Water Quality as a Measure to Understand Vulnerability and Viability Issues in Small-Scale Fisheries of Chilika Lagoon, India

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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ABSTRACT

Small-scale fisheries (SSFs) sustain millions of livelihoods worldwide by contributing to food security and income. However, small-scale fishing communities are marginalized and vulnerable due to cumulative impacts of sea-level rise, hydrological changes, hydrodynamic disruptions, overexploitation of resources, aquaculture, coastal and inland habitat loss, overfishing, lack of livelihood alternatives, along with food insecurity, occupational displacement, and outmigration. While most studies on SSF vulnerability have focused on economic, social, and political factors, limited research links these vulnerabilities with changes in the water quality. My research addresses this gap by examining the effects of water quality changes on the vulnerability of SSF and using this examination to advance potential approaches for achieving viability. A range of human-induced and natural factors shape the hydrodynamics of the lagoon. These include invasion of weeds, agricultural runoff, wastewater releases from industries, domestic discharge and sewage pollution, variation in the phytoplankton, fish species composition and fish landing, introduction of many chemical feeds, and uneaten food pellets and fish waste pollutes related to aquaculture production. Typically, a number of these factors come together to produce eutrophication and algal blooms which, in turn, control conditions of vulnerability and viability of fishing communities related to water quality.

This research analyzes pathways of vulnerability resulting from water quality changes in small-scale fisheries systems in Chilika Lagoon, the largest coastal lagoon on the east coast of India and lifeline of the state of Odisha. Chilika Lagoon is a designated Wetland of International Importance (Ramsar Site under the Convention on Wetlands) since 1981. In the Lagoon, traditional small-scale capture fisheries support livelihoods of over 140,000 fisher communities in the vicinity of 424 villages within two kilometers of the wetland boundary. These communities are now being affected by the catastrophic influence of an endangered social-ecological system. An abrupt degradation phase between 1950 and 2000 in Chilika was due to opening of artificial sea mouth and introduction of aquaculture. The degradation phase resulted in major declines in fisheries influencing substantially the livelihood of coastal communities. Since then, the direct and indirect impacts of natural and anthropogenic factors had profound impacts on the poor and vulnerable populations, which are disproportionately dependent on small-scale fishing for their livelihoods.

The study aims to examine processes and drivers of water quality changes in the social-ecological system of the lagoon resulting in key vulnerabilities of fishers and analyzing adaptive approaches that can create viable SSF. Evidence for the work is collected through a mixed approach of qualitative and quantitative research methods such as I-ADApT and systematic literature review. Based on this scrutiny, I produce schemes and solutions that can be used to assemble feasible approaches to advance viability for SSFs confronting various vulnerabilities now and into the future. Overall, the research addresses sustainable management of SSFs by providing details on how fisher vulnerability may be closely linked to water quality and its related impacts. Further, the research provides some answers to how SSF viability can be achieved through coping and adaptive responses by small-scale fishing communities to the changes in water quality.

Keywords:

Adaptation, Aquaculture, Chilika, Cyclone, Drivers, Governance, Livelihood, Marginalization, Small Scale Fisheries, Social-Ecological Systems, Vulnerability, Water quality

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°C	degree Celsius
BOD	Biological Oxygen Demand
CDA	Chilika Development Authority
Chl-a	Chlorophyll-a
CO2	Carbon Dioxide
COD	Chemical Oxygen Demand
CWPRS	Central Water and Power Research Station
DO	Dissolved Oxygen
FAO	Food and Agriculture Organization
GPS	Global positioning System
I-ADApT	IMBER Assessment of Responses based on Description, Appraisal, and Typology
IMBeR	Integrated Marine Biosphere Research
IPCC	Intergovernmental Panel on Climate Change
IWRM	Integrated Water Resources Management
NIO	National Institute of Oceanography
NTU	Nephelometric Turbidity Units
PO_4	Phosphate
ppm	part per million
ppt	Parts Per Trillion
SDGs	Sustainable Development Goals
SES	Social-Ecological System
Si	Silicates
SSF	Small-Scale Fishery
WT	Water Temperature
WTI	Wildlife Trust of India

CHAPTER 1

Introduction

1.1 Background

Poor water quality is a multidimensional problem that makes it difficult to provide effective water management as well as a proper living standard for small-scale fisheries (SSF). Water pollution is one such dimension, as it has an impact on the health and quality of a social-ecological system. Many coastal communities are dependent on SSF to sustain their livelihoods (Chuenpagdee & Jentoft, 2018). Rising impacts from natural and anthropogenic drivers of change put SSF communities at risk. Consequences are likely to amplify the burdens faced by the coastal communities, including those brought on by ongoing environmental degradation.

Chilika Lagoon, India's first Ramsar site, is Asia's largest brackish water lagoon with estuarine characteristics. It is a mosaic of habitats, including the greatest wintering habitat for migrating birds and productive grounds for both fish and shell fish. One of the major issues faced in the Chilika Lagoon is the diverse and considerable water load resulting from various anthropogenic and natural drives of change. The improper balance of social and ecological functions associated with water quality issues has affected the diversified biological wealth. Declining water quality and impacts to biodiversity loss has harmed traditional fishing practices that, in turn, decreased the viability of SSF communities. The coastal lagoon, which is connected to rivers by an extensive pear-shaped wetland that allow water to be retained, act as filters, deposits, and sources for various substances, and are the habitat of diverse species. The existence of a distinct salinity gradient allows the wetland to support a diverse spectrum of wildlife while also providing ecosystem services to dependent communities (Kumar & Pattnaik, 2012). The lagoon basin has been divided into 6 watersheds, 16 sub-watersheds, 56 mini-watersheds, and 218 micro-watersheds based on drainage (Kumar & Pattnaik, 2012).

SSFs represent food and financial security in developing countries, including India. SSFs are affected by the cumulative impacts of social and ecological drivers such as sea level rise, hydrological changes, coastal and inland habitat loss, overfishing, lack of livelihood alternatives along with food insecurity, occupational displacement, and outmigration (Nayak, 2017). These growing threats can be categorized into two areas: natural or ecological drivers (e.g., environmental change, erosion and deposition, cyclones, droughts, and floods) and human or anthropogenic activities (e.g., overfishing, competition with industrial fleets, and population growth). Such factors lead to water pollution, degradation of fish populations, loss of biodiversity, and species. At the ecosystem scale, factors produce observable trends of extinctions and decline of fish resources at different biotic scales. Ultimately, this will make them less resilient to the changing global climate (Bell et al., 2018; d'Armengol et al., 2018). Similar patterns of change can be found in Chilika.

Between 1950 and 2000, Chilika experienced fast degradation as a result of increased silt loads from catchments and decreasing connectivity with the sea (Kumar & Kumar Pattnaik, 2013). Changes in land use, sea mouth creation, land cover variation, aquaculture, tourism, natural phenomena (e.g., cyclones, droughts, and floods) lead to siltation, changes in salinity regimes and eutrophication. The lagoon fisheries suffered a significant drop along with exotic weeds proliferation, and the decline of wetland area and volume (Kumar & Pattnaik, 2013). Other impacts are the indirect effects of these threats, such as water pollution and acidification due to the development of industries and tourism, encroachment by markets, and demand for land in coastal areas (Rau, 1980). These drivers contribute to the increasing vulnerability of SSF communities around Chilika. The essence of SSF vulnerability need to be better understood, including its drivers, impacts and ways in which SSF communities can respond to these forces.

Sustainable water management is required for wise use of wetlands and is an important strategy for the viability of SSF communities (Kumar & Pattnaik, 2013). Sustainable water management can help understand, anticipate, and address social-ecological stressors impacting SSFs and livelihoods in SSF communities. While there are significant studies and analysis of water quality as well as research on SSF in Chilika Lagoon, research has yet to connect water quality issues and vulnerability of coastal communities along with opportunities in sustainable water management for viability of SSF in Chilika. My research addresses this lacuna by examining the effects of water quality changes on vulnerability of SSFs in the Chilika lagoon and exploring approaches for viability of SSF communities.

1.2 Research Context

The research context includes different dimensions such as geographical analysis of the case study location, exploring water quality variation in the specific region to understand the drivers of vulnerability, and finally to identify the viability measures to cope up with these drivers. The analysis, as well as its methodological approaches, claims, observations, conclusions, and recommendations are tied to this multi-dimensional context. Geographic (location), historical, cultural, or topical contexts are all possible. In this research, Chilika Lagoon is the case study location and the major problems related to social-ecological changes in lagoon ecosystem are elaborated in the following sections.

1.2.1 Problem Context

SSF thrive in viable marine, lacustrine or riverine ecosystems in various developed and developing countries (Kurien, 2007). There is, however, a lack of knowledge about the scale of various social

-ecological challenges, their impacts, as well as limitations in governing them for the purposes of development. This leads to difficulty in assessing the present conditions of SSFs and opportunities for sustainability, such as with indicators of over-exploitation in several areas leading it to a challenging endeavor. Small-scale fishers are often categorized as poor, marginalized populations of society, yet have weak representation in national and international policy forums (Nayak et al., 2014; Schuhbauer & Sumaila, 2016). Rising human activities in coastal-marine systems lead to major shifts in the ecological and social subsystems. Sometimes, the biodiversity of lagoons is altered so significantly that it drastically impacts the ecosystems' overall biotic population resulting in loss of fisheries, coastal marine eutrophication, algal bloom, and mangrove transformations (Biggs et al., 2012; Lade et al., 2013). This type of change is characterized as a social-ecological regime shift or a "sudden, long-term and substantial changes in linked human and nature systems with uncertain consequences for ecosystem services and human wellbeing supporting habitats" (Nayak et al., 2016; Nayak & Armitage, 2018).

Although many past studies have been carried out in Chilika, none have explicitly addressed the influences of water quality degradation on SSF communities. Analysing the interaction of vulnerability factors may lead to novel perspectives for understanding the nature of water quality deterioration in Chilika lagoon and the dynamics involved in the interactions between society and the environment (Finlayson et al., 2020). This research will focus on the state of small-scale fishing communities leading to pathways and strategies which are necessary to resolve ecological problems (Jentoft et al., 2017). Impacts of water quality changes, habitat loss in small-scale fisheries systems and the overall influence they have on wellbeing will be analysed (Jentoft & Chuenpagdee, 2018). The pollution of water resources in Chilika Lagoon is caused by the release of vast amounts of improperly treated, or untreated, wastewater into coastal waterways. A significant reduction in the availability of the water resources is caused due to the pollution. Furthermore, hydrological interventions such as sea mouth creation and destructive aquafarming practices such as shrimp aquaculture pose water quality problem, with long-term effects on human health and ecosystems that are still unknown.

1.2.2 Research Gap

Perceiving the relationship between water quality and vulnerability of SSF community through a case study on the Chilika Lagoon will contribute to developing possible adaptation measures for viability of SSF communities. Various adaptive and mitigation measures for tackling vulnerability of SSF and to improve viability are needed (Bennett et al., 2016; Jentoft, 2000; Nayak & Berkes, 2010), including in Chilika (references). Multilevel drivers play a significant role in defining and affecting vulnerability and viability (Nayak & Armitage, 2018; Scheffer & Carpenter, 2003). Vulnerability also occurs when resilience is compromised by external or non- place-based drivers' operation on local communities' ability to deal with challenges or respond to problems (Chuenpagdee & Jentoft, 2018). Extensive human interferences including deforestation, urbanization, tourism also pose a great threat to the lagoon waters. These disturbances are preventing the free flow of water into the lagoon, limiting the growth of fish, which are eaten by a variety of birds and impacting livelihood of fishing communities. The roles of the societies alone are not to reduce vulnerability and improve viability. Governments and regulating bodies at local, national, and international levels may actively work with or against them, using those rules and regulations. A considerable amount of research on water pollution in coastal areas, gender inequalities of SSF communities, economic impacts on declination of fish catch, analysis of the social ecological systems, marginalization of fishing communities have been conducted. However, few research studies have focused on impacts of hydrological intervention and adaptation of SSFs.

My research bridges this gap of the literatures in Chilika lagoon and gives attention to the improved lives of fishing communities.

Degradation of water quality has a direct impact on the environment, society, and economy. Water quality is one of the most pressing issues that SSF communities face in the twenty-first century, diminishing ecological services, posing threats to human health, limiting food production, and impeding economic growth. This study recognizes the drivers of water quality variation in the lagoon that analyzes various social and ecological threats in the lagoon. Vulnerability of small-scale fishing communities, who experience marginalization in their daily lives are explored to suggest possible adaptation measures.

1.3 Research Purpose and Objectives

The main objective or overall intent of the research project is defined by a research purpose and objectives. As a result, it serves as a focal point for the thesis and clarifies what analysis is been done and why. A research purpose specifies what the analysis will answer, and the research objectives specifies how it will be answered. They break down the research purpose into smaller chunks, each of which represents a key section of the analysis. As a result, almost every research objective is organized as a numbered list, with each component receiving its own chapter in the thesis.

1.3.1 Purpose Statement

The purpose of this research is to examine the vulnerability in coastal fishing communities of Chilika Lagoon due to the water quality degradation and assess how to achieve an adaptation strategy to make communities less vulnerable and more viable.

1.3.2 Objectives

Three objectives will guide this research:

- To understand the processes of water quality variations in Chilika lagoon
- To examine vulnerability issues faced by the small-scale fishing communities due to changes in water quality
- To analyze various coping and adaptive responses of the fisher communities and their potential for creating viable small-scale fisheries

1.4 Research Questions

The main research questions involve:

1) How is vulnerability in SSF communities impacted by water quality?
2) What are the responses of small-scale fishers to these vulnerabilities?
3) What are the adaptation strategies for making small scale fisheries more viable?

1.5 Research Design and Methodology

This thesis takes a case study and mixed method research design, with a focus on both qualitative and secondary quantitative research methods. To gather relevant data for this study, in-depth systematic literature review was conducted. A descriptive-interpretive methodology along with convergent parallel mixed approach was used to evaluate the results (Creswell & Clark, 2017).

1.5.1 Literature Review

In chapter two, relevant areas of literature are explored. In order to explain and validate the conceptual interpretation used in this thesis, this section provides a synthesis of all related literature. Figure 1.1 indicates the elements involved in the literature review.

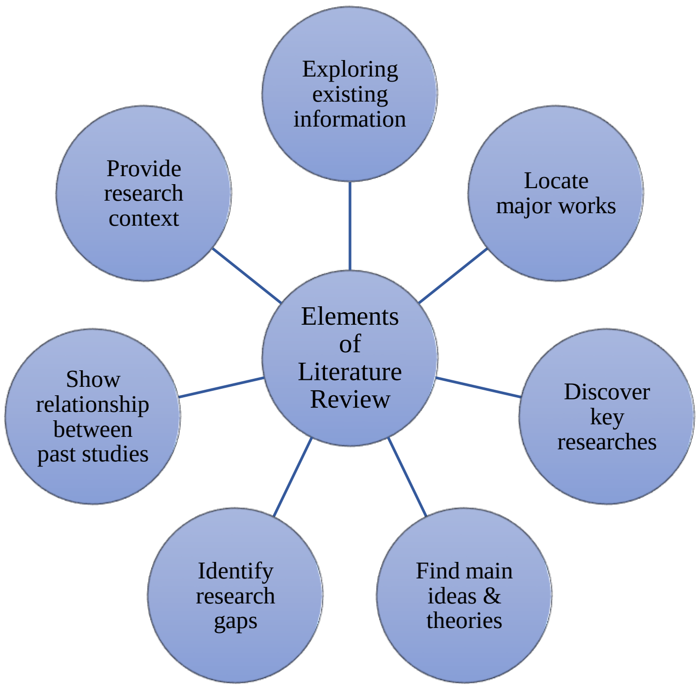

Figure 1.1: Elements in a Literature Review

Adapted and modified from (Braun et al., 2009)

Three areas of literature were reviewed:

a) Hydrological and Water Quality Variations

The first area focuses on the hydrology of Chilika lagoon which is a collection of marine, brackish, and freshwater environments that vary from shallow to very shallow (see Section 2.1). The various hydrological regime changes (1950 and 2015) are also captured particularly those that were highly influential on the social and ecological lagoon system.

b) Vulnerability and Viability of SSF

The second area describes various aspects of vulnerability and viability concepts for analysing marginalisation of SSF in Chilika (see Section 2.3). For example, SSFs suffered a significant reduction in fish catch, proliferation of exotic weeds, and the shrinkage of wetland's size and volume. This had a huge impact on the livelihoods of SSF communities including their vulnerability.

c) Coping and Adaptation

The third area addresses the overall measures for viability (see Section 2.4). Various mitigation measures are reviewed including adaptation methods and coping strategies that emerge as a result of shifting social ecological conditions. The social-ecological exposure and sensitivities of Chilika lagoon are discussed that shape the vulnerability of SSF communities.

1.5.2 Study Area and Methods

Specific study location helps in validating the study and provide relevance to the issues addressed. The case study area for this study is Chilika Lagoon. Like many other lagoon ecosystems, Chilika is also facing issues based on natural and human activities. As described above, the lagoon is highly vulnerable to natural and anthropogenic drivers of change resulting in water pollution, fish decline and poverty in SSF communities in the study site. This study’s descriptive qualitative analysis investigates many problems and possible improvements in social-ecological system of Chilika Lagoon. Mixed methods are employed in this study including document analysis, graphical interpretation of secondary data on water quality parameters and case study approach providing a sequential explanatory design. A mixed method approach was particularly useful for deciphering discrepancies between quantitative and qualitative findings (Schoonenboom & Johnson, 2017).

Further, combining data sets can help investigators gain a deeper understanding of issues and provide more complete evidence bases in terms of both depth and scope (Shorten & Smith, 2017).

1.6 Research Significance and Contributions

The research identifies drivers of water quality in Chilika lagoon, and the trend of variation is plotted from 1950 to 2015. Linkages of water quality issues in relation to the SSF communities are explored in this study. The research addresses the gap between the connectivity of water quality and SSF that has led to social-ecological changes. Proper allocation of resources for securing livelihood of the SSF communities are recognised by exploring the gap addressed above. The study highlights the issues faced by the marine environment and resource use allocations: social-ecological systems, resilience, sustainability, livelihoods and well-being, governance, and adaptation to climate change (Armitage et al., 2012). This study's results can be utilized for developing the knowledge of the fishing community to identify peculiarities and local features by regional and global levels for preserving the ecosystem. The researchers, governmental and non-governmental organizations, and stakeholders can use the results to support sustainable water management related to the development and protection of the environment in lagoons. In addition, analyzing the specific adaptations and responses of coastal communities to the socio-ecological changes can support novel governance approaches for better dealing with vulnerability, strengthening community and institutional adaptation. Overall, the research can potentially contribute to research and practice for the viability of marine environments, SSFs and SSF communities. Such benefits will extend beyond Chilika, and results can be replicated in a variety of similar coastal contexts.

1.7 Thesis Organization and Structure

The thesis consists of six chapters, organized as follows. The first chapter of the thesis introduces the theoretical and practical context, research purpose and objectives, research design and methodology, and the importance of research being undertaken. The second chapter discusses a synthesis of three bodies of literature and development of a conceptual framework on which additional research in this thesis is based: hydrological and water quality variations, vulnerability and viability of SSF, and coping and adaptation. Chapter Three expands the case study background, the methodology, and the challenges faced in the study due to the transition to desktop research and data collection. Chapter Four describes the main results on variations in water quality parameters and its impacts on SSF (Objectives 1 and 2). Chapter Five examines the main vulnerabilities from water quality as a driver of change along with possible adaptation and coping strategies employed by SSF communities (Objective 3). Finally, Chapter Six outlines the most relevant observations and discussions of the research and suggests areas for future studies. Chapter Six provides concluding remarks that summarize key points, recommendations, and suggestions for future studies in the field of water quality as a source of vulnerability and related pathways to achieve viability of SSF.

CHAPTER 2

Role of Water Quality in Vulnerability and Viability of Small-Scale Fisher Communities: A Literature Review

2.1 Introduction

This chapter explores the literature base for empirical research in this study. The chapter considers ideas of natural change, social-environmental framework, existing local information, management, and adaptation strategies. Coastal ecosystems around the world are vital to human survival, but they have degraded significantly in recent years. Understanding how water quality affects the structure of the SSF communities is a major step to effective recovery of degraded ecosystems' health. The impact of water quality variations on the vulnerability of SSF communities have been rarely studied, resulting in the low success rate of viability initiatives of coastal communities in Chilika Lagoon. The literature review reveals a gap in the existing research base and approaches previously used in similar study areas. The literature review assesses around 250 academic and grey literatures based on three categories: (1) hydrological and water quality variations; (2) vulnerability and viability of SSF; and (3) coping and adaptation. This provides a strong conceptual and empirical foundation on which to address research objectives in later chapters. Further, the resultant conceptual framework draws on interfaces of social and ecological change, with an attention to water quality variations, drivers of alterations, commons and resources, management and accommodation plans in the Chilika lagoon.

2.2 Hydrological and Water Quality Variations

SSF communities might have variability at higher levels on account of geographic dispersion of species, alterations in streams and encompassing terrain, disappearance of native species, biodiversity loss and natural changes. This indicates the heterogeneous structure of SSF due to natural and physical characteristics. Elevation differences, variations in natural surroundings, water quality and temperature alterations, and other significant attributes of the ecological system also shape water quality variation, including degradation (Deacon, 1997). Access and availability of fish for SSF depends considerably on water quality variation. Yet, most efforts to address water quality degradation have concentrated on the physical and synthetic properties of water such as dissolved oxygen, soluble or insoluble inorganic and organic components, temperature, heavy metal concentration and a wide assortment of toxic materials. Such variations may influence reduction in native species, extinction of habitats and even invasion by new species. Water quality parameters play critical roles in a region's appropriateness for oceanic living beings which, in turn, shape sustainable livelihood of SSF communities dependent on them. Synergistic impacts of various human activities may hasten social and ecological degradation (Karr & Dudley, 1981).

Along with natural phenomena, human activities can cause water quality changes leading to ecosystem variations and adverse impacts on SSF communities (Panigrahi, 2007). In a study in Chilika on hydrographical and physiochemical parameters, Nayak and Behera (2004) as well as Patra and colleagues (2010) stated observed changes in both seasonal and spatial scales from local climatic variations and water exchange mechanisms between the lagoon and the sea. As a result, direct or indirect impacts can include intensifying change on ecosystem structure and functions that affect lagoon fisheries (Panigrahi et al., 2007). Changes in the frequency, strength and complexity of hydrological relations can have drastic and potentially unpredicted consequences on the quality of water (Muduli & Pattnaik, 2020; Panda et al., 2013). Such changes in the lagoon ecosystem are causing concern for local and national governments. Further, growth of aquaculture, land reclamations, tourism, industrial and agriculture advancements function as drivers of rapid changes in the social-ecological system of the lagoon. The changes may include water spread reduction and siltation, receded salinity, disease outbreaks, eutrophication, and biodiversity loss

(Panigrahi et al., 2007), reduction in fish production, incomes for fishers and persistence of their livelihoods (Iwasaki et al., 2009; Iwasaki & Shaw, 2008; Nayak & Berkes, 2010), opportunities to express fishing rights and access customary fishing grounds (Nayak & Berkes, 2011), and job displacement and outmigration to cities (Robson & Nayak, 2010).

Transitions in salt content decide estuarine qualities of lagoon and characterize structure and composition of flora and fauna as well as spatial variation of fish and other aquatic species (Panda et al., 2015). The overall salinity of Chilika lagoon waters raised due to the free entrance of seawater associated with the creation of artificial sea mouth in 2001. Seawater interruption along with quicker decline of weeds and flush out of sediments helped in higher catch, scattering of restricted contamination, lagoon deepening, and reclamation of lagoon wetland system were some of the resulting consequences of sea mouth creation (Nayak & Behera, 2004). Quick residual flows and transitions through the sea mouth produced extreme changes ecological balances and altered physio-chemical characteristics of water which were basic attributes of high efficiency in the lagoon. Internal/outward movement of planktons were facilitated by water motions that control flushing in lagoon keeping up water quality (Panda et al., 2015). Higher estimations of nitrate were observed during the pre-monsoon period. Microbial activities set conditions for quick recharging of nitrate. Even temperature rise along with quick blending of sub-surface and surface water also contributed to nitrate renewal mechanism (Nayak & Behera, 2004). These were some of the hydrological changes experienced by Chilika waters as a part of sea mouth opening.

The hydrological state of lagoon water was influenced by aquaculture practices resulting in nutrient imbalance, eutrophication, and seaweed growth, decline in fish stocks, species variation and biodiversity destruction that brought about decline in lagoon biological system (Patra et al., 2010). Flow regime variations, water quality parameters, inflow-outflow discharges, salinity changes, wind patterns, difference in vegetation growth and species composition come together to make the Chilika lagoon uneven and complicated in nature. Unevenness was also facilitated by irregular physical geography such as channel openings around the lagoon system affected by anthropogenic activities such as land reclamations and dredging (Panda et al., 2015). The resultant water quality changes shape social ecological changes that ultimately affects the livelihood of communities dependent on lagoon resources. The SSF sector will be particularly affected by loss of biodiversity, fish stock reduction, water pollution, disease outbreaks, nutrient imbalance, and ultimately food insecurity. Some terminologies of water quality parameters are listed in Box 2.1 below.

Box 2.1: Definitions of water quality parameters (Adapted from Omer, 2019)

Definition
Alkalinity & Buffering Capacity: Alkalinity is the ability of water to resist acidic changes in pH; in other words, alkalinity is the ability of water to neutralize acid. This ability is referred to as a buffering capacity.
Biological Oxygen Demand (BOD): The amount of oxygen required by bacteria and other microorganisms while decomposing organic matter under aerobic (oxygen present) conditions at a specific temperature is referred to as biochemical oxygen demand.
Dissolved Oxygen (DO): The amount of oxygen present in water is referred to as dissolved oxygen (DO). It constitutes the amount of free, non-compound oxygen contained in water or other liquids. Because of its impact on the life of aquatic organisms, it is a crucial metric in determining water quality. Fish and other aquatic species require it for survival.
pH: The pH of water is a measurement of how acidic or basic it is. The range is 0 to 14, with 7 being the neutral value. Acidity is indicated by a pH less than 7, while a pH greater than 7 indicates a base. pH is a measurement of the proportion of free hydrogen and hydroxyl ions in water.
Salinity: Measure of the number of dissolved salts in water. It is usually expressed in parts per thousand (ppt) or percentage (%).

Turbidity: Metric used to measure the clarity of water. The amount of light dispersed by particles in the water column determines the turbidity of the water. Turbidity can be caused by suspended sediments like silt or clay, inorganic materials, or organic matter like algae, plankton, and decomposing debris.

2.3 Vulnerability and Viability of SSF

Vulnerability is the degree to which a system is exposed to threats unable to cope and adapt to negative consequences of disruption (Adger, 2006 ; Morzaria-Luna et al., 2014; Thompson et al., 2016). The building up or degradation of the elements of social-ecological resilience influences vulnerability of social-ecological systems. Resilience is defined as the ability to return to a functional state after the disruption as well as the adaptation to handle the stress in future (Adger, 2006). Other definitions of vulnerability exist. For instance, vulnerability is typically viewed as a result of sensitivity, or susceptibility to harm. Alternatively, vulnerability can be viewed as exposure or stress level associated with social and ecological changes, or limited adaptive capacity or people's ability to foresee, respond to, and recover from the effects of change (Adger, 2006b). A multi-dimensional view of vulnerability has been used and measured using indices that reflect these definitions: sensitivity, exposure, and adaptive capacity (Morzaria-Luna et al., 2014). Various natural and human-induced activities create an imbalance in the social ecological ecosystem of Chilika Lagoon affecting the livelihoods of fishing communities (Kumar & Pattnaik, 2012). Lagoon water quality is one of the critical factors affecting the vulnerability of fishing-dependent communities, with the potential shape patterns of access to the shoreline and outmigration. To cope with the emerging changes, the social-ecological system, including SSFs, must adapt to new domains which can make SSF more vulnerable when adapting strategies are not consistently monitored.

For SSF communities, sources and causes of vulnerability abound. These can include interactions among the lack of resource availability, the presence of overcapacity and overfishing in the fishery, competition with commercial fisheries or other sectors such as tourism, reduced access to markets and poor governance, as well as larger-scale factors like climate change, urban development, industrialization, international markets, hydrological interventions, and land transformation (Chuenpagdee, 2011; Schuhbauer & Sumaila, 2016). Agriculture, manufacturing, fishing, and international commerce all contribute to the increase of the human population and the resource base utilized by SSF. For ecosystems and by extension the availability and health of fish stocks, these activities modify the land surface and water quality (via farming, forestry, and urbanization), alter important biogeochemical cycles, and introduce or remove species and genetically unique populations. These impacts interact to disrupt the livelihoods of SSF communities, A conceptual model of human alterations to ecosystems is depicted in Figure 2.1 that leads to generation of irreversible biodiversity loss and global climatic change (Vitousek et al., 1997).

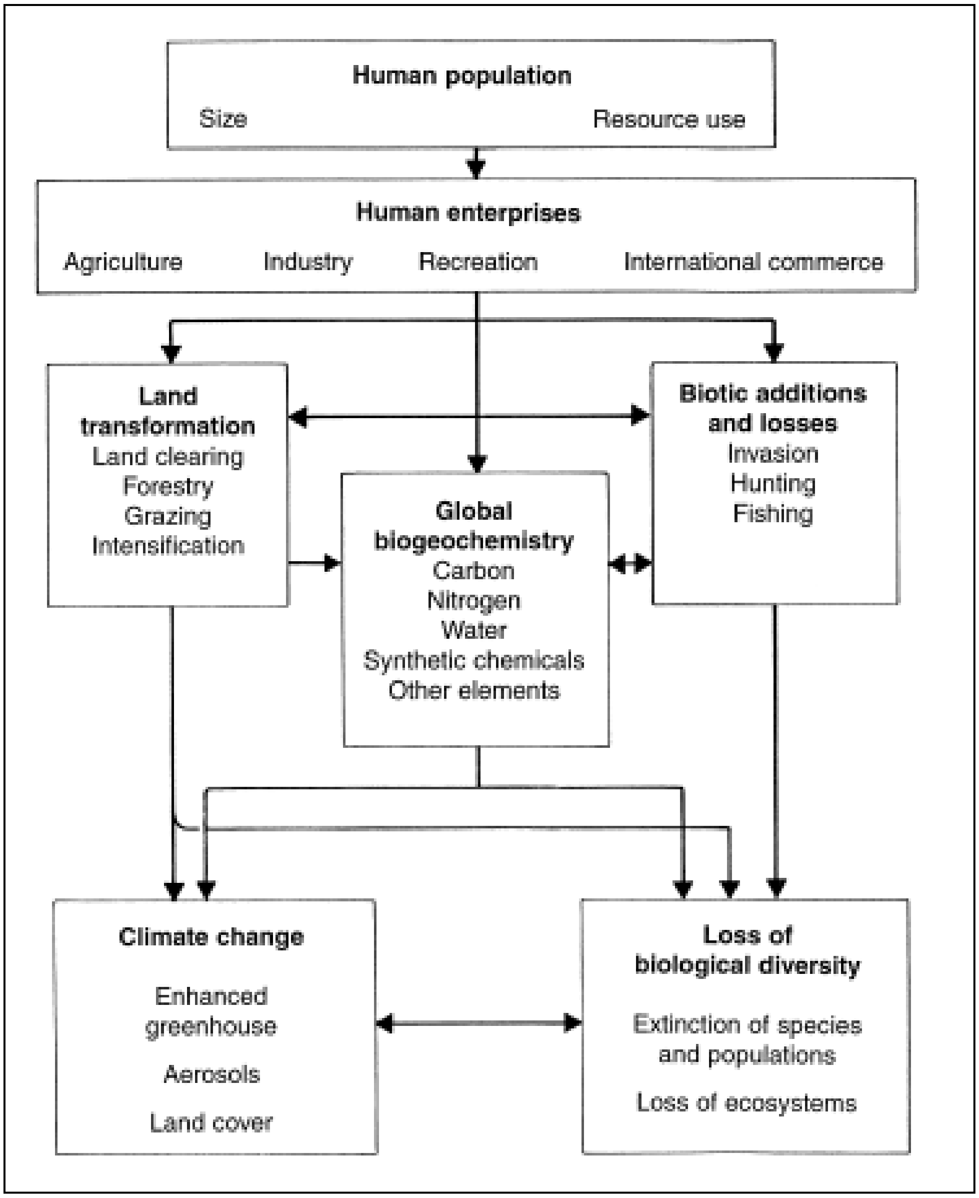

Figure 2.1: A conceptual model which outlines direct and indirect impacts of humanity on the Earth system

Source: (Vitousek et al., 1997)

SSFs are important at local, regional, national, and global levels as they are the key sources of food and jobs for millions of people in coastal communities (Martins et al., 2019; Nayak, 2017; Parrill, 2012). Current changes—environmental, social, market and institutional—put SSF communities at risk of vulnerability, unless their capital, social networks, and cultural identity are protected (Chuenpagdee, 2011). Global drivers respond to local and national level vulnerabilities causing adverse changes, but in effect these changes may serve as drivers affecting sustainability at higher rates.

For SSF, complex, dynamic, and multidimensional vulnerabilities may result in the absence of wellbeing, lack of access to capital and loss of resilience (Nayak & Berkes, 2019). Building resilience into human–environmental processes is a way to tackle uncertainty associated with vulnerabilities, such as change specified by surprises and unforeseen threats (Walker et. al., 2004; Haque & Etkin, 2007; Song & Chuenpagdee, 2013; Son, 2013). Resilience defines a systems' ability to absorb disruption and reorganize when undergoing change to effectively maintain the same identity, purpose, structure, and feedbacks (Adger, 2006). In the last few decades, Chilika Lagoon has been affected by impacts associated with anthropogenic change processes. The rise of shrimp aquaculture in the 1980s followed by the introduction of sea mouth opening in 2001 prompted concerns about livelihoods, access, and usage rights, as well as a shift in the lagoon economy and society's rules of engagement.

As a result, the capital, and resources of SSF communities in Chilika have been seriously threatened, contributing to a significant drop in resilience and wellbeing, as well as a worsening vulnerability. Table 2.1 shows the various vulnerabilities to which Chilika SSF communities are exposed. The Table also demonstrates the relationships between those vulnerabilities to different drivers of change, absence of wellbeing and resilience, availability of resources and capitals of the SSF community (Nayak & Berkes, 2011).

Table 2.1: Main aspects of vulnerability of small-scale fisheries in Chilika Lagoon to global change (Source: Nayak & Berkes, 2019)

Absence of wellbeing	Lack of access to capitals	Loss of resilience	Areas of vulnerability in Chilika small-scale fisheries sector	Resulting vulnerabilities in Chilika small-scale fisheries sector
Material	Natural Financial Physical	Lack capacity to absorb disturbance and reorganize while undergoing change	Ecological Problems Economic crisis Physical resources	• Loss of primary income and increased indebtedness • Lack of asset holding • Decline in quality and quantity of food - food insecurity • Pollution and adverse ecological changes • Shrinkage in lagoon fishing area and fish diversity • Protracted court cases, extraordinary financial implications • Fishing is capital intensive therefore unaffordable • Migration – income is not financially rewarding
Relational	Human Social	Lack capability for self-organization, learning and adaptation	Social crisis Economic dependence Political issues	• Breakdown of joint family/family support system • Increased dependence on external market • Increase in inter-village conflicts • Competitive fishing practices – unsustainable fishery • Encroachment – lack of access to fish stock and fishing grounds • Migration – family members forced to live separately • Migration – long absence weakens fishing rights • Loss of political voice
Subjective	Human Social		Individual and community level	• Loss of customary skill sets and knowledge • High dropout from school and low enrolment • Fishers turned wage labourers from entrepreneurs • Non-fishing activities disconnect fishers from 'Mother Chilika' • Fishers find it difficult to return to fishing after migration • Adverse mental and physical health conditions

Vulnerability stems from a lack of resilience in SSF communities and in societies' adaptive capacity to cope with and respond to stresses caused by social, cultural, economic, political, and environmental changes (Norris et. al., 2008; Berkes & Nayak, 2018). The notion, resilience, helps to determine hazards in social-ecological systems and give emphasis on the ability of a system to handle those hazards, including absorbing and withstanding disturbances or even adapting to them. Resilience is forward-looking, as it helps explore potential strategies and approaches including assisting in the development of policy alternatives to tackle with uncertainty and future changes (Berkes, 2007; Faulkner et. al., 2018). Vulnerability is a multidimensional, highly dynamic, complex, and relative concept. As such, its analysis requires transdisciplinarity (Nayak & Berkes, 2019; Chuenpagdee & Jentoft, 2018). Transdisciplinarity does not offer a mechanism to combine views; rather, it offers an approach that brings diverse ways of knowing and valuing in relation to one another by bringing attention to the variances and contradictions in how SSF are valued or not valued Johnson (et. al., 2019). As transdisciplinarity is aimed at bringing many disciplines and forms of knowledge to understand the multiple wicked problems related with SSF. This helps in building resilience and sustainability of social-ecological system changes. For example, understanding different perspectives of water pollution leads to understanding of fish diversity, structure of flora and fauna. The knowledge help in sustainable management of fisheries that maintains economy of SSF communities improving their livelihoods. Also, the information help in eradicating poor hygiene and sanitation practices in the region.

Resilience is tied to wellbeing, capital, and ultimately, viability. Enhancing wellbeing, improving access to capital assets, and increasing resilience will typically foster viability for SSF communities (Nayak & Berkes, 2019; Naranjo-Madrigal et. al., 2015; Chuenpagdee & Jentoft, 2018). Wellbeing is an outcome that includes material goals, such as economic production, food supply and job opportunities along with non-material aspects including safe, healthy, decent, and non-discriminatory working conditions in fisheries or ecological preservation of marine and coastal ecosystems (Nayak and Berkes 2019; Naranjo-Madrigal et. al., 2015; Weeratunge et. al., 2014). Wellbeing is also an analytical tool that can draw policy-makers' attention to the non-material benefits of fisheries, while also adding to their understanding of social and economic conditions in fishing communities (Fish et. al., 2016; Weeratunge et. al., 2014). The importance and usefulness of the concept of wellbeing as a normative definition and analytical tool provides one holistic lens to enhance understanding and governance of SSF (Weeratunge et. al., 2014).

A lack of access to capital assets - individual, physical, natural, economic, social, and financial—results in vulnerability (Chuenpagdee & Jentoft, 2018). Capitals and resources are a help for individuals and communities to advance their wellbeing through their management of facing multiple challenges in SSF (Chuenpagdee & Jentoft, 2018). Enhancing the wellbeing and access to capital for fishing-dependent communities including both fish workers and consumers has been suggested as a possible key aim of fisheries management. Access to capital can be achieved through capacity growth, as opposed to using development of the 'deficit' model which assumes that there exist deficiencies in the capability of the group in question. Addressing the deficit involves placing communities at the heart of capacity building and participation and empowerment in decision-making (Bockstael, 2017).

2.4 Coping and Adaptation

Coping reflects temporary responses to stressful situations, and they frequently manifest during periods of crises such as exceptional seasons or years such as time of flood or cyclone. Adaptation refers to changes in ecological, social, or economic systems as a result of existing or anticipated stressors (such as climate change, natural disasters), as well as their ramifications or consequences. It refers to adjustments in procedures, practices, and structures that are made to mitigate the effects of social ecological change or to take advantage of the opportunities that come with it. Adaptive strategies are the manners by which individuals or families and communities reform their profitable exercises and alter local guidelines and institutions (Diduck, 2010; Berkes & Armitage, 2010). Adapting is a behaviour that allocates people and financial resources toward various economic and non-economic opportunities (Ellis, 2000). Coping mechanisms are the ways people employ to adjust with painful or difficult situations while also maintaining their emotional health. Coping entails utilizing current resources in order to pursue, enjoy, or defend the same opportunities (Møller et al., 2019). Both responses may be used by different groups and organizations during a similar event and over time, coping may lead to adaptive strategies (Orr & Inoue, 2019; Berkes & Jolly, 2002). Coping mechanisms are bound to develop at the degree of the individual or household levels around at slight spatial scales in contrast adaptive strategies are identified with factors, for example, social qualities that change more gradually, are bound to rise at larger spatial scales (Jones & Boyd, 2011; Berkes & Jolly, 2002). Coping and adapting can be done by individuals, groups, organizations, communities and societies. It is a matter of behaviour and planning. In situations, where coping does not work, it leads to adaptation. Under conditions of adverse social-ecological change, adapting becomes more frequent and so it 'scales up'. The ability to express observation regarding these two sorts of responses helps to feature the multiscale idea of the progressing threats (Berkes & Jolly, 2002).

Three elements of coping strategies include: 1) innovation, 2) networking and 3) formation of identity (Bærenholdt & Aarsæther, 2002; Salmi, 2015). Innovation refers here to the capacity to discover new solutions to social, ecological, and economic issues. Networking focuses on the advancement of interpersonal relations that help people access different forms of capital. The ideas of ‘bridging’ and ‘bonding’ are utilized to feature various aspects of the institutions and upkeep of systems. Networks made up of bridging links to a varied web of resources can help a community adapt to change, but networks made up solely of local bonding links, which enforce social norms and nurture group homophily, might limit adaptation (Salmi, 2005; Salmi, 2015). Assessment of adaptive capacity is a key approach to articulate vulnerability and identify pathways for viability (Armitage, 2005).

Adaptation incorporates the capacity and ability to alter risk exposure related with environmental changes, assimilate, and improve losses coming from detrimental natural and human-induced in ecosystems. Vulnerability can serve as a motivator for versatile adaptive resource management as observed in some small-scale fisheries facing varying levels of uncertainty as a result of climatic change. A better understanding of how people adapt and adjust to fisheries with drastic natural changes would aid in the development of processes for dealing with the additional effects of future environmental change (Moreno & Becken, 2009). The overall dangers of environmental change on fisheries segments should also be understood in terms of their impact on other natural resource segments. There can be different risks that bring about elevated poverty levels including epidemic disease outbreaks, food insecurity, biodiversity reduction, vulnerabilities and marginalization, loss of livelihood and out-migration, political minimization, imbalance, and poor administration (Allison et. al.,2009). Allison and Ellis (2001) utilized a 'livelihoods approach' as a way to identify and learn from adapting strategies for fisheries management contrasting. 'Resilience' and 'sensitivity' were two significant concepts recognized by the authors that associated with adapting to sustain livelihoods. Allison and Ellis (2001, p. 378) explained that "resilience refers to the ability of an ecological or livelihood system to 'bounce back' from stress or shocks; while sensitivity refers to the magnitude of a system's response to an external disturbance" (Salmi, 2005; Salmi, 2015). In Resilience Alliance (2001), defines three characterizing attributes of resilience concept: It is an evaluation of (1) the measure of progress the system can experience and still hold similar controls on capacity and structure, (2) how much the system is fit for self-association as well as self-organization, and (3) the network's capacity to construct and increment its ability for adaptation and learning (Berkes & Jolly, 2002). Appropriate adaptation strategies enhance resilience in SSF communities and increases the contribution to proper water quality management.

Adaptive capacity follows a pathway of adapt, respond, and cope. The Intergovernmental Panel on Climate Change (2001, p. 982) defined adaptive capacity as ''the ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.'' (Orr & Inoue, 2019). Because adjustment does not happen quickly, the relationship between flexible capacity and defenselessness is very dependent on the time scales and threats we are dealing with. However, vulnerability to risks associated to climate variation that may occur in the near future will be determined by a current transient adapting capability rather than the ability to seek out long-term adaptation strategies (Brooks et al., 2005).

Viable adjustments are needed that help SSF in providing good nutrition from fish despite fast rise in human populations, high pressure on fishing, pollution, and lagoon developments. Adaptations are needed to minimise impacts from environmental change on fish stocks and biodiversity. Adaptations are best when they address both short-term and longer-term effects of social-ecological changes (Berkes & Jolly, 2002). Research suggests that information relating to sudden climatic changes and their impacts as well as environment-based methods need to be adopted to help SSF and fisheries managers to remain aware of potential rapid changes. Information can include vectors such as atmospheric variations on marine fish stocks, biodiversity and habitats with standard marine residency and potential influence on social capital, capacity in local administrations, culture, fishing rights and individual catch (Bell et. al., 2018). With regards to SSF, research suggests that adjustments should concentrate on building organizations and management decisions that will expand the capabilities of ecosystem and individuals to co-exist with unusual and potentially irreversible change (Berkes & Jolly, 2002). Adaptable and responsive organizations will offer the best approaches of mitigating negative impacts of irreversible change. As a result, there is a need to develop integrated and all-encompassing techniques that encourage strong and resilient small-scale fisheries that perceive both the threats to fisheries and livelihoods posed by environmental change (Allison et. al.,2009).

Explanation of a few terms associated with the last two literature sections on vulnerability and viability as well as coping and adaptation are listed in Box 2.2.

Box 2.2: Terminologies related to Vulnerability and Viability concepts

Definition
Adaptation: Responses to the risks posed by the combination of environmental hazards with human vulnerability (Smit & Wandel, 2006). Adapting is a pattern of behavior in which individuals and financial resources are allocated to diverse economic and non-economic opportunities (Ellis, 2000).
Adaptive capacity: Defined as a collection of resources and the ability to organize and employ them to respond to or adapt to stressors. The ability to adapt does not entail the presence of such resources, but rather the ability to use them wisely (Nelson, 2011). In the many definitions of adaptive capacity, capitals and resources are key components (Freduah et al., 2018).
Capital: Refers to the stocks of natural, social, or financial assets such as habitat, economy, and culture. It is the source of a variety of ecosystem "goods and services" that allow humans to exist and utilize the services in environment (Freduah et al., 2018).
Coping: Coping mechanisms are strategies that people use to adjust with painful or difficult situations while retaining their emotional health/well-being. Coping entails making use of available resources to pursue, enjoy, or defend the same opportunities (Møller et al., 2019).
Resilience: The ability of a system to respond to and absorb disturbance while maintaining essentially the same function, structure, and feedbacks is referred to as resilience (Holling, 1973).
Viability: The sets of traits that allow a system to survive and develop only in an environment to which it is adapted, or has adapted to it, are referred to as viability (Cury et. al, 2005). The viability strategy can aid in the gradual integration of ecosystem factors into fisheries management, such as conservation (Bossel, 2002).
Vulnerability: Refers to the state of susceptibility to get injured as a result of exposure to stresses connected with environmental and societal change, as well as a lack of ability to adapt (Adger, 2006). Vulnerability is defined as (i) lack of access to resources or capitals, (ii) absence of wellbeing, and (iii) loss of resilience in a three-dimensional context (Nayak & Berkes, 2019).

Wellbeing: A state of being in community with people, where human needs are addressed, where one may act purposefully to achieve one's objectives, and where one has a satisfying quality of life (McGregor, 2008).

2.5 I-ADApT as a Conceptual Framework for Social Ecological Systems

To characterize different sources of vulnerability related to water quality, my research uses an analytical tool called IMBeR Assessment of Responses based on Description, Appraisal, and Typology (I-ADApT). I-ADApT is an integrated assessment process designed to allow and improve decision-making in fisheries confronted with issues related to change (Bundy et. al., 2016; Whitney et. al., 2017). I-ADApT recognizes that marine environments are subjected to a complex collection of natural, social and governance drivers of change, with responses and interactions occurring at multiple levels and scales. I- ADApT emphasis on understanding how humans interact with the marine environment can help tackle important sources of vulnerability such as lack of shelter, declining livelihoods, food insecurity, poor nutrition, and declining health. The assessment aims to allow researchers, managers, decision-makers, and local stakeholders to understand and mitigate vulnerability, enhance resilience of coastal communities to global change through appropriate responses, effective decisions, and efficient resource allocation (Bundy et. al., 2016). The assessment is developed by the Human Dimensions Group of IMBeR (Integrated Marine Biogeochemistry and Ecosystem Research) project.

I-ADApT helps clarify different parts of a SES including identification of drivers in social ecological degradation (for example, reasons for water quality changes), how social and ecological variations work and interact at different scales to impact human response to change, and finally to find out responses as well as feedback effects on ecosystem structure and function. Using I-ADApt these linkages of the SES system including its governance that may cultivate or hinder adaptation are explored. The distinct segments inspect how stresses and changes in Chilika affect the environment, social, and administrative frameworks. The section looks at what the effects are, and how they react to administration at various institutional and administrative levels (Bundy et. al., 2016). The central area of my research investigates how water quality is affected by social and ecological changes and how SSF in Chilika see, decipher, and react to impacts related to vulnerability associated with these changes. In Figure 2.2, the outer circle describes a continuous loop, that can be entered at any level, and the inner circle implies that the natural, social, and governing systems should be extended to each portion of the Description (Bundy et. al., 2016).

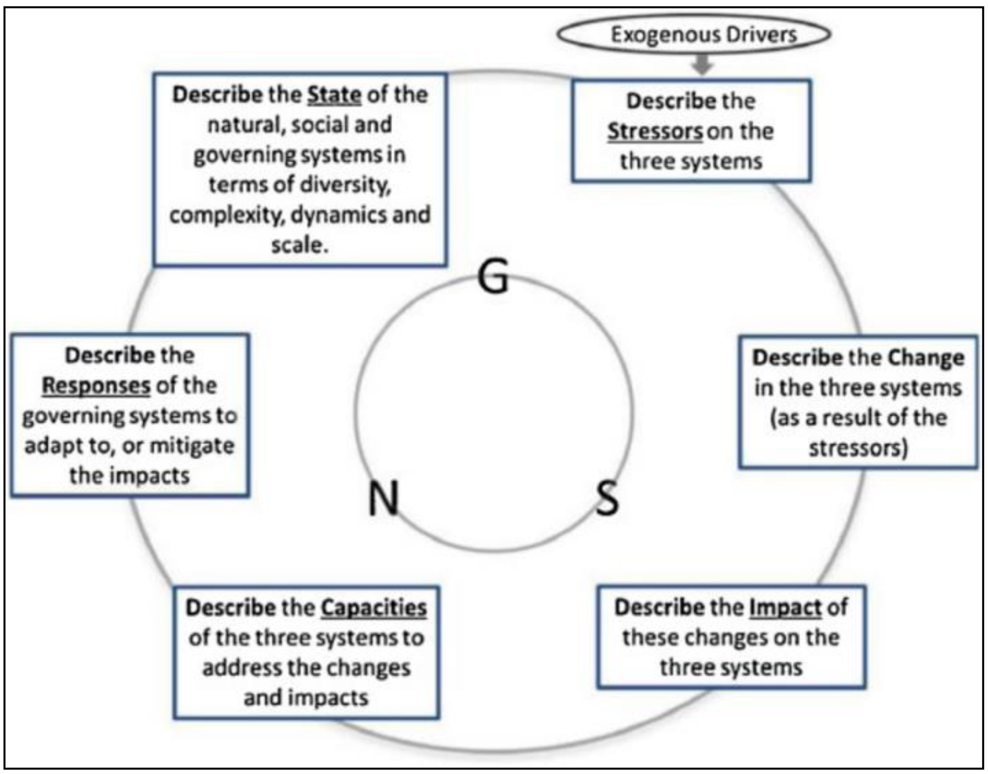

Figure 2.2: Layout of the distinctive steps for the Description and Response component of IMBeR-ADApT. N, S and G represents Natural, Social and Governing Systems. Note Stressors refers to anthropogenic or natural drivers of change**.**

(Source: Bundy et. al., 2016)

The I-ADApT Framework is designed to empower decision-makers, analysts, administrators, and local stakeholders in: (i) efficient decision making; (ii) triage and improved responses; and (iii) determining where resources are most efficiently deployed to minimize vulnerability and improve resilience in coastal communities to global change (Bundy et. al., 2016). The framework utilizes two basic theoretical and empirical tenets: (i) it reflects a system thinking approach to the relationships and interactions between people and their environments and (ii) it is focused on relational theory of governance which puts a great emphasis on understanding the interactions which takes place between human and natural systems. The structured nature of the tool, as well as consistent application in a range of cases encourages a stable frame of reference for research and recommendations based on natural, social, and governing processes and the global change threats to which researchers and decision-makers are responding. Figure 2.2 offers a visual portrayal of the theoretical system that arranges and depicts the key ideas applicable to my research in Chilika Lagoon. It is a good way to conceptualize my research intent and its aims of mapping relations between them using knowledge as derived from the literature review. Interactions among water quality changes, vulnerability, and viability along with adaptation are examined and these are captured in Figure 2.3.

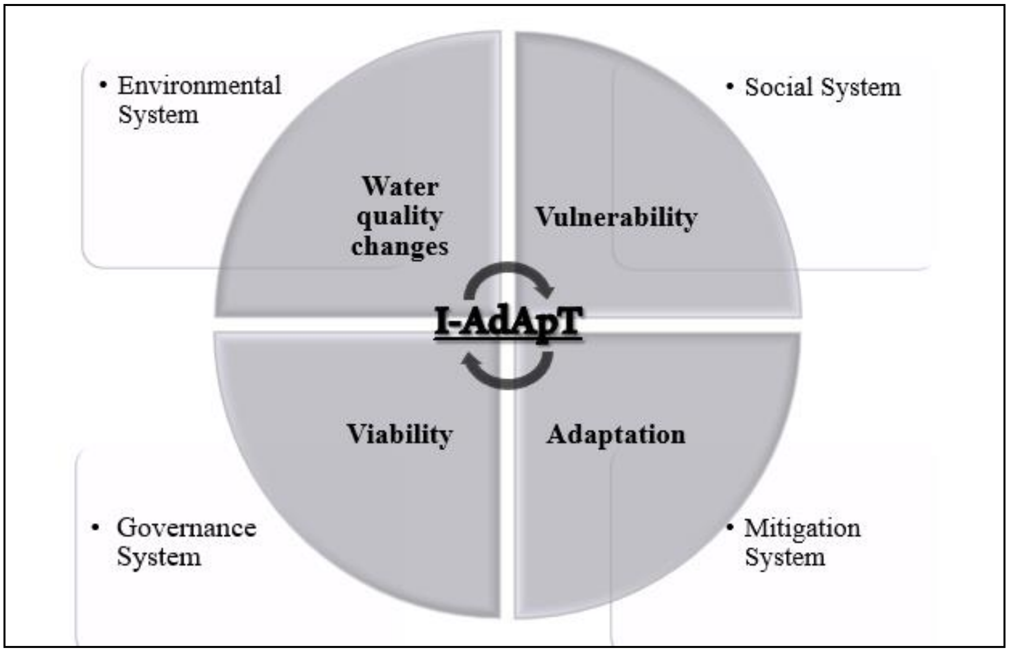

Figure 2.3: Conceptual framework representing core relationships in the research

In this research study, I-ADApT helps to frame questions such as "what can be learned from local or national responses to local and global changes that affects water quality and small-scale fishing communities", and "how can this knowledge be used to guide decisions about adaptation and mitigation strategies, to improve resilience and achieve viability?". I-ADApT provides the research tool to explore, examine and learn from the context-specific case studies such as in this research. The basis of the typology contributing to the learning platform, enabling comparative evaluations of response, and learning about vulnerability and viability and a classification tool for guiding decisions and policy evaluation is also obtained (Bundy et. al., 2016).

Using the I-ADApT tool, the current case study looked at the factors affecting water quality impacting livelihoods of small-scale fisheries in Chilika Lagoon. The study discusses various hydrological interventions including alterations in water quality parameters as well as stressors, vulnerabilities, and governance, and uses the I-ADApT decision support tool to assess the responses to these issues. The I-ADApT decision support tool is used to evaluate the whole-of-system concerns related to water quality and vulnerability of SSF in Chilika. This tool aided in assessing the dynamics inside and across social, environmental, and governance subsystems. The tool also revealed the system's current capabilities in terms of promoting viability through governance. Governance strategies include a variety of policy approaches, adaptation and mitigation measures, co-management, and multi-stakeholder participation, as well as accountability, and the integration of scientific and local ecological knowledge (Amparo et.al, 2017; Guillotreau et. al., 2017; Hofmann et.al, 2015; Vlachopoulou & Makino, 2017).

CHAPTER 3
Research Area and Methodology

3.1 Introduction

This chapter describes the case study area, research approach, and data collection methods. The case study area is Chilika Lagoon, Odisha, India. A mixed method research approach is used in the study to analyse water quality and vulnerability of SSF communities in the case study area. Possible strengths of both quantitative and qualitative methods were drawn through this approach. Strengths include enabling exploration of different viewpoints and revealing connections between the dynamic layers of complex issues faced by small-scale fishing sectors.

A descriptive–interpretive qualitative research approach was used to assess the historical context of the study area. Correlational as well as causal-comparative analysis were applied in evaluating secondary quantitative data associated with water quality in Chilika Lagoon. The limitations associated with the research methods and approaches are considered towards the end of this section.

3.2 Case Study Area: Chilika Lagoon, India

Chilika is Asia's biggest brackish water lagoon, situated on the East coast of India in the state of Odisha (Gupta, 2014). Since 1981, Chilika, the lifeline of the state of Odisha, has been listed as a Wetland of International Importance (Ramsar Site under the Convention on Wetlands) (Figure 3.1). Chilika fluctuates between a cumulative monsoon of 1,165 km^2 and a minimum dry season of 906 km^2. With a horizontal axis of 64.3 km and an average width of 20.1 km, the pear-shaped wetland stretches between 19°28'-19°54 'N and 85°6'-85°35' S (Kumar & Pattnaik, 2012). By means of an artificial sea mouth opening made in September 2001, the lagoon is connected to the Bay of Bengal near Satapada. Earlier, the lagoon was connected by a 24 km long narrow and curved channel running parallel to the coast joined with the Bay of Bengal near Arakhakuda (Sarkar et al., 2012). Chilika is an assemblage of marine, brackish, and freshwater habitats that are shallow to very shallow (Kumar & Pattnaik, 2012). A substantial part of this lagoon remains underwater during the winter and functions as a wetland and breeding and nesting grounds for millions of migratory bird species (Sarkar et al., 2012). It is the largest wintering ground found anywhere on the Indian subcontinent for migratory waterfowl and is the birthplace of Irrawaddy dolphins. It is estimated that the total number of fish species is over 225 (Sahu et, al., 2014).). The lagoon area also hosts over 350 species of nonaquatic plants, along with several species of phytoplankton, algae, and aquatic plants (Nayak, 2014). Chilika is also known for its rich array of fishing tools, typically used by fishermen belonging to specialized fishing caste classes. Those fishermen live in approximately 150 villages in and around Chilika (Nayak & Berkes, 2014). The abundant and complex assemblage of fish, invertebrates and crustacean species provides the resource base for fisheries. The resource base includes 73 fish, prawn, and crab species of economic importance with an estimated annual yield of 12,000 MT (Kumar et. al, 2020). Fisheries provide livelihoods to more than 140,000 fishing communities living around Chilika. The lagoon's high biodiversity and strong cultural values make it one of the significant tourist attractions in the state of Odisha. Per year, 300,000 domestic and foreign tourists visit Chilika (Kumar & Pattnaik, 2012). About 800,000 non-fisher villagers are also supported by Chilika's watershed. Some of them have turned to aquaculture as an income source (Nayak & Berkes, 2014).

Several hydrological effects are occurring in the lagoon such as (i) runoff from unregulated and depleted catchment basins lying on the western and southern borders, (ii) silt borne freshwater discharges from Mahanadi River distributaries and (iii) lagoon water exchanges with Bay of Bengal (Das & Panda, 2010; Panda et. al., 2013; Sarkar et. al., 2012). Changes in the frequency and complexity of these hydrological interactions for the lagoon may have dramatic and potentially unpredicted consequences, causing concern for local and national governments (Panigrahi et. al., 2007). As a response, conservation initiatives have been implemented such as dredging a new sea mouth and public awareness campaigns (Panda et. al., 2013; Sahu et, al., 2014).

Development of shrimp aquaculture and the introduction of an artificial sea mouth have served as drivers of rapid change in the lagoons' social-ecological environment (Jentoft, 2017). First, the sudden rise in the worldwide shrimp markets during 1980s and an increase in send-out costs made shrimp aquaculture a major driver of growth in the lagoon (Jentoft, 2017; Nayak & Armitage, 2018). Encroachment on standard fishing practices by non-fisher people from a higher caste increased significantly with the adoption of intensive shrimp aquaculture. This led to resource conflicts among caste-based catch fisheries, forcing poverty and marginalization for SSF livelihoods in communities (Nayak, 2017; Nayak & Armitage, 2018). Second, the state government created an artificial ocean mouth with the Bay of Bengal to manage persevering siltation problems in the lagoon in 2001. The consequences of the ocean mouth led to changes in water inflow-outflow rates and disrupted saltwater-freshwater balance (Nayak, 2017; Nayak & Armitage, 2018). Past research in Chilika highlights the adverse impacts of these changes contributing to the (1) reduction in fish production, incomes of fishers and impacting their livelihoods (Iwasaki & Shaw, 2008; Nayak & Berkes, 2010; Jentoft, 2017), (2) restrictions of fishing rights and access to customary fishing grounds (Nayak and Berkes, 2011; Jentoft, 2017), (3) shrinkage of water distribution and decrease in depth due to siltation, salinity decline, infestation of macrophytes, eutrophication and loss of biodiversity (Panigrahi et al., 2007; Panda et. al., 2010) and (4) increase in employment displacement and migration to cities for job opportunities (Robson and Nayak, 2010). Ever-growing impacts on the ecosystem components and functions affecting fish and fisheries of the lagoon can be grouped into direct impacts such as eutrophication, physical alterations, over-exploitation, socioeconomic issues, and pollution, while indirect impacts include sedimentation, watershed problems, channel or canal shallowness and human settlements (Panigrahi et al.,2007).

In Chilika, key environmental changes have included biodiversity loss (Nayak, 2017) and introduction of novel multi-species, and changes in the water system, including salinity variations (Panda et. al., 2010). Cultural and caste elements reflect loss of access, privilege, and jobs for SSF bringing about elevated levels of relocation of small-scale fishers, breakdown of fishery cooperatives and dynamic structures (e.g., related to water quality, production system) along with rising conflicts brought drastic changes in social system of the lagoon (Nayak, 2017; Nayak & Armitage, 2018). According to conservative estimates, illicit prawn aquaculture continues to occupy more than 60% of the Chilika Lagoon fishing area. The burden of extra lease costs combined with the decrease of fish output and fishers' falling income levels have become critical elements in fishers' loss of authority over resources in Chilika (Nayak & Berkes, 2011). Changes in hydrological regimes such as salinity variations and tidal interactions at the Chilika acted as ecological drivers, guiding large-scale changes in ecological (biodiversity loss, water quality variations), economic (reduced income and loss of livelihoods), institutional (breakdown of traditional leadership and fish co-operatives) and social (resource conflicts, culture, and identity loss of fishing communities) domains (Nayak & Armitage, 2018). Approaches that reflect less interference in fishing and assigning separate fishing techniques to each caste’s demands can prevent conflicts to some extent (Nayak & Berkes, 2011). Governmental policies and civil society's solutions to the ongoing crisis have failed to produce the anticipated results, and there are still unsolved concerns and complex uncertainties looming large over Chilika's future (Nayak & Armitage, 2018).

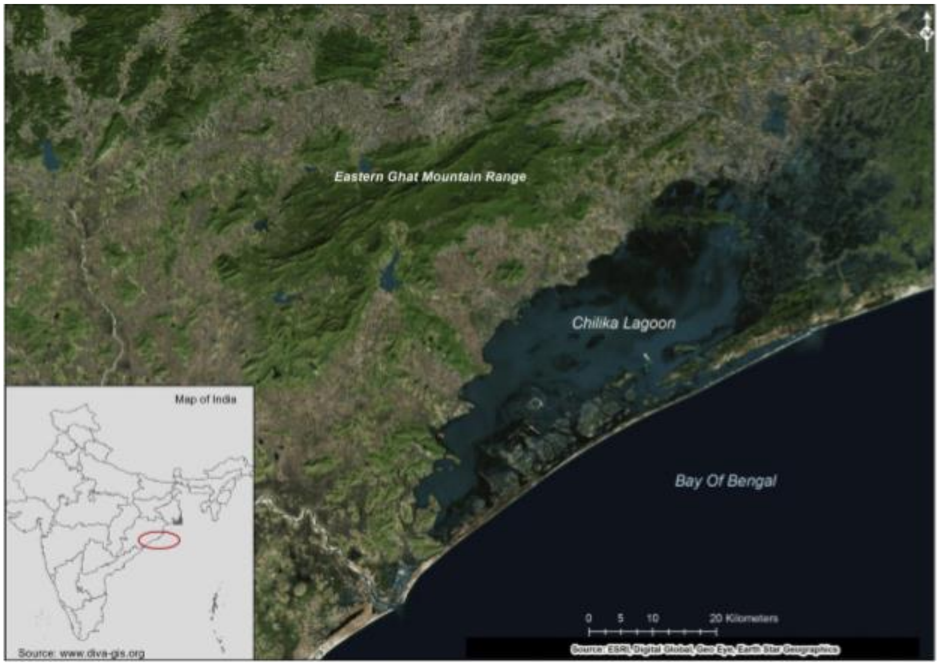

Figure 3.1: Map indicating study region in Chilika Lagoon
(Source: Nayak & Armitage, 2018)

3.3 Research Approach

As per Creswell and Creswell (2003, p. 3) a research approach reflects “plans and the procedures for research that span the steps from broad assumptions to detailed methods of data collection, analysis, and interpretation.” The broad approach to analysis is the study plan or proposal, which includes the convergence of theory related to the philosophical worldviews, research designs associated with the philosophical assumptions, and specific procedures or methods that convert them into practical aspect (Creswell & Creswell, 2003). Based on the problem context addressed, a research approach is selected for data collection, reasoning, and interpretation. Philosophical worldviews or paradigms are based on the set of underlying beliefs. They affect the research methods used in the methodology to provide credible data on the research study. I adopt a pragmatic worldview in my study where no one paradigm of thought or truth is dedicated to the research approach. Pragmatic research believe that every strategy has its own drawbacks, but each can be complementary to each other. This includes using a mixed method of study where both qualitative and quantitative perspectives are engaged in the research.

3.3.1 Case Study Approach

Case study approach enables in-depth and multi-faceted analysis of complex problems in a real-life context (Yin, 2012). The technique is especially useful when there is a need to gain deeper insights into an issue, occurrence, or phenomenon of interest (Crowe et al., 2011). Data are predominantly biographical and relates to historical and contemporary events. The research approach is used widely in social sciences and a broad range of disciplines. Case studies can be utilized to illustrate, characterize, and investigate events in daily situations. For instance, they help to clarify and describe casual ties and mechanisms resulting in a new policy proposal or development of services (Yin, 1994; Yin, 2012). The case study methodology is well suited to collect data on more explanatory issues responding to questions such as 'how', 'what' and 'why'. A case study approach can be based on how the intervention is being carried out providing insights into what weaknesses remain in the situation and why one method for implementation could be preferred over another. This then helps to build or refine theory (Crowe et al., 2011; Yin, 2014).

In the setting of Chilika Lagoon, a case study approach pivots to 'how' water quality conditions of Chilika Lagoon came to be, 'what' are the implication of water quality variation on small-scale fishing communities and 'why' maintaining quality of water important in vulnerability and viability of SSF. The case study approach reflects the historical context of social-ecological changes in Chilika Lagoon and importance of coping and adaptation strategies.

The qualitative case study is a research methodology that encourages the investigation of phenomena using a variety of data sources that speak to the research context. This means that the problem is not explored through one lens, but rather through a number of lenses that make it possible to expose and appreciate various dimensions of phenomena (Baxter & Jack, 2008). Case studies also shed light on facets of human thought and conduct that would be impractical from the perspective of other research approaches because of case study analyses' in-depth, exploratory, and multi-dimensional approach. Case studies will help create new ideas which are an effective way to explain and refine theories and can help clarify how various aspects of the life and livelihoods are connected to each other, drawing on a holistic point of view. Usually, case study includes a review of literature, grey literature, media, studies and more, to provide a basic understanding of the situation and to contribute to developing research questions (Heale & Twycross, 2018).

3.3.2 Mixed Method Approach

The combination of qualitative and quantitative research aspects is characterised in a mixed method research approach. As per Johnson et al. (2007, p. 123) mixed method approach is defined as: "Type of research in which a researcher or team of researchers combines elements of qualitative and quantitative research approaches (e.g., use of qualitative and quantitative viewpoints, data collection, analysis, inference techniques) for the broad purposes of breadth and depth of understanding and corroboration". Research on mixed methods is about increasing understanding and validity by comparing from a wide range of perspectives (Schoonenboom & Johnson, 2017). Figure 3.2 shows different combined research approaches along with subtypes of mixed methods. Mixed methods help to obtain a better understanding of quantitative and qualitative data links or contradictions. This also enriches the evidence base by exploring various perspectives and assisting in addressing the research questions in-depth (Shorten & Smith, 2017).

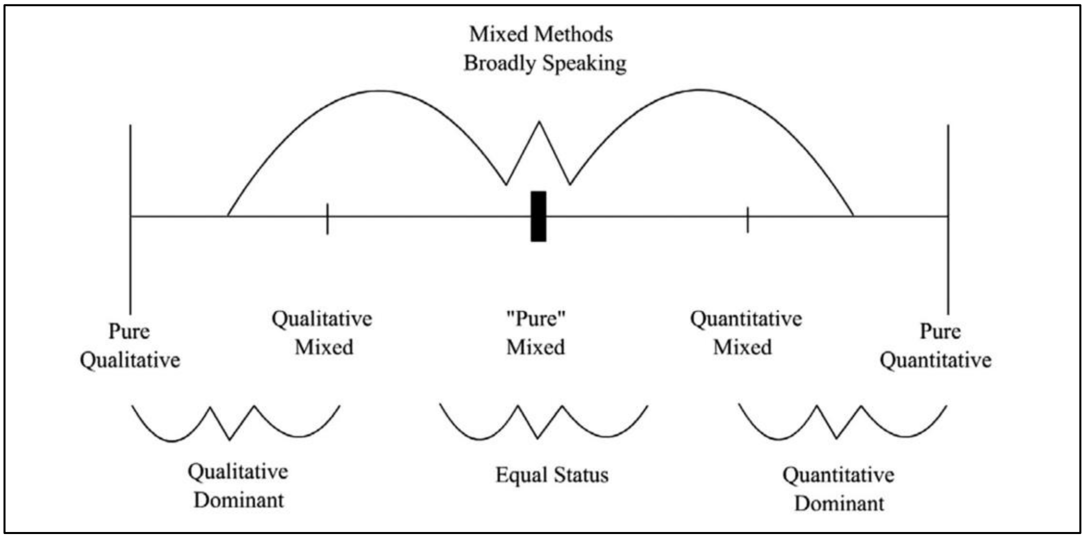

Figure 3.2: Major research paradigms including various research approaches
(Source: Johnson et. al., 2007)

In this research, the problem context of Chilika Lagoon is qualitatively assessed and quantitative studies on water quality in Chilika over the years are analyzed to obtain more detailed information. The convergent parallel design is employed for fulfilling the purpose which is indicated in Figure 3.3. In the same step of the research process, a convergent parallel design means that the researcher performs the quantitative and qualitative elements simultaneously, weighs the approaches equally, analyses the two components separately and interprets the findings together (Creswell & Clark, 2017).

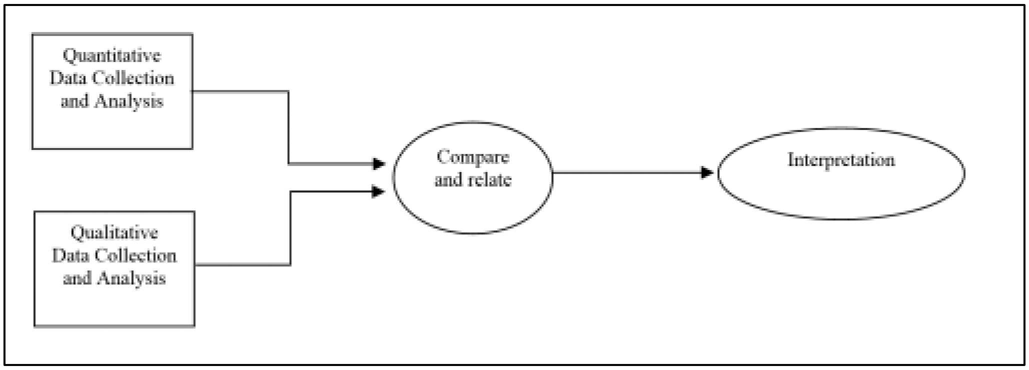

Figure 3.3: A convergent mixed-parallel design is used in this study
(Source: Johnson et. al., 2007)

In comparison to quantitative research which uses statistical data, qualitative research relies on non-numeric data. A descriptive–interpretive design is utilised to gather qualitative data which are ideal for defining interrelated, dynamic, complex issues in social processes and investigating hidden motives behind those processes. The design has its base in sociology, philosophy, and anthropology, while all endeavour to connect lives and livelihoods of people to a specific study location. The connection reflects exploring the whole life context of the community in a research location to understand human experiences and opportunities for effective governance (Elliott & Timulak, 2005; Seltman, 2015). While descriptive–interpretive research centers on qualitative data, quantitative data may provide a more reliable and clearer understanding than qualitative data of the context of study. In this study, various water quality parameters are assessed within a timeframe of 1950 to 2015 using the available secondary statistical data. The extent and trend of relationship of variables with time is interpreted leading to a correlational results. A quasi-experimental or causal-comparative research is also established through the connection of fish production and water quality.

3.4 Research Methods

Research methods refers to the procedures, strategies or techniques used to gather data for evaluation in order to find new knowledge or establish a better understanding of the research context. In this study, a mixed method research combining qualitative and quantitative research is used that offers a systematic and replicable approach. The approach blends, analyses and compares statistical data with more contextualised observations, allowing for triangulation.

3.4.1 Data Collection Methods

In this study, systematic method of data collection was followed on data related to water quality issues associated with vulnerability of SSF in Chilika Lagoon. It is focused on descriptive, qualitative, and quantitative data from the past studies conducted in the research area. Due to the travel restrictions of COVID-19 pandemic, various data collection methods planned for this research were not conducted such as semi-structured interviews, focus group discussions, surveys, and participant observation. Rather, I used a systematic literature review as method to gather data addressing the research gap of finding a link between water quality issues and small-scale fishing communities.

3.4.1.1 Literature Review

Literature refers to academic writing such as books, articles, peer-reviewed journals, dissertations, and conference papers on a specific topic. A systematic literature review refers to a secondary study to classify, consolidate, analyze critically, and collect the findings of related primary studies on a specific topic. The goal of the analysis would be to define, interpret, and critique the current existing literature to reveal research gaps in the current evidence base and to provide a conceptual and theoretical foundation for addressing those gaps (Aveyard, 2014). It is important to follow appropriate steps and measures to ensure that the analysis is conducted in reliable, accurate, credible, and replicable manner(Snyder, 2019). In systematic review, the typical phases of research process involve defining a research question, identifying relevant literature, reviewing that literature, analyzing the data, and interpreting the results. New ideas emerge that address the research question by filling in the gaps in the existing knowledge base, necessitating further investigation. The following steps explains the necessary stages in a research study of a literature review and is represented in Figure 3.4 (Aveyard, 2014).

- Research Question: The study query for the literature review set to progress the research.
- Methods: The search approach, method of evaluation and data analysis.
- Results: The included studies based on the objective of the research and the findings that address the research question.
- Recommendations: Discussion of the findings and suggestions for improving the research gap.

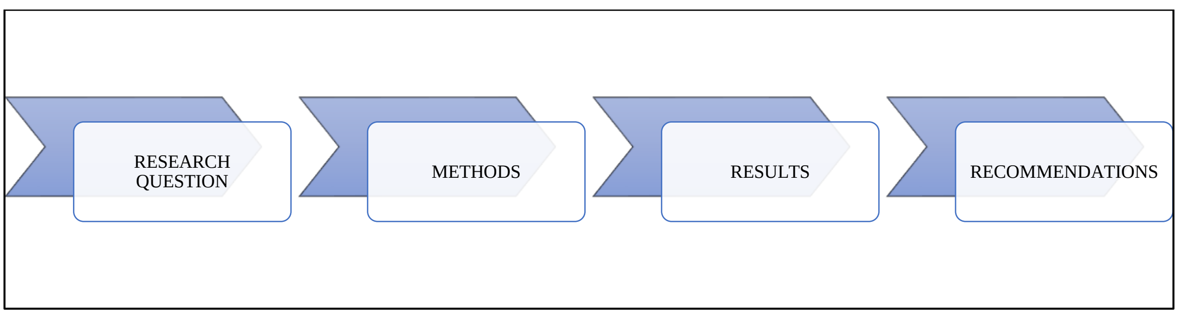

Figure 3.4: Phases of research process in a literature review

3.4.1.1.1 Systematic Literature Review

A systematic literature review can be defined as a tool in research as well as a process to classify and critically evaluate relevant information, including by collecting and analysing data from past studies. The main aim of a systematic review is to find all the empirical data that matches the research objectives and to answer the research questions or hypothesis of the study (Snyder, 2019). One of the key characteristics of a systematic literature review is that the academicians adopt a strict procedure to confirm that the review process conducted is rigorous and transparent, using clear methods to classify, objectively analyse and synthesize applicable work to address a predefined research question (Aveyard, 2014). High quality literature in addition to systematic literature reviews can be very important to address the research question and analyse the research gap. Systematic reviews have a comprehensive research methodology and analysis which could be treated as a rigorous type of evidence applicable to mark the research question. The aim is to summarise the whole information on the specific subject allowing to depict the entire content of the research rather than identifying a small potion of it (Aveyard, 2014). The key steps involved in a systematic analysis of literature for this study are as follows as (Figure 3.5):

1. *Framing Questions*: As a primary step, I explained the need of the study and described its purpose and necessary objectives. I identified the research question to investigate the specific topic. At this step, initial searches can be used to scope potential areas of concern and topics. I tried to explore the context of Chilika Lagoon by using this process which helped to pin down various issues in the SSF communities. In turn, the scoping helped me formulate research questions.
2. *Literature Identification*: The next step was to explore and screen the relevant literature to be included in the analysis. I reviewed published and unpublished research included in the study area. These include related papers in few top-tiered journals related to the study area and previous works related to the thesis’ topics and case study area such as the conceptual papers or empirical studies. I selected popular journal databases such as Scopus, ScienceDirect and Jstor and included papers specific to the relative to my study area and research objective.

3. *Screening and Inclusion*: This step focuses on the applicability of the material gathered by refining the search through determination of relevant papers collected. This improves objectivity and minimises errors. I omitted the papers that address issues like climate change in coastal fisheries broadly and papers in different study contexts. I included papers that reflected studies in Chilika Lagoon related to topics such as water quality and aquaculture.

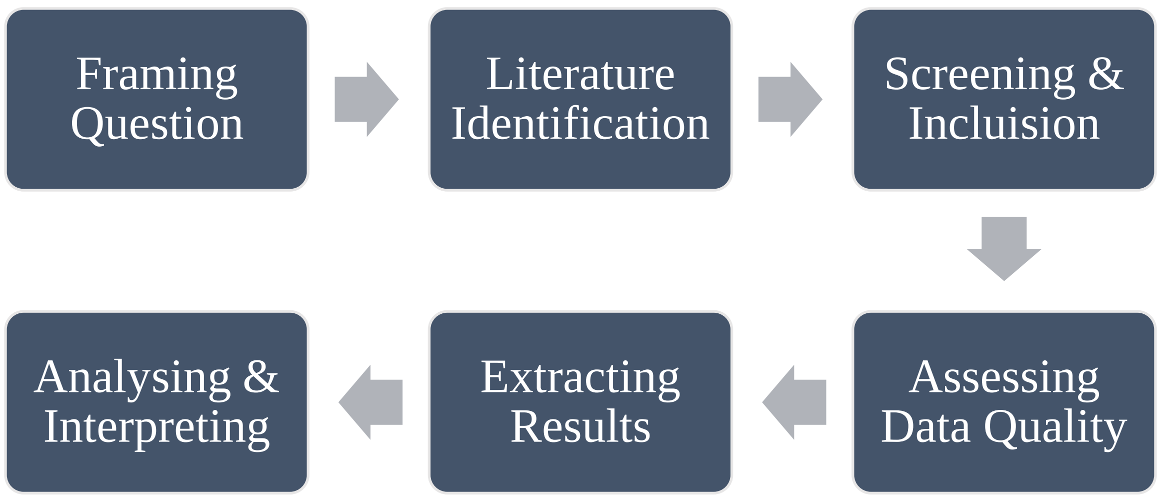

Figure 3.5: Phases of research process in a literature review

4. *Assessing Quality of Data*: Along with the screening, quality of the data needs to be investigated to evaluate the empirical validity of each study. This is the effect of evaluating the rigour of the study design and methods used across the sample. I carried out such formal evaluation independently and within our research group to exclude more studies of less quality and decide the factors that influence evaluate and interpret the results.

5. *Extracting Results*: This step involves collecting and extracting relevant information from the studies. Qualitative and quantitative data were extracted related to various water quality analysis conducted in Chilika to get an idea about the changes in water quality as well as the hydrological interventions. Various social-ecological changes in Chilika Lagoon, vulnerability, and viability of SSF are recognised in this process.
6. *Analyzing and Interpreting*: As a concluding step, relevant data are collated, analysed, evaluated, arranged, and compared across the sample. This step involves creating conclusions on the status of the SSF, problems of vulnerability in Chilika, and related research gaps and opportunities.

While all the above steps are discussed in sequential order, they may occur iteratively in the evaluation process in which several activities can be introduced and subsequently refined during the later stages. Thus, quantitative analysis of water quality variation and qualitative studies on SSF and changes in SES in Chilika are carried out. Spotting literatures linked to my research topic confirmed the research gap discovered in my study.

3.4.1.1.2 Zotero as a Research Tool for Systematic Literature Review

In my study, a systematic literature review to supplement previous studies carried out in comparable contexts of coastal and marine populations, understand the social and environmental changes as well as the consequences affecting the livelihood and wellbeing of small-scale fisheries sector, uphold the data obtained and draw on the current hypothesis and answer the research questions. The systematic literature review was carried out with the aid of the citation and reference management tool, Zotero. Zotero is a digital research platform that lets users to gathers and format bibliographic and citation sources. It is a more comprehensive reference manager that helps to compile, organize, annotate, and distribute references for users (Winslow et. al., 2016). Zotero is compatible with Google Scholar, ScienceDirect and various other internet browser-accessible databases and library tools upbringing an order of resources helping users a frequent access (Vanhecke, 2008).In addition to the creation of in-text citations and bibliographies, Zotero offers functions such as integration of web browsers and word processors. Based on the three literature areas, study area and methods employed in the study, bibliographic data of more than 335 research materials were added and arranged in Zotero.

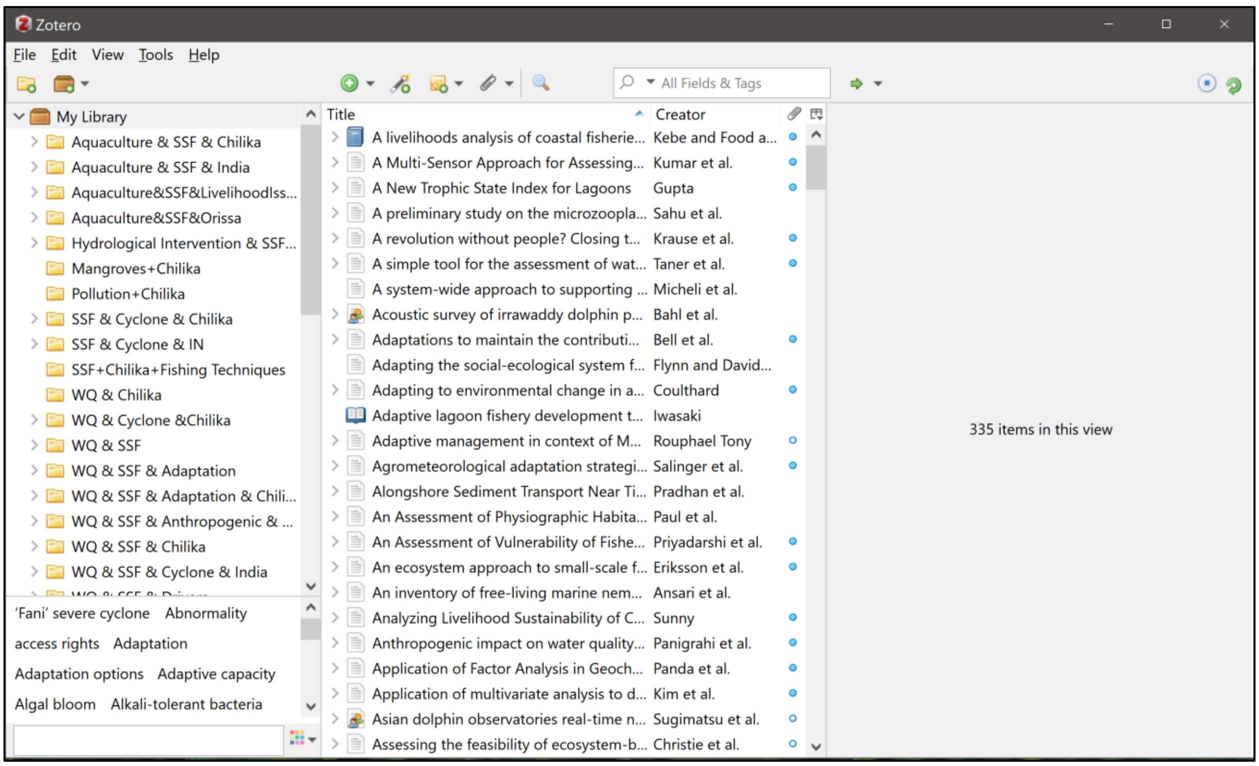

Figure 3.6: Zotero used as a reference management tool for enhancing systematic literature review process

The various steps involved in reaching to 335 research materials related to the specific research of water quality analysis and small-scale fisheries are described below:

- *Formulating Keywords & Creating Search Category*: The search for literature started with preparing keywords and combinations of keywords related to the study. To ensure the search is thorough, it is necessary to find all the appropriate keywords for the research topic by identifying word variants, synonyms, and related concepts. Table 3.1 indicates several search terms that was selected initially to identify proper keywords for the study. Typically, scoping exercises help in producing best range of keywords in the study findings. Combining keywords using the Boolean logic supports effective use of combinations of keywords. The most popularly used operators are AND, OR and NOT. As shown in Figure 3.6, my search involved AND as it will narrow our search results based on studies that use both terms. The truncation symbol is another generic search operator that was added to the end of the root word to search all the ending variations of a search word. For example, small-scale fish* would find small-scale fisheries, small-scale fishing, and so on. Providing quotation marks can also assist in filtering with a specific keyword or sentence to provide an exact match such as “small-scale fisheries”.

Table 3.1: Initial development of keywords for searching relevant literatures

Objective 1	Objective 2	Objective 3
Water quality	Drivers	Small-Scale Fisheries
Aquaculture	Anthropogenic Activities	Livelihoods
Eutrophication	Human-Environmental Relation	Wellbeing
Hydrological Variation	Social-Ecological Change	Marginalization
Chilika Lagoon, India	Sustainability	Governance
Orissa	Stressors	Viability
IMBeR-ADApT	Natural Disasters	Resilience
	Cyclone	Coping
	Vulnerability	Adaptive Responses

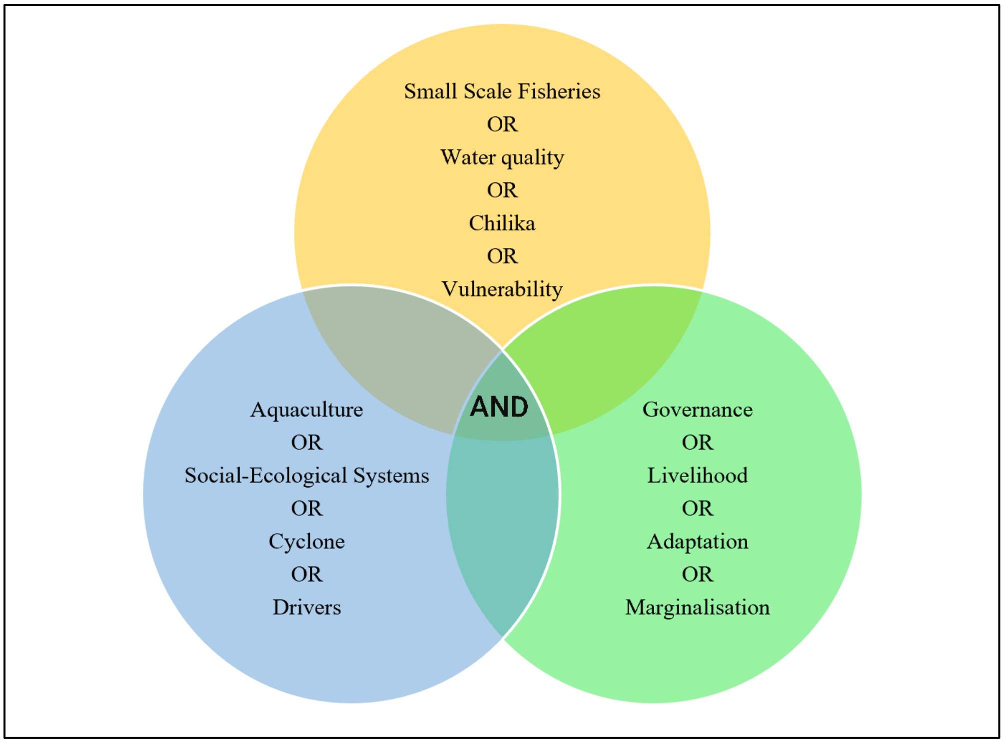

Figure 3.7: Illustration of combining keywords using Boolean operators

- *Identifying Databases & Gathering Information*: Databases of similar studies were checked out to find the common sources with Scopus, ScienceDirect and Jstor. Illustrated in Table 3.2, the initial search in databases started off with keywords and their combinations. The combinations indicated in red font did not yield results in any of the databases. The use of various databases when looking for specific references is advisable although the process can be a bit time consuming and laborious. I found Scopus, ScienceDirect and Jstor as more discipline-specific database which strengthened systemization of my review. Google Scholar's advanced search features were also used for searching individual papers in terms of citation index. Materials collected as per the search in each data base were transferred to Zotero.

Table 3.2: List of keyword search combinations used to obtain literatures (S-Scopus, J- JSTOR, SD- ScienceDirect, GS- Google Scholar)

Search Combination	S	J	SD	GS	Total
"Mangroves" AND "Chilika"	0	0	0	5	5
"Pollution" AND "Chilika"	0	0	0	6	6
"Water quality" AND "Chilika"	0	0	0	165	165
"Water quality" AND "Small Scale Fisheries"	1	0	0	2	3
"Water quality" AND "Small Scale Fisheries*" AND "Chilika"	0	5	2	2	9
"Water quality" AND "Small Scale Fisheries" AND "Orissa"	0	1	0	0	1
"Water quality" AND "Small Scale Fisheries" AND "India"	0	10	0	0	10
"Water quality" AND "Small Scale Fisheries" AND "Livelihood Issues	0	0	0	0	0
"Aquaculture" AND "Small Scale Fisheries"	0	0	0	0	0
"Aquaculture" AND "Small Scale Fisheries*" AND "Chilika"	3	6	4	1	14
"Aquaculture" AND "Small Scale Fisheries" AND "Orissa"	0	4	0	0	4
"Aquaculture" AND "Small Scale Fisheries" AND "India"	0	13	16	0	29
"Aquaculture" AND "Small Scale Fisheries" AND "Livelihood Issues"	0	1	2	0	3
"Hydrological Variation" AND "Small Scale Fisheries" AND "Chilika"	0	0	0	0	0
"Hydrological Variation" AND "Small Scale Fisheries" AND "India"	0	0	0	0	0
"Water quality" AND "Small Scale Fisheries" AND "Cyclone" AND "Chilika"	0	0	0	0	0
"Water quality" AND "Small Scale Fisheries*" AND "Cyclone" AND "India"	0	1	1	2	4
"Small Scale Fisheries" AND "Chilika" AND "Fishing Techniques"	0	0	0	16	16
"Small Scale Fisheries" AND "Cyclone" AND "Chilika"	0	0	0	2	2

“Small Scale Fisheries” AND “Cyclone” AND “India”	0	4	10	0	14
“Water quality” AND “Cyclone” AND “Chilika”	5	3	10	0	18
“Water quality” AND “Small Scale Fisheries” AND “Anthropogenic” AND “Chilika”	0	2	1	2	5
“Water quality” AND “Small Scale Fisheries” AND “Viability”	0	9	9	0	18
“Water quality” AND “Small Scale Fisheries” AND “Viability” AND ‘Chilika”	0	3	0	0	3
“Water quality” AND ‘Small Scale Fisheries” AND “Vulnerability”	0	13	9	0	22
“Water quality” AND “Small Scale Fisheries” AND “Vulnerability” AND “Chilika”	0	2	1	0	3
“Water quality” AND “Small Scale Fisheries” AND “Encroachment”	0	3	0	0	3
“Water quality” AND “Small Scale Fisheries*” AND “Encroachment’ AND “Chilika”	0	1	1	0	2
“Water quality” AND “Small Scale Fisheries” AND “Drivers”	1	11	22	0	34
“Water quality” AND “Small Scale Fisheries” AND “Drivers” AND “Chilika”	0	5	1	0	6
“Water quality” AND “Small Scale Fisheries” AND “Livelihood”	0	12	13	3	28
“Water quality” AND “Small Scale Fisheries” AND “Livelihood” AND “Chilika”	0	5	2	3	10
“Water quality” AND “Small Scale Fisheries” AND “Marginalization”	0	10	8	0	18
“Water quality” AND “Small Scale Fisheries” AND “Marginalization” AND “Chilika”	0	5	1	0	6
“Water quality” AND “Small Scale Fisheries” AND “Adaptation”	0	12	8	1	21

“Water quality” AND “Small Scale Fisheries” AND “Adaptation” AND “Chilika”	0	4	1	0	5
“Water quality” AND “Small Scale Fisheries” AND “Governance”	0	14	12	0	26
“Water quality” AND “Small Scale Fisheries” AND “Governance” AND “Chilika”	0	5	2	1	8
“Water quality” AND “Small Scale Fisheries” AND “Social-Ecological Systems”	0	0	0	15	15
“Water quality” AND “Small Scale Fisheries” AND “Social-Ecological Systems “AND “Chilika”	0	4	1	0	5
“Water quality*” AND “Small Scale Fisheries*” AND “Physicochemical parameters” AND “Chilika”	0	0	0	0	0
“Hydrological Intervention” AND “Small Scale Fisheries” AND “Chilika”	0	1	1	0	2
“Hydrological Intervention” AND “Small Scale Fisheries” AND “India”	0	0	0	0	0
Others	0	0	0	0	0
Grand Total Papers					**543**

- *Categorising Data*: Different folders were created in Zotero based on the keyword combinations and databases to sort the collected materials into specific document cases. A total of around 983 materials were obtained with all the various combinations of keywords and various databases. Additional features in Zotero like notes helps in providing annotated bibliography of added resources; tags can be added to categorize items with detailed characterization and the collections arrange sources in groups and subgroups hierarchically which manages items belonging to specific topic or source.
- *Assessing and Retaining Relevant Materials*: Narrowing down of materials and organizing them can be achieved by sorting them chronologically related to water quality assessments

over time in Chilika, consequences of events in Chilika, and conceptual categories. Specific search hedge or filter can aid in screening the data such that only sources that are relevant to the research study are picked which is a most powerful feature of a database. The collected materials were screened based on the location-specific and objective oriented structure related to my research to form a more concise sample. Scrutinising resulted in a comprehensive sample of 335 materials (Figure 3.7).

- *Analysing and Interpreting Results*: The selected resources were utilised to develop the results chapter to further refine the research objective. The comparative analysis and evaluation of the past studies pillars the research purpose and objective filling out the identified gap in my research study.

This process through Zotero, assisted in creating a systematic literature review to address the research question and draw up the results. Zotero is integrated with Microsoft word and other computer formats making the process of developing the research in a convenient way (Winslow et. al., 2016).

3.4.2 Data Analysis and Interpretation

From the systematic literature review, I collected secondary quantitative data on water quality parameters of Chilika lagoon from 1950 to 2015 and created graphical representation of the water quality variation. The contrast trend in water quality parameters assisted qualitative interpretations of the hydrological conditions of Chilika. I used qualitative content analysis approach to interpret my data employing deductive and inductive data analysis (Hsieh & Shannon, 2005). In this analysis, I related my observations to the literature areas associated with the social-ecological changes in Chilika and similar coastal context. Analysis of qualitative content is one of numerous research techniques used to interpret knowledge about content. The focus of qualitative content analysis is on linguistic features as a correlation with material or conceptual sense. Maintaining notes on relevant literatures identified improves data analysis. It will be progressive and viable to set up updates to account contemplations on the various phenomena, connections between subjects, categories, and codes. Thematic analysis is a type of example that includes distinguishing key subjects that develop from various phenomena under investigation (Hsieh & Shannon, 2005).

3.5 Limitations

There are a few main limitations which are commonly associated with the research approach used in this study:

- *Lack of availability in reliable data*: Variation in livelihood perception may result from obtaining ineffective data sources (Holkup et. al., 2004). Effective ways of integrating qualitative and quantitative data can leads to misinterpretation on data. The credibility or reliability or validity of mixed studies is also a potential problem (Johnson et al. 2007). Case study approaches that lack scientific rigor and providing the general public with no basis for generalization of findings can also be considered.
- *Ethical issues*: Confidentiality issues can pose a concern associated with collaborative research. Therefore, active members in the research, who plays dual roles as community representative and research teammate, might be favoured in accessing unavailable data (Holkup et. al., 2004). There is also a chance of portraying the community and data collection in an inaccurate way when working across societies which are multi-cultural.
- *Social circumstances:* Working within a culture other than one's own is complex in nature although from the start it may appear to be consistent and direct. In spite of the fact that it is critical to comprehend across cultures, it is similarly significant not to expect that each individual inside a culture will display all social and cultural characteristics and practices.

Alert is required when attempting to utilize culture as a structure for understanding individual behavior. Similarly, researchers need to pay attention to their own biases, social reasoning, and standards of conduct. Furthermore, it is essential to understand that government administrations and different organizations will impact the cultural group in general or potentially the evolution of an undertaking. Working with socially diverse communities requires a multicultural direction on numerous levels and carries a level of unpredictability that requires our mindfulness and a skilful route (Holkup et. al., 2004).

- *Other restraints*: Various other obstructions such as lack of geographical awareness, social and cultural operations as well as activities of communities and consensus can lead to misinterpretations of data collection. Fewer studies relating to water quality issues and livelihoods of communities limit the body of literature demanding exploratory research. Conflict issues in association with caste-based system in cultural-social sectors of communities make it difficult in obtaining accurate information in secondary sources. The research aims will be constrained by data relating to highly influential anthropogenic activities. As the research even has time boundaries, quantitative analysis of water and fish samples to identify their diversity for traversing through the biodiversity loss is not possible. Also, travel restrictions and absence from field study adds up to this.

3.6 Researcher's Reflection

The COVID-19 pandemic had a significant impact on my research methods proposed for field study in Chilika Lagoon. I had questionnaires for a survey, interviews and focus groups prepared for fieldwork in Chilika during May 2020. However, fieldwork was prevented by initial travel restrictions determined by the university for conducting in-person research, followed by flight cancellations and then, adverse conditions in India. The COVID-19 cases were rising while

I kept my ethics on hold in the hope of conducting methods by virtual or no-contact techniques such as interviews over the telephone. At every step of the way, hoping for and navigating the desire to return to in-person research was really challenging. So, I shifted to desktop research using mixed methods. Although the research was completed with interesting results, the research process was extremely difficult. I kept thinking that more could be learned through primary data collection involving participant observation and to exactly capture the feelings and experiences in SSF communities in Chilika. In the end, however, my ethics application was cancelled as there was no option of conducting virtual data collection due to huge spike of pandemic cases and related deaths during December 2020. The pandemic also touched me personally. My family was scattered in regions and was significantly affected by the virus. My father was in the Middle East. My mother and sister were in two far cities in South India. It was incredibly stressful just to get their updates every single day while wrapping up my thesis.

The online research along with stay-at-home order, declaration of state emergency, lock down updates from India, news relating to numerous deaths and hospitalizations temporarily slowed my thesis work. How can one concentrate and work or study when the whole world around is going through such an event without any anticipated solution? For me, life during this pandemic season has two sides like on a coin. On one side, I was observing challenges and struggles faced by entire world with increasing illness and death rates. On the other side, as an environment researcher, I saw environmental improvements in many countries such as China, Iran, South Korea, Italy, United States and even my home country. Lockdowns fostered spotless skies and clear visons replacing unbearable levels of smog. Some before and after pictures of lockdown in India are shared below in Figure 3.8. It is a silver lining that can be found over the world, with megacities reporting extraordinary reductions in pollution due to varied coronavirus restrictions.

Figure 3.8: Before and After lock-down pictures in New Delhi, India: Yamuna River pollution (Top); India Gate war memorial (Middle);
Aerial view of the Connaught Place area (Bottom) during October 2019 and April 2020
(Adapted from Fadnavis et. al, 2020)

Unfortunately, silver linings did not help the huge difficulty I faced during this writing phase. I hope to make good use of my fieldwork plans during my upcoming doctoral studies with the same working group “Vulnerability to Viability”. So, I am very optimistic that I can add additional perspectives to this current study. In other words, I look forward to studying a better tomorrow with less pollution and better living conditions.

CHAPTER 4
Water Quality as a Determinant of Vulnerabilities in Small-Scale Fishing Communities of Chilika

4.1 Introduction

The unique morphological, biological, and hydrodynamic characteristics of coastal lagoon environments serve as intermediate areas between inshore and open freshwaters. Lagoons act as an interface among terrestrial, coastal, and aquatic environments. Lagoons can be considered as an ecotone between the terrestrial and aquatic ecosystem that obtain variable freshwater quantities. Due to the rising population and human activities along with natural drivers of change such as cyclones, lagoons become degraded without proper management. Coastal lagoons are often prone to pollution and eutrophication leading to degradation of water quality over the long term. Movement of water in coastal lagoons can vary widely based on the evaporation, water inflow-outflow rates, surface runoff, groundwater discharge and precipitation. Understanding water quality often seems to be complex due to the variations and interactions between biological and physio-chemical parameters. Water safety is a significant factor related to a range of issues from entertainment (in terms of tourism) to public welfare (such as domestic purposes). From the perspective of lagoons, Chilika ecosystem sustains vegetation, birdlife, marine populations, and livelihood of SSF communities. The nature and quality of water in Chilika lagoon play principal roles in managing productivity of ecosystem health and services. Water pollution is not just about increasing waste accumulation in coastal lagoons, but instead is a highly complicated phenomenon affected by additional several variables. These include availability of fish, food abundance and nutrition, complexities of economy and livelihood, gender, and other social ties. In this chapter the focus is on the linkages between water quality changes and the related problems in SSF, and how both are collectively driven by social-ecological changes that produce vulnerability of SSF.

Emerging literature on SSF and variation in water quality parameters addresses different themes including community needs and development, biodiversity loss and protection, ecological sustainability, and resilience and adaptation. Yet, discussions are limited on the connection between water quality change and SSF communities compared to other sources of vulnerability in SSF research such as areas of nutrition, economic fallout, and poverty (FAO, 2015; Kurien, 2015). My goal is to illustrate how water quality variation is worth studying by analyzing associated vulnerabilities faced in SSF communities. Hence this chapter focuses on findings of the first two study objectives (Box 4.1) to understand changing water quality parameters and the vulnerabilities for coastal communities resulting from water quality as a significant driver of change, including its associated causes and impacts.

Box 4.1 Outline of research objectives

1. ***Understanding processes of water quality variations in Chilika lagoon***
2. ***Examining vulnerability issues faced by the coastal communities due to changes in water quality***
3. Analysing various coping and adaptive responses of the fisher communities and their potential for creating viable small-scale fisheries

4.2 Chilika Lagoon: Social, Biological and Physical Features

Chilika lagoon is the biggest tidal lagoon in India's eastern coast. The lagoon is a key hotspot for diversity with respect to rare, fragile, endangered, and threatened species on the Indian sub-continent. The Chilika lagoon ecosystem is home to around 225 fish species, 710 plants varieties and 800 diverse fauna races (Nayak, 2014). Chilika represents a shallow lagoon with an estuarine character. This supports a highly productive habitat with abundant opportunities for fisheries (Mohapatra et. al, 2007; Myrbo, 2012). The fertile fishing area once supported the livelihoods of over 400,000 fishers residing in and around the lagoon (Nayak, 2014).

The lagoon is pear-shaped. It is 64 km wide and is connected to the sea by a channel that reduces flow of water. A narrow spit separates the lagoon from Bay of Bengal. The spit was formed by rapid shifts in coastal vegetation such as winds moving sand towards shoreline, high precipitation, and tidal currents. Due to the rising sedimentation and siltation, the lagoon became shallow forming sandbanks and many islands. Substantial portions of the lagoon stay underwater throughout the winter acting as wetlands, which often support millions of migratory birds as their feeding and shelter areas. In summer, there is a major effect on the water spread area of the lagoon due to the strong evaporation from deep waters and large freshwater inflow from numerous streams and rivers. The lagoon ecosystem is under extreme pressure from siltation over the years, salinity variation, algae infestation, and pollution. This leads to biodiversity loss. Drastic implications are also brought about by intense natural drivers of change such as a cyclone in 1999. Seasonally, the level of water in the lagoon fluctuates with tidal currents. Likewise, every year, different areas of the Chilika lagoon submerges and reappears (Myrbo, 2012).

4.2.1 Small-scale fisheries communities

Globally, SSFs account for more than half of the world's catch, and they employ approximately 120 million people for their livelihoods. Among which, more than 90 per cent of population is from developing countries and this provides food security for millions of people (FAO, 2015; Kurien, 2015; Cohen et. al., 2019). SSF are exploited extensively by competition from commercial and industrial sectors, lack of infrastructural facilities and services, increased catastrophe and climate change risks, and insufficient fisheries management plans. They can be characterized by a "tragedy of the commons" (Hardin, 1968; Berkes, 1985; Ostrom, 2008). The concept, “tragedy of the commons”, refers to individuals’ overutilization and exploitation of natural resources at the expense of others, leading to collective vulnerability. The tragedy can be seen in some SSF where fishery resources are utilized without limits, thereby increasing the pressures on availability of those resources with potential of collapse. SSF contribute to a variety of livelihood benefits. Further, coastal ecosystems also serve as a context of the economic, religious, and political activity of SSF communities. SSF communities are commonly categorized as backward and experience marginalized society (exhibited by Figure 4.1). And to make matters more difficult, SSF are poorly incorporated into governance and decision-making (Berkes, 2001; Nayak & Berkes, 2019). SSF are generally neglected in studies on water conservation and management, rural growth, and poverty alleviation (Macfadyen & Corcoran, 2002; Schuhbauer et. al, 2017). Fishing households not only are fishery-resource dependent, but they also diversify their livelihood through farming and non-farming practices such as small trades as a source of revenue.

This study’s location, Chilika Lagoon, is rich in biodiversity with great scenic beauty and aesthetic views that attracts tourism and development. The lagoon has a history that spans over 5000 years, providing local residents with livelihood and inspiration from poets, philosophers, and naturalists admiring the picturesque beauty and panoramic view of the Eastern Ghats in the background. The lagoon appears to be a critical lifeline for over 400,000 residents living in more than 150 villages (Nayak, 2014). Chilika’s ecological services are vital to the overall functioning of over 200,000 vulnerable local fishermen.

Several social and ecological drivers of change led to series of issues such as siltation and pollution. Domestic agricultural and aquaculture sectors have resulted in salinity variation, reduced water spread area and choking of the sea mouth. These changes create extreme pressure on fisheries and communities that rely on fishery resources. Urbanization, sea mouth opening, tourism and aquaculture have forced local fishermen to chase fish further away from traditional fishing grounds. To do this, fishermen obtain loans from intermediaries to acquire motorized boats. These adjustments made by traditional fishers tend to create resource and social conflicts over lack of access rights. A range of social and ecological changes create indifference to the fisheries' livelihood and communities. For example, SSFs are extensively ignored in regional development strategies aimed at eradicating poverty and at addressing transboundary control of water resources.

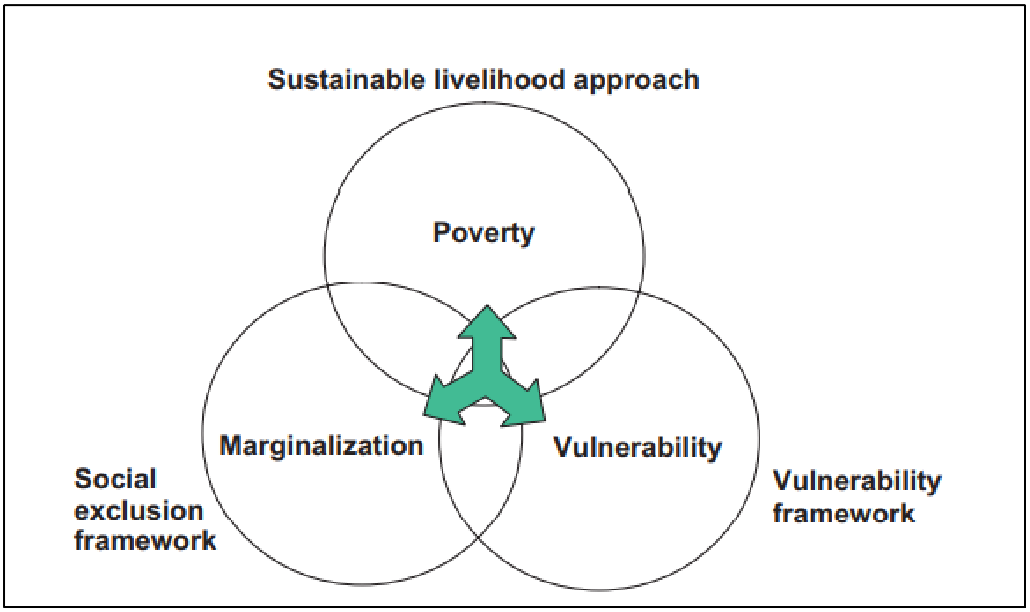

Figure 4.1: Representation of oppression in fishing communities through the primary aspects of poverty, vulnerability, and marginalization
(Source: Allison et al. 2006)

SSF issues are context-specific and very unique to the study area. Detailed analyses is needed to understand connections between SSF and water quality changes as well as their relationship with sustainability. Along with the rising awareness that SSF are "too big to ignore" (Chuenpagdee, 2011; Jentoft and Chuenpagdee, 2015; Chuenpagdee, 2019), there is immediate need to identify sources of vulnerability of small-scale fisheries in terms of water quality alteration resulting from diverse social and ecological changes. While research on food security and nutrition related to SSF are increasingly recognized, there remains both a research gap and limited context-specific knowledge on water quality variation as a source of vulnerability for SSF in Chilika and beyond. Sustainable development in capture fisheries should be valued based on possible habitat destruction costs and effects on marginalized fishing communities. Poverty in combination with vulnerability, insecurity and marginalization are main concepts for understanding the process of impoverishment in SSF communities (Allison et al. 2006). The socio-economic interest of SSF fishermen and ecological requirements of SSFs are generally considered to be inconsistent with water conservation or economic development objectives. The emphases on these objectives often set the conditions for limited access and influence from SFF communities in decision making that affects them.

4.2.2 Hydrological Regime and Water quality

Coastal lagoons are estimated to occupy 13% of world's coastline (Barnes, 1980). Increasing pressures from anthropogenic sources through various hydrological interventions such as aquaculture and dam construction result in pollution and biodiversity loss which, in turn, lead to economic losses worldwide. Pervasive water contamination epidemic is placing risks for safety and health of SSF communities. Every year, unsafe water kills a huge number of ecological species. Extreme influence from developments and novel activities such as aquaculture and land reclamation releases enormous number of toxic pollutants into water bodies. Coastal waters are susceptible to accumulated pollutant-related impacts from point to non-point sources located near and far. These include airborne pollutants. Aquaculture practices sometimes interact with other activities like tourism, swimming activities and artificial sea mouth opening to stress coastal waters. These drivers cause nutrient imbalance, hydrodynamic fluctuations, disruption in water balance and modifications in physio-chemical parameters. Drivers of change come together to degrade water quality.

The three hydrologic sub-systems, the Mahanadi distributaries, 52 rivers and rivulets and streams draining from the western catchment and the Bay of Bengal flow into the lagoon to influence Chilika lagoon hydrologically (Finlayson et. al., 2020). The lagoon is divided into four separate areas centered on salinity in water, water spread area, yield from fisheries and dispersion of biotic components: (i) the northern sector, (ii) central sector, (iii) southern sector and (iv) outer channel area (Sahu et. al., 2014).

Chilika is an assortment of coastal, brackish, and freshwater ecosystem from shallow to very shallow. The lagoon provides a dynamic environment throughout its river basin and coastal zone. The supply of freshwater through the rainy season from the small streams and rivers results in the natural salinity variations and offers nutrients in addition to maintaining the brackishness of the lagoon. The water quality of Chilika varies significantly in different seasons and because of numerous ecological characteristics in localized pockets. Three inlet mouths connect the lagoon to the Bay of Bengal: (i) an artificially dredged mouth near Sippakuda, (ii) a natural opening of mouth at Gabbakunda and (iii) another natural opening through southern part of Palur canal (Panda et al., 2015). The lagoon’s northern region is deltaic and adjacent with agricultural land. The region is traditionally vulnerable to waterlogging and floods. The outer channel at the other end of lagoon extends along the Bay of Bengal connecting it with Indian Ocean with the help of sea mouth. Numerous habitable and inhabitable islands such as Somolo, Krushnaprasad, Kalijai, Nalaban and Birds Island are located in the lagoon. The various physical and geographical parameters of the Chilika lagoon is represented in Table 1.

Table 4.1: Physiographic attributes of the Chilika lagoon

(Adapted from Panda & Mohanty, 2008)

Location	Lat. 19° 28′–19 º 54′ North Long. 85° 05′–85° 38′ East
Boundaries	East: Bay of Bengal West: Rocky hills of Eastern ghats North: Alluvial plain of Mahanadi delta South: Rocky hills of Eastern ghats
Designations	Lagoon Net Biodiversity Priority Ramsar Site
State and District	Odisha; Puri, Khurda and Ganjam
Shape	Pear shaped
Length and Breadth	Max length: 64.3 km Max breadth: 18.0 km Min breadth: 5.0 km
Water spread area	Maximum: 1,020 km^2 (Monsoon) Minimum: 704 km^2 (Summer)
Spit (Sand bar)	Length: 60 km Width: 0.6–2.0 km
Total area of islands	223 km^2
No. of rivers and rivulets draining into the lagoon	52 Nos.
Lagoon mouth	3[a] (Sipakuda, Gabakunda and Dhalabali)
Major ecological divisions	Northern sector, Central sector, Southern sector, and Outer channel
Depth	0.38–6.20 m

Catchment area	3,987 km^2
Fishermen families	12,363 Nos.
Fishermen villages	127 Nos.
Total no. of primary fish cooperative societies	66 (Active)
No. of jetty	19

The lagoon was adversely affected by tidal exchanges as a result of the shift of the lagoon mouth opening to the sea. The shift was caused by the littoral drift and transport of sediment along the coast of Bay of Bengal. The ecological viability, geomorphology and water quality of the lagoon have undergone significant changes over the years from many natural disasters (such as cyclones) and anthropogenic activities (such as hydrological changes and varied fishing techniques). Several hydrological effects that have occurred in the lagoon have led to changes in water quality parameters. Hydrological effects include (i) runoff from unregulated depleted catchment basins lying on the western and southern borders, (ii) silt borne freshwater discharges from Mahanadi River distributaries and (iii) lagoon water exchange with Bay of Bengal (Jyethi & Khillare, 2019; Panda et. al., 2010; Sarkar et. al., 2012). Changes in the frequency and complexity of these hydrological relations for the lagoon may have dramatic and potentially unpredicted consequences. One significant consequence includes biodiversity loss and related ecological changes (Panigrahi et. al., 2007). In general, the Chilika hydrological regimes is strongly influenced by the hydraulic structures such as dam construction. The quantity and quality of water in the lagoon depends on the pace at which precipitation, runoff, groundwater recharge, ocean trade and evaporation cause the lagoon to lose or add water (Iwasaki & Shaw, 2010). Figure 4.2 indicates the major bifurcations of the delta rivers in Chilika Lagoon along with approximate flow distribution across its distributaries. The tides and wave action play a significant role in the flow between the lagoon and ocean, including maintaining the water equilibrium. The retention rate of constituents in water depends on the flushing level. Climatic factors such as monsoon, humidity, temperature, and wind direction have substantial impacts on the hydrodynamics and process of circulation of lagoon waters. Research on water quality and ecology of Chilika shows that water flow between the sea and the lagoon plays a significant role in preserving the tranquility and protecting the coastal ecosystem (Iwasaki et. al, 2009). The impaired drainage of lagoon along with impacts from siltation, salinity variation, eutrophication, macrophyte infestation, and biodiversity loss exacerbate factors for environmental degradation as well as make them susceptible to anthropogenic pollution. Water quality degradation is a dynamic and complex problem with various interactions among physical, chemical, and biological processes.

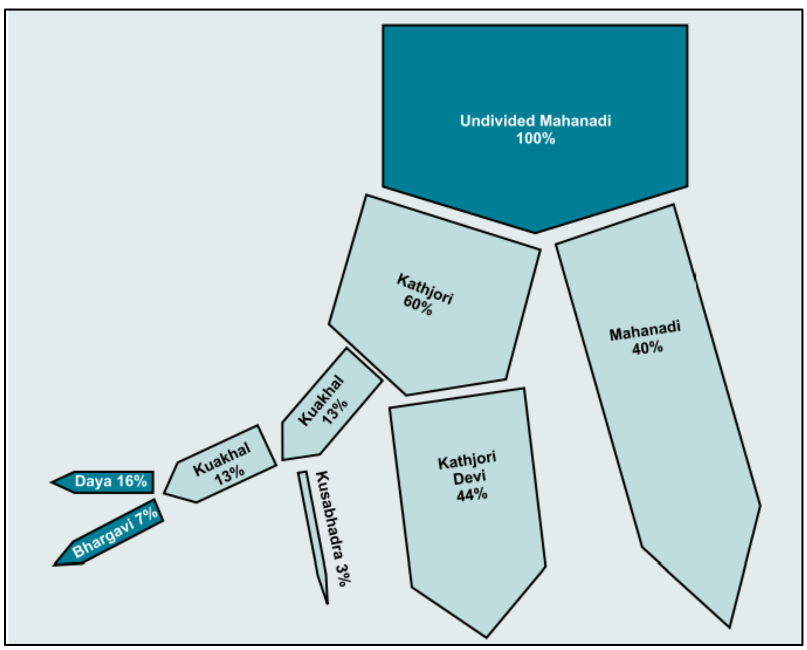

Figure 4.2: Flow distribution in Mahanadi Delta (Kumar & Pattnaik, 2012)

Water quality is a foundation for all marine flora and fauna as well as affects human ecosystem. Public well-being associated with SSF communities, and conservation of aquatic habitats are two key considerations based in environmental safety requirements for coastal waters. Understanding physio-chemical and biological properties of coastal waters serves an important role in identifying and anticipating lagoon conditions amidst the higher human-induced and natural waterborne pollutants. Those pollutants trigger eutrophication and subsequent toxic algal growth which, in turn, forms dead zones. Dead zones impact the survival of living entities.

4.3 Social and Ecological Changes

In the lagoon, changes in social and ecological systems are influenced by various ecological degradations such as shrinkage of water spread area, declining depth due to siltation and sedimentations, pollution from urbanization and industrialization, changes in salinity, biodiversity depletion, macrophyte infestation and eutrophication (Finlayson et. al., 2020). Additionally, the lagoon is seriously affected with a collection of environmental shifts that influence social, cultural, and environmental problems by numerous global and national drivers. Environmental shifts make habitats susceptible to transition even with the mild disruption, and this affects both ecosystems and humans dependent on ecosystem services. Social and ecological changes vary from seawater - freshwater influx, water quality variations, differences in salinity, fish decline, loss of biodiversity to the subsequent destruction of both natural and human ecosystem (Panigrahi et. al; 2007). Climate change along with concurrent disruptions at various spatial and temporal scales are of major habitat disruptions. Certain stressors related to drastic climate change emerge gradually which lead to rapid and major impacts on coastal ecosystem. Activities such as land reclamation, hydraulic constructions, aquaculture, sedimentation, runoff, and overfishing can have very complex and unexpected implications for lagoon environment (Panigrahi et. al., 2007; Panigrahi et. al., 2009). Specific social and ecological components of SSF are integrally linked to the ecosystems' influence and transformation. Increasing pressure on the lagoon from several drivers has led to the social-ecological transformation of its characteristics. All these drivers come together to make the lagoon system vulnerable.

In Chilika, key environmental changes produced biodiversity loss (Nayak et. al., 2016) and the introduction of novel multi-species, and changes in the water system, including salinity variations (Panda et. al., 2010). Table 4.2 shows some major factors influencing changes in water quality of Chilika lagoon. For example, in 1957, the construction of Hirakud Dam was one of the major changes in the Mahanadi River system. The Hirakud Dam supplies water to the Chilika Lagoon. The dam was supposed to reduce silt flow to the lagoon, but instead, sediment flow to the lagoon rose significantly. This led to high rates of sedimentation into the lagoon. In the western section, large-scale deforestation, overgrazing, and illegal felling has also caused along with excessive silting (Das & Jena, 2007). To reduce floods in the deltaic Northern Sector, many other dams and barrages were built downstream. For example, the Naraj Dam in Cuttack diverted the waters of the Daya and Bhargavi Rivers. These control structures neither served the purpose of flood protection nor power generation. Rather, they reduced the flow rate of water to Chilika Lagoon (Dujovny, 2009).

The rising international shrimp markets in Chilika during 1970s led to the starting of intensive prawn aquaculture in 1980s. The rapid boost in shrimp aquaculture led to encroachment on traditional fishing grounds and their conversion to aquaculture farms has resulted in major access and entitlement concerns. Fish production reduced drastically, affecting the livelihoods of fishing-based communities. As a result, many people started migrating due to job loss. The fluctuations in water flow rates and salinity variations also destructed wetlands which, in turn, impacted biodiversity of the lagoon and its multi-species fish stock (Nayak et. al., 2016; Nayak & Armitage, 2018). In 2001, an artificial sea mouth was created by the state government to address the persistent siltation problem in the lagoon. The new sea mouth facilitated the free circulation of water between the sea and the lagoon, resulting in significant improvements in the lagoon's water quality and ecosystem, flood mitigation, and fish and shellfish output. The salinity of lagoon water increased bringing back the dolphin population and reducing weed attack (Dujovny, 2009; Ghosh & Pattnaik, 2005; Sahu et. al, 2014). Despite its positive intentions, the opening of the sea mouth resulted in unforeseen negative consequences, such as hydrological shifts and subsequent impacts in social ecological ecosystem. Several other drivers came together to impact SSF in Chilika. These included fluctuations in the water regime with salinity imbalance, disruption in water input and outflow rates, sand infestation and invasion of marine organisms such as barnacles, and an increase in the speed, intensity, and uncertainties connected with the lagoon's contact with the Bay of Bengal (Nayak, 2014; Nayak et. al., 2016; Nayak & Armitage, 2018).

Table 4.2: Factors influencing Water Quality in Chilika Lagoon

Year	Major Factors
1957	Hirakud Dam
1980	Shrimp Aquaculture
1999	Super Cyclone
2001	Sea Mouth Opening
2013	Cyclone Hud-Hud and Phailin
2019	Cyclone Fani

Between 2013 and 2014, the lagoon was hit by two cyclones in a row. Cyclone “Phailin” made landfall in Chilika Lagoon on October 12 , 2013, and another high-impact cyclone, “Hud Hud,” made landfall on October 12, 2014. Following Hud Hud, a severe flood hit the river system draining to Chilika Lagoon (Sundaravadivelu et al. 2019). Earlier, in 1999, Orissa faced a "Super Cyclone," the state's greatest disastrous cyclone in 100 years, affecting many lives of fishing communities. The cyclone wreaked havoc on fishing gears and homes in and around the lagoon (Iwasaki et. al., 2009). Then, Phailin (2013) had a substantial impact on the biogeochemistry and water quality of Chilika Lagoon. There was a decline in salinity, change in nutrient dynamics, reduction in phosphates and nitrates, high silicate and ammonia content, and destruction of seagrass (Barik et. al., 2017; Nazneen et. al., 2019). The ecological interruptions in the lower food chain had a big influence on the fishing sectors that resulted in vulnerability of the fishing communities (Sahoo et. al., 2014).

The cyclonic effects were accompanied with many drastic effects that comprises of: uprooting of mangroves and Casuarina woods exposing the lagoon to the Bay of Bengal, inundation of soil in the lagoon's neighboring land region with sea water, infertility of land, damage to cultivation of local populations, decline of fish habitats and water salinity imbalance (Nayak & Armitage, 2018).On the 3rd of May 2019, the extremely strong category four cyclonic storm 'Fani' hit with 250 km/h wind speed. Fani wreaked havoc on Chilika lagoon and surrounding catchment areas with strong winds, tidal surges, torrential rain, and flooding. This resulted loss of lives, huge economic downfall, damage to fishing equipment and boats. The cyclone also created two new inlets that might bring in imbalance of salinity level in Chilika waters and disrupt the ecosystem (Acharyya et. al., 2020). Besides cyclones, droughts and floods are quite common in Chilika making livelihood of small-scale fishing communities vulnerable. Water pollution and scarcity resulting from these natural drivers along with anthropogenic pressures have damaged livelihoods of fishing communities in Chilika and disrupt daily lives of fishers and fishing families (Sundaravadivelu et al. 2019).

The changes in lagoon ecosystem have turned out to be a cause of concern for local and national governments (Panigrahi et. al., 2007). Resultant conservation initiatives have been implemented such as dredging a new sea mouth and public awareness campaigns (Panda et. al., 2010). A standard caste-based catch fisheries and quickly adopted intensive shrimp aquaculture led to encroachment on standard fishing practices by non-fisher people from higher caste (Nayak et. al., 2016 and Nayak & Armitage, 2018). Further, the consequences of the artificial sea mouth led to changes in outward and inward water flow rates and disrupted freshwater-saltwater balance (Nayak et. al., 2016 and Nayak & Armitage, 2018). Past research in Chilika highlights the adverse impacts of these changes contributing to the (1) shrinkage of water distribution, salinity decline, reduction in depth due to siltation, eutrophication, infestation of macrophytes and loss of biodiversity (Finlayson et. al., 2020; Panda et. al., 2010; Panigrahi et al., 2007), (2) reduction in fish production, incomes of fishers and viability of livelihoods (Iwasaki & Shaw, 2008; Nayak & Berkes, 2014; Jentoft et. al., 2017), (3) restrictions in access to customary fishing grounds and limits in fishing rights (Nayak and Berkes, 2011; Jentoft et. al., 2017), and (4) increase in employment displacement and migration to cities for job opportunities (Robson and Nayak, 2010). Ever-growing impacts on the ecosystem components and functions affecting fish and fisheries of the lagoon reflects direct impacts to eutrophication, physical alterations, over-exploitation, socioeconomic issues, and pollution, while indirect impacts including sedimentation, watershed problems, channel or canal shallowness and human settlements (Panigrahi et al.,2007).

The social system of the lagoon was also affected by drastic changes brought through cultural and caste elements (i.e., beliefs and ideas related to caste, ethnicity, and religion), loss of access (i.e., political rights and ownerships), privilege (i.e., quota or reservation available to indigenous community) and jobs (i.e., from encroachment of non-fishers in fishing activities) bringing about elevated levels migration and outmigration of fishers, breakdown of fishery cooperatives and dynamic fisheries management structures along with rising conflicts (Nayak et. al., 2016; Nayak & Armitage, 2018).

4.4 Assessment of nature and variation of water quality parameters

Over the last few decades, the intensifying natural and human-induced pressures such as industrialization have altered water quality in the Chilika Lagoon. Natural ecological changes along with rising anthropogenic performance of maintaining the lagoon ecosystem have a huge impact on the physio-chemical parameters and biogeochemical cycles of the coastal system. The imbalance in seawater and freshwater influx influences the nutrient sources and creates salinity variation. Combined effects of temperature, tidal action and water dynamics result in seasonal water quality variation in Chilika. Siltation, industrial pollution, weed proliferation, bio-resource depletion and salinity changes pose threats to the lagoon ecosystem. The economic transition due to the rapid development changes has boosted production volumes but releases domestic and industrial pollutants that endangers coastal ecosystem. The changes in water quality parameters are listed in Table 3 indicating both pre- and post-restoration phase of sea mouth opening.

Table 4.3: Fluctuations in average water quality parameters in Chilika Lagoon during the cycles of pre- and post-restoration (Adapted from Mohanty et.al, 2015)

Water quality parameter	**Pre-restoration phase (1999-2000)**	**Post-restoration phase (2001-2002 to 2013-2014)**
Water Temperature (C)	28.1	28.56
Mean depth (cm)	180	149.35
Transparency (cm)	77	64.76

pH	8.4	8.3
Total Alkalinity (ppm)	94	106.83
Salinity (PSU)	8.5	11.47
Dissolved Oxygen (ppm)	7	7.15
BOD (ppm)	Not Recorded	2.73
Nitrate (ppm)	0.260	1.12
Ortho Phosphate (ppm)	0.230	0.28

Water pollution in fisheries results in fish killing, poor reproduction and abnormalities, decline in cultured species and eutrophication which ultimately impact directly and indirectly the livelihood of fishing communities (Deepananda & Macusi, 2012; Ogutu-Ohwayo et. al., 2016). External influences cause modification in morphological and hydrodynamic environments and deeply influence the sensitive balance of the coastal environment. When the amount of toxins and dissolved salts in water exceeds the threshold level, aquatic abundance and production starts to decline. This exposes small-scale fishers to the verge of vulnerability by decline in fish population and poverty. High doses of agrochemicals, fertilizers and pesticides used in and around the agricultural land of Chilika are eventually washed out in large concentrations into the coastal waters. These diverse water quality issues are impacted by different parameters that affect the traditional SSF. As this relationship reflects a research gap, it is further examined in the following sections. As per Objective 1, the different changes in physical and chemical structure of water due to the various natural and anthropogenic impacts around the Chilika Lagoon are analyzed.

4.4.1 Water quality parameters

Further assessment of various water quality parameters is done in the following sections to address the research gap.

1) Water depth, Turbidity & Transparency

The depth of the lagoon is primarily managed during the summer by the amount of tidal influx and in monsoon by the freshwater inflow. During the monsoon season, the water depth differed between 0.8m and 2.5m while it ranged between 0.4-2.5m and 0.365-2.5m respectively during post-monsoon and summer (Panigrahi et al., 2007). The existence of suspended particles in coastal waters is a main component in regulating light penetration. Evaluating water quality in inland and coastal waters bodies in terms of water clarity assessment is very important. Transparency is positively associated with pH, biological oxygen demand, salinity, nutrient content, and chl-a. These indicate that high turbid waters of lagoon maintain a high concentration of these elements. During the cyclone Phailin in 2013, there was a significant drop in transparency by 25%. This was due to increased turbidity of 32-61 NTU as result of the high sediment load in lagoon. The transparency was then restored back within 4 months due to the lagoon's integrity and was managed to maintain till now (Barik et. al., 2017).

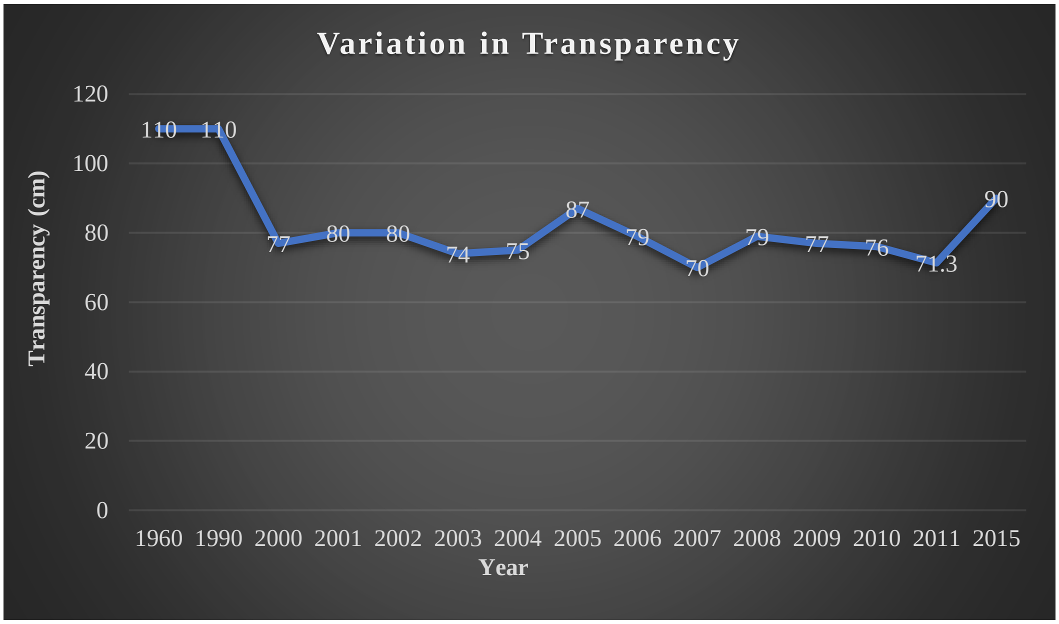

Figure 4.3: Variation in transparency of Chilika lagoon

(Developed from data listed in Mohanty& Panda, 2009; Mohanty et.al, 2015; Mohapatra et. al., 2007)

2) pH, Alkalinity & Buffering activity

Overall, coastal waters resist pH value variation. It is the amount of carbon dioxide levels changed during the vegetation growth that has dramatic effect on pH in pure waters. That is attributed to the seawater alkalinity that offers better protection against excessive carbon dioxide build-up. Higher alkalinity results in high buffering ability against pH. The carbonate buffering mechanism is critical in fish production as photosynthesis is the main natural oxygen source. The spectrum of concentration of hydrogen-ion increased in coastal waters. Increase was dependent on free CO_2 removal in photosynthesis via saltwater-freshwater flow rates, water temperature, organic matter decomposition and salinity decline (Kumar & Pattnaik, 2012). The interplay of environmental and geological influences alters the form and quantity of ions transported from the drainage basin which dominates the total alkalinity of the lagoon. In 2015, the alkalinity seemed to be very low when compared to the data in 1960s. There was unrecovered reduction in the pH decline till date after Phailin i.e., 8.48 (pre-Phailin duration from July 2011 to Sep 2013) to 7.98 (post-Phailin span from Oct 2013 to June 2015). The persistent reduction could be due to the enhanced respiration cycle over the predominance of freshwater influx into lagoon in consecutive monsoonal cycles of lower pH (Barik et. al., 2017).

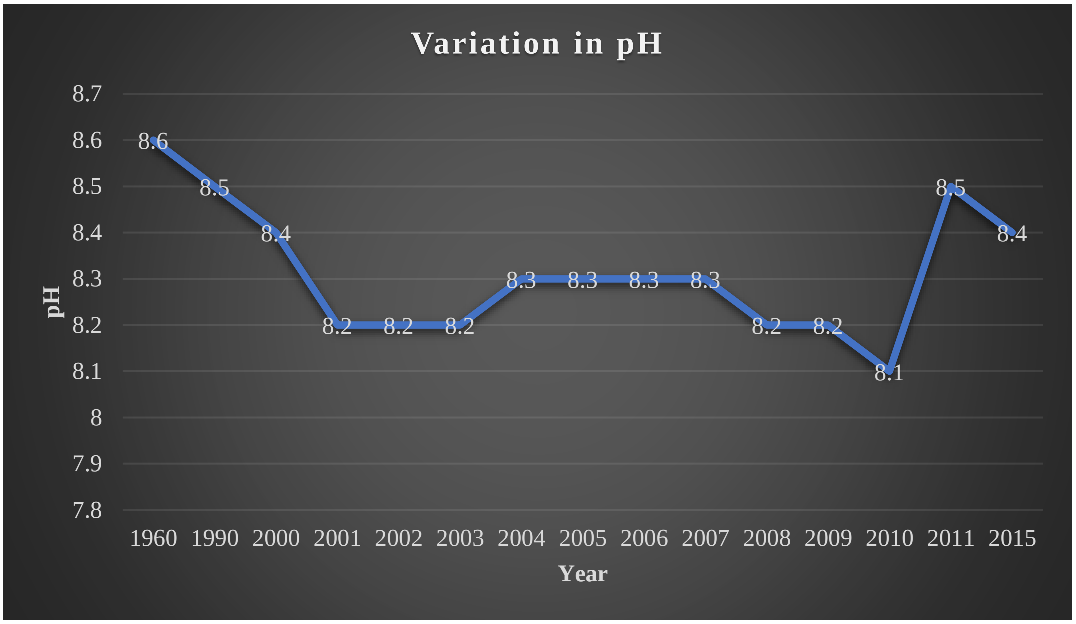

Figure 4.4: pH variation of Chilika lagoon

(Developed from data listed in Mohanty et. al, 2008; Mohanty et.al, 2015; Mohapatra et. al., 2007)

3) *Trends in Salinity Variation*

Salinity represents the number of dissolved substances that remain after the complete oxidation of organic matter. The relevance of salinity, in terms of physiological and ecological point of view resides in the osmotic pressure of saltwater. Variation in salinity is an important factor in the reproduction of aquatic species, their development, and their distributions. Salinity is a significant variable that determines the metabolic rate and biological productivity of Chilika which, in turn, supports a wide range of biodiversity. Seasonal fluctuations in salinity have a major impact on the reproduction of fish species and shrimp, their development, feeding behaviours, spawning, production, and survival. Variation in the salinity regime is an important factor for the presence and absence of phytoplankton and even for migratory birds which regulate the level of body fluids according to surrounding ecological changes (Kumar & Pattnaik, 2012). In the 1960s, a high salinity trend was observed with earliest data available among all water quality characteristics of the lagoon. Between 1995-1998, there has been a steady abatement in the salinity level of lagoon with near freshwater levels which was completely re-established to normal by the hydrological intervention in 2001 (Finlayson et. al., 2020; Mohanty et.al, 2015). The tidal flow rose by 44% and lagoon salinity by 35% with the artificial sea mouth opening when compared to the pre-restoration phase. Between 2001-2012, average lagoon salinity varied from 11 to 14 ppt and was observed to be higher during drought conditions. There was a drastic decline in salinity during the cyclone Phailin in 2013 (11.12; 2012–2013 > 8.75; 2013-14) because of the huge freshwater runoff and substantial precipitation. During the Phailin month, the rainfall was 2.5 times greater than during the pre-Phailin month and accounted for about 45% of the overall precipitation during 2013 resulting in predominant floods into the lagoon (Barik et. al., 2017).

Figure 4.5: Salinity trends in Chilika lagoon over the years

(Developed from data listed in Mohanty et. al, 2008; Mohanty et.al, 2015; Mohapatra et. al., 2007)

4) Water Temperature (WT)

Due to the diurnal and seasonal variations, coastal water temperatures fluctuate and change with latitude and longitude. On shallow coastal waters, water temperature is highly influenced by changes in atmospheric temperature. As a freshwater ecosystem, Chilika does not exhibit a wide spectrum of spatial and horizontal variation in temperature. During winter, the surface temperature is seasonally low, and the average lagoon temperature usually remain between 28.1-29.2°C (Kumar & Pattnaik, 2012). Weather factors like temperature, precipitation, humidity, and wind speed have a direct effect on the hydrodynamics and circulation pattern of coastal waters. A warm, sub-humid, tropical monsoon climate is typical in Chilika lagoon. The temperature rises with seasonal fluctuations from March to May and subsequently begins to fall in tandem with the beginning of southwest monsoon (Panigrahi et al.,2007).

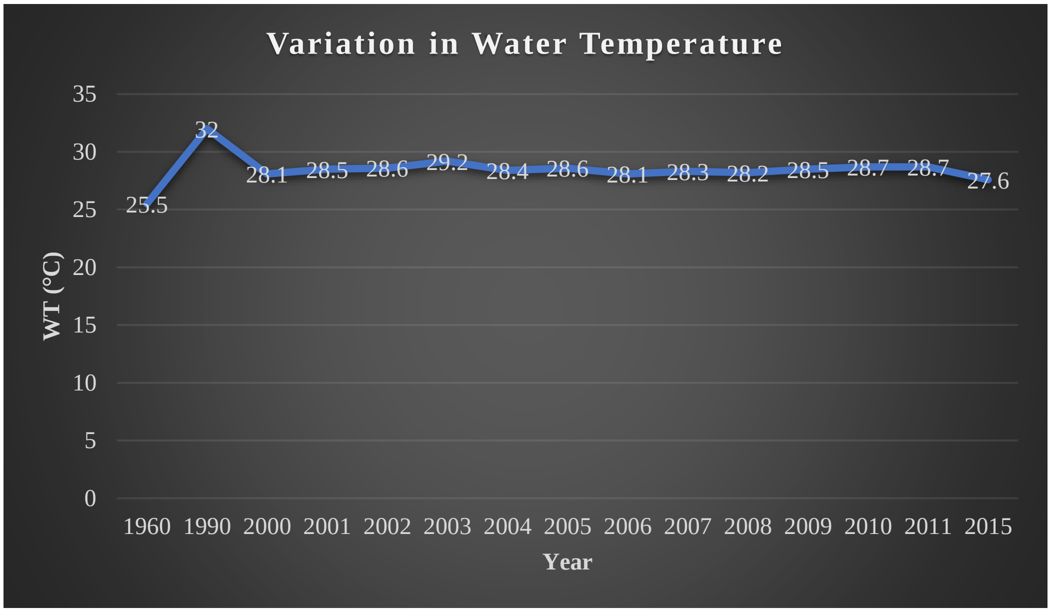

Figure 4.6: Changes in water temperature of Chilika lagoon

(Developed from data listed in Mohanty& Panda, 2009; Mohanty et.al, 2015; Mohapatra et. al., 2007)

A common trend of temperature variability was found in similar temporal environments with extreme solar radiation and winter cooling of surface waters. The trend includes notable seasonal variability. A remarkable decline in water temperature was observed after Phailin. The decline could be a result from the mixing of river water and precipitation with lower temperature. An inverse relationship can also be observed with dissolved oxygen and water temperature. This may be attributed to the less oxygen solubility in warm waters (Barik et. al., 2017).

5) ***Dissolved Oxygen (DO) & Biological Oxygen Demand (BOD)***

Dissolved oxygen indicates the health of a coastal ecosystem and provides conditions favourable for effective metabolism of all aquatic organisms. Normal coastal waters display major differences in the dissolved oxygen level both globally and seasonally. The variations resulted from photosynthetic activities, de-nitrification process of bacteria as well as free trade with the atmosphere through mixing, circulation, and wind action. Aquatic life is affected by variation in DO as fish cannot survive below 4-5ppm. DO variation influences the ability of the lagoon to accept organic matters without harmful impact. In general, Chilika is well oxygenated during the year because of its large size, strong photosynthetic activity, and churning impact of winds on the coastal waters. Chilika maintains a DO content ranging between 6-8ppm (Nayak et. al., 2004). The cyclone Phailin culminated in an acute rise in DO that has since sustained 6.9-7.4 mg/l in the coastal ecosystem. Such an increase in DO could be due to wind-induced aeration triggered by low temperature and increased vertical mixing, rather than photosynthetic activity, as productivity decreased just after the Phailin (Barik et. al., 2017). The biodegradation of organic matter in coastal waters exerts nutrient depletion. The quantity and composition of organic matter provides an understanding of the nature of the contamination in water. A high level of BOD may be a result of weed and macrophyte decomposition by increased salinity and mixing decomposed organic matter complemented by rise in wind flow and churning of sediments. There was a drop in BOD after the Phailin which has since continued. The drop may be due to the expelling of organic matter by strong freshwater drainage (Barik et. al., 2017).

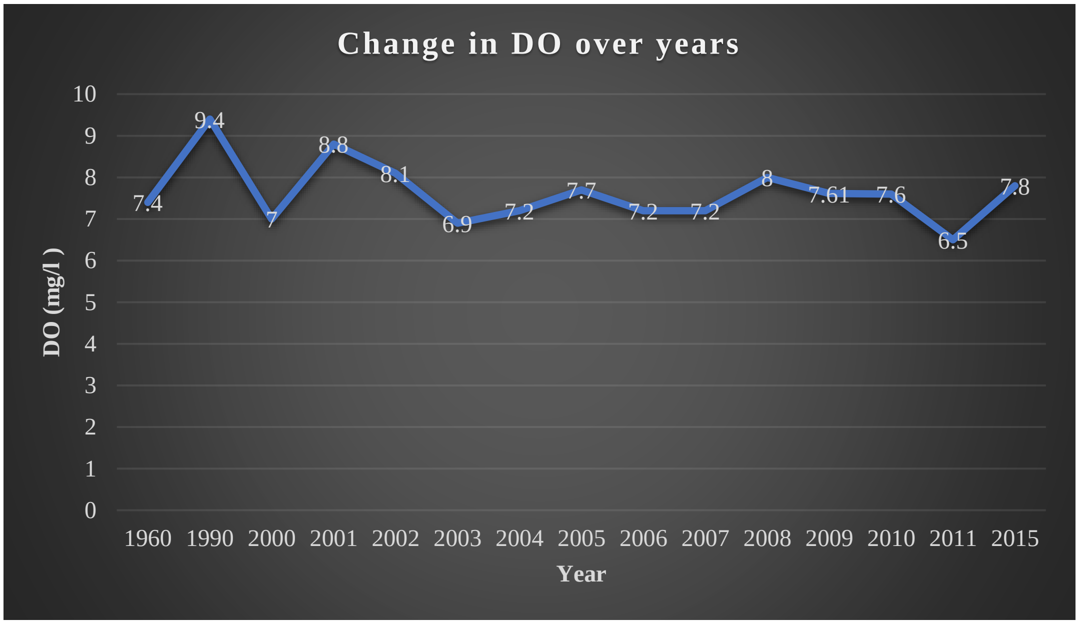

Figure 4.7: Fluctuations in DO content of Chilika lagoon

(Developed from data listed in Mohanty& Panda, 2009; Mohanty et.al, 2015; Mohapatra et. al., 2007)

6) Nutrients Disparity & Trace Elements

Nutrients are regarded as one of the most indicative criteria in marine ecosystem that affects the development, fertility, and metabolic function of living organisms. Nutrient allocation is dependent mainly on the coastal patterns, seasonal fluctuations and freshwater flow from rivers and surface streams (Barik et. al., 2017). Nutrients like nitrate-nitrogen and phosphate-phosphorus have a well-recognized function in the ecological growth of marine environments and serve as limiting factors that influence development of algal cell.

Chilika lagoon is a rich nutrient source system greatly affected by water characteristics due to freshwater movement and ocean interaction. Surface runoff provides nutrients and tidal interactions of ocean water that usually dilute nutrient amounts. The nitrate and phosphate concentration in Chilika lagoon usually vary from 0.036-1.96ppm and 0.2-4.66ppm, respectively. The amount of nitrate concentration in lagoon suggests that the coastal mechanism is beneficially active and shows high values during post-monsoon. High concentration of phosphates is found during monsoon. High concentration may be attributed to terrestrial runoff and heavy precipitation. Phosphates, released from sediments by wind churning of water, serves a significant role as an inorganic nutrient for macrophyte and phytoplankton growth. Components that appear in tiny concentrations of seawater—generally referred to as trace elements like silica (Si)—are very critical to the survival of aquatic ecosystem. Silica concentration determines the growth rate of diatoms required for silica frustule production. Data related to concentration of Si in Chilika is scant. The silicate content is ranging from 0.5- 10.2 ppm in Chilika Lagoon. Low silicate concentrations were observed during the pre-monsoon period in the southern sector and highest in the northern sector during the post-monsoon period (Kumar & Pattnaik, 2012; Barik et. al., 2017; Mohanty et. al, 2008).

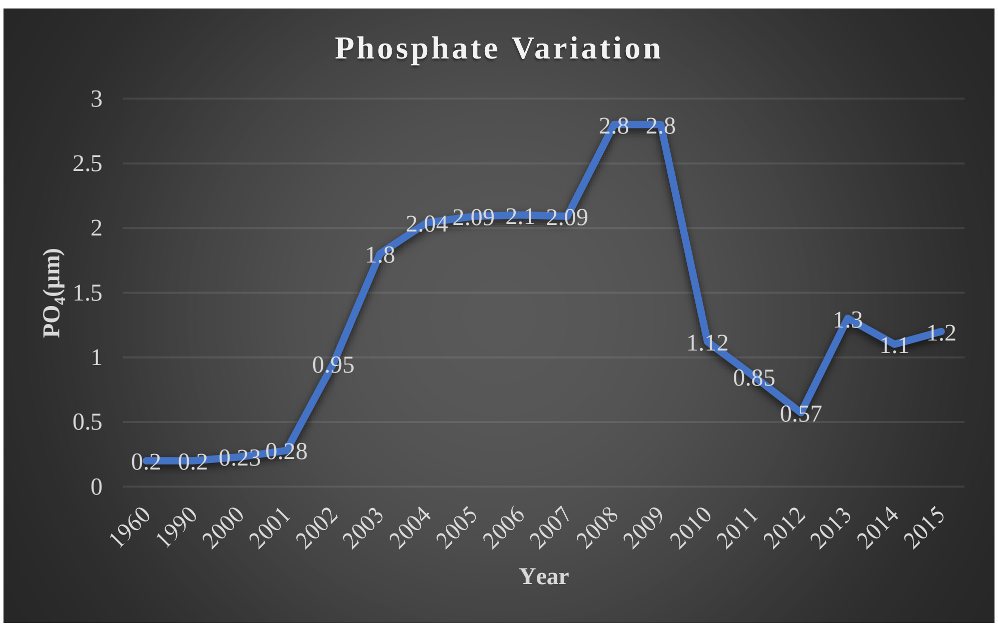

Figure 4.8: Distribution of phosphates in Chilika lagoon

(Developed from data listed in Mohanty & Panda, 2009; Mohanty et.al, 2015; Mohapatra et. al., 2007)

Higher levels of nutrients could be due to the contaminant dispersion from runoff created by river networks. Soil, farm fertilizers and pesticides used from cultivation were washed out from agricultural land and washed into lagoon waters (Nayak et. al., 2004). Rapid phytoplankton assimilation and surface runoff enhancement resulted in large-scale spatial-temporal variability of nitrate and phosphate in the coastal ecosystem. The mineralization cycle, which released nutrients to the environment due to prevalence of higher residence period, produces larger nutrient buildup in riverine discharge zones. The nutrient accumulation displays a negative relationship with salinity.

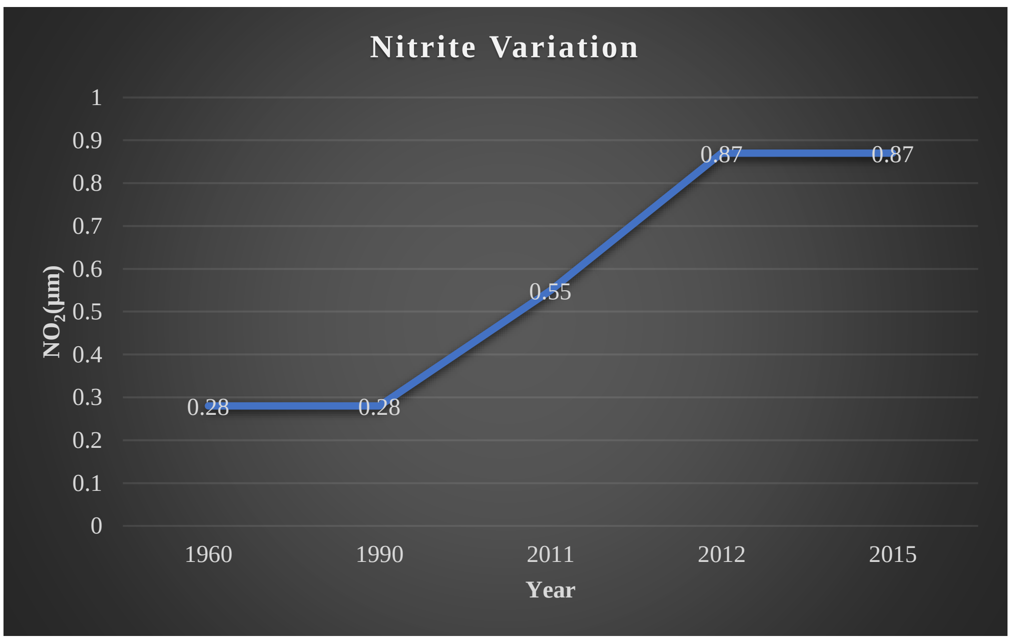

Figure 4.9: Nitrite changes in Chilika lagoon

(Developed from data listed in Mohanty & Panda, 2009; Mohanty et.al, 2015; Mohapatra et. al., 2007)

The observed productivity reduction after Phailin might be the reason for the marginal nitrogen removal by fixation or denitrification. The amount of oxygen has also been well maintained. Immediately, after the Phailin, there was a sudden decline in PO_4 concentration. About half of the decline could be attributed to dilution impacts by mixing of river water or ingestion of low saline suspended particulate matter. About a month after Phailin, the decrease in concentration was restored. Overall changes in nutrient concentration may be due to sea water exchange, water mass balance and absorption of sediments (Barik et. al., 2017).

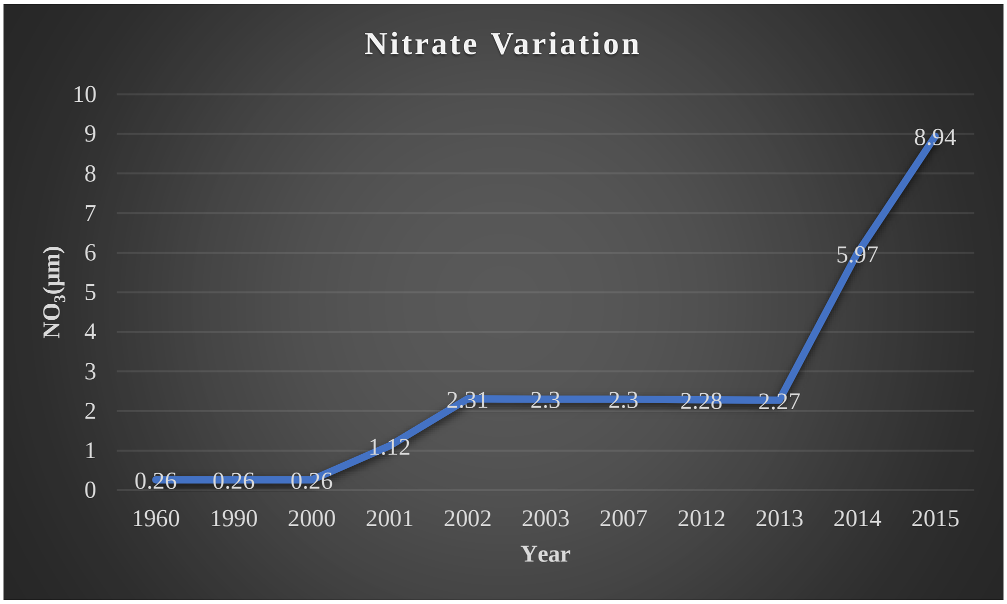

Figure 4.10: Nitrate (bottom) changes in Chilika lagoon

(Developed from data listed in Mohanty & Panda, 2009; Mohanty et.al, 2015; Mohapatra et. al., 2007)

The silicate concentration showed wide spatial variation between 0.1 and 258µM which could be silicate absorption by phytoplankton for their metabolism, co-precipitation of soluble silicon with iron, chemical reaction with clay minerals and adsorption onto suspended sedimentary particles. Weathered silicate content that exists in rivers is transported to the lagoon, resulting in high silicate content. An increase in Si by ~69% was observed during Phailin. Si returned to normal levels after two months through balance with saline water (Barik et. al., 2017). Nutrient stoichiometry in coastal lagoon is controlled by seasonal shifts and biogeochemical cycle. The interaction leads to changes in population and diversity of planktons. The runoff from agricultural drainage canals and major rivers connected to the lagoon creates high nutrient concentration. Data show a positive correlation with salinity during summer which is likely due to microbial organic matter decomposition (Barik et. al., 2017; Panigrahi et al., 2007).

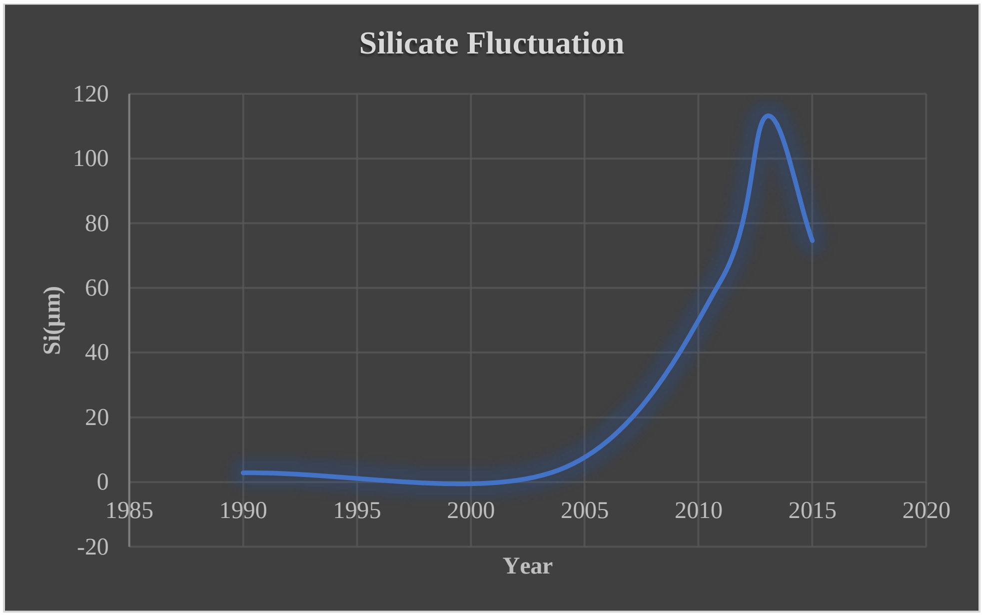

Figure 4.11: Variation of Si in Chilika lagoon

(Developed from data listed in Mohanty & Panda, 2009; Mohanty et.al, 2015; Mohapatra et. al., 2007)

7) *Chlorophyll-a (Chl-a) & Photosynthesis*

The diversity of phytoplankton in Chilika lagoon consists of four main classes of algae- green algae, blue-green algae, diatoms, and dinoflagellates. An excess of green and blue-green algae was found in northern-central regions while diatoms prevail in saline dominated the outer channel. Chl-a is the most significant element in the coastal lagoon. Chl-a promotes the development of phytoplankton, and its abundance is a strong predictor of algae found in the marine ecosystem. In Chilika, Chl-a usually ranged between 0.13 and 51.10 µg/l. In 2001, a high concentration of 54.04 µg l^{-1} was recorded as a result of the artificial sea mouth opening (Nayak et. al., 2004; Nazneen et. al., 2019). Due to the contribution of benthic chlorophyll, a sudden rise in chlorophyll content was observed following Phailin by wind mediated churning (Barik et. al.,2017).

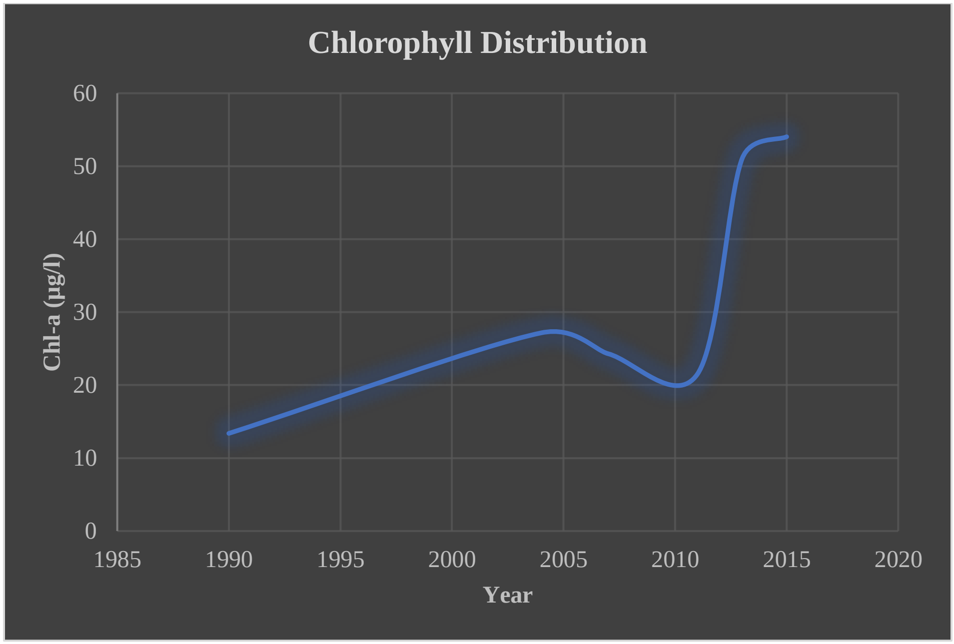

Figure 4.12: Distribution of Chl-a in Chilika lagoon

(Developed from data listed in Mohanty & Panda, 2009; Mohanty et.al, 2015; Mohapatra et. al., 2007; Sahoo et. al, 2017)

Higher suspended particles prevent light penetration which alters the photosynthetic activity. Algal blooms reduce the level of dissolved oxygen. The larger the bloom, higher will the chlorophyll concentration. The bloom creates a turbid environment in lagoon waters reducing transparency and light penetration. Salinity also serves as a key element that regulates the production and spread of phytoplankton. Some sectors of the lagoon exhibited direct relation of chlorophyll with DO while holding an opposite relationship with transparency, salinity, and depth. This indicates that the shallow areas of lagoon promoted photosynthesis at suitable light intensity generating oxygen (Panigrahi et. al., 2009; Sahoo et. al., 2015).

4.5 Implications of water quality changes on small-scale fisheries in Chilika

Water supports diverse human demands such as residential needs or commercial needs like fishing or aquaculture, farming, and power generation (FAO, 2020). Increasing expansion of human settlement and rapid industrialization contribute to intensified contamination of coastal lagoons, wetlands, and estuaries. Pollution levels differ depending on the region, its topography and hydrology. Pollution levels required proper management to maintain ecosystem integrity and sustain resources for fisheries and further development of communities. Human induced pressures in Chilika through agro-based industries, aquaculture and industrialization resulted in agricultural drainage, urban sewage discharge and dumping of waste, all of which affected the quantity and consistency of lagoon waters. The quantity and consistency significantly modified the biodiversity and biotic population of the ecosystem (Panigrahi et. al., 2007). Although the sea mouth opening boosted salinity rates and enhanced fish landings and weed growth, heavy sedimentation and silt accumulation reduced the depth of lagoon and intensified macrophyte production. Faecal matter, excess feed and uneaten pellets from aquaculture created a threat to the coastal ecosystem along with rising concerns about on water, sanitation, and hygiene.

Fishing communities especially women and children were exposed to the vulnerability associated with a lack in public health and high exposure to water-borne diseases. The fishing communities are exempted from development of regional growth strategizing and transboundary management of water resources within and around the lagoon, even though fishing in the coastal lagoon ecosystem is a popular source of livelihood. Water quality issues and fish availability relating to damage of coastal ecosystem has added importance, as they are directly linked to livelihoods of a significant number of families residing near Chilika. Vulnerabilities of SSF communities has had major implications, including habitat loss, destruction of mangroves, fish mortality, increased tourist pressures, water contamination and reduced employment. These issues robbed coastal areas of environmental security and affects the well-being of fish dependent communities (Panigrahi et. al., 2007; Putri & Pearson, 2014). With the goal of sustainability, a holistic solution is needed for ecological preservation and economic viability of lagoon along with water storage, habitat restoration, sustainable development of resources and utilization of economy.

4.5.1 Impact of water quality changes on SES

A primary cause of decline in fish productions is the depletion of the lagoon water ecosystem and the services they provide. Addressing the causes of the depletion highlights the need for comprehensive strategies to manage SSF. A significant aim of the study is to integrate various environmental effects and impacts of vulnerabilities in SSF communities. The Table 4 indicates the impact of various water quality parameters on social-ecological system of Chilika Lagoon.

Table 4.4: Impacts of water quality changes on lagoon waters of Chilika and SSF

<table>
<tr><th>Water Quality Attribute</th><th>Ecological Impact on Chilika Lagoon</th><th>Socio-Economic Impacts on SSF communities of Chilika</th></tr>
<tr><td>Water depth, turbidity & transparency</td><td>• Low light penetration
• Hinderance on photosynthesis
• Heavy sedimentation</td><td rowspan="3">• Low fish catch
• Food insecurity
• Stress in fish breeding grounds
• Health hazards for communities
• Increased tourist pressure
• Resource conflicts
• Poverty</td></tr>
<tr><td>pH, Alkalinity & Buffering activity</td><td>• Excessive CO_2 buildup
• Survival risk to aquatic ecosystem</td></tr>
<tr><td>Salinity variation</td><td>• Juvenile transfer from the sea</td></tr>
</table>

	• Biodiversity loss • Invasion of new species- Barnacles	• Overexploitation of fisheries resources • Detrimental fishing practices • Loss of livelihoods and out-migration
Water temperatures	• Less oxygen levels • Loss of species	
Dissolved oxygen & Biological oxygen demand	• Macrophyte invasion • Pollution	
Nutrients disparity & trace elements	• Eutrophication • Phragmites invasion	
Chlorophyll-a	• Algal bloom • Hypoxia	

1) Water depth, Turbidity & Transparency

Fish manure, uneaten pellets of feed, waste particles from sewage or plankton may all trigger problems related to aquaculture recirculation. Turbidity induced by these particles will restrict the passage of light, reduce photosynthesis, even impact fish production, and kill protective colonies of microorganisms and other species.

2) pH, Alkalinity & Buffering activity

pH is an essential environmental parameter important for the existence of aquatic species, their metabolism, physiology, and chemical processes. pH controls the life cycle and distribution of nutrients in coastal environment. It also maintains the carbonate and bicarbonate buffering mechanism, which plays an important role in aquatic plant survival and development.

3) Trends in Salinity Variation

Salinity fluctuations can alter fish behavior in a variety of ways. Salinity regulates the metabolism of living organisms, causing evaporation and dilution, which has an impact on intertidal biodiversity. Dynamics in salinity levels are a major motivating force for improving fisheries in general and faunal diversity. Salinity level dynamics were enhanced during the post-reclamation period. The artificial sea mouth creation in 2001 had an overall positive impact in terms of improved aquatic abundance, effective maritime migration of fish and promoted restoration of damaged ecosystem (Mohanty & Panda, 2009; Mohanty et al. 2009; Mohanty et.al, 2015). Low salinity values are recorded in nearly all lagoon areas during monsoon season and most of the winter season since the lagoon receives ample amount of freshwater along with clear mixing. During the summer, a gradual rise in salinity can be seen due to the high evaporation rate, less freshwater influx, and influences from tidal action of sea (Barik et. al., 2017). Hydrological intervention resulted in many beneficial outcomes like high fish, prawn and crab landings and enhanced movement of juveniles from the sea end. This brought improvements in the overall ecology of the lagoon ecosystem (Sahu et. al., 2014). At the same time, intervention triggered resource conflicts, overfishing and vulnerability to the livelihood of fishing communities.

4) Water Temperature (WT)

Temperature of coastal waters is very critical for fish welfare. Temperature can influence fish development, behaviour, and reproduction along with disruption in food web functions. Metabolic production of aquatic species and their patterns of migration are affected by minor shifts in temperature. Rise in temperature proliferates the growth of invasive species that can make the wild aquatic species vulnerable. The reduced dissolved oxygen with rising temperatures results in regular water column stratification that affects mixing and circulation. Warmer temperatures are often believed to lead cause of declining seagrass. WT shows a direct relation with salinity level and inverse association with DO. WT drives algal blooms that in turn increases the affinity for nutrient uptake. Nutrients influence water clarity indirectly by promoting the formation of organic matter by phytoplankton and reduces solubility. Low nutrient uptake and reduced DO impacts fisheries, as the interaction puts aquatic life under stress and even affects a wide range of other biochemical and aesthetic (e.g., clarity and transparency) water indicators.

5) Dissolved Oxygen (DO) & Biological Oxygen Demand (BOD)

Rapid decomposition of plant detritus leads to low DO levels during the summer. Rapid decomposition is attributed to increased water temperature, low water depth and high levels of BOD. The turbid water inflow from the land runoff and the river lowered the amount of clarity and increased the intake of oxygen for organic matter decomposition. Submerged macrophytes and accessible plankton population may have contributed to the high oxygen concentration and to a higher rate of photosynthesis (Barik et. al., 2017).

Like humans, aquatic organisms require oxygen for their survival and hence low levels of dissolved oxygen leads to fish kills. The quantity of oxygen available impacts the intensity of feeding, degree of movement and temperature of water. The volume of oxygen that can be absorbed in water rises with temperature as well as with salinity and altitude. Tracking oxygen demand ensures water protection in marine ecosystem which can be used as an instrument to analyze ecosystem integrity. Surface water diffusion, photosynthesis rate, water turbulence and tidal action have strong influence on amount of dissolved oxygen. Reduced dissolved oxygen has a detrimental impact on aerobic biota, stressing benthic populations most significantly. Saltwater intrusion in lagoons with large flushing rates disrupts the stratification allowing the water column to blend. In restricted lagoons with low flushing rates and strong nutrient inputs, the high temperature raises the risk and extent of hypoxic incidents. This leads to persistent change in biodiversity distribution and loss of species.

6) ***Nutrients Disparity & Trace Elements***

Coastal regions are typically susceptible to potential environmental shifts. The combined impacts of environmental changes are likely to continue and to worsen the trajectory of eutrophication from estuarine to marine waters. This is due to population growth, rapid industrialization and agricultural technologies, climate change and fishing. Eutrophication is the excessive buildup of nutrient salts in water followed by excessive algal growth. The coastal lagoons are altered to be a fragile ecosystem due to the structural changes in the surrounding (e.g., extinction of fish species, excessive growth of aquatic plants and algal boom, degradation of water quality and precluding usage, salinity variation and changes in hydro dynamics of water). Dangerous oxygen depletion from extreme algal bloom threatens the aquatic ecosystem such as, for example, with hypoxia, habitat loss and decline of natural resources. Impacts to the coastal environment from aquaculture through uneaten feed and fish wastes play important roles in the presence of excess nutrients along with natural nutrient spikes from coastal ocean upwelling, land- and ocean-based sources, urban wastewater discharge and agricultural runoff. The resultant overall effects of decline in fish and water quality negatively affects SSF livelihoods and increase poverty rates.

7) Chlorophyll-a (Chl-a) & Photosynthesis

Due to variations in water quality, Chl-a changes are associated with seasonal fluctuations and chlorophyll concentration can act as an index of phytoplankton biomass influencing plant production. Chl-a content helps in exploring algal bloom rate and its impact on fish populations. Identifying safe fish population protect the fisheries from vulnerability and preserve the fish habitats. The introduction of nitrogen and phosphorous to coastal waters interfere in the coastal functioning. The introduction was from agricultural runoff containing fertilizers and pesticides containing ammonia and urea, intrusion of sewage, waste dumping from industrial and domestic sectors, macrophyte litter, exchanges of water between lagoon and sea and various inputs from anthropogenic sources. The nutrient content variation, stoichiometric fluctuations, benthic chlorophyll mixing from bottom sediment churning altered the water quality which resulted in stress to fisheries and the communities dependent on them (Panigrahi et. al., 2009; Sahoo et. al., 2017).

4.5.2 Drivers of Water Quality Change

As a part of this research, I have explored water quality as a major driver leading to vulnerability of small-scale fishing communities in Chilika lagoon, describing the essence of water quality variations and analyzing how it is affecting livelihood. The various causes of water quality deterioration are listed in Table 4.5 with specific issues associated with deterioration. Numerous drivers have led the cycle of social and ecological changes in Chilika Lagoon and ultimately, the vulnerability and marginalization of the SSF communities (Nayak & Berkes, 2019; Nayak, 2012; Nayak, 2014). Any natural or man-made aspect that induces a direct or indirect transition to system is generally referred to a driver. Drivers are generated from layers of social as well as political organizations in terms of national and international scales (Nayak, 2014). Growing human activities and coastal developments are changing the biodiversity.

Table 4.5: Distinct categories affecting water quality changes in Chilika Lagoon and its associated issues

Categories	Specific Issues
Agriculture Application • Livestock Grazing & Feeding Operations • Fertilizers & Pesticides	Eutrophication Macrophyte proliferation Danger to food chain
Hydrological Interventions • Dam construction – Hirakud • Artificial Sea mouth	Salinity Variation Sedimentation
Commercial & Recreational • Tourism-motorized boats • Road construction	Water Pollution Threaten aquatic lives Noise Pollution
Fishing Operation • Modern Fishing Techniques • Aquaculture	Eutrophication Algal Bloom Resource conflicts
Industrial Activities • Bridge construction • Drain pollution	Mangrove destruction Water Degradation Biodiversity loss
Domestic Practices • Household Waste • Sewage Discharge	Plastic Pollution Loss of Aquatic Species Water Pollution
Natural Calamities • Cyclone • Floods and Droughts	Nutrient Enrichment Seaweed Infestation

The social-ecological system of Chilika is further worsened by two major factors: development of shrimp aquaculture in 1980s and the creation of an artificial sea mouth to the Bay of Bengal in 2001 (Finlayson et. al.,2020; Nayak & Berkes, 2019; Nayak, 2014). Along with these, heavy siltation, untreated discharge of wastewater, agricultural runoff, aquaculture waste products, industrial and domestic waste dumping intensifies the problem. Pollution and effects from anthropogenic activities affect the coastal ecosystem in a variety of ways such as from toxic waste poisoning, water quality alterations, sub-lethal effects of contaminants leading to reproductive interference and disease resistance, habitat destruction and bioaccumulation of toxic metals.

i. Agricultural Application

Dams and industries need to release fertilisers and hazardous chemicals into water bodies such as streams, rivers, and estuaries. The most obvious consequence is reduced water quality, but the invasion of nutrients has a more subtle impact. Agricultural drainage, run off from agro-based industries (prawn processing units) and urban sewage effluents are all anthropogenic activities that influences the quality and quantity of water in Chilika Lagoon. These types of inputs have had a significant impact on the lagoon's ecology, as well as the ecosystem's total biotic community (Panigrahi et. al, 2007). Fertilizer runoff allows coastal algae to multiply which consumes oxygen extensively in the water. The process results in death of fish and interrupts the structure of food web dynamics. Due to a lack of proper soil conservation measures, agriculture run-off became severe. In addition, untreated effluent from Bhubaneshwar, the state capital, found its way to the lagoon. However, as with agricultural run-off, determining how much effluent makes it to the lagoon and how much settles out or changes along the way is challenging (Ghosh et. al., 2006). Continuous rise in coastal population puts pressure the coastal ecosystem raising food demand. It is therefore very important to control agriculture in order to maintain the required food supplies for society with appropriate management practices.

ii. Hydrological Interventions

From the 1950s, diverse hydrological and hydraulic variations occurred in Chilika lagoon. The primary change was initiated in 1953 by the construction of the Hirakud Dam. Periodic droughts and floods started to destroy crops in the deltaic region of Mahanadi River. Dams and barrages were constructed to solve these issues by the construction of a reservoir and regulation of water flow into the irrigation network (Dujovny, 2009). In the attempt to reduce negative consequences, the building of Hirakud Dam became a big sediment trap (Das & Jena, 2007). Rather than upholding the claimed goal of avoiding sedimentation and controlling river flow, dam development has resulted in decreased flows into Chilika Lagoon. The situation worsened the conditions for fishers as fish life in the lagoon depends on the regular influx of freshwater that drives away and replaces the polluted waters of previous monsoons. This prevents the area from converting into a swampy and marshy lagoon which is unsuitable for fish survival (Dujovny, 2009). The second and most prominent attribute contributing to the lagoon ecology was the artificial sea mouth opening. The artificial sea mouth created in 2001 connecting the sea and lagoon was facilitated to encourage proper drainage of sediments and silt from lagoon into the Bay of Bengal. Local fishers found this to be a failure since the sea mouth enhanced inflow-outflow rates of water with low and high tides regularly allowing high amount of sea water (Kim et. al., 2015; Nayak & Berkes, 2014). Finally, the intensive shrimp aquaculture along with salinity variations created with the sea mouth opening encroached the livelihood of capture fisheries affecting the local people of Chilika (Nayak, 2014). Recently, creation of water aerodromes, suggested by Union Government at Chilika Lagoon, faced strong criticism from green activists as the emissions and noise pollution from aircraft operation may negatively impact the fragile environment.

iii. Commercial & Recreational Activities

Although Chilika lagoon is a popular tourist destination in Odisha, there is no viable framework for the protection of environmentally sustainable tourism. In recent years, the activity of boats has risen dramatically to carry tourists to various parts of the lagoon for bird watching, dolphin viewing, and fishing activities (Sahu et. al.,2014). An estimate of around 2259 motorized vessels were used for tourism and fishing purposes with almost 15 small boat-docking sites enabling the transfers. Apart from dredging, boat services for transportation of people (such as ferries) are also operated along with the fishing boats. The tourist centric boats which use gasoline, kerosene, and petrol as fuel in conjunction with engine oil (Baliarsingh et al., 2014). Unregulated transportation of mechanized ships resulted in significant repellent for dolphins and migratory birds from spilling oil into the lagoon waters. Inadequate servicing and unsafe management of fuel are a cause for concern. Regular leakage of fuels into water develops a thick oil coating obstructing light penetration harming the aquatic life (Baliarsingh et al., 2014; Sahu et. al.,2014). Oil emission had both acute and chronic effects on biota causing genetic variations and corresponding effects on fishing livelihoods. The inclusion of trash, plastic litters and garbage are also an additional source of concern in tourism activities (Sahu et. al.,2014).

Even though ventures like road construction in Khirishai island in 2014 benefitted SSF communities in Chilika by connecting people to nearby markets and improving transportation facility, the construction has damaged the lagoon’s ecology to a great extent. The road and small tunnel construction slowed the movement of water which, in turn, impacted the migration of fish and other aquatic species. Implementation of the road even aggravated the prevailing issues of village’s shortage of fishing grounds sparking conflicts.

iv. Fishing Operation

Traditional fishing activities were focused on fishing seasons, unique fishing sites, various fishing gears and methods used by caste-specific fishing community. Inclusion of season-based fishing activities helped preserve a stable lagoon environment. As with the advent of technology and social-ecological changes in Chilika, dominance of non-fishers increased as did resource conflicts. Introduction of a variety of novel fishing strategies that replaced caste-based traditional fishing activities created disputes. Few prevailing methods of modern gillnets and trammel nets used by individual fishers was more kind of a personal achievement and competition in getting fish catch. The resources began to decrease and fishing areas were limited due to invasion of new techniques, overexploitation of lagoon resources through fishing that avoided customary restrictions on seasonality and resulted in intensification and extensification strategies (Nayak 2014). The new fishing techniques resulted in killing of juvenile fish, and drastic reduction of fish and other aquatic species caught in traps. This resulted in further income reduction in SSF communities (Nayak 2014).

In the early 1980s, Chilika, where tiger prawns naturally occur, latched on to the global trend of shrimp aquaculture (Nayak & Berkes, 2014). Fishing practices were governed on a caste basis which was later dominated by non-fishers engaging in aquaculture and other farming practices. A sharp rise in foreign shrimp demand and higher export prices turned out in place of tiger prawn aquaculture (Nayak & Berkes, 2010). Aquaculture is required to sustain demand and hold overfishing under control, but many existing activities have a negative effect on ecosystem. For example, the abundance of nitrogen and phosphorous within a specified lagoon environment is one of the major issues in aquaculture. Farm waste including antibiotics, fish feces, uneaten pellets and dead species pollutes the water and even threatens the life of other fish and aquatic species.

v. *Industrial Activities*

The constructions of dams and barrages for promoting hydroelectric power generation have a huge impact on lagoon ecological system. This raises the demand of many connected industrial development near area causing water pollution with its effluent discharge affecting the fishery resources (Dujovny, 2009). The construction of Palur canal is an extra opening for saline water inflow along with pathways for marine species. However, due to excessive siltation on the canal bed and changes in the SES, fisheries have reached a point of no return. The reduced salinity and blockade in Chilika mouth resulted in significant alterations in fish catch (Ghosh, & Pattnaik, 2005). The feasibility analysis of an ambitious highway of 4km long bridge over the Chilika lagoon was discussed in 2019 by Union Ministry of Road Transport and Highways. Due to the opposition from environmental organisations, the project is not yet initiated. Those organizations claimed it can lead to detrimental effect on the biodiversity and natural function of the entire lagoon ecosystem. The project was supposed to boost coastal connectivity and leverage massive tourism capacity.

Palynological studies revealed that mangrove vegetation formed well between 4165- and 2549-years BP suggesting warm-humid climatic conditions that started declining in later years. Approximately till 2246 years BP, mangroves (depicted in Table 7) expanded again and achieved their zenith, after which it was disappeared indicating dry conditions, barrier spit formation, sand ridges and anthropogenic impacts (Pandey et. al., 2014; Khandelwa, 2008; Khandelwa et. al., 2008).

Table 4.6: Dynamics of the mangrove in Chilika Lagoon (Source: Khandelwa et. al., 2008)

Time interval (cal years B.P.)	**Environment and mangrove dynamics**
2,000–0	Regression of the sea level. Formation of the barrier spit. Degradation of the mangroves and establishment of the present-day conditions
7,500–2,000	Maximum sea level, high point around 5,000 cal years B.P. Start of the formation of the barrier spit. Development of Mahanadi River system. Increase of the freshwater discharge affecting colonization of core-mangrove
9,500–7,500	Transgression of the sea. Formation of an estuary. Development and proliferation of mangrove
13,500–9,500	Fresh to brackish water conditions. Dominance of freshwater plants

vi. Domestic Practises

Another major concern is the untreated domestic wastewater inflow from the five sewage discharge zones in Bhubaneshwar and from 141 villages residing near the enclosing area of Chilika Lagoon (Jyethi & Khillare, 2019; Ghosh, & Pattnaik, 2005). Wastewater can include toilet-flushing excreta, wastewater from household purposes, and plant and animal waste. Since the coasts are highly populated, the volume of waste dumped into lagoon waters is significant. Certain pollutants can cause damage to residents and pose danger to public health through transfer of pathogens. Sewage dumping leads to an over enrichment in nutrients contributing to eutrophication and algal bloom.

Another major source of environmental pollution in Chilika is rising plastic and polythene garbage by local residents and tourists (Singh et. al., 2013). Many plastic bag, bottles and household stuffs are thrown by fishermen operating in the lagoon and by other residents in communities nearby. Aquatic organisms consume the synthetic waste. This causes significant mortality, disruption of food chains and fatalities in human health. Overall, plastic contamination presents a danger to food security and sustainability.

vii. Natural Calamities

Floods and cyclones are a usual feature in Chilika Lagoon every year, including stronger cyclones such as the aforementioned Phailin and Fani (Sahoo et. al., 2014; Acharyya et. al., 2020). Storms, floods, surcharges, and cyclones have been common in Odisha's coastal regions, wreaking havoc on the lagoon environment. During a major flood, sediment, nutritional loads, and debris are carried into Chilika Lagoon causing siltation and eutrophication (Sundaravadivelu et al. 2019). Table 4.7 is a list of adverse climate events that have occurred in the past in Chilika Lagoon. The cyclonic effect along with high windstorm and rainfall caused increased nutrient availability due to water column mixing and layer stratification provided with a favourable phytoplankton growth. Resuspension of sediments increased the availability of nutrients, and this led to algal bloom and eutrophication in the lagoon. There was a considerable amount of loss in fishing machinery and equipment. Further residents' houses in and near the lagoon were drastically impacted (Kumar et. al., 2017; Iwasaki & Shaw, 2010). The sea mouth was shifting at a faster rate as a result of climate change, and the Chilika watershed was experiencing irregular rainfall. These climatic changes led to waterlogging and submergence of paddy fields (Sundaravadivelu et al. 2019). Even farmland drain into coastal waters was polluting them and causing potential harm to aquatic species. Rising trend of pollution in environment was notable by the changes in air and water quality, higher pollution levels and rising emission from motorized vessels.

Table 4.7: List of natural calamities in Chilika Lagoon
(Modified from Sundaravadivelu et al. 2019)

Category	Year of occurrence
Cyclone	1967, 1968, 1970, 1971, 1972, 1973, 1999, 2013, 2014, 2019
Drought	1956, 1970, 1987, 2000, 2002, 2010, 2015
Earthquake	2013, 2015
Flood	1956, 1959, 1969, 1970, 1986, 1987, 1988, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2001, 2003, 2005, 2006, 2008, 2011, 2014

4.6 Vulnerabilities faced by small-scale fishing communities in Chilika

Vulnerability refers to the susceptibility of a system to the detrimental impacts of changes and limited capacity to adapt or deal with those changes (Berkes, 2007). The main parameters of vulnerability are the stress subjected to a system, its exposure and sensitivity, and the capacity to adjust (Adger, 2006). Major vulnerability measurements can be classified into three categories: socioeconomic, political, and ecological (Adger, 2006; Berkes, 2007). The factors affecting vulnerability can either increase or decrease the susceptibility in each dimension. Increasing impacts of diverse natural and anthropogenic changes have an adverse impact on multiple sectors that threaten the subsistence of SSF communities and their livelihoods. Lagoon ecosystem in Chilika is vulnerable to a broad variety of consequences ranging from natural changes such as cyclones, droughts, and floods to many detrimental human activities such as sea mouth opening, aquaculture, and tourism. The variability in fishery production and various social-ecological changes have a remarkable negative impact on the livelihood and wellbeing strategies of fishing communities. Figure 4.13 illustrates various primary dimensions of vulnerability which are applied and explained to issues in Chilika in Table 4.8.

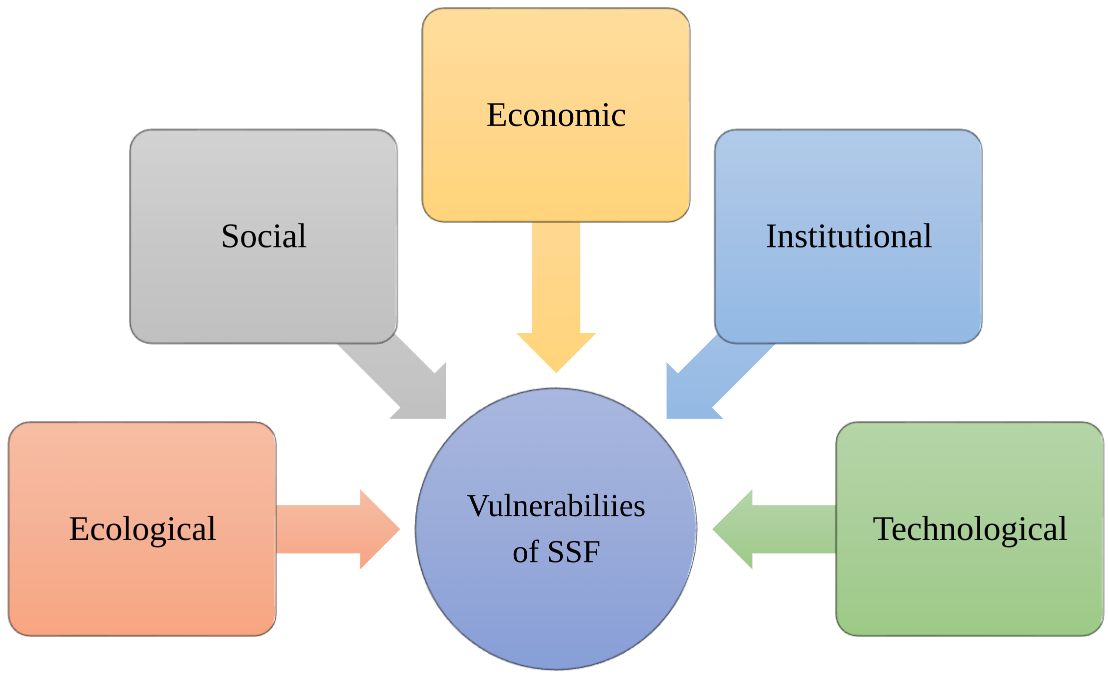

Figure 4.13: A framework on the various areas of vulnerabilities in Chilika SSF

Globally, small-scale fisheries sustain more than half a billion people's livelihoods (FAO, 2010). In developing countries, most of the people who rely on small-scale fisheries live under high pressures of external drivers such as cyclones, hydrological intervention, land degradation, overfishing and tourism which intensifies the stress on resources (Jentoft, 2017). These aggravating impacts affect the structure and productivity of resources disrupting fishing activities ultimately leading to the vulnerability of livelihoods which rely on fisheries.

Table 4.8: Key consequences of various drivers of water quality in Chilika Lagoon

Divers/Issues	Effects (General)	Impacts on water parameters	Impacts on Fishery
Sedimentation	• Shrinking of lagoon in terms of volume and area • Sediment coring of the lagoon bed	• Turbidity-decreased water clarity sources • Riverbed changes • Less light penetration into the waters	• Reduced the biological productivity of aquatic systems • Damage to fish gills and their feeding • Decreased plant growth • Lethal and sublethal effects of sediment on fish and their habitat
Artificial sea mouth	• Lagoon-sea connectivity with high water inflow-outflow variation • Drastic tidal fluctuations • Water imbalance • New aquatic species like stingray, jelly fish • Barnacle infestation • Sand infestation	• Changes in salinity, and pH • Variations in water depth	• Fishers and their equipment became incompatible • Decline in fish production and stress to livelihoods
Aquaculture	• Habitat degradation • Pollution from uneaten feed • Unique diseases and specific parasites	• Nutrient & wastes in lagoon waters • High organic pollution • Eutrophication	• Decline of natural fish production • Clash through competition for same

	• Possible genetic and environmental risks when modified fish can interact with the wild. • Harmful by-products and toxic destructive gases arising from chemical reactions	• Algal bloom • Depletion of oxygen • Death of corals • Habitat destruction	resources Cultural encroachment • International demand Decline in capture fishery • Right to access issues • Marginalised village fisher cooperatives • Huge debts • Food safety and security compromising and concerning the consistency and quantity in food intake; children's education; out-migration
Dam construction - Hirakud	• Sedimentation • Increased industrial and urban use • Pollution of the reservoir Competition for irrigation water	• Altered salinity regime • Changes in water flow pattern & channelization	• Displaced people by the reservoir, including fishermen • Improper rehabilitation and compensation
Tourism- motor boats - introduction of synthetic fibers for netting,	• Coastal erosion • Sedimentation from construction activities • Solid waste disposal • Toxics and nitrification	• Reduced DO and transparency • Polluted waters • Sewage and solid waste dumping	• Displacement of Traditional Uses • Physical Changes and Habitat Damage • Conflict and displacement of fishers

mechanized boats	• Visual impacts Noise pollution Damage to corals and sea grass beds Overharvesting of renewable resources	• Groundwater Depletion and Contamination	and other traditional water users • High foreign investment
Cyclone: Phailin	• Chocking of the mouth • Changes in phytoplankton composition	• Decline of salinity • Changes in the distribution of ammonia and silicate • Growth of diatomic species, green algae and cyanobacteria	• Ecological disruption in the lower order food chain
Floods and droughts	• Reduced surface flows and groundwater flows; Less salt-tolerant wetlands die • Crabs and shrimp domination • Dynamic balance between catchment runoff (rain events) and ocean wave / beach processes • Geochemical fluctuations	• Scarcity of water and contamination in tandem with natural as well as anthropogenic pressures • Poor aquifer recharge • Impacts on benthic ecology, which has already adapted to existing light conditions	• Damages to fishing vessels, materials, and machineries • Loss of wild and cultured fish stock • Poor access to adequate and potable water for domestic purposes (such as bathing, drinking, and cooking) • Low quality of available water

The present study is about assessing the vulnerabilities of the livelihoods of SSF communities of Chilika Lagoon by understanding the changes in water quality. Chilika Lagoon connected to the Bay of Bengal (located in Odisha State, India) reveals that SSF sustain 150 fishing villages with livelihood of approximately 400,000 fishermen and their families (Nayak, 2014). People in these villages have been active in traditional fishing activities and utilize available resources for their resilience and general wellbeing for decades. Nevertheless, over the last few decades, Chilika Lagoon has been swept up over cycles of transformation affected by several local and global drivers such as state-driven hydrological activities and aquaculture introduction. These dramatic modifications have a significant impact on small-scale fisheries sector of Chilika. Biodiversity loss and resource conflicts contributed to tremendous drop in the wellbeing and resilience of SSF communities. These social ecological changes resulted in dramatic rise in vulnerabilities of fishing communities in Chilika.

This research assesses water quality as a main driver for the vulnerability of coastal communities in Chilika Lagoon. The qualitative study focuses on how variations in water quality are factors for changing livelihoods in SSF communities. Coastal waters are vulnerable due to increased pollution, natural disasters, and human induced interventions. Several million people reside near the rural coastline along with the fishers that depend on lagoon waters for a range of purposes. The analysis involves study of impact of drivers such as cyclones, sedimentation, salinity fluctuations in the lagoon and pollution levels on water quality variation. Further, lagoon waters suffer from heavy siltation, contamination from aquaculture wastes, industrial and domestic dumping, sewage disposal, agrochemicals and sea mouth creation which all influence the availability of resources in Chilika and subsequently impact health, safety and sustainable livelihoods of local population. The addition of extreme weather events further undermines the livelihoods of fishermen leading to poverty, food insecurity, resource degradation and economic loss. Thus, it is necessary for a holistic analysis of water quality changes as a source of vulnerability for SSF communities in Chilika. From this analysis, more robust recommendations can be made for about how to support adaptation and mitigation.

Results of various studies on water quality changes in Chilika Lagoon, sediment dynamics and biodiversity have shown that exchange of water between lagoon and the sea plays an important role in sustaining the health and serenity of lagoon ecosystem (Sahu et. al., 2014). The previous section described the various factors related to the major driver of water quality variation. Now I will focus on the impacts caused by these social-ecological changes that lead to vulnerability of SSF communities.

i. Siltation & Water Quality Deterioration

Siltation is a major concern faced by Chilika Lagoon (Kumar & Pattnaik, 2012). The rivers joining the lagoon deposit over 1.8 million tonnes of sediment per year (Sarkar et. al., 2012; Rao, 2013). Over a period of time, the average lagoon depth has declined due to the fine sediment deposition through high inflow rates. Sedimentation affected the flow of water and sediments between lagoon and sea significantly led to the choking of lagoon and inlet mouth (Myrbo, 2012). The high rate of sediment deposition will reduce the light penetration of the lagoon waters leading to loss of aquatic life. Water quality is being deteriorated due to the increased turbidity hindering the life cycle of fish species.

ii. Pollution & Diseases

The pollution load from tourism, agricultural practices, aquaculture, domestic sources, and sewage dumping has increased generally. Introduction of aquaculture was an important factor that reduced the water flow as well as increased the sediment load in lagoon (Dujovny, 2009).

Although the intention of aquaculture was not to impact environment, but the rising market and the poorly managed farms caused a huge number of concerns. Nutrient and effluent build-ups from fish farms have a significant effect on the local wild fish population which sets the conditions for diseases and environmental degradation. Waste produced by fish, uneaten pellets of feed and antibiotics used by farmers to control diseases contribute to the rise in nutrients depleting oxygen content causing algal bloom, dead zone, and eutrophication. Many aquatic macrophytes and the distribution fish rate was affected by the impacts caused by intensive aquaculture (Dujovny,2009).

iii. Biodiversity Loss

Chilika lagoon is subjected to several harmful fishing practises and hydrological interventions posing major threat to the biodiversity (Kumar & Pattnaik, 2012). Many advanced technologies for catching fish have even resulted in destruction of juveniles with adverse implications to natural recruitment. The considerable changes in water quality and nutrient dynamics influenced by macrophyte proliferation created dead zones leading to loss of aquatic population (Myrbo, 2012). Aquaculture impedes flooding patterns impacting the feeding sites of fish as well as stress the breeding ground (Kumar & Pattnaik, 2012). The rising plastic litters along with no proper waste disposal and management system of local residents in Chilika threatens the health of ecosystem. Lagoon ecology can be affected in many ways by plastic pollution. The detrimental impacts include adverse effects on the trophic levels leading to decline in biological interactions and death of fragile organisms. This risks the life of huge number of migratory and resident birds that consumes the polluted aquatic organisms (Sahu et. al., 2014). Typically, migratory birds rely upon benthic species as food. Decline of benthic species results in loss of bird population. The huge impact of noise pollution from motorized boats affects the life cycle of fish species and even migratory birds. Pollution from the oil will adversely affect birds and associated wildlife affecting their body structure leading to threatening of biodiversity (Baliarsingh et al., 2014).

iv. Resource Conflicts, Food Insecurity & Economic Downturn

The world's number of undernourished people have crossed the poverty line of 9000 million (FAO, 2010; Mathiesen, 2015). Chilika contribute to this number as the number of marginalised fishermen is approximately 400,000 (Nayak & Berkes, 2014). These SSF communities are suspected to be poor and vulnerable. Fisheries suffer a range of additional impacts such as reduction in valuable species and rate, changes in climatic changes, biodiversity loss and extinction of certain aquatic species. These changes in ecology of Chilika lagoon affect the food chain and impacting drastically livelihoods in SSF community. Traditional fishers are experiencing reduced catches and less incomes. This has made increased poverty rates. Water quality degradation therefore results in a complete imbalance of their lifestyle in direct and indirect ways through reduced resource access and health and safety risks for operating in the lagoon environment. The decline in fisheries and rising demand of international shrimp markets created competition between local fishermen and non-fishers resulting in overfishing which was accompanied by a reduction in per capita fish harvest. This signifies the impoverishment of fishing communities, their inability and financial condition to afford a normal living condition, and lack of maintaining proper hygiene and sanitation.

v. Loss of Livelihood & Migration

Water quality deterioration has led to reduction in diversity of fish species and other aquatic organisms. Changes in salinity levels and high nutrient levels raised the condition of algal bloom as well as dead zones resulted in drastic decreases in fish capture. This has placed livelihoods of SSF communities in and around Chilika lagoon in jeopardy (Nayak, 2012). The tremendous decline in the fishery poses a state where rising human demand and consumption cannot be met (Panigrahi, 2007). The economic downturn forced families to borrow to meet their daily demands for sustaining lives. Studies showed that the ratio of loan to overall household income was so high that the loans taken by the fishing community overtook their earnings in a year. In addition, most of these loans come from outlets involved with perpetuating debt cycles from which the communities have trouble escaping (Nayak & Berkes, 2010). Distressing social and economic conditions of SSF communities were forcing them to over-fish and shift to improper fishing practices. The incessant clashes between fishermen and non-fishers for resources led to traditional fishers to seek alternative of livelihoods outside of their communities (Panigrahi, 2007). Approximately, half of the adult population was displaced from fishing to work as wage labourers and even at construction sites in urban areas for better living and earning money (Nayak & Berkes, 2010). Water quality degradation has direct influence on poor sanitation and fish decline while creating indirect effects of low catch, poverty, and marginalisation for fishing communities dependent on the lagoon resources.

Vulnerability is context dependent. An understanding regarding the current situation of fishing communities and identifying their needs is a necessary step to assess what makes SSF communities vulnerable, determine realistic policy measures to mitigate that vulnerability, and examine opportunities for improving viability (Badjeck et. al., 2015). SSF around the world face a variety of complicated environmental, economic, and political pressures and changes that put them at risk. Due to the significant reliance on natural resources and deep connections to coastal environment, SSF communities are particularly vulnerable to global and local change processes (Chuenpagdee and Jentoft, 2015). Natural and anthropogenic influences, inherent problems within their own socio-economic conditions and political situations contribute to their susceptibility and limit their capacity to maintain viable livelihoods (Allison et al. 2006). The main domain of Table 4.9 describes vulnerability in Chilika according to five categories: ecological, social, economic, institutional, and technological. Figure 4.14 summarizes the aspects of vulnerabilities faced by fishing communities in Chilika Lagoon connecting the various drivers and impacts on water quality.

Table 4.9: Main aspects in vulnerability of small-scale fisheries in Chilika Lagoon

Domain of vulnerability	Emerging vulnerabilities
Ecological	• Water pollution • Change in climatic conditions • Natural calamities such as cyclones and droughts • Biodiversity loss
Social	• Disease outbreaks • Flaws in regulations and policies • High rate of migration • Poverty and food insecurity • Loss of livelihood and fragmentation of family • Political marginalisation
Economic	• Loss of income • Restricted access to local and international markets • Low education • Lack of access in facilities
Institutional	• Slow progress in government projects for welfare of SSF • Lack of subsidies to fishing communities • Lack of employment opportunities • Encroachment to fishing grounds

Technological	• Unavailability of fishing sophisticated fishing equipment • Increased advancements in tourism

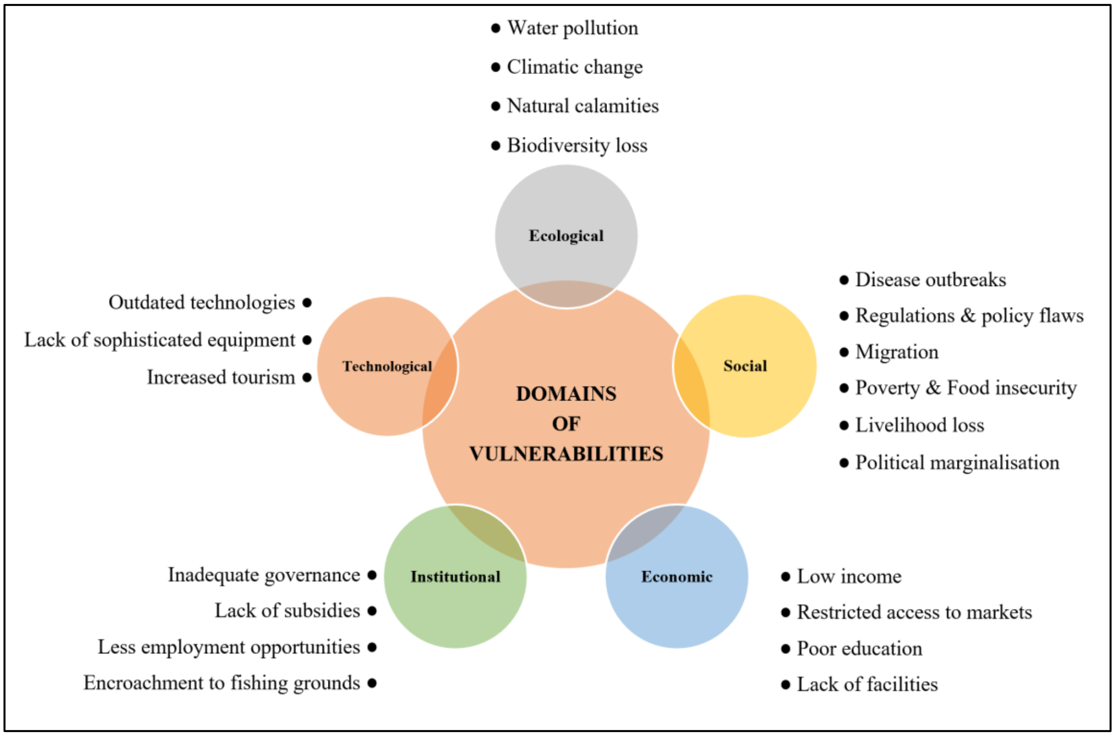

Figure 4.14: Domains of vulnerability assessing social-ecological impacts on Chilika Lagoon

a) Ecological Vulnerability:

The ecological domain pertains to natural resources such water quality, status of biodiversity, natural drivers, and various climate change factors. A composite ecological vulnerability index combines the three dimensions of ecological vulnerability. Higher Exposure and Sensitivity raise the index, whereas Recovery Potential lowers it (Ruiz-Díaz et. al., 2020).

$$\text{Vulnerability}_{\text{Eco}} = \text{Exposure} + \text{Sensitivity}_{\text{Eco}} - \text{Recovery Potential}$$

Exposure in SSF communities refers to the degree to which natural resources are impacted by natural and anthropogenic changes. In the same context, ecological sensitivity indicates the susceptibility of SSF to stressors such as water pollution, invasion of macrophytes and barnacles. The ability of the fisheries to overcome stresses and recover after the disturbance is referred to as recovery potential (Ruiz-Díaz et. al., 2020). The changes in water quality parameters in Chilika lagoon due to hydrological interventions, biodiversity loss due to anthropogenic activities and natural calamities, erratic rainfall and sedimentation constitutes to ecological vulnerabilities.

b) Social Vulnerability:

Within fishing community, social domain includes risks associated with livelihoods in communities. The different fishery-dependent indices to analyse social vulnerability involve unemployment rate, poverty, job opportunities of women, food, and nutritional security (Jepson and Colburn, 2013). A study conducted by Colburn et. al., 2016 showed that fishing communities with high rates of commercial engagement and/or reliance of commercial activities are more socially fragile. Understanding both social vulnerabilities and community adaptation mechanisms to environmental changes are critical for developing activities that will improve community conservation and survival (Martins and Gasalla, 2020). Communities that rely heavily on fishing are more likely to be socially vulnerable than other coastal communities, when fishing resources decline. These findings highlight the importance of continuing to investigate climate change and social vulnerability, as minor changes in coastal communities, their income and existence may have an impact on their ability to adapt to change (Colburn et. al., 2016).

c) Economic Vulnerability:

Savings, income, credits, and loans are all part of the economic domain. Natural disasters and anthropogenic activities have caused a significant increase in the amount of damage to SSF communities (Badjeck et. al., 2015). The constant exposure to these effects results in significant economic loss to the people in Chilika Lagoon as a result of fish stock decline, damaged fishing gear and equipment. Also, families in communities near to the water bodies are at high risk of losing their homes and lives due to the unexpected natural drivers of change such as cyclones.

The importance of the fisheries sector in ensuring adequate protein consumption and as a source of economic and social growth for rural coastal communities cannot be overstated (FAO, 2014). Among the economic vulnerabilities of fishing communities identified were low revenue due to fewer fish, restricted access to local and international markets, personal safety concerns due to unemployment or more frequent hazardous natural calamities, and poverty leading to less education and nutritional insecurity.

d) Institutional Vulnerability:

The institutional domain of vulnerability refers to the role of community-based laws and governmental regulations in influencing access to natural or financial resources. There have been major changes in the status of the Chilika lagoon resources and their customary rights, resulting in livelihood loss and a rising sense of detachment from the lagoon by most fishers. Dwindling local institutions and the loss of resource access rights intensified with aquaculture development and a profitable export market rate of white prawn and tiger prawn. Rich businesspeople (non-fishers) from outside the lagoon established shrimp farming in Chilika that displaced the fishing villages from their resource base (Nayak & Berkes, 2010). In favor of aquaculture-based fisheries and the granting of rights to non-fishers, policy support for caste-based capture fishing was withdrawn. Issues of access and entitlements have arisen as a result of developments concerning fishing area encroachment and lease (Nayak & Berkes, 2010; Nayak, 2014). Not only is the environment deteriorating, but there is also a conflict between fishermen and non-fishermen in the area over ownership of the Chilika water body (Samal, 2002). Improper public policies, disputes in access rights to fishery resources, ineffective stakeholder engagement, lack of management and planning results in institutional vulnerabilities. These put the livelihoods of traditional fisher communities in jeopardy, wreaks havoc on the local fishing sector, and harms the fragile Chilika ecosystem (Nayak, 2014).

e) Technological Vulnerability:

The technological domain of vulnerability that refers to the major assets required to expand fishing activity such as boats, gears, and infrastructure. Lack of sophisticated equipment for protecting the fishers from the invasion of barnacles is a major risk faced by people in Chilika. Excessive loans that the communities take to buy fishing equipment and the burden of debts intensified poverty (Nayak, 2017). Pollution from tourism and industrial fishing vessels worsened the situation of Lagoon ecosystem (Monnier et. al., 2020). Although tourism increases economy one side, the improper technology to handle waste dumped into Chilika waters risks the aquatic life and in turn affect the livelihood of people leading to poor sanitation and hygiene. Local fishing communities are aware of the danger that tourism operations pose to dolphins as well as ecological disturbance and mortality (Sutaria, 2009).

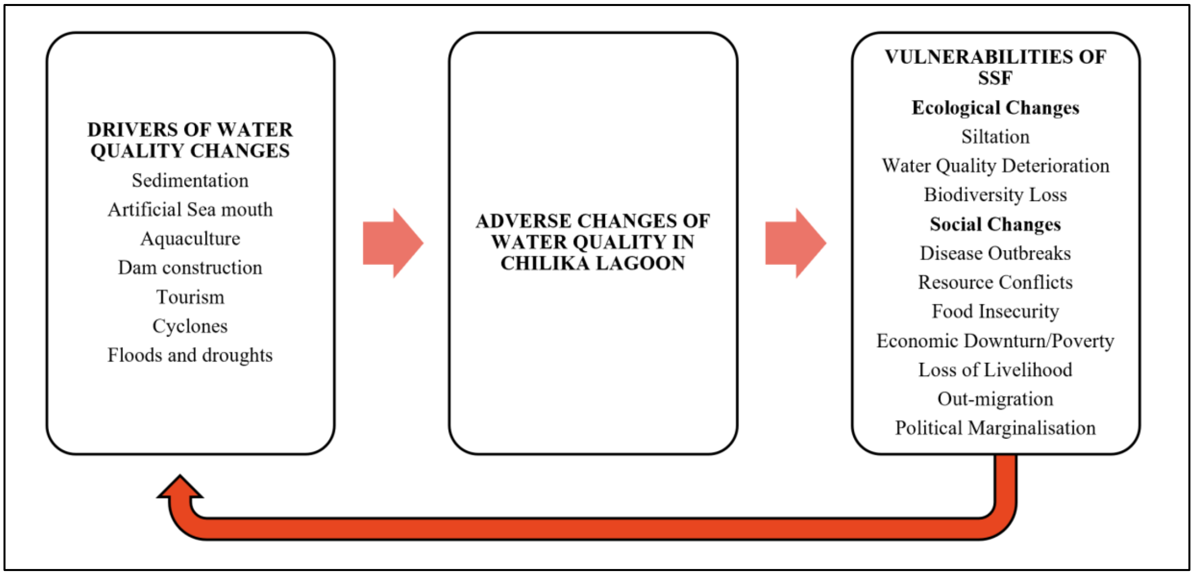

Figure 4.15: Relation between drivers of water quality changes and vulnerabilities of small-scale fisheries

Figure 4.15 represents the connection of how water quality as a major driver is impacting the social-ecological system of Chilika Lagoon and resulting in the vulnerability of small-scale fishing communities. Polluted water puts the lives of communities in Chilika at risk in the aspects of cleanliness too as communities are forced to have a low-quality lifestyle and food due to their reduced earnings. The changes in water quality and climatic variation in combination with resource conflicts created a situation where fishermen had to give up their livelihood activities for weeks at a time.

Vulnerability is considered to a function of nature, magnitude and intensity of changes and variation to which small-scale fishing communities are exposed (IPCC, 2007; Thornton et. al., 2007). Fishing is an occupation with high risk of survival due to the variation in hostile sea, transient existence of capitals and perishability of commodities (Islam et. al., 2014). The exposure and sensitivity of hydrological interventions as the key driver highly impacted water quality. Reduced water quality is so detrimental that it has outweighed the adaptive capacity in SSF communities. This finding contributes important insights to an understanding of water quality variation as a driver of vulnerability in SSF communities.

4.7 Summary & Conclusion

Intensifying changes in Chilika due to the anthropogenic interventions and natural drivers of change have deteriorated water quality which, in turn, has resulted in poverty of SSF communities. As discussed above, the various activities in Chilika lagoon like industrial wastewater disposal, sewage dumping, aquaculture, hydrological interventions, and cyclones are causing salinity variations, sediment deposition, nutrient enrichment to eutrophication and dead zones. The drastic decline in environmental conditions poses high risk of fish survival and other important species which reduces the income of fishermen and leads to their poverty and marginalization. The different categories of drivers affecting water quality of Chilika Lagoon portray the multiple faces of vulnerabilities in SSF communities. This analysis has revealed dimenisons of a wicked problem.

Wicked problems are probems that are complex which are difficult to describe and differentiate to provide a permenant solution (Jentoft and Chuenpagdee, 2009). The features of a wicked problem are reflected in the several faces of vulnerabilities. Vulnerability is viewed in a three-dimensional context as (i) absence of wellbeing, (ii) lack of access to resources or capitals, and (iii) loss of resilience (Nayak & Berks, 2019). In this case, vulnerability of SSF communities and its relationship with water quality degradation was assessed. Applying water quality as a driver in the similar context leads to the three-dimensional phase: First, *vulnerability in terms of absence of wellbeing*: low water quality leads to biodiversity loss and pollution. These affect livelihoods of SSF and lead to poverty. Second, *vulnerability as lack of access to resources or capitals*: hydrological interventions, tourism and international markets creates resource conflicts and leads to low income. Third, *vulnerability based on loss of resilience*: continuous disturbance or pressure on Chilika waters affects the self-purification capacity of the lagoon leading to more adverse effects of eutrophication along with pollution.

This chapter addressed water quality in Chilika lagoon, the status of water quality parameters, how they are being impacted by various changes in social-ecological system and the way they are impacting fishing communities of Chilika. The chapter also directs to the leading link of water quality to vulnerability and how they are interconnected along with considerable influence on the fishery resources. The chapter provides a robust basis for exploring various coping and adaptive measures of SSF communities in Chilika Lagoon. It is those opportunities to cope and adapt that are addressed in the following chapter.

CHAPTER 5
Responses to Vulnerabilities and Prospects for Viability for SSF Amidst Changing Water Quality in Chilika Lagoon

5.1 Introduction

SSF play a vital role in social, economic, and cultural aspects globally. Viability of SSF can be promoted through poverty eradications, food security, employment opportunities, livelihood provisions, and rural and economic development. Human-induced impacts of hydrological interventions mentioned in Chapter 4 resulted in water quality degradation. This may induce irreversible changes in the Chilika lagoon ecosystem and irrevocably disrupt the livelihood of SSF communities. Based on that water quality analysis, various coping and adaptation strategies can assist the viability of SSF . The objective three (Box 5.1) is addressed in this chapter, as it outlines strategies employed by fishers to adapt to the changes in social-ecological system where water quality acts as a key driver. By constructing multidimensional zones with possible management options, viability measures are explored to simplify complicated ecosystem dynamics of Chilika Lagoon especially in terms of water quality. Diverse methods of short-term and long-term approaches for sustaining livelihood are described in this chapter to address the viability measures to aid in access of capitals, build resilience and improve wellbeing.

Box 5.1 Outline of research objectives

- Understanding processes of water quality variations in Chilika lagoon
- Examining vulnerability issues faced by the coastal communities due to changes in water quality
- ***Analysing various coping and adaptive responses of the fisher communities and their potential for creating viable small-scale fisheries***

5.2 Coping Strategies

Coping is a short-term reaction to an impact (e.g., response to natural driver of change or hydrological interventions). Coping may undermine adaptation activities as the time scale for coping measures is short-term (Shelton, 2014). This refers to reacting to disruptions in a way that mobilizes the capacity of the actor to draw on the skills, resources, and experiences available. Coping mechanisms are usually associated with smaller changes to improve viability, such as reductions in abundant species and the occurrence of new species in the case of changing stocks (Ojea et. al., 2020). Coping mechanisms may be categorized into those that aim to minimize vulnerability and avoid entry into poverty as *ex ante* risk control strategies and those that are *ex post* coping mechanisms are attempting to promote a transition out of poverty (FAO, 2014). Coping plans in SSFs are listed in Table 5.1 which include setting limits to the catch and changes in market strategies. It may also entail occasional changes without any systematic trend in fishing practices (Ojea et. al., 2020).

Table 5.1: Coping strategies of small-scale fishing communities in Chilika Lagoon (Developed from information listed in Allison, 2011; Kumar & Pattnaik, 2012; Nayak & Berkes, 2014; Nayak, 2017)

Coping Measures	Activities
Lagoon water protection plans	• Raising awareness about social & ecological balance and healthy waters • Identifying vulnerable species and habitats • Lagoon clean-ups • De-silting water bodies • Clearing sediment filled channels • Wastewater treatment plants • Watershed management practices
New fishing practices	• Change in the fishing technique

	• Improved fishing gears • Varied fishing grounds • Restructuring vessels • Intensification methods • Extensification methods
Livelihood approaches	• Credits, remittances, and loans • Borrow money from bank & non-bank institutions • Aids from religious group • Gifts from relatives & non- relatives • Utilize savings • Reduced consumption • Assistances from government & non-governmental organizations • Selling assets including land and property • Withdrawing children from school • Diversification methods
Social cohesion	• Hobbies/Skill development activities • Add value to existing products • Training programs • Strengthening of community support systems • Expanding inter-village communication and cooperation by developing networks • Social and political empowerment, especially of women • Women's education developing voice in politics and self -esteem
Transitioning to alternative occupations	• Temporary shift to other income sources • Switching to additional occupations • Casual labour • Shrimp Aquaculture • Livestock rearing

	• Seasonal cropping • Farming

5.2.1 Lagoon Water Protection Plans

Many improvement measures can be adopted for upgrading the water quality of Chilika lagoon. One of the major steps is generating awareness among the SSF communities regarding the importance of maintaining water quality. Education about the importance of maintaining water resources should be recognized as a tool, that is essential to facilitate the implementation of lagoon water management plans (Kumar & Pattnaik, 2012). Execution of community awareness about diverse social-ecological changes and resulting water issues helps in prevention of water quality degradation. Proper strategies on watershed management should be implemented as many lagoons are contaminated from anthropogenic waste input. Removing sediments from the chocked channels and mechanical scraping of algal weeds from the lagoon waters can also be considered to confront lagoon water issues. Building treatment plants can reduce water pollution to an extent which provides safe and potable water to SSF communities dependent on Chilika waters. Creation and implementation of a framework for the active management of lagoon waters including the salinity levels can help in habitat restoration. The development plan also helps to save vulnerable and threatened species of the lagoon ecosystem.

5.2.2 New Fishing Practices

SSF communities can rely on modified fishing activities to increase the sustainability of the social-ecological environment, in addition to managing the direct effects of water pollution. This will increase the populations of target species and help in restoring damaged areas to upgrade the ecosystems. Due to the low catch using traditional net catching, low landings of fish and shrimp along with reduced incomes shifted communities into coping by using new fishing techniques.

Modifications in gear can be an option to enhance selective but it often catches non-targeted species. Some fishers in Chilika have switched to this new technique for enhanced fishing. Limiting the mesh size can be a suitable measure to avoid the capture of target species at immature stages, but there are limitations in multi-species fisheries due to the probability of organisms in various size and shape in the same fishing ground. This situation can be remediated by incorporating excluder devices for non-targeted species and improved operational techniques with sorting grids. The other intensification measures include neglecting the time and space restrictions in fishing areas as well as catching the targeted species, personalized fishing operations, fishing for year-round in addition to overnight catching to get long fishing hours; intensive aquaculture and emphasis on one species based on the market value and availability (Nayak, 2014).

Introduction of synthetic nets, higher monetary investment and improved laboratory fishing can also be considered in intensification coping strategies. Several extensification initiatives such as moving far in new fishing areas for expanding production and operation, extensive aquaculture, capturing all available species and using motorized boats. The emissions of gases and vibration can have negative impacts of the lagoon habitats and even pollutes water. Improved management of fishing gears and restructured vessels can result in energy optimization, reducing the emissions and disturbances in lagoon waters.

5.2.3 Livelihood approaches

Some coping mechanisms endorsed by fishing communities in Chilika lagoon are increased dependence on credits, debits and taking loans, utilization of money from financial sectors, non-financial institutions and from multiple sources like grants or aids. Appropriate incentive measures can be used by establishing economic premiums in the form of subsidies and taxes; creating marketing endorsements for instance eco-labels and access rights can promote easier implementation of rules and regulations for controlling vulnerabilities faced by fishing communities. The best way to minimize the effect of natural disasters on fisheries is to include relief funds and subsidiaries from governmental and non-governmental organizations. Trading household properties and land, mortgages and sale of fishing equipment are also practiced in Chilika as part of coping measures. Some diversification strategies replace appropriate incentives measures and a few of them are discontinuing education of children to engage them in income-generating activities. Women are engaged in daily wage labour, temporary transfers to other sources of income and reduced consumption to save food for future (Nayak, 2017).

5.2.4 Social cohesion

Additional coping strategies include teaching other skills to fishing communities so that they can support themselves by earning money from sources other than fishing. This sustains their livelihood by earning income and also eradicates the poverty in SSF communities. from an alternative source other than fishing. Empowering women in terms of social and political aspects act as an integral part of food and nutrition protection. This has far-reaching benefits for societies to increase opportunities for women and increased household income, particularly in fishing households headed by women. Collective action is recognized as a key element to successfully implement sustainable fisheries. Collective action is widely acknowledged as a critical component of implementing sustainable fisheries (Torre et. al. 2019). Education of women often leads to ecological monitoring, fishery, and habitat restoration. The role of women in the community as decision-makers, leaders, and entrepreneurs helps strengthen community and eradicate gender biases. Many collaborative projects and training programs can create opportunities for establishing connections to benefit the upliftment of small-scale fishing communities. Involvement of social companies can produce marine value-added goods allowing direct means of approach to wholesale fish markets, by laying off cash lenders and intermediaries. Proper system to understand the value of social-ecological system by utilizing the local knowledge and traditional expertise of fisher folks needs to be employed. Revenue should be invested in information, training, health, and education sectors to upskill children and adults in fishing communities to lead a sustainable life.

5.2.5 Transitioning to Alternative Occupations

Fishing communities focus on effectiveness of alternative income generating opportunities. The reduced wages, short season, and low landings of fish and shrimp force fish harvesters to find employment opportunities outside of fishing. Some families shift to agriculture and livestock rearing as it provides wide opportunities for employment. Animal husbandry and seasonal cropping play important roles in supplementing family incomes and generating productive jobs in fishing sector as it supports food and nutrition. Although there are both advantages and disadvantages associated with this transformation to new job markets and casual labour, regional fishing communities prefer to get involved in them to generate income. Incorporating aquaculture into local fishing communities opens the window for fish farming, mitigates conflicts in fishing grounds and boosts the economy (Hugues-Dit-Ciles, 2000). Aquaculture can contribute to improving the local community's skill levels and create jobs, valuable linkages with external production sites and draw public investment.

5.3 Adaptation Techniques

Adaptation means adopting reasonable measures to stop or mitigate a harm caused by adverse effects of social-ecological changes and take advantage of future opportunities. Adaptation may be planned (e.g., planned action based on climate-induced changes, implementation of rules and regulations) or autonomous (i.e., spontaneous response to environmental change such as migration of fish to cold water, new fishing grounds, changing time of fishing) for the potential survival of fisheries (Holbrook & Johnson, 2014; Shelton, 2014). Adaptation operations can address short-term or long-term impacts which are categorized in Table 5.2, while adaptation may often be confused with coping. To avoid potential maladaptation, deliberate adaptation needs to consider into account such as identifying vulnerable communities, possible social-ecological changes and expected mitigation measures to respond effectively to future change (Ojea et. al., 2020).

Table 5.2: Adaptation strategies followed by small-scale fishing communities in Chilika Lagoon (Developed from information listed in Allison, 2011; Kumar & Pattnaik, 2012; Salagrama, 2012; Nayak, 2017; Chuenpagdee and Jentoft, 2019; Nayak & Berkes, 2019)

Adaptive Measures	**Activities**
Water quality monitoring	• Maintaining water quality by testing • Reducing pollution • Eliminating destructive fishing activities • Proper coastal infrastructure development • Proper management of tourism
Out-migration	• Seasonal migration • Permanent migration • Out of state employment
Lagoon habitat conservation	• Minimise habitat degradation • Tracking wild populations • Sustainable fishing practices • Proper spatial management • Preserve mangrove areas • Wetland conservation • Afforestation

Information system	• Early warning system • Communication and response system • Proper weather forecasting facilities
Institutional and Policy Changes	• Rise in political voice • Improved education, health, and economic wellbeing • Local and traditional knowledge at the forefront • Community members (mainly women) becoming entrepreneurs and innovators

5.3.1 Water quality monitoring

The monitoring and forecasting of water and wastewater quality play an important role in the management of SSF (Jentoft and Chuenpagdee, 2015). Water quality parameters such as nitrate, sulphate, salinity, pH, and conductivity can be determined along with global emission parameters such as biological oxygen demand (BOD) and chemical oxygen demand (COD). Remote monitoring systems for water quality were developed to create a wireless sensing network integrated with a forecasting model for providing real-time information and complex water quality patterns at various monitoring sites. The data detected can be obtained and analyzed via internet at any time to know the ecosystem's status and changes (Li & Liu, 2013). Mindful observation of water quality parameters facilitates the interactions between parameters and the impacts on aquatic habitats, their growth rate and existence. Use of aerators and chemical treatments can reduce phytoplankton growth and low oxygen content to a limit.

Production of new feed forms can contribute to less emission load of feed in aquaculture. The implementation of good feeding and management practices on fish farms will minimize feed loss. Recycled waters can be used. There are chances of parasite and disease outbreaks when fish treated with pesticides or antibiotics are concentrated in aquaculture systems. Lagoon water pollution can be controlled by practices including the analysis of diseases, adequate dosage of antibiotics, banishing destructive fishing activities, and water treatment prior to discharge into the ecosystem. Land-based fish farming can be considered as an alternative for reducing water pollution and impact on adjoining social-ecological system. Chilika's beautiful landscapes, rich biodiversity and attractive fishing sectors make them popular tourist destinations (Kumar & Pattnaik, 2012). Rise in economy from tourism raises the standard of living but at the same time, it becomes increasingly difficult to make a decent living for local fishers. They have difficulty to rely on fishing alone.

Plastic pollution is one of the major challenges faced by lagoon waters and tourism. Upgrading to sustainable wastewater management techniques and improvement in stormwater treatment includes incorporating filtration, drains and removal of sediments or river mouth settlements. This will prevent pollution from flowing into the lagoon waters such as microplastics, litters and chemicals (Panigrahi et. al., 2007).

Sustainable fishing tourism is a widely adopted method to minimize the intensity of fishing operations, maintain resources, retain economy, and promote the cultural heritage of SSF. This is very effective solution that can be advocated for in the lagoon ecosystem to ensure sustainable livelihoods of SSF communities. These practices can be enhanced by encouragement of effective regulatory structures, campaigns to protect marine ecosystems and biodiversity creating opportunity for thriving resource markets.

5.3.2 Out-migration

Migration is considered as a basic adaptation strategy for improving the lives of vulnerable SSF communities and their families. Some of the root causes of out-migration are restriction in fishing rights and access to resources, decline in fish catch, decreases in fishing opportunities, rises in standard of living, unpredictable natural disasters, and climate change issues health and social-cultural problems, reduced employment options, deprivation of education, and pressure from non-fisher communities and development in technologies (Himes-Cornell & Hoelting, 2015; Nayak & Berkes, 2010). Creating multiple opportunities (e.g., alternative jobs) inside and outside fishing sectors will provide fishing communities diverse options to sustain the livelihoods. Migration can be seen as a transforming resilient strategy to learn new skills and trades which improves the social life of individual fisher folks. They can also return to their homeland with the acquired knowledge to benefit their familied and create pathways of community resilience (Himes-Cornell & Hoelting, 2015).

Based on the systematic literature review and case study analysis, the following migration categories have been established (Njock & Westlund, 2010):

- ***Internal migration:*** Migration between fishing communities within the same country for the purpose of monitoring fish stocks, fish processing, production, and marketing during specific periods of the year or for a longer period.
- ***International migration:*** Migration that occurs across national boundaries which can be long-term but often short-term.
- ***Rotational or seasonal migration:*** During the high demanding season, fishermen move over to fishing for fish and shrimp catching and marketing. Fishermen might stay for one or more

seasons out of province or in international fishing settlements and then return back to home for a short duration.

- ***Permanent migration:*** Fishermen of the second or third generation who end up being integrated into the new local population and who also have the nationality of the host country.
- ***Temporary or Contractual migration:*** Migration that is driven by a contract of employment formally in a different place which can be within or outside the province (or state). The term of the contract can be one or several years and during this time, the fishermen make visits to their home country.
- ***'Stop-over' migration:*** Migrants who wish to continue their migration but who take rest in between their path to reorganise or recover their journey for a shorter or longer time. Various temporal and spatial aspects of the migration patterns observed are defined rather than being exclusive.
- ***Short-term migration:*** This kind of migration is usually seen in fisherwomen. Short-term migration lasts for a few weeks or even less than a season of fishing for the purposes of processing and marketing. Sometimes, this form of migration can extend to few months which involves the fisherwomen who go to stay with their husbands in helping them.
- ***Long-term migration:*** Fishing people who migrate abroad for many years (3-4 years or even more) but who, regardless of the duration of their stay abroad, still ultimately return to their home country.

Out-migration and migrant work are both relevant when it comes to migration. Migrant workers keep their houses in the community and return on a regular basis, whereas outmigration often means moving away. A large proportion of people who return from migrant labour, particularly young fishermen, have no ties to the village fishery institution or resource base.

Migrant laborers (temporary migration) and out-migration (permanent migration) are both present in the context of Chilika Lagoon (Nayak, 2017). However, to a certain extent, communities benefit from migration by gaining knowledge on improved technology, financial remittances and developing interactions between different countries and regions.

5.3.3 Lagoon habitat conservation

Wetlands (such as mangroves, seagrass, mudflats) and sandy beaches adds to the complex ecosystems of Chilika lagoon along with the diverse faunal biodiversity that make up the ecological system and provide fishing communities and marine life with invaluable benefits (Sundaravadivelu et al. 2019). Lagoon habitat conservation and restoration programs can be initiated by creating schemes aimed to protect valuable land surrounding the lagoon, restoring degraded ecosystems, utilizing advanced technologies, and supporting vegetation. Management plans such as zoning, proper land use and agri-environmental program expect to give more productive outcomes in generating employment opportunities and food security (Kumar & Pattnaik, 2012). Efforts to restore biodiversity can be proliferated in reaction to increased public knowledge regarding care and stewardship of social and ecological assets in the lagoon. In order to address common challenges, projects can be formulated involving public-private partnerships, local fishing community members, government departments, and corporations. More attempts comprising considerable volunteer effort, outreach, and education among SSF are required to strengthen stewardship. Projects entailing engineering and building solutions can restore natural hydrological functions and water quality. Broad assessment and inventories need to be used to identify the critical habitats and set goals to preserve them and future monitoring. This is likely to allow decision-makers to make good use of scarce resources. Demarcating lagoon protected areas such as fisheries management sectors, sanctuaries, reserves, and zoning provide a greater degree of protection of the environment through the restriction on over-fishing, mineral extraction, and other habitat-altering activities.

Wetlands and mangroves provide a number of important ecological services such as recharging groundwater, enhancing water quality, stabilizing shorelines, preventing pollution, and mitigating natural floods (Arie et. al., 2018; Bell et. al.,2018). These helps reduce carbon emission which is a major contributor of greenhouse gas and climate change. Further, replanting mangroves, restoring wetlands, and building artificial reefs can recover ecological structure of lagoon. Fish populations and other aquatic species will receive an opportunity to flourish via land migration by allowing inundation to the adjacent low-lying land to mangrove forests. Integrated approaches for land use and management along with the development of regulation provide viable solutions to protect lagoon ecosystem. Development of defense structures such as breakwater, groins and sea walls are intended to shield fishing communities and environment from tides and natural disasters (Arie et. al., 2018). These hard structures reflect technical adaptation strategies.

Sustainable fishing practices must be followed to reduce impacts of commercial activities, overfishing, hydrological interventions, and pollution leading to social-ecological changes affecting water quality. Some of the sustainable fishing applications involve: stabilization of the seabed; carbon conscious fishing (for instance, surfboard fishing); conservation of grounding sites; use of lead-free tackles; practicing catch and release to prevent over-exploitation of aquatic species; targeting plentiful species; enhancement of biological regeneration; monitoring wild native populations; recreation of stable reef platforms; use of exclusionary devices to remove non-targeted species; recolonization by coral; utilizing all that are caught; long-term monitoring of structural and biological restorations; prohibiting shark finning and other wasteful activities.

5.3.4 Information system

Technologies such as Global Positioning Systems (GPS) can be employed in fishing sectors to track the fish population. That reduce the process of catching in unsustainable ways. Users of fishing technology have stronger adaptation practices compared to users that leverage traditional techniques in SSF communities. Fishing technology is portable and handy during severe weather conditions. For instance, GPS helps small-scale fishermen navigate back to the jetty safely and accurately, while the echo-sounder enables fisherfolks to assess the depth of the water, which can greatly improve the efficiency of fisheries (Abu Samah et. al., 2019). If these user-friendly and easy-to-use fishing technologies are embraced by SSF communities, physical movements, efforts, unorthodox ways of maneuvering areas for fishing and energy utilized are reduced. Early warning and monitoring technologies can be adopted to deal with weather issues in a timely manner and reduce vulnerabilities faced by fisher communities (Arie et. al., 2018; Chen, 2020). A disaster risk mitigation plan that emphasizes proactive activities such as lagoon zone management, accurate weather forecasts, an early warning and emergency response system can promote the advancement of livelihood of SSF communities. The system can help in early harvesting, allocating proper fishing grounds, time of catch or relocation of fish net from extreme hypoxic conditions. Early alert information systems (e.g., detecting areas of algal bloom, identification of hypoxic locations, and weather forecasts) and risk communication using mobile communication devices (e.g., pocket PCs, cell phones, smartphones, and tablets), virtual and cloud-based data systems are examples of recent developments in remote sensing platforms (e.g., sonar systems, drones, autonomous vehicles, sensors and satellite constellations) are now being integrated with information and communication technologies (Barange et. al., 2018). Broader use of these warning and information systems can help in reducing risks through prevention and preparedness, improve shock response and promote resilience management (Watkiss et. al., 2019; Shelton, 2014).

5.3.5 Institutional and Policy Changes

Flexible policies that encourage political and social empowerment of SSF communities need to be formulated to mitigate the socio-economic impacts of declining fisheries (Jentoft and Chuenpagdee, 2015). Policies should also address overfishing and provide opportunities to diversify the livelihood of the fishing communities. The implementation of best practices for better management of fisheries and aquaculture (e.g., adaptive strategies, precautionary principles, and ecosystem management), planning tools, regulatory techniques, including zoning and land use planning and integrated lagoon management for nearshore fisheries will enhance resilience and increase system adaptability (Kumar & Pattnaik, 2012). Equal fishing rights, co-management, allocation of proper fishing grounds, growth of new markets, national enforcement of fishing regulations, formation of new international fishing agreements, and other possible policy solutions may help to make it easier for fisheries to maintain healthy fish populations and adapt to abrupt changes in the distribution of target species. Co-management and community-based management regimes is a participatory method of management involving local fishing communities, various levels of government agencies and other stakeholders that agree to share benefits and obligations for the sustainable use of renewable natural resources. Co-management approach values the positions and contributions of fishers and local authorities and is a largely successful way to restore fish stocks, eliminate overfishing, protect biodiversity, and secure better livelihoods. This will empower fishing communities by providing greater access to decision-making processes, stronger legal representation, and increased visibility within society (Nayak & Armitage, 2018).

Some of the other possible solutions are as follows: rules to control fishing efforts, restrictions in quantity of fish catch as a means of protecting water resources; diversifying economy and allowing communities to secure their livelihoods through integration of fishing or aquaculture with agriculture; financial assistance, training opportunities, strengthen knowledge base and awareness to reduce fishing communities' exposure to the impacts of natural and anthropogenic changes; supporting innovation via research on marine environments and management systems (Magawata & Ipinjolu, 2013). Building responsive strategies and scenarios which are coherent at regional and national levels help policy makers in creating viable measures for sustaining livelihood of SSF communities. Raising local authorities, societies and other resource user groups' awareness of water quality issues and the irreversible nature of the impacts ensure mutual awareness and dedication to take action against vulnerabilities. Strengthening cooperation and collaborations can be facilitated in the fisheries sector by developing partnerships with regional institutions to assist in securing lives of fisher communities and preservation of lagoon resources. Promoting disaster risk mitigation and preparedness can result in reducing fishing and fish farming communities' vulnerability to natural disasters and severe weather events. Such mitigation can also reduce economic and environmental impact and improve productivity, efficacy, and long-term sustainability of fishing communities. Integrated watershed management and integrated lagoon zone planning provides a best management strategy to address constraints and challenges faced by SSF sectors (Wang et. al., 2014).

5.4 Viability Measures

Fisheries are profoundly rooted in the sustainability of ecosystems. This serves as an integrative level for managing fishing resources, as well as the entire complexity of the social-ecological system. The influence of social-ecological changes on lagoon ecosystem as well as the need to shift towards an ecosystem approach to fisheries have been widely recognized. Achieving viability in small-scale fisheries is about adopting measures to reduces vulnerabilities faced by the fisher communities involving attainment of wellbeing, proper access to capitals and promoting resilience (Nayak & Berkes, 2019). The ability to reform from abrupt changes in ecosystem through various coping and adaptive measures makes viable small-scale fisheries (Cury et. al., 2005; Doyen et. al., 2017; Schuhbauer & Sumaila, 2016). Figure 5.1 illustrates that the term viability of SSF communities can be expressed in terms of ecological, social, economic, institutional, and technological dimensions. Viability in fishing communities is essential to restore the balance of lagoon ecosystem, increase economy and wellbeing of SSF's livelihood.

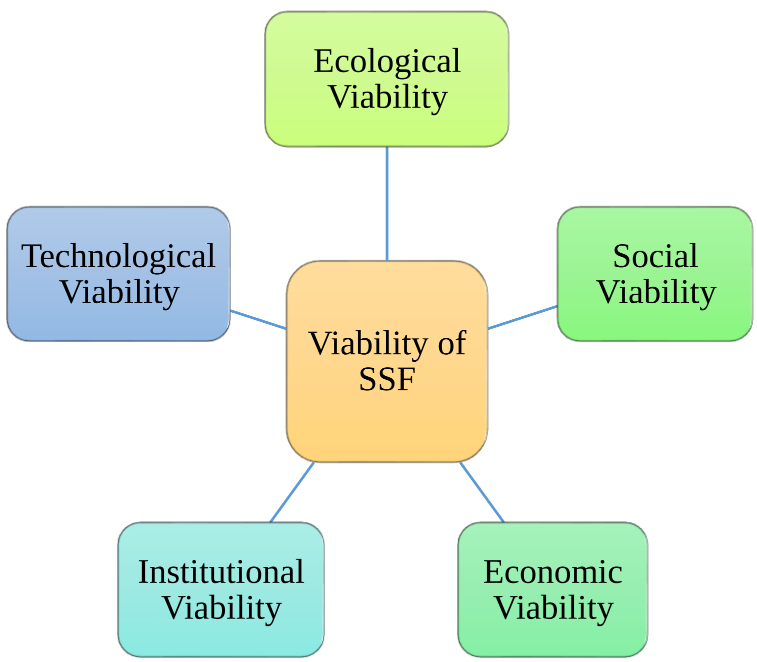

Figure 5.1: Framework of various domain in viabilities of SSF

The contribution of small-scale fisheries, both now and in the future, to food protection, nutrition, economy, and livelihoods depends on a variety of factors, including environmental, economic, governance, policy, technological and social changes. The resulting framework expands the ecological aspects (biodiversity, productivity and trophic structure, and ecosystem integrity of habitats), economic aspects (sustainable livelihoods, economy generation, viability and stability, allocation of access and profits, regional and community benefits), technological as well as institutional concepts (advanced fishing techniques, successful decision and policy-making, legal responsibilities, strong framework of government and regional institutions) and social aspects (health and well-being, ethical fisheries, sustainable livelihood of communities) (Stephenson et. al., 2019). Table 5.3 lists various indicators of viability that provides insight to address the concerns due to lack of capitals, loss of resilience and wellbeing issues.

Table 5.3: Various viability measures in response to the social-ecological changes (Gathered information from Salagrama, 2012; Schuhbauer & Sumaila, 2016; Nayak & Berkes, 2019)

Viability Domain	**Emerging Viability**	**Resilience**	**Capitals**	**Wellbeing**
Ecological viability	• Improved water quality • Biodiversity conservation • Protecting vegetation • Protecting fish habitats • Preserving coastal species • Wetland Conservation	• Self-purification capacity • Capacity to withstand disturbance • Self-organization capacity • Capacity to withstand disturbance • Capacity to withstand disturbance	Natural	Material
Economic viability	• Increase in income	• Self-organization capacity	Financial	Material

Social viability	• Food security • Health and wellness	• Capacity to withstand disturbance • Self-organization capacity	Social	Relational, Subjective
Institutional viability	• Access to resources & education	• Reorganization capability	Political, Physical, Cultural	Material
	• Water quality monitoring stations	• Capacity to withstand disturbance	Natural	Material
	• Employment opportunities	• Capacity to withstand disturbance	Human	Relational, Subjective
Technological viability	• Advanced sustainable fishing techniques • Employing GPS to track fishing locations	• Self-organization capacity	Physical	Material
	• Weather resistant crop generation	• Capacity to withstand disturbance	Natural	Material

- ***Ecological Viability***

Ecological viability can be achieved by improvement in water quality, restoration of habitat to maintain biodiversity, conservation of wetlands and mangroves, elimination of overfishing, and preservation of wild species**.** This can promote the self-purification capacity of Chilika Lagoon and help it withstand disturbances to a certain extent. The gain of natural capitals, which must be conserved in Chilika, is the great aspect of ecological viability.

- ***Social Viability***

  Securing livelihoods of fishing communities, providing food security, educational advancements, raising standard of living and access to resources promote resilience of livelihoods of fishing communities in Chilika. It has a mixed outlook of relational and subjective wellbeing to reduce social crisis (such as decreased conflicts, less migration, more bonding in family) as well as community level advancement (which includes promoting education, acquiring fishing skills and connection to Chilika Lagoon).

- ***Economic Viability***

  Enhancing the economy, creating employment opportunities, diversifying markets and availability of financial sources surrounds the economic viability addressing financial capitals. More attention is required for improving the financial assets with regards to the social dimension of Chilika. The economic assets must be profitable now and into the future. Cost benefit analysis is frequently seen as a suitable method for determining how economically viable an operation (such as fisheries) is, as it incorporates time into the assessment of net benefits (Schuhbauer & Sumaila, 2016).

- ***Institutional Viability***

  Implementation of rules and regulations, proper planning of land and water resources and setting policies for adequate fishing and catch collection reflect institutional viabilities in SSF sector. Proper allocation of funds for sustainable fisheries in government projects, improving subsidies to fishing communities, continuous monitoring of water quality with appropriate equipment and stations are some of the approaches for conserving natural assets along with promoting material wellbeing in terms of political, physical, and cultural assets.

- ***Technological Viability***

Innovations with advanced telecommunications involving utilization of technological advancement to improve fishing, identifying species, water quality monitoring, and executing warning and monitoring system lead to technological viabilities. The use of GPS is seen to be a major influence in saving time, effort, and fishing costs as the boats can get to the target fishing stations much more quickly than before. Wireless communication, both vessel-to-vessel and vessel-to-shore, has been shown to improve fishing efficiency, emergency response, and shore arrangements for preservation, transport, and trading. In deeper seas, mobile phones are ineffective, yet they are widely employed in small-scale operations and in many aspects of shore-based activity (Salagrama, 2012). These improvements in natural resources promotes material wellbeing on terms of job security, standard of living and better access to markets.

Viability theory identifies ‘‘viable evolutions” rather than attempting to identify any ‘‘optimal solution” based on provided criteria. These evolutions are consistent with the restrictions because they always satisfy them, and the viability kernel can be identified (Cury et. al., 2005). Overall, a viability approach involves an integration of all ecological, economic, social, institutional, and technological dimensions into fisheries management. When economic, social, and ecological restrictions are met, viability is achieved; it specifically evaluates a fisheries quota system (Schuhbauer & Sumaila, 2016). Focusing on Sustainable Development Goals can be very significant in achieving viability measures in the Chilika Lagoon preserving the capitals (political, physical, cultural, natural, social & financial) and improving wellbeing (relational, subjective, material) of small-scale fishing communities.

5.5 Global approaches of viability for securing the social-ecological system of Chilika Lagoon

In the case of SSF, viability extends beyond economic gains. Viability indicates that favorable economic conditions must always be accompanied with social and ecological well-being. Global approaches are studied in the research to supplement the viability approach. This provides a solution to describe the multiple facets of the Chilika Lagoon resource system. Alleviation in vulnerability of SSF and investigation for existing opportunities to improve the viability of fishing community's livelihoods are provided through the approaches (Millán, 2019). There are various advantages in involving communities to determine both vulnerability and viability solutions, as they can become agents in working towards better livelihoods (Chuenpagdee 2011). Some of the global approaches initiated in Chilika for improving and monitoring the sustainability of the ecosystem are detailed below.

5.5.1 Ramsar Convention on Wetlands

The water environment at Chilika Lagoon reflects a complex assemblage of coastal, brackish, and freshwater habitats with estuarine characteristics. This combination, including endangered species like the Irrawaddy dolphin, has created a highly active ecosystem with important biodiversity (Iwasaki & Shaw, 2010). These valuable features granted Chilika Lagoon to be classified under the Ramsar Convention as a wetland of international significance. This became India's first Ramsar site in 1981 (Behera et. al., 2020; Sarkar et. al., 2012). The framework of the management plan outlines the policies and actions needed to achieve the wise use of resources in Chilika and to advance the protection of its rich biodiversity, the components and processes of the ecosystem and the livelihoods of dependent fishing communities. A thorough analysis of scientific evidence and consultations with stakeholders, especially with local communities, were key contributions to the formulation of the strategy. The plan also involves the Chilika Development Authority's institutional reorganisation strategy to improve its effectiveness, exceptionally by connecting Chilika's management to the river basin and coastal zone management. An ecosystem restoration approach was adopted by Chilika Development Authority (CDA) including opening of sea mouth for habitat conservation, avoiding the deterioration of the lagoon, improving levels of salinity, fish capture, biodiversity, and strengthening livelihoods of dependent fishing communities. In 2002, the restoration effort was honoured with the prestigious CDA "Ramsar Award" as it was successful in managing the ecological services in all aspects of biodiversity, hydrology, wetland ecology, and conservation (Finlayson et. al., 2020). With the support of Wildlife Trust of India (WTI) inside the Chilika lagoon, CDA has a bird rescue and rehabilitation centre for fishing cat (a smaller feline predator, about twice the size of house cats), Irrawaddy dolphins, and otters to resolve habitat degradation and rehabilitate biodiversity.

5.5.2 Integrated Water Resources Management

An ecosystem approach was followed in wetland conservation aimed in sustaining ecological aspects of the lagoon ecosystem. Due to the major changes in hydrological regimes in Chilika lagoon, an integrated approach for the management of water resources was included in the management plan. Integrated Water Resources Management (IWRM) is based on the fact that water is an integral part of an environment, a natural resource and a social and economic good that defines the quantity and quality of its use (Kumar & Kumar Pattnaik, 2013). To save the body of water, the National Institute of Oceanography (NIO) and the Central Water and Power Research Station (CWPRS) also play a significant role by setting out strategies. The framework brings stakeholders, institutions, and communities together at all levels, taking into account their needs and desires, while ensuring that the wetland environment within the river basin is maintained.

The introduction of land use, water planning and management mechanisms based on the river basin and coastal zone scale is a crucial prerequisite for IWRM implementation in Chilika. Some of the strategies implemented by central and state governments collaborating with national and international agencies are the following: collaboration and institutional arrangements for ecosystem restoration; maintaining connectivity in hydrology by creation of sea mouth; construction of barrages to improve freshwater inflow; conservation of catchments to manage flow regimes; monitoring water quality using buoy mounted sensors; executing community education, training and awareness program; research and development involving assessments of ecosystem services (Kumar & Kumar Pattnaik, 2013).

5.5.3 Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries and Sustainable Development Goals

Another viability measure is using the Small-Scale Fisheries Guidelines. They consist of principles discussing SSF policies, strategies, and legal mechanisms, but also other concerns affecting livelihoods of fishing dependent communities. Key concerns in the SSF Guidelines are as follows: resource management and responsible distribution of tenure rights; encouraging decent work and social development; promoting gender equality; social and political empowerment; looking at fish workers across the entire value chain from catching through harvesting to fish trading; considering climate change and disaster risk.

The SSF Guidelines are tools for millions of people employed in SSF to meet the Sustainable Development Goals (SDGs) and the 2030 Agenda for Sustainable Development. (FAO, 2017). The primary target of the study is maintaining water quality of lagoon ecosystem which adheres to SDG 6: Clean water and sanitation. The mutual correlation between the 17 goals impacts each other for sustainability of SSF even tough water quality is given primary focus in this study. The other SDGs that are influenced are illustrated in Figure 5.2 with darkest shade representing an immediate relationship and decreasing towards the light shade. Maintaining water quality in SSFs is not only one of the main players in lagoon governance but can also play an important role in achieving reduced poverty (SDG1), food security (SDG2), community health and well-being (SDG3), quality education (SDG4), gender equality (SDG5), economic development (SDG8), industry, innovation and infrastructure (SDG9), reduced inequalities (SDG10), climate action (SDG13), life below water (SDG14), life on land (SDG15), peace, justice and strong institutions (SDG16), and partnership for goals (SDG17). There goals have close ties to SSF communities and is socially and culturally embedded in achieving viability.

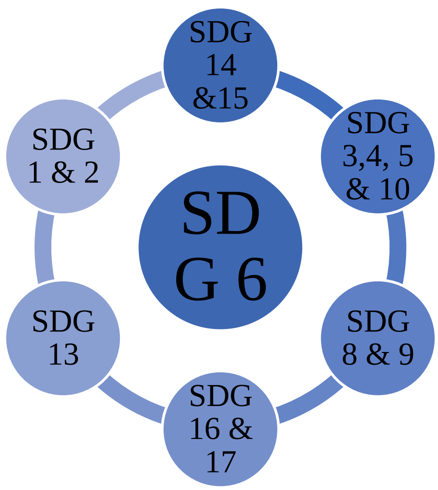

Figure 5.2: Sustainable Development Goals pertaining to the major driver "Water Quality"

The possibility of attaining viability in SSF is greatly improved by the SSF Guidelines. SDGs are wide in context and without a requisite scope. This provides enough room and versatility for interpretation as they serve to touch on major objects. The SSF Guidelines, on the other hand, are clear about how current governance structures can be strengthened and provide insight into how

SDGs can be achieved and how they can help promote sustainability through governance. For instance, apart from defining marine biodiversity, SDG 14 also indicates the following aspects: lowering marine pollution; conservation of marine habitats; minimize acidification in the seas; establish and develop scientific capabilities associated to fisheries; improve the enforcement of international law for the sustainable use of the oceans. The SSF Guidelines provide recommendations on the implementation of specific measures to comply with distinct components of the SDG14, such as those relating to the control of harvesting and overfishing (14.2), the contribution of small-island states to economic benefits (14.7), and the execution of the management of marine areas (14.3).

Throughout the SSF Guidelines, solutions on how to accomplish other SDGs are available (Said & Chuenpagdee, 2019). There are six high-level priorities in the SSF Guidelines that are related to the delivery of different SDGs which includes (FAO, 2017):

- Emerging contribution to food security and nutrition of small-scale fisheries (SDG1, SDG2)
- Poverty eradication and change in socio-economic growth (SDG1, SDG3, SDG5, SDG6, SDG7, SDG8, SDG9, SDG10)
- Utilisation of sustainable fishing practices, management, and restoration (SDG11, SDG14)
- Stimulate benefaction of small-scale fisheries to attain a sustainable future (SDG13, SDG15)
- Provide direction on small-scale fishery policies, strategies, techniques, and legal structures (SDG16, SDG17)
- Strengthen public knowledge of small-scale fishing (SDG4, SDG12)

5.6 Conclusions

Although SSF are impacted by natural and anthropogenic activities, but the changes and impacts are not uniform. There is also an urgent need for fisheries to adapt to these shifts and, given the variety of changes predicted for fishery systems, diverse coping and adaptation strategies will be needed in Chilika. As more extreme changes (such as catch composition, catch capacity, biodiversity variations, water quality and fishery revenues) in the Chilika lagoon environment are projected, international policy has become more interested in remediation and adaptation methods to the impacts of social-ecological changes on fisheries. Given how widely variable SSF ecosystem are likely to be across continents, there will not be a one-sized-fits-all solution to these changes. The chapter outlined various methods of coping and adaptation techniques to water quality degradation being the predominant driver behind vulnerability and marginalization of SSF communities. Adaptation practices can sometimes mutually affect two different sectors and can have unintended repercussions for fisheries and fishing communities. Any unintended effects of adaptation can be resolved by long-term preparation and identified through scenario analysis to reveal future alternatives.

CHAPTER 6
Summary and Conclusions

6.1 Thesis Overview

In this thesis, I explored the relationship between water quality variations and vulnerability and viability of SSF communities of Chilika Lagoon, India. Water pollution in Chilika Lagoon is impacted by a range of drivers that come from natural disasters and anthropogenic activities which, in turn, negatively affect SSF communities. SSF play a major role in subsistence of human life. The various threats faced by them results in changes related to fish decline and marginalization of fishers. SSF fall under UN Sustainable Development Goal No. 14, "Life under Water." However, the majority of what happens in SSF, and certainly what social scientists are interested in, takes place above water—on the water and near the water (Jentoft, 2020). The vulnerability of SSF to drivers of water quality are identified and discussed in this thesis, including how those drivers respond to diverse shocks and pressures from changing environment.

In this chapter, the research goal and methodology are summarized in the first section of in connection with the conceptual framework that drove my research objectives and design. The next section discusses major findings in connection to the three research objectives (see Chapter 4 and 5). This chapter also covers the most important findings and contributions of my thesis. After which, the chapter concludes with a review of recommendations and some reflections related to the study area.

6.2 Summary of Findings

My research aimed to evaluate the influence of water quality issues on vulnerability and viability of SSF communities of Chilika Lagoon. This study had three primary research objectives. I presented findings that address each objective and ultimately the main research goal (see Section 1.2). Findings were analyzed with respect to the conceptual framework built from a synthesis of secondary research in literature reviewed in Chapter 2. According to this study, social-ecological conditions of Chilika are linked to negative lagoon water quality. To be more specific, this research answers three key questions: 1) Why did water quality issues arise? 2) What is going on right now with social - ecological systems? 3) How to make SSF a more sustainable future necessitate?

6.2.1 Objective One

Understanding processes of water quality variations in Chilika lagoon

The social, biological, and physical features of Chilika lagoon were identified by describing the context of biodiversity, SSF communities, hydrological regimes, and water quality. Human induced and natural changes in Chilika were explored that led to the social ecological changes from 1950s to 2015 through systematic literature review. Various changes related to water quality in Chilika Lagoon such as salinity variation, water flow imbalance and nutrient proportion leading to numerous shifts in ecosystems were analyzed by gathering secondary quantitative data on water quality parameters of Chilika during this time period. The data were graphically plotted to understand the gradation of water quality parameters and its impact on SES over time. Water quality parameters such as temperature, pH, transparency, turbidity, water depth, salinity, alkalinity, BOD, DO, chlorophyll-a, nutrients such as nitrites, nitrates and silicates were examined by graphical analysis (see Chapter 4). The analysis revealed that the water quality in Chilika Lagoon degraded between 1950-2015 due to the impacts from natural and anthropogenic activities addressing my first objective.

6.2.2 Objective Two

Examining vulnerability issues faced by the coastal communities due to changes in water quality

My second objective was to investigate and evaluate the factors and drivers that influence the water quality degradation and analyze the impact of this hydrological variation on the livelihood of SSFs. To achieve this goal, I first identified drivers that affect the hydrological regime such as construction of dam, sea mouth opening, aquaculture, and cyclonic pressures. Drivers of change had both positive and negative consequences. Notably, negative impacts included biodiversity loss, proliferation of macrophytes, infestation from barnacles, economic loss, poverty, and out-migration. Mapping revealed that various categories of drivers and its interaction with Chilika waters were influencing the social subsystem. Based on the data gathered, five dimensions of vulnerabilities that were being impacted by the water quality degradation were assessed. The findings indicated that poverty and marginalization in SSF communities was linked to a variety of drivers other than low income, poverty and education which has direct and indirect influences. The findings also highlighted existing flaws in the SES which created further exploitation of resources and communities. As a result of the shifting SES, the system's capacity to provide advantages for SSF communities has severely decreased which, in turn, led to vulnerability and marginalization.

6.2.3 Objective Three

Analysing various coping and adaptive responses of the fisher communities and their potential for creating viable small-scale fisheries

Most SSF are not properly managed in Chilika (Berkes, 2001). This happens as a result of lack of proper governance, policy, and adaptation strategies. Importantly, including more considerations in decision-making can actually benefit local fishers. As a part of addressing

Objective 3, the research explored a variety of short- and long-term measures that reflected coping and adaptation strategies (see Chapter 5). Those served the basis for considering various responses and strategies for viability of SSF communities in Chilika. Efforts to promote viability should focus on the SDGs and SSF Guidelines to protect the social-ecological ecosystem from further degradation. Many global initiatives that were taken out in Chilika to maintain SSF were also mentioned in the section.

The systematic literature review provided guidance in laying out the measures for sustainable fisheries and proper water management. On numerous scales and levels, having a management approach to diminish the negative effects of water quality degradation may lower social ecological risks and vulnerability of SSFs. Linking a management strategy to hydrological conservation is first step in figuring out how to deal with ongoing SES changes in a practical way. Most of the data needed to achieve this objective comes from past studies (see Chapters 1-2, 4-5). I attempted to integrate all of the pieces of information gathered to address my objectives and analyze the water quality changes. This helps in implementation of viability to SSF communities in Chilika along with the presence of all different drivers. Using I-Adapt as a conceptual framework helped to develop response measures in terms of the five main domains of viability which included ecological, social, economic, institutional, and technological dimensions.

The overall connection between Vulnerability to Viability of SSF communities is represented in Figure 6.1. Opening of sea mouth, shrimp aquaculture, frequent industrial and commercial encroachments (dam construction and tourism) and recurrent natural disasters (cyclones, floods, and droughts) damage water quality and affect the fish and other aquatic resources in Chilika Lagoon. This results in the disturbances of social-ecological system of Chilika. These factors lead to multidimensional vulnerabilities such as water pollution, resource overexploitation, biodiversity loss, disease outbreaks, livelihood issues, poverty, and migration. On a vulnerability and viability level, there is a lack of understanding of the interaction and interconnection between water quality and SSF which is addressed in this research.

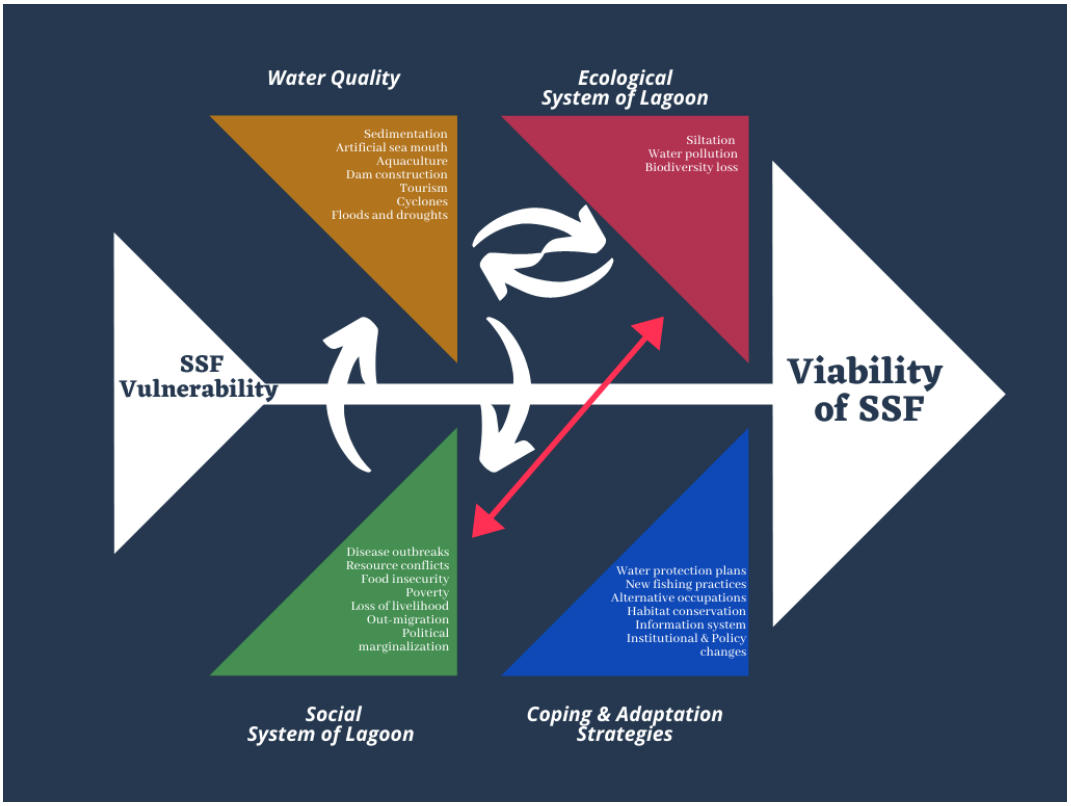

Figure 6.1: Connection in "Vulnerability to Viability" (V2V) of SSFs with "Water Quality" as a major "Driver of Vulnerability"

Also, by utilizing existing opportunities and constraints, the study provides pathways to strengthen the viability of SSF community by various coping and adaptive measures. The visual representation helps in understanding the multi-dimensional connections involved in vulnerability to viability of SSF communities. Perceiving these interactions will help in proper execution of strategies for SSF sustainability.

6.3 Key Lessons & Contributions

The research provides a scholarly and practical contributions to the literature. There was a predominant research gap in linking the water quality issues to vulnerability of SSF in Chilika. There were previous studies focusing on SSF and water quality separately but understanding the integration and interactions of both components is critical for outlining resilience measures and formulating strategies to advance viability. The importance of this study lies in recognizing key variables, drivers, and consequences of water quality issues and influences in a social-ecological system of Chilika. As such, this research provided new knowledge on water quality variation and its drivers in Chilika lagoon is the first empirical contribution to the research literature. Rich description of lagoon system changes in Chilika broadens the literature on SES.

SSF are at the land and sea interface bridging numerous sectors that the SDGs address. Hence this research contributed practical insights into advancing local water sustainability through management and governance of fishery resources that focus on the viability of SSFs. Fulfilling several SDG objectives and targets can ensure sustainable and viable SSF. This would be the first case study, to my knowledge, to look at the role of water quality variation in vulnerability and viability of SSFs in Chilika Lagoon, India to provide such insights. Overall, information and recommendations in this study could help to ensure the survival of SSFs, their proper governance, sustainability of fishing communities, and maintenance of water quality and hydrological regimes. Such contributions will extend beyond Chilika and can be utilised in many similar contexts.

6.4 Recommendations for Future Studies

Chilika is one of India's many coastal lagoons. Water quality variation is also a problem in other lagoons in India such as Vembanadu in Kerala, Nizampatnam in Andhra Pradesh, Kaliveli and Pullicat in Tamil Nadu. The findings of the research can be used to provide suggestions for preserving water quality and SSFs of the India's lagoons. For example, inclusive governance and decision-making that actively involves and recognizes fisher communities is recommended. Comparing and reporting on role of water quality in SSFs will be possible if similar studies are conducted at different case study locations. The SES changes and progression research will be an important document for policymakers to review and use in making informed decisions. Other types of research involving impact of land use changes, climatic variation and air quality leading to vulnerability of SSF could be carried out on a larger scale. The thesis suggests many potential areas for future research:

- The role of wetlands such as mangroves and seagrass in SSF enhancement of wellbeing
- Insights on SDG-14 "Life below water" and SDG-15 "Life on land" in connection with wellbeing of biodiversity and SSF communities in Chilika
- Application of SDGs and SSF Guidelines to SSF communities in different countries for securing sustainable utilisation, management, and conservation of fisheries
- Investigating future uncertainties in Chilika lagoon in terms of exogenous drivers like climate change on water quality variation
- Importance of promoting and protecting traditional knowledge in small-scale fisheries about water quality changes and past experiences with viability
- Opportunities to implement viable technologies at the community level

Finally, this research is extremely significant in today's world of rapid urbanization and population growth since it shows how to encourage resilience and positive transitions by understanding the underlying issues in SES of Chilika ecosystem. The research approach aided in the understanding of past, present, and future challenges in social ecological systems, as well as how fishing communities are responding to them.

6.5 Final Reflections

Chilika Lagoon is a microcosm of several complex and multi-faceted issues relating SSFs. Clearly, SSF communities in Chilika who rely on the lagoon for their social, cultural, and economic requirements are continually adapting to social and environmental change and chronic instability. The study of SSF in Chilika lagoon reveals a lot about the interconnectedness of social and ecological systems, as well as the many environmental change processes such as rising temperatures, water quality and climate change that are constantly reconfiguring the Chilika resources. Moving forward, it is critical to continue working towards a deeper understanding of Chilika lagoon's social-ecological system, as well as natural and human drivers of change. I am so excited and hopeful to further explore more on water quality conditions and SSF in Chilika with fisher folk’s perceptions in the future.

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