mg L^{-1} or less (CPCB, 2019). For *L. vannamei* culture, the free ammonia (NH_3-N) should not be more than 0.01 mg L^{-1}. Higher amount of NH_3-N occurs due to high decomposition of organic material in the pond water which is harmful (MPEDA, 2003; Skretting, 2024). It was found that the NH_3-N was highest (0.29 mg L^{-1}) in Baguran Jalpai. It was also high in Uttar Amtalia (0.19 mg L^{-1}), Mandarmani (0.18 mg L^{-1}), Tajpur (0.13 mg L^{-1}), Uttar Kanaigighi (0.12 mg L^{-1}), and Thakurchak (0.11 mg L^{-1}). This might have happened due to over application of shrimp food and accumulation of food residues. For *L. vannamei* culture, it is prescribed that the TN should not be more than 2 mg L^{-1}. Higher TN denotes high residual of organic mineral in the pond water which is detrimental for shrimp health. High amount of TN might also be due to high temperature and high pH, and excessive feeding (MPEDA, 2003; CIBA, 2016; Skretting, 2024). TN was found to be high in most of the CBA ponds that were taken into consideration. TN was highest in Shoula (7.42 mg L^{-1}), followed by Sonamuhi (5.76 mg L^{-1}), Thakurchak (5.50 mg L^{-1}), Baguran Jalpai (5.29 mg L^{-1}), Bankiput (5.25 mg L^{-1}), and Mandarmani (4.88 mg L^{-1}). It was more than 3.00 mg L^{-1} in Tajpur, Sapua, Raniya, Beltaliya, Uttar Kanaidighi, and Uttar Amtalia. This might be again due to the excessive feeding and over use of fertilizers which denotes lack of farm management practices.

For brackishwater aquaculture, the maximum TP limit is ≤ 0.4 mg L^{-1}. Over use of fertilizers during the growing period of shrimp might be the cause of high TP. For high growth of shrimp, especially in the over intensive shrimp culture the farm owners add supplementary superphosphate (20% P) fertilizer into the pond twice a month. As a result, nutrient accumulation in the ponds increase. It is noteworthy to mention that, over application of fertilizers is a major concern of intensive brackishwater shrimp farming (PCD, 2004). In the study region, very high concentration of TP was found in Mandarmani (26.90 mg L^{-1}) and Tajpur (17.40 mg L^{-1}). It was also high in Sonamuhi (4.40 mg L^{-1}), Raniya (4.06 mg L^{-1}). Over use of superphosphate for quick growth of the shrimp might be the reason behind this. According to CPCB guideline of water quality monitoring (2007), the 'D' Category water must have chloride level less than 1000 mg L^{-1} (Moore, 1991; CPCB, 2007). The high level of chloride in the CBA ponds might be due to overuse of Cl^- (Suguna, 2020). Cl_2, $MgCl_2$, NaCl, and KCl are also used as mineral supplement for quick growth and survival of shrimp (Estrada-Mata, 2022). In most of the CBA ponds under the present study, especially in the areas practicing highly intensive culture, such as Mandarmani, Sonamuhi, Tajpur, Shoula, Thakurchak, Baguran Jalpai, Uttar Kanaigighi, and Uttar Amtalia, it was found that the level of $Cl^-$was high. it was found during the study that to reduce the running mortality, the shrimp farm owners used high amount of mineral supplement such as NaCl, KCL, and $MgCl_2$. According to Global Seafood Alliance (2024), for *L. vannamei* culture the TDS must range between 528-650 mg L^{-1}. However, in the present study, it was found that in most of the CBA ponds the TDS level was very high. Very high TDS level was found in the areas practicing intensive farming with excessively high stocking density which included Mandarmani, Sonamuhi, Tajpur, Sapua, and Raniya in Ramnagar II Block, Shoula, Thakurchak, and Boguran Jalpai in Contai-I Block, and in Uttar Kanaidighi, Uttar Amtalia, and Bankiput in Deshapran Block. Thus, the aquatic indicators enabled to understand the water quality standard of the CBA ponds which is essential to maintain the ecological health of the ponds. However, it was found that many of the CBA ponds had low water quality which was detrimental for the shrimps to survive and thus the vulnerability level was high. it is noteworthy to mention here that the distribution pattern of all the water quality indicators were not uniform. This is because of the presence of various localized factors like high stocking density, high running mortality rate, lack of knowledge about the optimal uses of food, fertilizers, and various minerals, and lack of farm management system. Moreover, it was found that in most of the ponds, the pollutant load was very high. For many ponds, this pollutant loaded effluent water gets discharged from the CBA ponds to the sea or tidal rivers directly without any treatment. This might have numerous detrimental effects on the coastal and estuarine ecosystem.

These CBA ponds also have their impact on the adjacent croplands. Especially, leaching of water from the aquaculture ponds to the agricultural fields increases the soil pH and salinity which impairs the crop productivity impacting the regional vulnerability (Ojha & Chakraborty, 2018; Mondal et al., 2023). In the present study, it was found that the pH and salinity level of the agricultural fields adjacent to the aquaculture ponds were high in the areas where the CBA ponds also had high pH value and high EC level. In other words, the distribution pattern of pH and EC of the CBA ponds and the soil was almost analogous. This denotes that, the CBA ponds have their direct impact on the soil quality of the adjacent agricultural areas. Although in the study region, the soil pH is normally moderately acidic to slightly acidic (Chesworth, 2008; Sahu, 2014; Oshunsanya, 2018), it was found that soil pH was high in Mandarmani, Sonamuhi, Tajpur, Sapua, Raniya, Shikharbar, located at the southern section of Ramnagar-II C.D. Block. In Contai-I C.D. Block Shoula, Thakurckak, and Boguran Jalpai recorded high pH values. Uttar Amtaliya, Bankiput and Uttar Kanaidighi located in the Deshapran C.D. Block also had high pH value. pH value of these areas was higher than the pH level suitable for rice cultivation (FAO, 2021). Leaching of alkaline water from the adjacent CBA ponds was the reason behind the high soil pH level in these areas. Similarly, soil EC was high in Mandarmani, Sonamuhi, Tajpur in Ramnagar-II Block, in Shoula, Thakurchak, and Boguran Jalpai in Contai-I C.D. Block, and Uttar Kanaidighi, Uttar Amtalia, Bankiput, and Aladarput in Deshapran C.D. Block. The EC level of the CBA pond in these areas was also very high. Thus, it is clear that the pH and EC level of the soil got directly impacted from the adjacent CBA ponds.

High soil pH usually leads to a lack of soil nutrients such as low OC, N, P, and K and deters crop growth (Sirsat, 2017; Ojha & Chakraborty, 2018; Maiti et al., 2021; Mandal et al., 2021). TOC and N of soil are inversely correlated with the soil pH (Zhou, 2019). It was also found in the present study region. For instance, TOC was low in Mandarmani, Sonamuhi, Tajpur, and Raniya located at the southern section of Ramnagar-II C.D. Block. In Contai-I C.D. Block; Shoula, Thakurckak, Krishna Khayratibar, Beltaliya, Chata Padmapukur, and Boguran Jalpai recorded low TOC values. Uttar Kanaidighi, Uttar Amtaliya, Bankiput and Uttar Kanaidighi located in the Deshapran Block also recorded low TOC level. In these areas pH values were higher. Conversely, in Mahishamunda and Lachhanpur TOC values were higher and the soil pH level was relatively lower. Almost same pattern was found for the case of soil TN, i.e., areas with high soil pH had low soil N. an exceptionally high amount of soil TN was found in Lachhanpur, which might be the localized factor of over use of nitrogen rich fertilizer. Almost similar pattern was observed for the case of soil TP. It was found that soil TP was very low in Sonamuhi, Thakurckak, Boguran Jalpai, Krishna Khayratibar, Beltaliya, Chata Padmapukur, Uttar Amtaliya, and Aldarput. In these areas soil pH was also relatively high. The TK level was found to be generally high throughout the area. However, TK content in the soil was relatively low in the areas having high soil pH. Thus, it can be stated that due to the leaching of alkaline water from the CBA ponds, the pH level of the soil of adjacent agricultural areas also increased. Moreover, due to high pH level, the soil nutrient level decreased.

The study also used various perception-based indicators, including ecological, economic, and social factors, for a comprehensive vulnerability assessment. The perception-based ecological indicators showed that energy consumption was highest in Manarmani, Bankiput (< 800 L), followed by Tajpur and Shoula (600–700 L). Consumption levels were also elevated in Thakurchak, Uttar Amtalia, Uttar Kanaidighi, Baliya, and Aladarput. This is because intensive shrimp farming requires constant operation of diesel-powered aeration systems. In areas with high-intensity shrimp farming, the use of chemical fertilizers to promote rapid shrimp growth was high, as was the use of medicines to combat diseases. Despite these ponds becoming pollutant-laden due to fertilizers, feed additives, and medicines, very few owners treated the water before releasing it into natural bodies. It was surprising to find that in regions where shrimp farming has recently expanded, pond owners displayed a low awareness of the environmental risks associated with intensive commercial shrimp farming. Numerous environmental threats, including mangrove destruction and biodiversity loss, were reported in coastal areas like Mandarmani, Sonamuhi, Tajpur, Dhoula, Thakurchak, Baguran Jalpai, Bankiput, Uttar Amtalia, and Uttar Kanaidighi, with saltwater intrusion and obstruction to natural water flow common across all sites. The perception study also revealed the conversion of mangroves, wetlands, and fallow lands into shrimp farms in coastal areas, while cropland and other vegetation were converted in inland areas.

Economic indicators highlighted several dimensions of vulnerability assessed through the perception-based study. The study revealed that farm owners with ≥2 or ≤25 ponds were particularly vulnerable, as smaller farmers are often left without capital when facing crop loss due to disease and fall into debt. For large-scale farmers managing multiple ponds, viral diseases quickly spread across ponds, leading to substantial crop loss with limited time to respond, as seen in Sonamuhi, Raniya, Belmani, Ahmedpur, Mandar, Shoula, Beltaliya, Lachhanpur, Dakshin Shilampur, Bankiput, Chendibeti, and Aladarput. Ownership type also influenced economic vulnerability; farm owners renting ponds were more vulnerable because they had to pay rent regardless of profits. This pattern was evident in Mandarmani, Sonamuli, Tajpur, Sapua, Shoula, Baguran Jalpai, Beltaliya, Lachhanpur, Dakshin Shilampur, Bankiput, Uttar Kanaidighi, Chandibeti, Baliya, Aladarput, Mahoshamunda, and Benipur, where most owners rented ponds. Many farm owners borrowed money from fish feed and medicine suppliers, creating a cycle of debt. Market fluctuations, primarily due to international market volatility, pose a risk to shrimp farm owners. The perception study showed that, except for a few owners in Tajpur, Shoula, Thakurchak, Krishna Khayratibar, and Uttar Kanaidighi, most owners experienced economic loss due to low demand in 2020–2021. High production, combined with low demand and prices, led to economic setbacks, further exacerbated by disease outbreaks and natural disasters, including cyclones and coastal floods from 2000 to 2023. These issues contributed to significant economic losses in areas like Bankiput, Aladarput, Sonamuhi, Tajpur, Sapua, Raniya, Beltaliya, Chata Padmapukur, Lachhanpur, Badalpur, Uttar Amtalia, Chandibetti, and Benipur, where most farm owners deviated from normal profit levels.

The introduction of CBA in the region led to numerous social issues, including reduced paddy production, rapid conversion of cropland to shrimp farms, forced land sales, rising landless labour, social stratification, unequal political influence, loss of grazing lands, increased migration, and erosion of traditional livelihoods. The perception-based study found these issues most severe in Thakurchak, Beltaliya, Uttar Kanaidighi, and Aladarput, followed by Sonamuhi, Tajpur, Raniya, Baguran Jalpai, Krishna Khayratibar, Lachhanpur, and Baliya. Notably, since this study was based on the perceptions of local people and shrimp farm owners, some areas may have additional issues not reported by respondents due to varying awareness levels. It was also found that shrimp farms occasionally compensated adjacent rice farmers for saline water damage to crops; however, this practice was not prevalent in many areas, including Mandarmani, Sonamuhi, Sapua, Shikharbar, Belmani, Mandar, Shoula, Thakurchak, Krishna Khayratibar, Beltaliya, Chata Padmapukur, Bankipput, Uttar Amtalia, Uttar Kanaidighi, Chandibeti, Baliya, and Benipur. Many residents reported that shrimp farm owners, through political influence, often avoided compensating rice farmers, creating social resentment, particularly among rice producers, and sparking conflict between paddy growers and shrimp farm owners. While there was substantial discontent, conflicts remained largely non-violent due to the political power of shrimp farm owners, who could suppress opposition. Additionally, residents feared losing social benefits from local government if they opposed it. Organized resistance emerged only in Aladarput and, sporadically, in areas like Tajpur, Sapua, Beltaliya, and Badalpur, with support from opposing political groups, though most protests were ultimately subdued.

Gender equity was also assessed as a vulnerability indicator. Many gender-related issues were reported by residents and shrimp farm workers, such as social abuse, loss of economic opportunities for women, exclusion from business decisions, lack of training opportunities, and reduced social status. Women had limited employment options in shrimp farms, which were male-dominated. Consequently, the conversion of rice fields to shrimp farms significantly impacted women's livelihoods, especially those previously employed as agricultural labourers, reducing their social standing. This impact was consistent across the study area.

7.5 Major Findings

The CBAIRVI was derived using 5 criteria and 34 indicators, revealing that vulnerability levels were unevenly distributed across the region. Most indicators were human-induced, varying based on localized factors such as farm technology, management practices, and awareness among pond owners. Poor farm management resulted in polluted water being discharged directly into natural water bodies, including rivers and the ocean, potentially harming coastal biodiversity. Additionally, saltwater intrusion from brackishwater shrimp farms increased soil salinity, negatively affecting adjacent cropland productivity. Unscientific farm practices led to multiple disease outbreaks, as farms often used the same polluted water sources. These practices, combined with market volatility and natural disasters, contributed to frequent economic losses among shrimp farm owners. Due to low international demand, especially after the COVID-19 pandemic, low prices, and frequent cyclones; the shrimp farming system in the region struggled substantially. Additionally, the spread of CBA triggered social issues, creating resentment among local residents, especially paddy farmers. However, protests were generally non-violent owing to the awe to the political clout of shrimp farm owners.

Chapter VIII:

Conclusions and management guidelines

8.1 CBA: an epilogue

CBA has rapidly spread across many coastal states of India in general and in the coastal C.D. Blocks of Purba Medinipur in particular since 1980s. As a result, wide tracts of lands along the coastal plain having higher soil salinity and low productivity of rice were rapidly converted to commercial brackishwater aquaculture farms, causing considerable land use transformation. Although the growth of brackishwater aquaculture generated considerable livelihood opportunities and foreign revenue, it also triggered a number of environmental as well as social problems. Major landscape transformation had taken place in the coastal areas of Purba Medinipur district owing to the brisk growth of CBA. In the study region, the proportion of land under CBA had grown at an exponential rate between 1991 and 2021 at the cost of croplands, coastal mangroves, other vegetation, waterbodies, and fallow lands. However, the unplanned expansion and unscientific farming practices introduced notable environmental threats to the surrounding areas, raising concerns about the sustainability of brackishwater aquaculture in the region. A notable increase in soil salinity and soil pH in the areas encompassing the CBA ponds had a debilitating impact on rice productivity. It was found that, in most of the farms, due to proper farm management practices the water would get polluted and this water, in most of the cases, was directly discharged to the natural waterbodies including tidal rivers and ocean, which in turn might have jeopardized the biodiversity of the pristine coastal environment. The unscientific farm practices also caused multiple disease infestations as the farms used the same polluted water from the common source. This along with the market fluctuation and devastation by the natural calamities has caused recurrent economic losses among the shrimp farm owners. As a cumulative result of a lack of demand in the international market, very low prices, especially after the COVID-19 pandemic, recurrent occurrence of massive cyclones, the entire system of shrimp production in the study area has been floundering. Along with this, the introduction of CBA in the area has triggered a number of social problems which has triggered social conflicts.

8.2 Proposed guidelines for policy level interventions

Based on the three objectives discussed in the previous Chapters which included identification of the spatio-temporal patterns of growth of CBA, assessment of the effects of its growth on the coastal environment, and evaluation of its socio-political consequences in the study region, the researcher made the comprehensive observation of the impact of growth of CBA at landscape level, socio-economic scenarios, and political ramifications. These observations enabled the researcher to formulate a set of implementable guidelines for policy-level interventions towards the sustainable management of the coastal agroecosystems (Fig. 8.1).

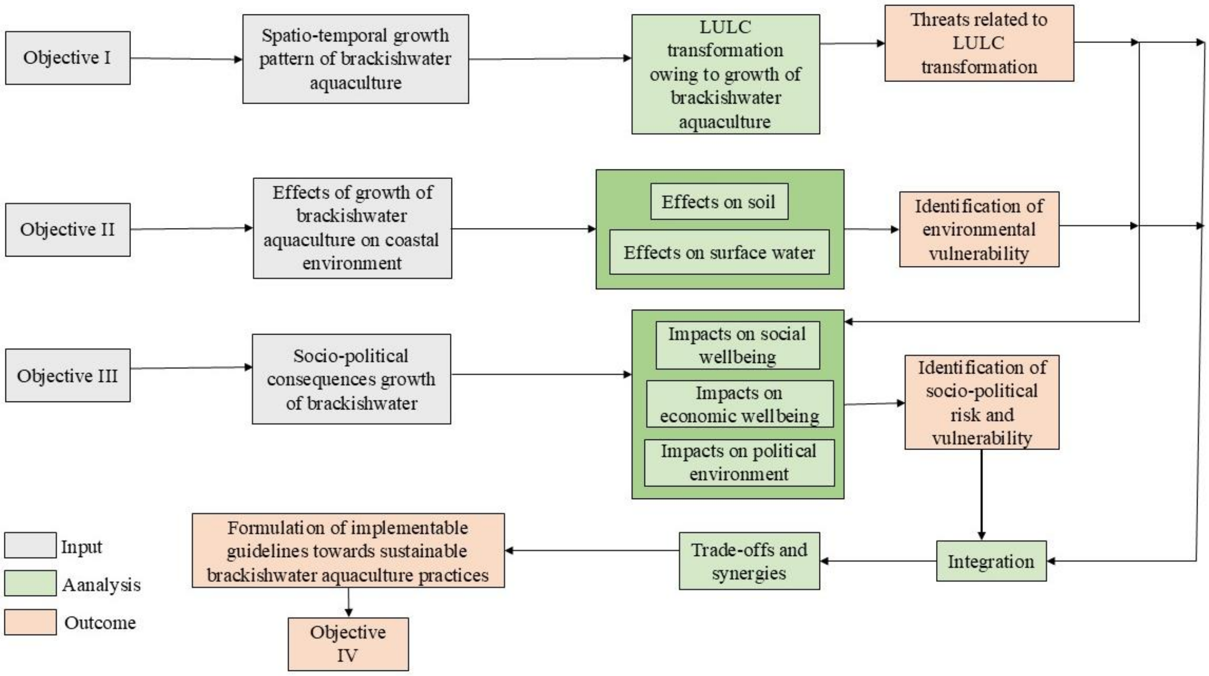


Figure 8.1: Methodological framework to formulate implementable guidelines towards sustainable management of the coastal agroecosystems in the Medinipur Coastal Plain.

8.2.1 National level guidelines

A. Recommended practices:

i. Periodical coastal surveillance and monitoring should be introduced for combating negative effects of changing LULCs and habitat loss through geospatial technologies and provide updated guidelines to line departments of the State for implementation of sustainable CBA.

ii. Each socio-ecological production landscape in the Integrated Coastal Zone Management (ICZM) should be connected through climate-information-networking and an early alert system for disaster preparedness.

iii. Emission assessment and remediation systems should be brought to practice in CBA through regular and intermittent surveys and assessments.

B. Recommended policy guidelines:

i. It is essential to engage national institutes of excellence like CIBA (Central Institute of Brackishwater Aquaculture), CIFRI (CIFRI), CSIR-NIO (Council of Scientific & Industrial Research- National Institute of Oceanography) and as well universities with specialized departments for developing sustainable CBA action-plans and protocols.
ii. It is crucial to develop a national framework for decarbonization of CBA through adaptive mitigation and statutory carbon credit plans benefiting marginal fishers and farmers.
iii. A plan must be framed for incentivized regulatory mechanisms for coastal conservation through state machineries to promote 'Restorative Aquafarming'.

8.2.2 Regional level guidelines

A. Recommended practices:

i. Issuance of 'Green Licensing' for eco-friendly CBA practices should be adopted as a mandatory formality, as well enabling Climate-Information-Networking (CIN) for climate risk aversion and real-time contingency planning.
ii. It is necessary to propound fiscal schemes to support sustainable CBA through soft-loans, subsidies, allowances etc. Risk coverage schemes should be introduced for compensation of damage and loss through group insurance schemes.
iii. Supervision, monitoring, training, and extension education boot-camps are to be regularly organized for promoting sustainable CBA for all stakeholders.

B. Recommended policy guidelines:

i. Development of innovative financing models is needed to encourage sustainable CBA and engage financial institutions (Banks and MFIs) for the same.
ii. Policy mandates on specialized training and awareness for district-level administrators and planners on sustainable CBA, 'Green Licensing' and regular monitoring plus evaluation are of immediate need.
iii. Policy framework for research-based decision support system for framework development, standardization of protocols, and impact assessment are needed to ensure the environmental sustainability.
iv. It is necessary to promote locally-led adaptations, indigenous sustainable practices, and collective farming for sustainable CBA.

8.2.3 Local level guidelines

A. Recommended practices:

i. Pre-farming field assessment of carrying capacity for sustainable production is crucial before establishment of any CBA farms.

ii. It is crucial to develop place-based monitoring for refusal treatment and its disposal to avert the debilitating impacts of CBA on the surrounding environment.

iii. It is essential to ensure local level 'systemic control' of hazardous actions or malfunctioning of CBA practices at the earliest.

iv. Training and visit program to ensure sustainable aquaculture are to be organized for farmers for promoting adaptive practices, self-regulatory mechanisms, restorative aquafarming etc.

B. Recommended policy guidelines:

i. It is recommended to develop Block and Panchayat level standard protocols for sustainable CBA, in areas of dominance.

ii. Village level Community awareness and sensitization programs are to be organized for promoting sustainable CBA. For implementing such initiatives, village stewards like '*matsya-saathi*' are to be engaged.

iii. Local helpline services are to be initiated for troubleshooting, lodging of complaints, and disaster remediation. Real time information dissemination system through risk communication channels such as social media, local television channels, and community radio channels are to be introduced.

8.3 Best practices and management guidelines

Based on this comprehensive study, the researcher has prepared a set of best practice recommendation for sustainable management of the coastal agroecosystems, which are stated in the following section.

8.3.1 Regional level guidelines

i. Develop place-based monitoring for refusal treatment and its disposal.

ii. Bring emission assessment and remediation systems to practice.

iii. Issuance of 'Green Licensing' for eco-friendly CBA practices.

iv. Risk coverage for compensation of damage and loss through group insurance schemes.

v. Pre-farming field assessment of carrying capacity for sustainable production.

vi. Village level Community awareness and sensitization program for promoting sustainable CBA, selection of village stewards like '*matsya-saathi*'.

8.3.2 Site-specific guidelines

Based on the outcomes of present study and the nuanced field-based observations regarding the present trend of CBA in the study region, the researcher has also made site-specific recommendations regarding the alternative livelihood options which is at present crucial for maintaining the ecological and economic sustainability. Three sets of recommendations were formulated based on the assessed vulnerability level of the areas investigated under the present research, which are as follows:

A. Alternative livelihood recommendation for the areas with high vulnerability:

These areas include Madarmani, Sonamuhi, Tajpur, Sapua, Raniya in Ramnagar-II, Shoula, Thakurchak, Boguran Jalpai in Contai-I, and Bankiput, Uttar Amtaliya, and Uttar Kanaidighi in Deshapran C.D. Blocks. The following alternative livelihood options can be recommended for these areas:

i. Mangrove cum shrimp farming: Carbon credit can be earned along with semi-intensive shrimp farming with less pollutant load.

ii. Algae farming, including Enteromorpha and ULVA which can be used as source of bio-fuel, food, fodder, and fertilizers (5Fs) as alternative livelihood options.

iii. Cultivation of saline and semi-saline species other than shrimp including *Lates calcarifer, Sparus auratus, Dicentrarchus labrax, Argyrosomus japonicus*.

B. Alternative livelihood recommendation for the areas with high vulnerability:

These areas include Shikharbar in Ramnagar-II, Krishna Khayratibar, Beltaliya, Chata Padmapukur, Dakshin Shilampur, Badalpur in Contai-I, Chandibeti, Baliya, and Aladarput in Deshapran C.D. Blocks. The following alternative livelihoods can be recommended for these areas:

i. Hydroponic agriculture, float farming, for exotic vegetable culture and crab fattening can be done along with less intensive tiger prawn culture.

ii. Regenerative agriculture using artificial organic soil for growing exotic vegetables with high market demand on the abandoned brackishwater aquaculture ponds.

iii. Cultivation of saline and semi saline species other than shrimp including *Lates calcarifer, Sparus auratus, Dicentrarchus labrax, Argyrosomus japonicus.*

C. Alternative livelihood recommendation for the areas with low vulnerability:

These areas include Belmani, Ahmedpur, Mandar in Ramnagar-II, Lachhanpur in Contai-I Mahishamunda, Poddarchak, and Benipur in Deshapran C.D. Block. The following alternative livelihoods can be recommended for these areas:

i. Cultivation of more salt tolerant rice varieties such as Kala Rata 1-24, Nona Bokra, Bhura Rata, SR 26B, Chin. 13, 349, Jamainadu, Narasimha, Gedu white, Gedu Black, Marami, Jhora etc.; which were successful in various parts of India, Philippines, and Sri Lanka.

ii. Regenerative agriculture using artificial organic soil for growing exotic vegetables with high market demand on the abandoned brackishwater aquaculture ponds.

iii. Cultivation of saline and semi saline species other than shrimp including *Lates calcarifer, Sparus auratus, Dicentrarchus labrax, Argyrosomus japonicus*.

8.4 Contribution of the research work

The present research is a sincere attempt to assess the dynamic impacts of the growth of CBA in the landscape, socio-economy, and political environment in the study region. This could be considered as a pioneering work in the selected study region, which took into account the comprehensive approach of political ecology to understand the complex dynamics of CBA. This study will provide a valuable repository of knowledge and information regarding the impacts of unplanned growth of CBA on the landscape dynamics of the study area and its immediate impacts on the socio-economy of the local populace. Furthermore, the present study also analysed the detrimental environmental impacts of the unscientific farm management practices in the CBA farms. Adopting political ecology approach, the study has revealed how the changes at the landscape level due to the rapid growth of CBA and unscientific farm management practices can impact the socio-economy and political environment at local to regional scale. This research has also pointed out the recent trends and tried to find out the underlined causes of declining growth rate of CBA in the study area and it has also predicted the future trend of growth of CBA in the study area. The present study is a pioneering work which has developed CBA-induced regional vulnerability index based on multi-criteria decision analysis which indicated different vulnerability zones within the study area. The identification of the vulnerability zones is necessary for framing the site-specific policy guidelines. Altogether, the research will help to abridge the existing knowledge gap that was necessary for the formulation and implementation of policy guidelines at local to regional levels regarding sustainable CBA practice.

8.5 Future research directions

The methodology applied in the present research can be used at any other region of the world having CBA with region-specific minute alternations which will largely help in decision support mechanism. Investing more time and logistic supports, this sort of study can be extended over larger geographic extent, which will be enable understanding the region-specific dynamics of CBA and its implications. For instance, to prepare more realistic national level and region-specific policy guidelines for sustainable CBA, such research is necessary throughout the coastal tracts of India wherever CBA is practiced. More scientific researches and policy level researches are needed to make the CBA practice ecologically more sustainable and economically viable to ensure the wellbeing of the wide number of populaces involved in the system.

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Annexure I:
Questionnaire for Schedule-based Survey

Problems and prospects of brackish water aquaculture Questionnaire for Schedule-based Survey

Part A: Respondent's personal/ household information

1. What is your name?
[All information shall be kept strictly confidential]

2. What is your gender? Male/ Female

3. what is your place of residence?

4. wat are the levels of education in the family members?

Level	<4 years age		5-14 years age		15-44 years age		45-64 years age		>65 years age	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Illiterate										
Primary (Class 5)										
Secondary (10 +)										
Higher Secondary (12 +)										
Graduate										
Other (Post Graduate/ Vocational/ Technical/ Others)										

5. what are the occupations [primary (P), Secondary (S)] of the family members?

Occupation		Present		P/S	15 years back		P/S	30 years back		P/S	50 years back		Migrant (Yes/ No)
		M	F		M	F		M	F		M	F	
Agriculture	Cultivate own land												
	Landless labour												
Fresh water aquaculture	Cultivate in own farm												
	Farm worker												
Brackish water aquaculture	Cultivate in own farm												
	Farm worker												
Industrial worker	Small scale & handicrafts												
	Medium & large												
Business													
Service Sector													
Transport sector	Own vehicle												
	Rented vehicle												

6. what is the monthly income of the household?

Level of Income (Rs.)	Present Status	Status 15 years Back	Status 30 years Back
< Rs. 2,000/-			
Rs. 2,000/- to Rs. 5,000/-			
Rs. 5,001/- to 10,000/-			
Rs. 10,001/- to 20,000/-			
Rs. 20,001/- to 40,000/-			
Rs. 40,001/- to 60,000/-			
Rs. 60,000/- >			

7. Do you own land?

Yes ☐ No ☐

8. If yes, how much?

Land ownership (yes/ No)	Amount of land under various categories						Owner of the land		
	Agriculture	Pond	orchard	Homestead	Other	Total amount of land	Male family head	Female family head	Other

9. What is the type of your house?

Part of the house	Material
Wall	
Roof	
Floor	
Number of rooms	

10. Do you have the following assets?

Asset	No	Yes	Number and specification
Furniture			
T.V.			
Bicycle			
Motorcycle			
Mobile phone			
Tools for agriculture/ aquaculture			
Livestock			
Sanitation unit			
Fuel used (Wood -1/ Coal -2/ Cow dung- 3/ LPG -4)			
Source drinking of water (Well-1/ Tube well-2/ Tap-3/ Other-4)			

11. How much rice do you consume (per capita/day)?

12. Do you grow rice of your own or purchase from the market?

	present	15 years back	30 years back
Rice from own field			
Purchase from market			

13. How much protein do you consume per day (per capita)?

Type	Source [own production(O)/ market (M)]	present	15 years back	30 years back
Fish				
Egg				
Chicken/ mutton				

14. How long are you residing in this area?

< 5 years ☐ 5-15 years ☐ 15-30 years ☐ >30 years ☐

Part B: Questionnaire for the brackish water aquaculture farm owners

15.wat is your gender?

Male ☐ Female ☐

16. What is the nature of ownership of the farm?

Own ☐ Rented ☐ Private land ☐ Public land (Khas) ☐
Leased ☐

17. If rented/ leased, what is the amount of rent/ lease?

18. How long are you practicing brackish water aquaculture?

< 5 years ☐ 5-15 years ☐ 15-30 years ☐ >30 years ☐

19. Are you member of any fishing co-operative?

Yes ☐ No ☐

20. If yes, which?

21. Have you got any economic or technical support from the government or and private enterprises?

Yes ☐ No ☐

22. If yes, what are those?

Easy access to loan	
Reduced rate of bank interest	
Loan interest exemption	
Tax exemption	
Technical support	
Training	

23. What is the source of your investment in the aquaculture farm?

Own capital	
Loan from any nationalised bank	
Loan from private bank/ organization	
Borrowed from shrimp feed agents	
Borrowed from local financers	

24. Did ever market price affect the production?

Yes ☐ No ☐

25. Did ever access to market affect the selling price?

Yes ☐ No ☐

26. If yes, how it has affected? And when did it happen?

Decrease in market price ☐ Increase in market price ☐

27. What are the main costs involved in the brackish water aquaculture per year?

	Cost heads	Amount in INR
Infrastructure	Pond preparation	
	Fencing	
	Farm mechanizations	
	Transport	
	Labour	
Input	Shrimp Seed	
	Shrimp feed	
	Chemicals/ fertilizers/pesticides/ antibiotics	
	Energy	
Farm management	Pond maintenance	
Market supply	Packaging and marketing	

28. How many farm workers do you hire yearly/ seasonally?

Male worker	Female worker	Total worker

29. What is the nature of labour?

Seasonal ☐ Permanent ☐ Local ☐ Migrant ☐

30. How much is the wage (monthly) of the labours?

Male worker	Female worker	Total worker

31. What is the nature of brackish water aquaculture that you carry on?

Traditional ☐ Extensive ☐ Semi intensive ☐ Intensive ☐

Only shrimp farming ☐ Alternate shrimp and rice farming ☐

32. Please specify the characteristics of farming and farm management:

Pond size	
Stocking rate	
Production season	
Survival rate	
Nature of feed used	
Number of labour hired	
Types of species cultivated	
Amount of production	
Source of seeds	
Source of water	
Number of medicines used	

Number of fertilizers used	
Number of insecticides used	
Types of modern farm technologies used (aeration/ tractors)	
Place of discharge of water	
Place of pond sludge discharge	
Nature of water exchange	
Presence of water treatment	

33. Where do you discharge water?

Place	Frequency of discharge			
	daily	Weekly	Monthly	Other
River				
Canal				
Drainage outlet				
Pond				
Field/ farm land				
Fallow land				

34. Where from you have gained the technical farm skill?

Formal training ☐ Traditional knowledge ☐ From other farmers ☐

35. Do you hire any technical person for farm management?

Yes ☐ No ☐

36. Do you follow any quality control measure guided by the international body or national government or state government or international agencies?

Yes ☐ No ☐

37. If yes, what are those?

Treatment and reuse of waste water	
Artificial feed use reduction	
Chemicals/ medicine use reduction	
Treatment and reduction of sediments	
Make compost from sediment	
Mangrove plantation and discharge in plantation areas	
Establishment of treatment pond	

38. Have you ever faced any crop failure?

Yes ☐ No ☐

39. If yes, when did it happen?

40. What were the causes of that crop failure?

41. Have you faced crop failure due to disease outbreak?

Yes ☐ No ☐

42. If yes, when did it happen?

43. What was the type of disease?

Red colour disease	
Soft shell disease	
Tail rot disease	
Black gill disease	

44. Have you ever experienced shutdown of shrimp farm?

Yes ☐ No ☐

45. If yes, when and for how many days?

46. What was the cause of the closure of the farm?

Disease outbreak	
Contamination	
Low quality of product	
Other	

47. What are the major problems to continue brackish water aquaculture in the area?

Disease outbreak	
Market fluctuation	
Irregular supply of shrimp seeds	
Problems of getting loan	
Other	

48. Do you have any secondary occupation other than that of brackish water aquaculture?

Yes ☐ No ☐

49. If yes, what are those?

Occupation		Male	Female
Agriculture	Cultivate own land		
Fishing			
Fresh water aquaculture	Cultivate in own farm		
Industrial worker	Small scale & handicrafts		
	Medium & large		
Business			
Transport			
Service sector			
Other			

50. What is the effect of brackish water aquaculture practice on the overall household Income?

Highly increased	Increased	No change	Decreased	Highly decreased

51. How much is the yearly income from the fishery?

52.a. Are you aware of the environmental degradations caused by brackish water aquaculture practice?

Yes ☐ No ☐

52.b. If yea please rate the degree of awareness

Very highly aware	Highly aware	Moderately aware	Not aware	Highly not aware

53. If yes, what are those?

Mangrove destruction	
Salt water intrusion	
Disease outbreak	
Soil pollution	
Surface water pollution	
Ground water pollution	
Stress on ground water	
Reduction in biodiversity	
Eutrophication	
Loss of biodiversity	
Obstruction to the free flowing water	

54. Are you aware of the social problems caused by brackish water aquaculture practice?

Yes ☐ No ☐

55. If yes, what are those?

Deterioration of traditional livelihood	
Conversion of croplands to aquaculture ponds	
Increase in landless labour	
Decrease in paddy production	
Decrease in food security	
Increase in out-migration	
Increase in social and economic inequality	
Rural unemployment	
Disruption of existing rural social structure	
Social conflict	

56. Does this aquaculture farm fall under CRZ zone?

Yes ☐ No ☐

57. Are you aware of/ faced the CRZ notification?

Yes ☐ No ☐

58. Are you aware of the Aquaculture Bill, 1997?

Yes ☐ No ☐

59. Do you have government licence?

Yes ☐ No ☐

60. Have you faced any restriction on your aquaculture farm from the government?

Yes ☐ No ☐

61. Have you faced any damage of the aquaculture farm due to natural hazard?

Yes ☐ No ☐

62. If yes, what are those?

Type	Frequency in last 30 years	Nature of damage
Flood		
Cyclone		
Drought		

63. Has the land price increased in the area after the initiation of brackish water aquaculture practice?

Yes ☐ No ☐

64. What was this landuse before the establishment of the brackish water aquaculture farm?

Fallow land ☐ Waterbody ☐ Mangrove forest ☐ Crop land ☐

Other vegetation ☐ Salt pan ☐

65. Did any conflict between shrimp farmers and agricultural crop producers took place in this area?

Yes ☐ No ☐

66. If yes, what were the reasons?

Deterioration of traditional livelihood	
Conversion of croplands to aquaculture ponds	
Lack of access to common property resources	
Loss of grazing land	
Increase in landless labour	
Decrease in paddy production	
Decrease in food security	
Lowering of wage rate	
Rural unemployment	
Selling land in cheap rate	
Low rent for land lease-out	
Had to sell land by force	
Land appropriation	
Increase in salinity	
Decrease in productivity	
Introduction of urban elites in rural society	

67.a. How many times such conflict took place in this region in last 30 years?

67.b. If yes how was its intensity?

Very violent	Violent	Moderately violent	Less violent	Not violent

68. Do you have to pay any compensation to the crop producers of the surrounding land due to increase in soil salinity?

Yes ☐ No ☐

69. If yes, how much per year?

Part C: Questionnaire for the brackish water aquaculture farm workers

70. What is your gender?

Male ☐ Female ☐

71. What type of work are you engaged in?

Farm building worker	
Farm repairing work	
Shrimp harvester	
Farm guard	
Mud snail shell breaker	
Transport worker	
Trader	
other	

72. Had you been in other occupation before starting working in brackish water aqua-farm?

Yes ☐ No ☐

73. If yes, what was your past occupation?

Occupation		Male	Female
Agriculture	Cultivate own land		
Agricultural labour			
Fishing			
Fresh water aquaculture	Cultivate in own farm		
Brackish water aquaculture	Cultivate in own farm		
Industrial worker	Small scale & handicrafts		
	Medium & large		
Business			
Transport			

74. How many days in a year do you work in the fishery?

75. How much wage do you get?

76. Do you consume the fish grown in this fishery?

Yes ☐ No ☐

77. Are you aware of the environmental degradations caused by brackish water aquaculture practice?

Yes ☐ No ☐

78. If yes, what are those?

Mangrove destruction	
Salt water intrusion	
Disease outbreak	
Soil pollution	
Surface water pollution	
Ground water pollution	
Stress on ground water	
Reduction in biodiversity	
Eutrophication	
Loss of biodiversity	
Obstruction to the free flowing water	

79. Are you aware of the social problems caused by brackish water aquaculture practice?

Yes ☐ No ☐

80. If yes, what are those?

Deterioration of traditional livelihood	
Conversion of croplands to aquaculture ponds	
Reduced native fish availability	
Lack of access to common property resources	
Loss of grazing land	
Increase in landless labour	
Decrease in paddy production	
Decrease in food security	
Lowering of wage rate	
Rural unemployment	
Selling land in cheap rate	
Low rent for land lease-out	
Had to sell land by force	
Had to sell land due to increase in salinity	
Had to sell land due to due to low productivity	
Rapid rise in land value	
Increase in out-migration	
Increase in social and economic inequality	
Forced migration	
Disruption of existing rural social structure	
Introduction of urban elites in rural society	
Social conflict	

81. What was this landuse before the establishment of the brackish water aquaculture farm?

Fallow land ☐ Waterbody Mangrove forest ☐ Crop land ☐

Other vegetation ☐ Salt pan ☐

82. Did any conflict between shrimp farmers and agricultural crop producers took place in this area?

Yes ☐ No ☐

83. If yes, what were the reasons?

Deterioration of traditional livelihood	
Conversion of croplands to aquaculture ponds	
Lack of access to common property resources	
Loss of grazing land	
Increase in landless labour	
Decrease in paddy production	
Decrease in food security	
Lowering of wage rate	
Rural unemployment	
Selling land in cheap rate	
Low rent for land lease-out	
Had to sell land by force	
Land appropriation	
Increase in salinity	
Decrease in productivity	
Introduction of urban elites in rural society	

Part D: Questionnaire for the farmers of the surrounding areas

84. What is the type of ownership of your land?

Own ☐ Rented ☐

85. How much agricultural area do you own?

86. What are the crops do you cultivate in the land?

Name of the crop	Present	Amount of production	15 years back	Amount of production	30 years back	Amount of production
Paddy						
Vegetable						
Mustard						
Lentil						
Pea nut						

87. How many times do you cultivate your land in a year?

Frequency	Present	15 years back	30 years back
Once			
Twice			
More than twice			

88. Are you aware of the environmental degradations caused by brackish water aquaculture practice?

Yes ☐ No ☐

89. If yes, what are those?

Mangrove destruction	

Salt water intrusion	
Soil pollution	
Water pollution	
Stress on ground water	
Reduction in biodiversity	
Eutrophication	
Obstruction to the free flowing water	

90. Are you aware of the social problems caused by brackish water aquaculture practice?

Yes ☐ No ☐

91. If yes, what are those?

Deterioration of traditional livelihood	
Conversion of croplands to aquaculture ponds	
Lack of access to common property resources	
Loss of grazing land	
Increase in landless labour	
Decrease in paddy production	
Shift to salt tolerant paddy	
Lowering of wage rate	
Rural unemployment	
Selling land in cheap rate	
Had to sell land by force	
Had to sell land due to increase in salinity	
Had to sell land due to due to low productivity	
Rapid rise in land value	
Increase in out-migration	
Increase in social and economic inequality	
Forced migration	
Introduction of urban elites in rural society	
Social conflict	

94. How many farm workers do you hire yearly/ seasonally?

Male worker	Female worker	Total worker

95. What is the nature of labour?

Seasonal ☐ Permanent ☐ Local ☐ Migrant ☐

96. How much is the wage of the labours?

Male worker	Female worker	Total worker

Annexure II:
Primary Survey Data Base

Figure 6.4: Perception regarding increase of land price after introduction of CBA (n = 270).

Land price status	Percentage of response across various social groups		
	Aquaculture owner	Aquaculture worker	Other villager
Increased	80	70.37	77.78
No change	20	29.63	22.22

Figure 6.5: Number of labourers engaged in agriculture and shrimp farms.

Number of labourers engaged in agriculture and shrimp farms			
Agriculture		Aquaculture	
Male	Female	Male	Female
5	4	3	1

Figure 6.6: Different sources of investments of CBA owners (n = 54).

Source of investment	Percentage of response
Own capital	72.22
Loan from nationalized bank	20.37
Loan from private bank	27.78
Loan from feed agency	70.37
Loan from local financers	57.41
Other sources	24.07

Figure 6.7: Status of having license of the CBA owners (n = 54).

Status of having license of the CBA owners	
Response	Percentage of response
Yes	20.37
No	79.63

Figure 6.8: Various problems encountered by the CBA owners (n = 54).

Major problems encountered by the CBA owners	Percentage of response
Disease	79.63
Market fluctuation	100
Access to loan	50
Shrimp seed quality	31.48
Access to market	68.52

Figure 6.9: Various climatic hazards causing crop loss of CBA (n = 54).

Damage due to hazard	Percentage of response
Flood	92.59
Cyclone	94.44
Temperature fluctuation	90.74

Figure 6.10: Nature of CBA farm ownership (n = 54).

Ownership type	Percentage of response
Own	27.77
Mixed ownership	11.11
Leased	61.11

Figure 6.11: Intensity of crop failure (n = 54).

Crop failure in shrimp farm	
Response	Percentage of response
Yes	81.48
No	18.52

Figure 6.13: Composition of the farm owners and labourers based on origin (n = 135).

Duration of stay in the region	Percentage of response across various social groups		
	Aquaculture owner	Aquaculture worker	Other villager
< 5 Year	25.93	46.91	1.48
5 - 15 Year	40.74	28.4	2.22
15 - 30 Year	18.52	17.28	7.41
> 30 Year	14.81	7.41	90.37

Figure 6.14: Composition of the CBA labourers based on employment tenure (n = 81).

Nature of workers	Percentage of response
Seasonal	78.16
Permanent	21.84
Local	28.16
Migrant	71.84

Figure 6.15: The impact of CBA on regional food security (n = 270).

Percentage of response across various social groups	Food crop raised in own land		Food crop purchased from market	
	Present	Past	Present	Past
	Percentage of response			
Aquaculture owner	75.92	90.74	87.03	18.52
Aquaculture worker	72.84	85.19	71.6	32.1
Other villager	80.74	91.11	87.4	25.93

Figure 6.16: Education level of shrimp farm owner families (n = 54).

Education Level	Male (%)	Female (%)
Illiterate	5.67	3.84
Primary	10.73	6.57
Secondary	13.15	12.11
Higher secondary	16.96	9.69
Graduate	12.03	6.89
Other	2.08	0.69

Figure 6.17: Education level of shrimp farm labour families (n = 81).

Education Level	Male (%)	Female (%)
Illiterate	12.63	14.2
Primary	17.08	13.31
Secondary	10.78	6.96
Higher secondary	6.71	4.03
Graduate	5.15	2.01
Other	2.01	1.12

Figure 6.18: Education level of families of common villagers (n = 135).

Education Level	Male (%)	Female (%)
Illiterate	10.21	9.85
Primary	14.01	12.9
Secondary	17.49	13.5
Higher secondary	8.12	4.34
Graduate	5.4	1.27
Other	2.23	0.64

Figure 6.19: Livelihood diversities among the families of shrimp farm owners, shrimp farm labourers, and common villagers (n = 270).

Livelihood type	Percentage of response across various social groups		
	Aquaculture owner	Aquaculture worker	Other villager
Cultivate own land	77.77	58.03	72
Share cropping	3.7	20.99	16.3
Landless labour	0	11.11	11.85
Fishing	5.56	3.36	14.07
Carp aquaculture	29.63	9.88	38.52
Carp culture worker	0	0	2.33
Prawn pond owner	94.44	0	9.33
Prawn pond worker	0	100	14.44
Industrial worker	12.96	14.82	24.51
Business	40.74	7.41	13.33

Livelihood type	Percentage of response across various social groups		
	Aquaculture owner	Aquaculture worker	Other villager
Service	18.52	3.7	14.07
Transport	5.56	20.99	12.59
Marginal worker	0	20.98	36.33
Livestock raising	45.3	37.14	53.33
Land rent	3.7	8.64	35.6

Figure 6.20: Level of family income among various socio-economic groups (n = 270).

Income category	Percentage of response across various social groups		
	Aquaculture owner	Aquaculture worker	Other villager
< 5000	0	0	13.33
5000 - 10000	3.7	49.38	44
10000 -20000	11.11	40.74	25.33
20000 - 40000	14.81	8.64	8
40000 - 60000	22.22	0	5.33
>60000	46.3	0	4

Figure 6.21: Status of cropland ownership of socio-economic groups (n = 270).

Social group	Percentage of respondent having own agricultural land
Aquaculture owner	79.62
Aquaculture worker	51.85
Other villager	69.33

Figure 6.22: House types of various socio-economic groups (n = 270).

House types	Percentage of respondent having own agricultural land		
	Aquaculture owner	Aquaculture worker	Other villager
Concrete	74.07	20.69	30.37
Semi-concrete	22.22	29.63	39.26
Mud	3.7	60.79	30.37

Figure 6.23: Types of assets in the households of various socio-economic groups (n = 270).

Type of asset	Percentage of respondent having own agricultural land		
	Aquaculture owner	Aquaculture worker	Other villager
Furniture	90.74	24.69	42.96
Television	93	29.62	45.93
Bicycle	98.15	56.79	68.89
Motorcycle	75.93	16.05	20.74
Mobile phone	96.29	72.84	80
Sanitation unit	92.59	66.67	62.22
Livestock	61.11	45.68	52.59
LPG	87.03	33.33	43.7

Annexure III:
Soil and water data base

Table 1: Status of soil quality parameters in sampled brackishwater aquaculture ponds located in the study area.

Location code	Location	pH	EC (µmhos cm^{-1})	TN (mg kg^{-1})	TOC (%)	TP (mg kg^{-1})	TK (mg kg^{-1})
RNHD1	Mandarmani	7.41	2770	343.8	0.4	1229	2444
RNHD2	Sonamuhi	7.15	2070	298.8	0.4	922.2	4322
RNHD3	Tajpur	7.11	3920	371.8	0.3	1538	3630
RNMD1	Sapua	8.02	1211	305.4	0.5	1480	3859
RNMD2	Raniya	7.62	1604	322.1	0.4	1334	4370
RNMD3	Shikharbar	7.31	2500	314.1	0.5	1153	5293
RNLD1	Belmani	6.54	879	657.1	0.5	1183	5074
RNLD2	Ahmedpur	6.98	713	385.3	0.4	1615	4631
RNLD3	Mandar	6.54	331	449.1	0.7	3734	6791
COHD1	Shoula	7.49	1896	313.8	0.3	1306	1403
COHD2	Thakurchak	7.02	1913	308.2	0.4	165.8	3979
COHD3	Boguran Jalpai	7.64	1885	419.7	0.4	571.2	2708
COMD1	Krishna Khayratibar	6.96	1734	376.2	0.3	592.5	2322
COMD2	Beltaliya	7.72	1045	388.4	0.4	881.1	4451
COMD3	Chata Padmapukur	6.18	1453	266.5	0.4	727.2	4544
COLD1	Lachhanpur	5.55	390	1213	0.7	1401	5158
COLD2	Dakshin Shilampur	6.52	542	628.7	0.6	1407	4817
COLD3	Badalpur	5.6	946	519.2	0.7	1279	1366
DPHD1	Bankiput	7.38	2920	252.4	0.3	1195	328.4
DPHD2	Uttar Amtalia	6.74	4960	267.6	0.4	471	3120
DPHD3	Uttar Kanaidighi	7.54	2870	316.9	0.3	605.7	3167
DPMD1	Chandibeti	5.7	1320	436	0.5	1151	3393
DPMD2	Baliya	5.85	1883	278.3	0.4	1074	3854
DPMD3	Aladarput	6.8	1278	247.2	0.3	995.7	3359
DPLD1	Mahishamunda	5.33	161.8	566.7	1	1541	5086
DPLD2	Poddarchak	5.78	469	396.2	0.4	1228	4436
DPLD3	Benipur	5.3	200	343.8	0.7	1774	3507

Table 2: Status of water quality parameters in sampled brackishwater aquaculture ponds located in the study area.

Location code	Location	pH	EC (µmhos cm^{-1})	TDS (mg L^{-1})	BOD (mg L^{-1})	DO (mg L^{-1})	COD (mg L^{-1})	Cl (mg L^{-1})	TN (mg L^{-1})	TP (mg L^{-1})	NH3-N (mg L^{-1})
RNHD1	Mandarmani	9.7	11650	7540	12	5.45	58	5625	4.88	26.9	0.18
RNHD2	Sonamuhi	9.2	9650	7355	12	6.5	55	5305	5.76	4.4	0.09
RNHD3	Tajpur	9.5	9700	6894	12	6.93	53	7957	3.55	17.4	0.13
RNMD1	Sapua	8.55	7700	6982	11	7.6	49	1646	3.28	2.29	0.02
RNMD2	Raniya	8.5	8920	6757	10	6.74	51	3567	3.9	4.06	0.03
RNMD3	Shikharbar	8.8	9300	5942	9	7.7	52	2448	3	0.73	0.01
RNLD1	Belmani	7.51	1098	262	7	8.26	32	73	2.09	0.71	0.01
RNLD2	Ahmedpur	7.37	495	259	7	8.22	30	75	2	0.32	0.01
RNLD3	Mandar	7.51	509	274	9	8.54	40	151	2.08	0.26	0.01
COHD1	Shoula	8.13	11040	6846	11	4.8	46	4988	7.42	1.56	0.09
COHD2	Thakurchak	8.73	10650	6558	15	4.93	115	5099	5.5	0.37	0.11
COHD3	Boguran Jalpai	8.44	10690	6962	22	3.3	69	4177	5.29	0.55	0.29
COMD1	Krishna Khayratibar	8.05	8090	5096	9	5.59	45	3157	2.74	0.5	0.07
COMD2	Beltaliya	7.68	7900	4898	9	5.5	34	3837	3.97	0.34	0.07
COMD3	Chata Padmapukur	7.53	10240	5816	7	5.67	39	3788	3	0.21	0.03
COLD1	Lachhanpur	7.49	338	192	4	6.3	29	27	2	0.16	0.02
COLD2	Dakshin Shilampur	7.38	7080	3324	6	7.4	19	1807	2	0.05	0.01
COLD3	Badalpur	7.42	5290	4390	6	7.2	33	2613	2	0.15	0.01
DPHD1	Bankiput	8.68	11400	7300	7	3.86	41	4768	3.36	0.75	0.12
DPHD2	Uttar Amtalia	8.22	11320	6310	7	5.5	35	4808	3.25	0.57	0.19
DPHD3	Uttar Kanaidighi	7.95	10297	7250	11	5.7	56	3691	5.25	0.62	0.09
DPMD1	Chandibeti	7.74	7690	4768	5	4.23	28	2817	2.29	0.33	0.05
DPMD2	Baliya	7.71	8920	5708	6	6.5	27	3448	2	0.34	0.07
DPMD3	Aladarput	7.69	10010	4048	5	6.9	32	3030	2.49	0.44	0.07
DPLD1	Mahishamunda	7.45	6530	312	3	7.4	12	105	2	0.24	0.01
DPLD2	Poddarchak	7.64	583	1350	4	7.7	23	2623	2	0.16	0.02
DPLD3	Benipur	7.53	2330	2162	2	7.2	17	1068	2	0.28	0.02

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Zip File Upload (https://app.ithenticate.com/en_

Cut & Paste (https://app.ithenticate.com/en_

Doc-to-Doc Comparison (https://app.ithenticate.com/en_

View: Recent Uploads (https://app.ithenticate.com/en_

New folder

New Folder (https://app.ithenticate.com/en_

New Folder Group (https://app.ithenticate.com/en_

Folder Info

Name: MN

Shared with: nobody (https://app.ithenticate.com/en_

My Folders

My Folders (https://app.ithenticate.com/en_us/group/folders/2279100)

AM (https://app.ithenticate.cc

Mainul Islam (https://app.ithenticate.cc

MN (https://app.ithenticate.cc

My Documents (https://app.ithenticate.cc

Trash (https://app.ithenticate.com/en_us/folder/2921480)

MN

Documents (https://app.ithenticate.com/en_us/folder/4344815)
Sharing (https://app.ithenticate.com/en_us/folder/sharing/4344815)
Settings (https://app.ithenticate.com/en_us/folder/settings/4344815)

Folder Options (https://app.ithenticate.com/en_us/folder/settings/4344815)

Report Filters (https://app.ithenticate.com/en_us/folder/url_filter/4344815)

Phrase Exclusions (https://app.ithenticate.com/en_us/folder/excludephrase/4344815)

Folder Name *

MN

Check to exclude quoted text from comparison of documents submitted in this folder

☑ Exclude quotes

Check to exclude bibliography from comparison of documents submitted in this folder

☑ Exclude bibliography

Check to exclude phrases associated with this folder (or with your account) from comparison of documents submitted in this folder

☑ Exclude Phrases

Check to exclude match instances from reports that are below the set word count.

☑ Exclude Small Matches

Set match exclusion threshold:

Exclude all match instances below the set threshold from reports.

Word Count

10 words

Check to exclude sources below the set thresholds from reports.

☑ Exclude Small Sources

Exclude Sources by:

Based on a source's total match percentage or match word count.

◉ Word Count

10 words

○ Percentage

0 %

Exclude Sections:

Check to exclude the Abstract from comparison of documents submitted to this folder.

☐ Abstract

Check to exclude the Methods and Materials section from comparison of documents submitted to this folder. Includes variations: Method, Methods, Materials and Methods

Submit a document

2,279 Documents remaining

Upload a File (https://app.ithenticate.com/en_

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New Folder Group (https://app.ithenticate.com/en_

Folder Info

Name: MN

Shared with: nobody (https://app.ithenticate.com/en_

- [ ] Methods and Materials

Limit searches to these repositories *

Documents submitted in this folder will search checked repositories.

- [x] Crossref
- [x] Crossref Posted Content
- [x] Internet
- [x] ProQuest
- [x] Publications

Update Settings   Cancel (https://app.ithenticate.com/en_us/folder)