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Water Quality and Small-Scale Fisheries: A Vital Facet to Understand Vulnerability and the Transition to Viability

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Water Quality and Small-Scale Fisheries: A Vital Facet to Understand Vulnerability and the Transition to Viability

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Abstract

Small-scale fisheries (SSFs) have a strong role in sustaining millions of livelihoods worldwide, while contributing to global food security and securing income. However, SSF communities are being marginalized, leading to their vulnerability by the cumulative impacts from natural factors (such as cyclones, hydrological changes) and anthropogenic pressures (such as varied fishing techniques and overfishing). This results in food insecurity, occupational displacement, and outmigration. Rising pressures from natural and human-induced activities result in biodiversity loss, destruction of fish habitats and of communities at different biotic scales. These drivers contribute to the increasing vulnerability of SSF communities around the globe. It is necessary to understand the nature of vulnerability and possible ways to achieve viability. This paper focuses on the role of hydrological changes (water quality) as a crucial driver of multiple vulnerabilities in SSF. While there is considerable research on hydrological processes, fish decline, and marginalization of SSF communities, the connections between water quality and SSF vulnerabilities has remained largely unaddressed. Using the Chilika Lagoon in the East Coast of India as a case study, this paper aims to explore how variations in water quality contribute to SSF vulnerabilities and responses by SSF communities to achieve viability. First, this paper outlines the key water quality parameters in the context of SSF. Second, it examines how changes in water quality influences the levels of vulnerabilities. Third, it discusses the responses made by Chilika SSF communities to overcome vulnerabilities and move towards viability. A comparative mixed method approach is used to critically analyze a large body of literature on water quality and on vulnerabilities faced by SSF communities, with the goal of better understanding the relevance for water quality in improving viability of SSF.

Keywords Small-scale fisheries ● Water quality ● Vulnerability ● Viability ● Chilika Lagoon

1. Introduction

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.

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. Other contributing factors to water quality variation include elevation differences, variations in natural surroundings, temperature alterations (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, including: 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 it may even cause invasions by new species. Water quality parameters play critical roles in making a region habitable 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).

The 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 shellfish. One of the major issues faced in the Chilika Lagoon is the water pollution and sedimentation resulting from various anthropogenic and natural drivers of change. The improper balance of social and ecological functions associated with water quality issues has affected the diversified biological wealth such as decline in fish populations and changes in bird migration patterns.

Declining water quality and impacts to biodiversity loss ultimately 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 allowing water retention, 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).

Insight on the relationship between water quality and vulnerability of SSF communities through the Chilika Lagoon case study will help develop adaptation measures for viability. This will address the impending need to create various adaptive and mitigation measures for tackling vulnerability of SSF (Bennett et al., 2016; Jentoft, 2000; Nayak & Berkes, 2010). Multilevel drivers play a significant role in defining and affecting vulnerability and viability (Nayak & Armitage, 2018; Scheffer & Carpenter, 2003). 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 Chilika lagoon that analyzes various social and ecological threats occurring in the lagoon. Vulnerability of SSF communities, who experience marginalization in their daily lives are explored to suggest possible adaptation measures. The main aim of this research is to examine the vulnerability in coastal fishing communities of the Chilika Lagoon due to water quality degradation and assess how to achieve an adaptation strategy to make communities less vulnerable and more viable. This paper focuses on understanding the 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.

2. Methodological approach

This paper employs a mixed method of study with both qualitative and quantitative research. 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 the importance of coping and adaptation strategies. This study includes a systematic literature review to supplement previous similar studies on coastal and marine populations. It aims to understand the social and environmental changes around the lagoon as well as the consequences affecting livelihoods of small-scale fishers.

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 gathers and format bibliographic and citation sources. It is a comprehensive reference manager that helps to compile, organize, annotate, and distribute references for users (Winslow et. al., 2016). This study comprises of the three literature areas: Hydrological and water quality variations; Vulnerability and viability of SSF; and Coping and Adaptation. It also includes study methods and bibliographic data of more than 335 research materials which were systematically reviewed.

From the systematic literature review, secondary quantitative data on water quality parameters of Chilika lagoon from 1950 to 2015 were collected and a graphical representation of the water quality variation was created. The contrast trend in water quality parameters assisted qualitative interpretations of the hydrological conditions of Chilika. Qualitative content analysis approach was utilized to interpret the data employing deductive and inductive data analysis (Hsieh & Shannon, 2005). In this analysis, observations were related to the literature areas associated with the social-ecological changes in Chilika and similar coastal context.

3. Water quality and small-scale fisheries: A case study of Chilika Lagoon

The case study area is the Chilika Lagoon, in Odisha, India. Chilika is Asia's biggest brackish water lagoon, located in 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 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. Before, 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).

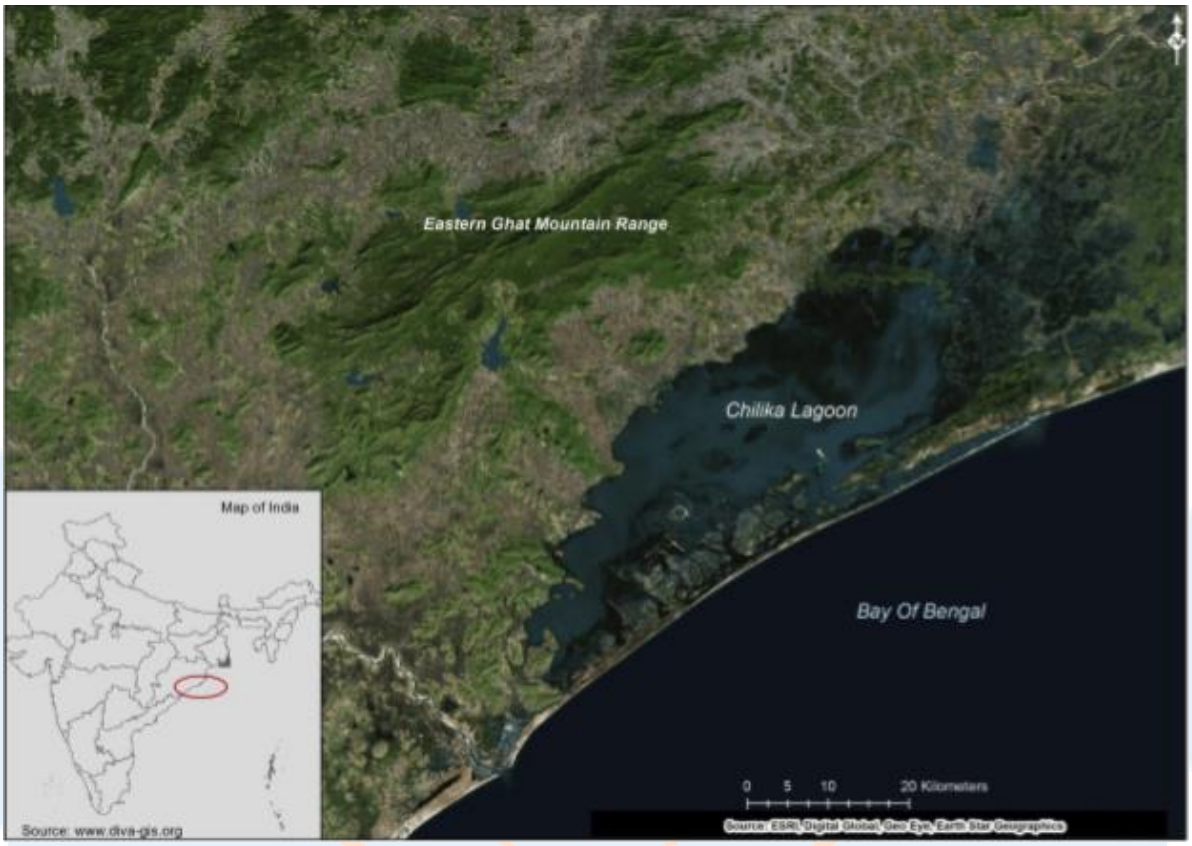
Chilika is an assemblage of marine, brackish, and freshwater habitats that are shallow to very shallow (Kumar & Pattnaik, 2012). A substantial part of this lagoon remains underwater during the winter and functions as a wetland and breeding and nesting grounds for millions of migratory bird species (Sarkar et al., 2012). It is the largest wintering ground found anywhere on the Indian subcontinent for migratory waterfowl and it 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).

Figure 1

Map indicating study region in Chilika Lagoon



Source. Nayak & Armitage, 2018

Between 1950 and 2000, Chilika experienced fast degradation because of an increase in silt loads from catchments and decreasing connectivity with the sea (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's fisheries suffered a significant drop along with exotic weeds proliferation, and a decline of wetland area and volume (Kumar & Pattnaik, 2013). These lead to more factors eventually impacting the landscape through 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.

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 are at high risk of degradation. 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 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). Fishing and boating activities have declined as a result of nutrient contamination and hazardous algal blooms in water bodies. Water pollution is often exacerbated by poor sanitation. The welfare of the population is dependent on public health which is dependent on water quality. The 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.

3.1 Hydrological attributes of Chilika

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 on the other end of lagoon extends along the Bay of Bengal connecting it with Indian Ocean with the help of sea mouth. Located in the lagoon are numerous habitable and inhabitable islands such as Somolo, Krushnaprasad, Kalijai, Nalaban and Birds Island. The various physical and geographical parameters of the Chilika lagoon is represented in Table 1.

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 as a result of 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.

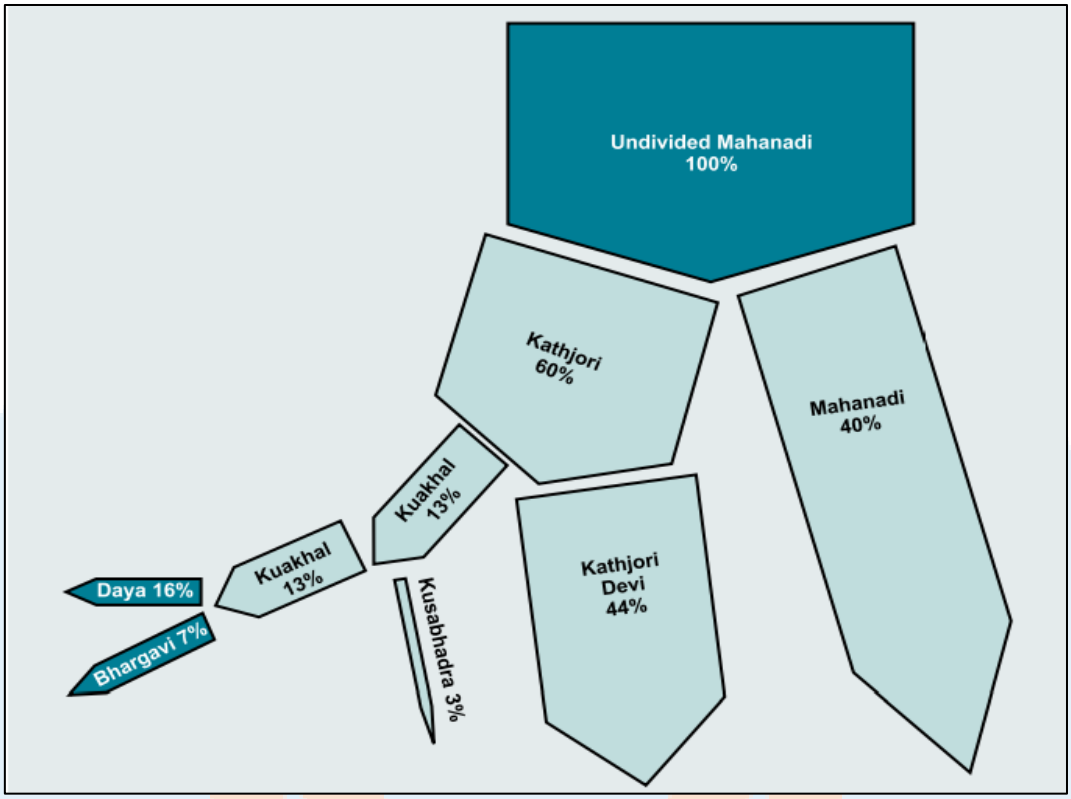
One significant consequence includes biodiversity loss and related ecological changes (Panigrahi et. al., 2007). In general, the Chilika hydrological regimes is strongly influenced by the hydraulic structures such as dam construction. The quantity and quality of water in the lagoon depends on the pace at which precipitation, runoff, groundwater recharge, ocean trade and evaporation cause the lagoon to lose or add water (Iwasaki & Shaw, 2008). Figure 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.

Table 1 *Physiographic attributes of the Chilika lagoon*	
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
Source. Adapted from Panda & Mohanty, 2008	

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 of the area and protecting the coastal ecosystem (Iwasaki et. al, 2009). The impaired drainage of the lagoon along with impacts from siltation, salinity variation, eutrophication, macrophyte infestation, and biodiversity loss, exacerbate factors for environmental degradation, while making them susceptible to anthropogenic pollution. Water quality degradation is a dynamic and complex problem with various interactions among physical, chemical, and biological processes.

Figure 2

Flow distribution in Mahanadi Delta



Source. Kumar & Pattnaik, 2012

Water quality is fundamental for all marine flora, and it affects human livelihoods. Public well-being associated with SSF communities, and conservation of aquatic habitats are two key considerations based on environmental safety requirements for coastal waters. Understanding physio-chemical and biological properties of coastal waters serves an important role in identifying lagoon conditions and anticipate the impacts of 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. The dead zone endangers aquatic life and causes problems for fishermen who rely on the lagoon for their livelihood. In order to conserve fisheries and lower hypoxia, an ecosystem-based resource management would be really useful.

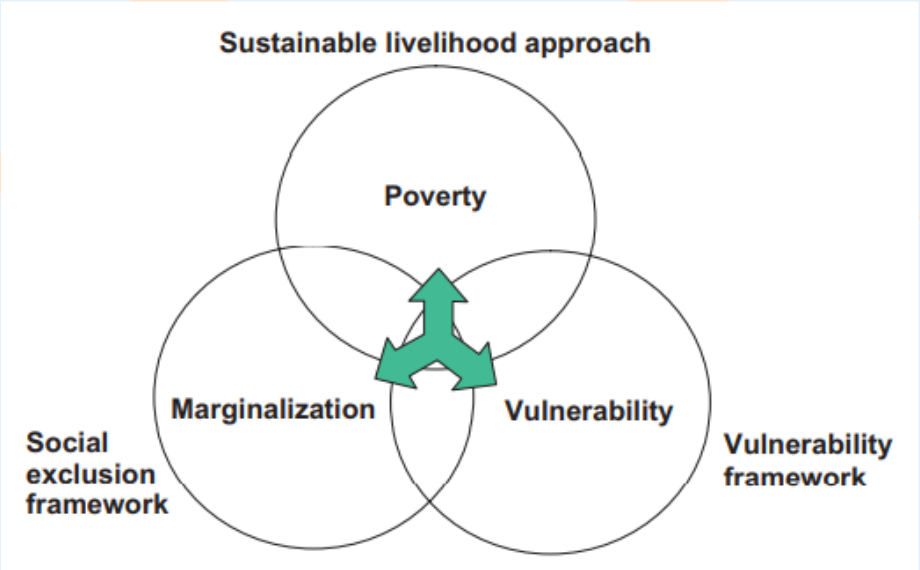
3.2 Social sub-system of Chilika

The Chilika Lagoon is rich in biodiversity with great scenic beauty and aesthetic views that attract tourism. The lagoon has a history that spans over 5000 years, providing local residents with livelihood and inspiration for poets, philosophers, and naturalists admiring the picturesque beauty 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). The Chilika's ecological services are vital to the overall functioning of over 200,000 vulnerable local fishermen. Despite this, SSF communities are commonly categorized as backward and are quite marginalized from society (exhibited by Figure 3). To make matters more difficult, SSFs' interests are poorly incorporated into governance and decision-making (Nayak & Berkes, 2019).

Several social and ecological drivers of change led to a 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 their 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. Trends like this one tend to conflict over resources over lack of access rights. A range of social and ecological changes such as migration, human being, changes in rainfall and vegetation can 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 3

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 unique to the study area. Detailed analysis is needed to understand the connections between SSF and water quality changes as well as their relationship with sustainability. Along with a rising awareness that SSF are "too big to ignore" (Chuenpagdee, 2011; Jentoft & Chuenpagdee, 2015; Chuenpagdee, 2019), there is an immediate need to identify sources of their vulnerability of in terms of water quality alteration. While research on food security and nutrition related to SSF is increasing, there remains both a research gap and limited context-specific knowledge on water quality variation as a source of vulnerability for SSF. 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 emphasis on these objectives often set the conditions for limited access and influence from SFF communities in decision-making processes that affect them.

3.3 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 by environmental shifts that influence social, cultural, and environmental problems. Environmental shifts make habitats susceptible to transition even with the mild disruption, and this affects both ecosystems and the people dependent on ecosystem services. Social and ecological changes in Chilika Lagoon vary from seawater - freshwater flowrates, hydrological variations, differences in salinity, fish decline, loss of biodiversity to the subsequent destruction of both natural and human ecosystem (Panigrahi et al; 2007). The fluctuations in water flow rates and salinity variations also destroyed wetlands which, in turn, impacted biodiversity of the lagoon and its multi-species fish stock (Nayak et. al., 2016; Nayak & Armitage, 2018).

Certain stressors related to drastic climate change emerge gradually, leading to rapid changes on the coastal ecosystem. Activities such as land reclamation, hydraulic constructions, aquaculture, sedimentation, runoff, and overfishing can have very complex and unexpected implications for lagoon environments (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. All these drivers come together to make the lagoon system vulnerable.

In Chilika, key environmental changes produced biodiversity loss (Nayak et. al., 2016), novel multi-species, and changes in the water quality, including salinity variations (Panda et. al., 2010). Table 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 have been taking place 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 market in Chilika during the 1970s led to intensive prawn aquaculture in the 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 to seek new employment opportunities.

In 2001, an artificial sea mouth was created by the government to address the persistent siltation problem in the lagoon. The new sea mouth facilitated free circulation of water between the sea and the lagoon, resulting in significant improvements in the lagoon's water quality and ecosystem, flood mitigation, as well as fish and shellfish output. The salinity of lagoon water increased the dolphin population and reduced 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 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

Source. Nair, 2021

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 the Chilika Lagoon (Sundaravadivelu et al., 2019). Earlier, in 1999, Orissa faced a "Super Cyclone," the state's most 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 significant 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 events: uprooting of mangroves and of Casuarina woods which exposed 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 in the Chilika lagoon and surrounding catchment areas with strong winds, tidal surges, torrential rain, and flooding. This resulted in loss of lives, a huge economic downfall, and damage to fishing equipment and boats (Acharyya et. al., 2020). Besides cyclones, droughts and floods are quite common in Chilika making livelihoods of small-scale fishing communities vulnerable.

The changes in the lagoon ecosystem turned out to be a cause of concern for local and national governments (Panigrahi et. al., 2007). Conservation initiatives have been implemented, spanning from dredging a new sea mouth and to launching public awareness campaigns (Panda et. al., 2010). A community-based 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). The social system of the lagoon was also affected by drastic changes brought by the caste-based system, (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. Ultimately, this led to the migration of local fishers, breaking down fishery cooperatives and dynamic fisheries management structures along with rising conflicts (Nayak et. al., 2016; Nayak & Armitage, 2018).

4. Assessment of water quality parameters for sustainable SSFs

Over the last few decades, the intensifying natural and human-induced pressures of industrialization altered water quality in the Chilika Lagoon. Natural ecological changes along with rising anthropogenic interference have led to significant changes in physio-chemical parameters of water and biogeochemical cycles of the coastal system. Further assessment of various water quality parameters is done in the following sections to address the research gap.

1) Water depth, Turbidity & Transparency

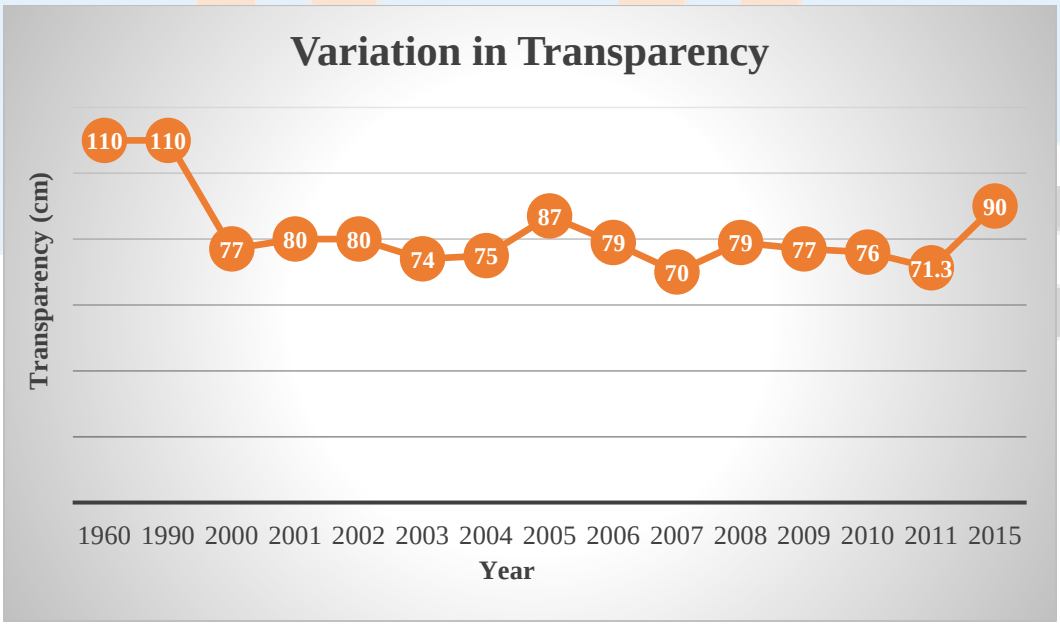
Turbidity is the metric used to measure the clarity of water. The amount of light dispersed by particles in the water column determines the turbidity of the water. Turbidity can be caused by suspended sediments like silt or clay, inorganic materials, or organic matter like algae, plankton, and decomposing debris (Omer, 2019).

During the monsoon season, 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).

Transparency is positively associated with pH, biological oxygen demand, salinity, nutrient content, and chl-a. During the cyclone Phailin in 2013, there was a significant drop in transparency by 25% (exhibited by Figure 4). 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 stability of the lagoon and was managed to maintain till now (Barik et. al., 2017).

Figure 4

Variation in transparency of Chilika lagoon



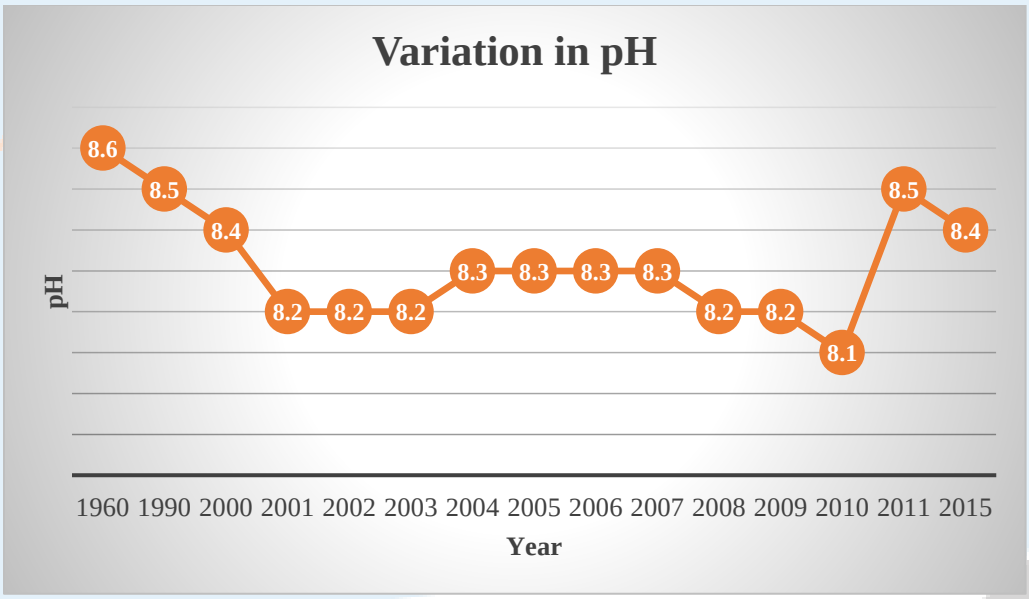
Source. *Source.* Developed from data listed in Mohanty et. al., 2008; Mohanty et.al., 2015; Mohapatra et. al., 2007

2) pH, Alkalinity & Buffering activity

The pH of water is a measurement of how acidic or alkaline 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 (Omer, 2019). Vegetation growth creates changes in carbon dioxide levels. With the amounts increasing, dramatic effects on the pH of water can be observed (exhibited by Figure 5). 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 compared to the data in 1960s. There was unrecovered reduction in the pH decline till 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 5

pH variation of Chilika lagoon



Source. 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. Variation in the salinity regime is an important factor for the presence and absence of phytoplankton. Even migratory birds are affected was they regulate the level of body fluids according to surrounding ecological changes and impacted by breeding in poor water quality. Salinity changes affect the availability of brine shrimp and other invertebrates, which are a vital food source for waterbirds. (Kumar & Pattnaik, 2012). Between 1995-1998, there has been a steady reduction in the salinity level of the lagoon with near freshwater levels. Then, the hydrological intervention in 2001 brought levels back to normal (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, the average lagoon salinity varied from 11 to 14 parts per thousand (ppt) and was observed to be higher during droughts

(exhibited by Figure 6). 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 (Barik et. al., 2017).

Figure 6

Salinity trends in Chilika lagoon over the years

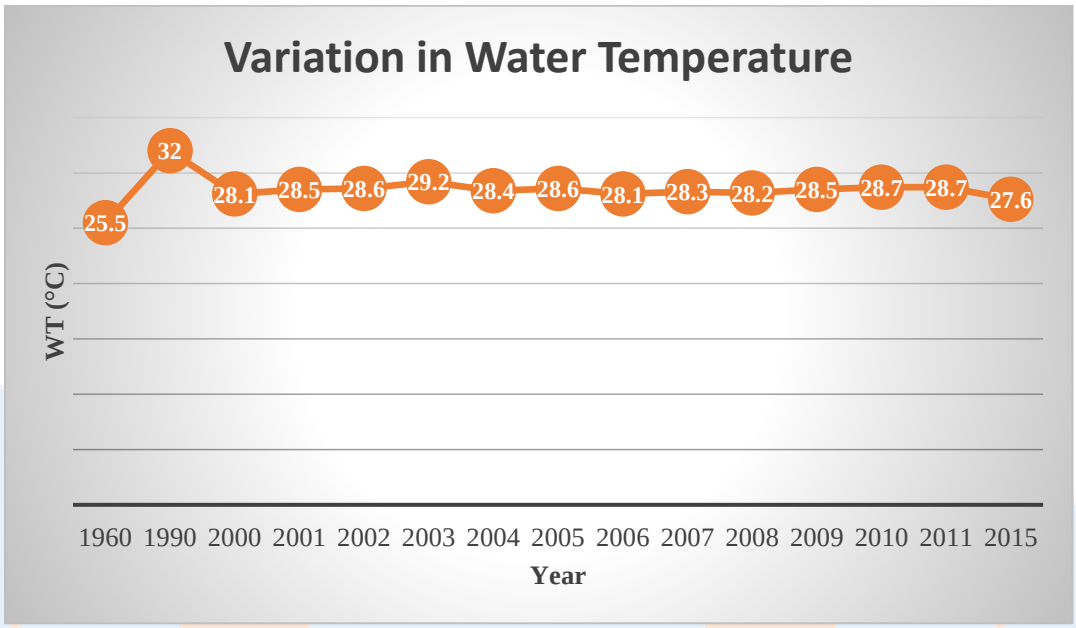
Source. Developed from data listed in Mohanty et. al., 2008; Mohanty et.al., 2015; Mohapatra et. al., 2007

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. 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 the Chilika Lagoon. The temperature rises with seasonal fluctuations from March to May and subsequently begins to fall in tandem with the beginning of southwest monsoons (Panigrahi et al., 2007).

Figure 7

Changes in water temperature of Chilika lagoon



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

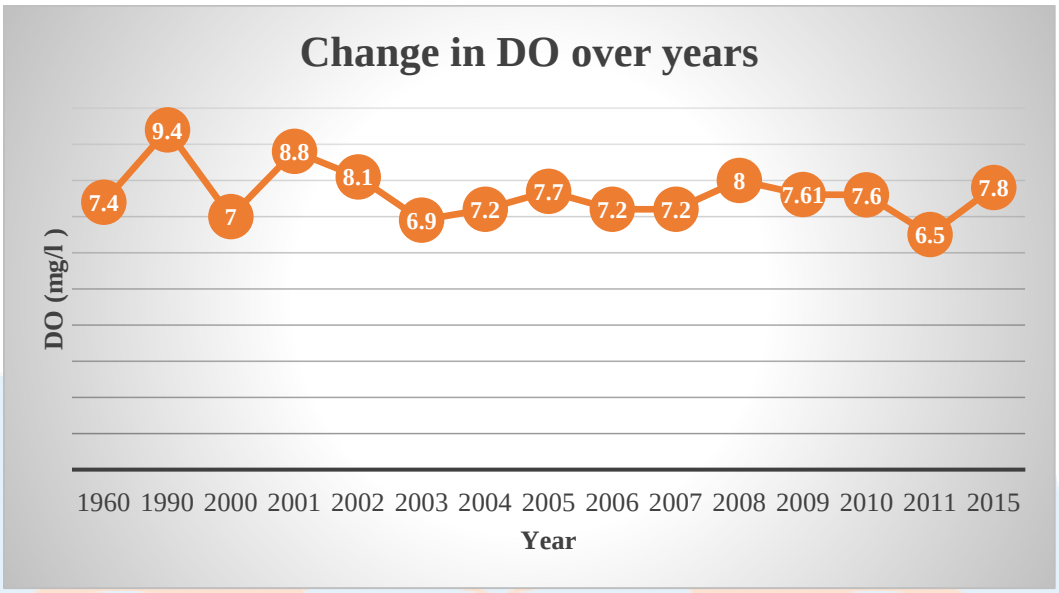
A remarkable decline in water temperature was observed after Phailin (exhibited by Figure 7). The decline could be a result of a mixing of river water with colder temperature precipitation water an inverse relationship can also be observed with dissolved oxygen and water temperature. This may be attributed to the decreased solubility of oxygen in waters (Barik et. al., 2017).

5) Dissolved Oxygen & Biological Oxygen Demand

Dissolved oxygen (DO) indicates the health of a coastal ecosystem and provides conditions favourable for effective metabolism of all aquatic organisms. Aquatic life is affected by variation in DO as fish cannot survive below 4-5 parts per million(ppm). DO variation influences the ability of the lagoon to accept organic matters. The 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 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). A high level of Biological Oxygen Demand (BOD) may result from weed and macrophyte decomposition. There was a drop in BOD after the Phailin which has since continued (exhibited by Figure 8). The drop may be due to the expelling of organic matter by strong freshwater drainage (Barik et. al., 2017).

Figure 8

Fluctuations in DO content of Chilika lagoon



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

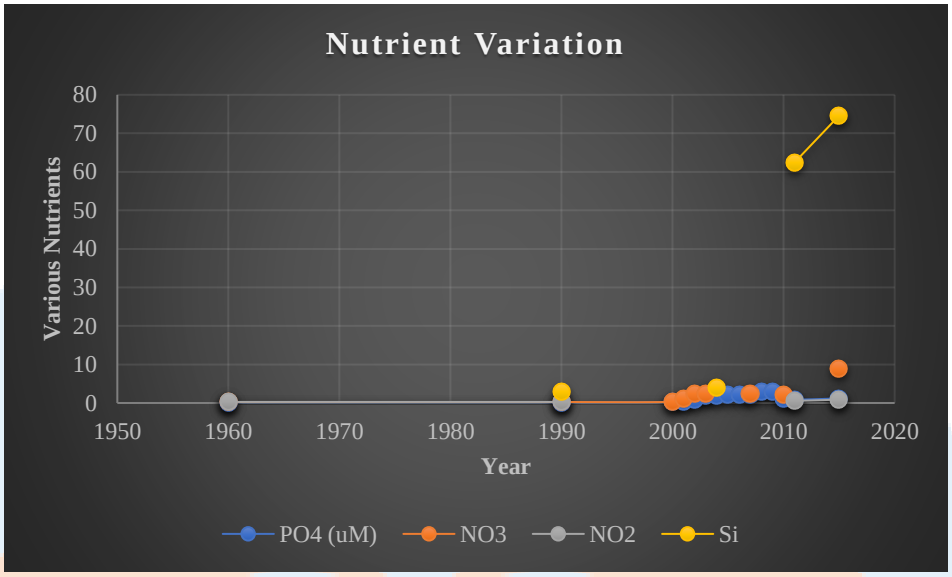
6) Nutrients Disparity & Trace Elements

Nutrients are regarded as one of the most indicative criteria in marine ecosystem that affects the development, fertility, and metabolic function of living organisms (Barik et. al., 2017). Nutrients like nitrate-nitrogen and phosphate-phosphorus have a well-recognized function in the ecological growth of marine environments and limit the development of algal cell. The nitrate and phosphate concentration in the 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 active and shows high values during post-monsoon seasons. High concentration of phosphates is found during monsoons.

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. The silicate content is ranging from 0.5-10.2 ppm in Chilika Lagoon (exhibited by Figure 9). Low silicate concentrations were observed during the pre-monsoon period in the southern area. High concentrations were instead found in the northern area during the post-monsoon period (Kumar & Pattnaik, 2012; Barik et. al., 2017; Mohanty et. al, 2008).

Figure 9

Variation of phosphates, nitrate, nitrite, and silicate concentration in Chilika lagoon



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

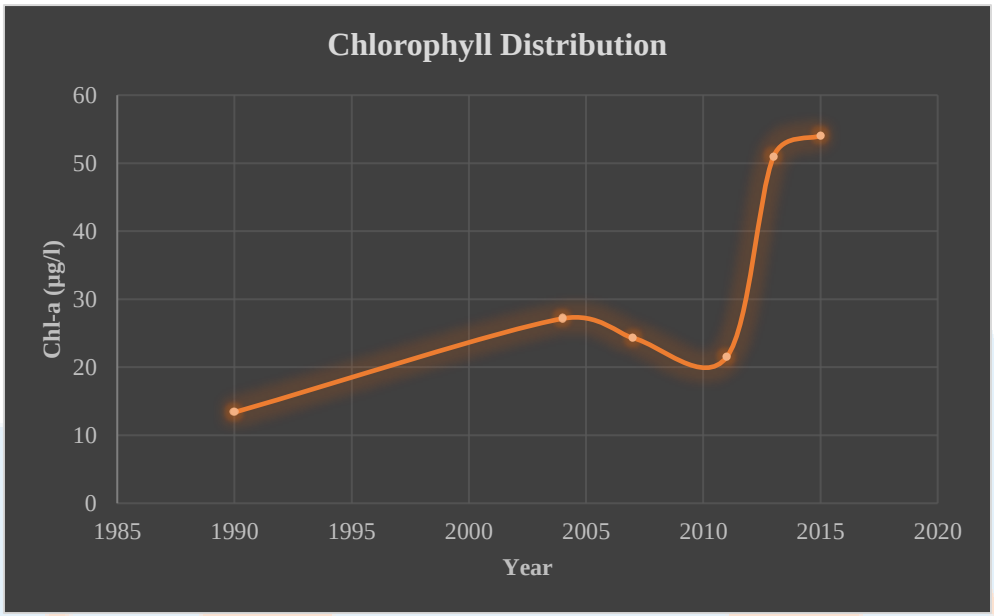
7) Chlorophyll-a (Chl-a) & Photosynthesis

The diversity of phytoplankton in the 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 (exhibited by Figure 10). 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).

Higher suspended particles prevent light penetration which alters the photosynthetic activity. Algal blooms reduce the level of dissolved oxygen. The larger the bloom, the higher the chlorophyll concentration. The bloom creates a turbid environment in lagoon waters reducing transparency and light penetration. This indicates that the shallow areas of the lagoon promote photosynthesis at suitable light intensity generating oxygen (Panigrahi et. al., 2009; Sahoo et. al., 2015).

Figure 10

Distribution of Chl-a in Chilika lagoon



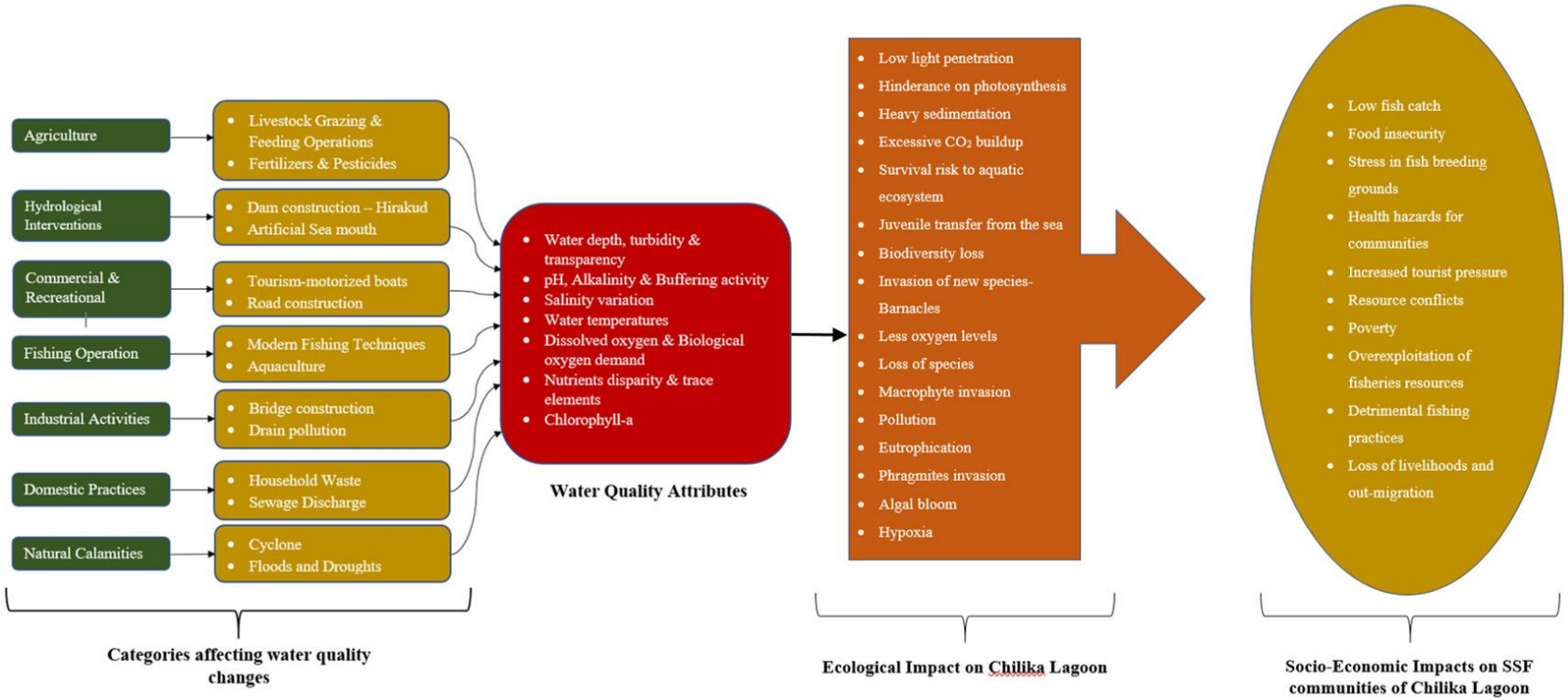
Source. Developed from data listed in Mohanty & Panda, 2009; Mohanty et.al., 2015; Mohapatra et. al., 2007; Sahoo et. al, 2017

5. Connections between changes in water quality parameters and Chilika Lagoon social-ecological system

Water supports diverse human demands such as residential needs or commercial activities 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 require proper management to maintain the ecosystem's integrity and sustain resources for fisheries and further develop 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 volume and consistency of lagoon waters. Ultimately, this significantly changed 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 the lagoon and intensified macrophyte production. Fecal matter, excess feed and uneaten pellets from aquaculture created a threat to the coastal ecosystem along with rising concerns about sanitation and hygiene.

Figure 11

Chain that links water quality and social-ecological outcomes of Chilika Lagoon ecosystem



Source. Adapted from Nair, 2021

Numerous drivers have led the cycle of social and ecological changes in the Chilika Lagoon and ultimately, the vulnerability and marginalization of the SSF communities (Nayak & Berkes, 2019; Nayak, 2012; Nayak, 2014). Growing human activities and coastal developments are changing biodiversity. Various causes of water quality deterioration involve agricultural applications (livestock grazing & feeding operations, fertilizers & pesticides); hydrological interventions (dam construction – Hirakud, artificial sea mouth); commercial and recreational activities (tourism-motorized boats, road construction); fishing operations (modern fishing techniques, aquaculture); industrial activities (bridge construction, drain pollution)l domestic practices (household waste, sewage discharge) and natural calamities (cyclone, floods and droughts) (exhibited by Figure 11) (Nair, 2021). The influence of these drivers impacts the ecological and socio-economic aspects of the Chilika Lagoon leading to vulnerability of SSF communities.

6. Interconnections between water quality and SSF vulnerability to viability

6.1 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. The main parameters of vulnerability are the stress subjected to a system, its exposure and sensitivity, and the capacity to adjust (Adger, 2006). 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. The lagoon ecosystem in Chilika is vulnerable to a broad variety of consequences ranging from natural changes to many detrimental human activities, such as building a sea mouth opening, or establishing aquaculture or tourism infrastructure. The variability in fishery production and various socio-ecological changes have a remarkably negative impact on the livelihood of fishing communities. Table 3 describes vulnerability in Chilika according to five categories: ecological, social, economic, institutional, and technological.

Ecological Vulnerability: pertains to the ecological domain and natural resources within the lagoon such as water, status of biodiversity, natural drivers, and various climate change factors. The changes in water quality parameters in the Chilika Lagoon are the result of hydrological interventions; biodiversity loss due to anthropogenic activities and natural calamities; erratic rainfall patterns and sedimentation (for eg: increased erosion and sedimentation into lagoon can be caused by more frequent and strong rain events) constitutes to ecological vulnerabilities.

Social Vulnerability: different fishery-dependent factors are used to analyse social vulnerability: unemployment rate, poverty, job opportunities for women, food, and nutritional security (Jepson and Colburn, 2013). Communities that rely heavily on fishing are more likely to be socially vulnerable than other coastal communities, because of their close dependency on fish stock. These findings highlight the importance of continuing to investigate climate change and social vulnerability to develop adaptation strategies (Colburn et. al., 2016).

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). 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. 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

Institutional Vulnerability: The institutional domain of vulnerability refers to the role of community-based laws and governmental regulations influencing access to natural or financial resources. Rich businesspeople from outside the lagoon-built shrimp farming in Chilika. This led to the displacement of local fishing villages from their resource base (Nayak & Berkes, 2010). Issues of access and entitlements have arisen because of developments concerning fishing area encroachment and lease (Nayak & Berkes, 2010; Nayak, 2014). Improper public policies, disputes in access rights to fishery resources, ineffective stakeholder engagement, lack of management and planning created institutional vulnerabilities. These put the livelihoods of traditional fisher communities in jeopardy, creating instability in the sector, and harming the fragile Chilika ecosystem (Nayak, 2014).

Technological Vulnerability: The technological domain of vulnerability refers to the major equipment and practices required to expand fishing activity such as boats, gears, and infrastructure. For example, sophisticated equipment against the invasion of barnacles is fundamental to fishers in Chilika. Lack of such equipment led to excessive loan-taking by the community, which intensified poverty (Nayak, 2017). At the same time, while tourism proves lucrative for some groups, the improper technology that handles waste further harms fishing communities. Local fishing communities are aware of the danger that tourism operations pose to dolphins as well as ecological disturbance and mortality (Sutaria, 2009). Poor sanitation technology is harming the aquatic life, which harms fishers' livelihoods.

Table 3

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

Source. Nair, 2021

6.2 Pathways to build viability through coping and adaptation strategies

The above data collected provides a robust basis for exploring various coping and adaptive measures of SSF communities in the Chilika Lagoon. It is those opportunities to cope and adapt that are addressed in the following section. Viability of SSF can be promoted through poverty eradication, food security,

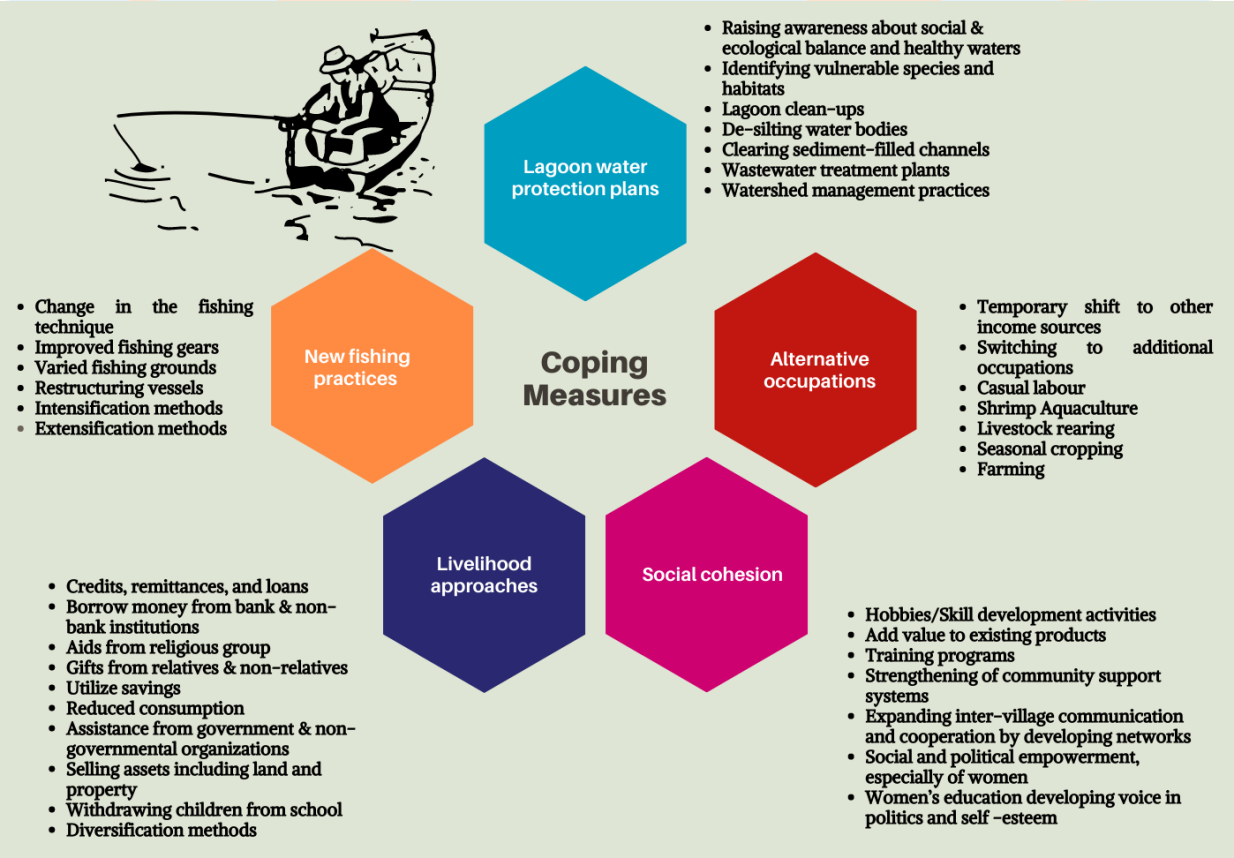
employment opportunities, livelihood provisions, and rural and economic development. Human-induced impacts of hydrological interventions in the Chilika Lagoon resulted in water quality degradation. This may induce irreversible changes in the Chilika Lagoon ecosystem and irrevocably disrupt the livelihood of SSF communities. Based on water quality analysis, various coping and adaptation strategies can assist the viability of SSF.

6.2.1 Coping strategies

Coping is a short-term reaction to an impact, for example, a community's response to natural driver of change is a coping strategy (Shelton, 2014). 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). Some of the coping mechanism include the following as shown in Figure 12. 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). Ex ante and ex post risk coping methods are literally measures conducted before and after shocks.

Figure 12

Coping strategies of small-scale fishing communities in Chilika Lagoon



Source. Adapted from Nair, 2021

Lagoon water protection plans: one of the major improvements so far has been the increased awareness among the SSF communities on the importance of maintaining water quality (Kumar & Pattnaik, 2012). Community awareness about diverse social-ecological changes and resulting water issues helps preventing water quality degradation (Nair, 2021).

- **New fishing practices:** traditional net catching yields low catch, which results in reduced income. SSF communities have thus turned to new fishing techniques. While allowing for more catch, new fishing practices by lead to catching non-targeted species. Introduction of synthetic nets, higher monetary investment and improved laboratory fishing are some examples of intensification practices.

- **Livelihood approaches:** some coping mechanisms endorsed by fishing communities in the Chilika Lagoon are an increased dependence on credits, debits and taking loans; and the utilization of money from financial sectors non-financial institutions and from multiple sources like grants or aids. 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 (Nayak, 2017).

- **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. Education of women often leads to ecological monitoring, fishery, and habitat restoration.

- **Alternative occupations:** 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 the fishing sector as it supports food and nutrition.

6.2.2 Adaptation techniques

Adaptation means adopting reasonable measures to stop or mitigate a harm caused by adverse effects of social-ecological changes while taking 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 Figure 13, while adaptation may often be confused with coping. Some adaptive measures are examined in the following section (Nair, 2021):

- **Water quality monitoring:** Remote monitoring systems for water quality were developed to create a wireless sensing network integrated with a forecasting model to provide real-time information and complex water quality patterns at various monitoring sites (Li & Liu, 2013). Upgrading to sustainable wastewater management 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).

- **Out-migration:** 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.

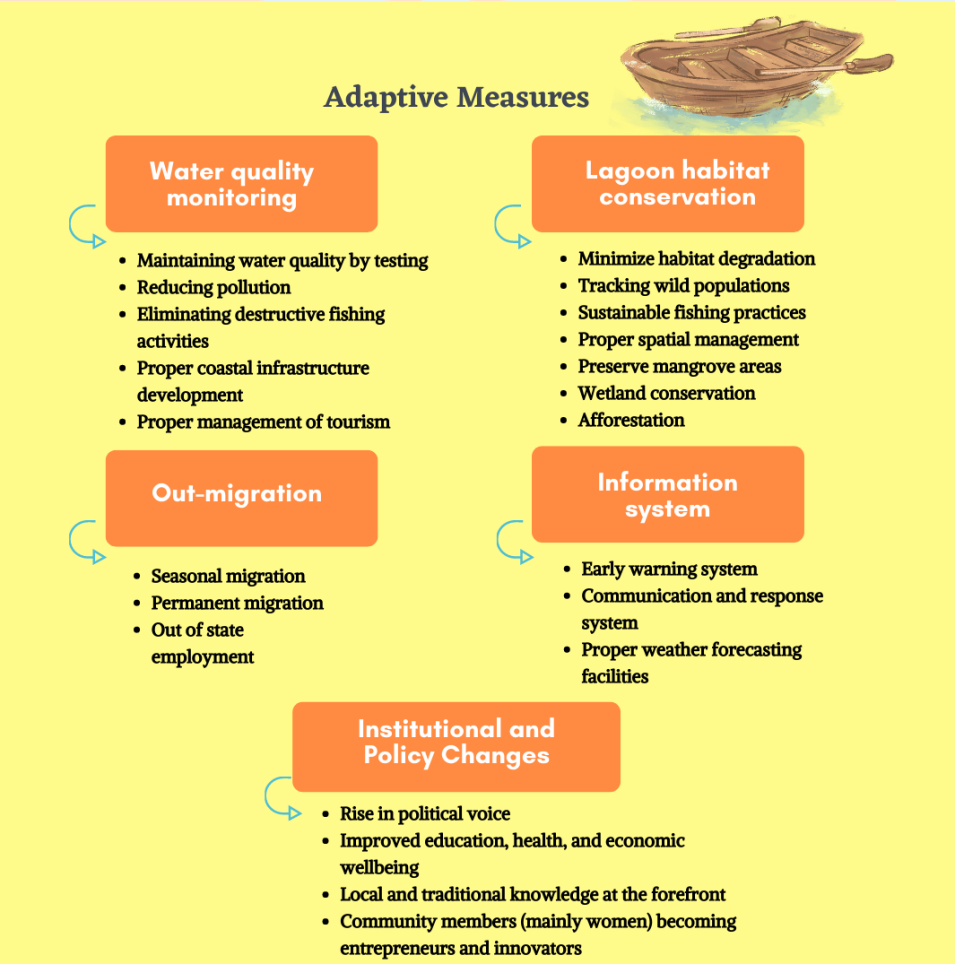
- **Lagoon habitat conservation:** Management plans such as zoning, proper land use and agri-environmental programs expect to give more productive outcomes in generating employment opportunities and food security (Kumar & Pattnaik, 2012). Projects entailing engineering and building solutions can restore natural hydrological functions and water quality.

- **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. 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).

- **Institutional and Policy Changes:** Flexible policies that encourage the 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 (Kumar & Pattnaik, 2012). 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).

Figure 13

Adaptation strategies followed by small-scale fishing communities in Chilika Lagoon



Source. Adapted from Nair, 2021

6.3 Global approaches to viability of SSF

Some of the global approaches initiated in Chilika for improving and monitoring the sustainability of the ecosystem are detailed below.

- **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 the 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 management plan outlines policies to achieve proper resource use while advancing the protection of: its rich biodiversity, the components of the ecosystem and the livelihoods of dependent fishing communities. 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.

- **Integrated Water Resources Management:** An ecosystem approach was followed in wetland conservation aimed at sustaining ecological aspects of the lagoon ecosystem. Due to the major changes in hydrological regimes in the Chilika Lagoon, an integrated approach for the management of water resources was included in the management plan. Integrated Water Resources Management (IWRM) rest on the idea that water is integral to the environment, as a natural resource of great social and economic value (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 while ensuring maintenance of the wetland.

- **Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries and Sustainable Development Goals:** Small-Scale Fisheries Guidelines 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 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 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).

7. Conclusions

Anthropogenic interventions and natural drivers of change have deteriorated water quality in the Chilika Lagoon. SSF-dependent communities ultimately bear the burden with poverty levels intensifying. As discussed, the various activities in the 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 a high risk of fish survival, which reduces income for fishermen, leading to their marginalization from society. The different categories of drivers affecting water quality of the Chilika Lagoon portray the multiple faces of vulnerabilities in SSF communities (Nair, 2021).

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 adaptation methods. Given how widely variable SSF ecosystem are likely to be across continents, there is no “one-sized-fits-all” solution. .

This paper’s findings can be used as suggestions for policies to preserve water quality and SSFs of the many coastal lagoon contexts. The 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 social-ecological system of Chilika ecosystem. The research approach aided understanding the past, present, and future challenges in social ecological systems, as well as how current responses. The study suggests many potential areas of exploration such as representation of fishing communities in law and policy making, understanding the importance of wetlands, protecting the blue economy of the coastal communities and further progress on achieving SSF Guidelines aligning to SDGs.

Acknowledgement

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Vulnerability to Viability (V2V) Global Partnership

The Vulnerability to Viability (V2V) project is a transdisciplinary global partnership and knowledge network. Our aim is to support the transition of small-scale fisheries (SSF) from vulnerability to viability in Africa and Asia. Vulnerability is understood as a function of exposure, sensitivity and the capacity to respond to diverse drivers of change. We use the term viability not just in an its economic sense but also to include its social, political, and ecological dimensions.

The V2V partnership brings together approximately 150 people and 70 organizations across six countries in Asia (Bangladesh, India, Indonesia, Japan, Malaysia, Thailand), six countries in Africa (Ghana, Malawi, Nigeria, Senegal, South Africa, Tanzania), Canada and globally. This unique initiative is characterized by diverse cultural and disciplinary perspectives, extensive capacity building and graduate student training activities, and grounded case studies from two regions of the world to show how and when SSF communities can proactively respond to challenges and creatively engage in solutions that build their viability. Further information on the V2V Partnership is available here: www.v2vglobalpartnership.org.

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