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Research Article

Systematic Review of Community-Based Adaptive and Coping Strategies to Emerging Covariate Shocks and Stresses in the Kenyan Fisheries and Aquaculture Sub-Sectors

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ABSTRACT

The significance of fisheries and aquaculture sectors in contributing to global food security is undeniable, albeit threats from emerging shocks. This article delves into the vulnerabilities of these sectors, examining the impacts of climate change, environmental pollution, the COVID-19 pandemic, and national geopolitical instability. Climate change has led to reduced incomes, increased prevalence of diseases, exacerbated food insecurity, and substantial damage to fishery infrastructure. To address these impacts, communities have adopted strategies such as; diversifying livelihoods, integrating indigenous knowledge with scientific approaches, developing climate-resilient aquaculture species, use of early warning systems, and adoption of cage aquaculture and insurance schemes to alleviate pressure on natural water bodies and mitigate economic losses. Environmental pollution has led to decreased fish productivity, loss of marine life, economic downturns, and declines in tourism. The use of Beach Management Units (BMUs) to train and raise awareness, and community engagement in beach cleaning initiatives have been undertaken to foster attitudes favoring environmental conservation. The COVID-19 pandemic resulted to lower fish prices, restricted access to essential inputs, decreased fish consumption, and heightened unemployment. Community-based market linkages, establishment of community fish seed and input banks, the introduction of precision aquaculture technologies and the strengthening of local food systems have emerged as critical responses. Furthermore, national geopolitical instability has affected market access, inflated fish prices, increased production costs, and diminished incomes. Adaptation strategies include diversifying aquaculture systems, enhancing governance through transparent policies, investing in community-based training, implementing short-term genetic improvement programs, and fostering collaborative research initiatives. It is imperative for policy makers and stakeholders to prioritize the implementation of these strategies to ensure sustainability of the sectors.

Keywords: Community-based adaption fisheries; Aquaculture; Climate change; Environmental pollution; COVID-19

INTRODUCTION

The blue economy is a fundamental pillar of human sustenance, heralded as a blueprint for sustainable economic development through the responsible utilization and conservation of oceanic and inland water resources. The oceans contribute half of the world's oxygen, absorb carbon dioxide, and provide essential resources for food, transportation, recreation, and tourism. It is estimated that the blue economy accounts for a substantial five to seven percent of the global GDP and supports one percent of the global workforce. Furthermore, the ocean fisheries sector provides livelihoods for approximately eight percent of the

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world's population, with global marine and coastal tourism generating an estimated USD 161 billion in annual revenues [1,2].

However, the sustainability of the sector is affected by shocks and stresses that include; climate change, environmental pollution, COVID-19 pandemic, and national geopolitical instability. These factors pose threats to ocean-based businesses and livelihoods and affect water-related ecosystems and biodiversity. The consequences of climate change including; alterations in ocean climate, sea level, water temperatures, acidity, water circulation, and ice distribution directly impact coastal ecosystems and the species that underpin coastal economic benefits. Moreover, climate change is expected to exacerbate the frequency and intensity of hydrological, meteorological, and climatological disasters, such as floods, tropical cyclones, and drought, further compromising the resilience and sustainability of the blue economy. The interconnectedness of aquatic ecosystems with the terrestrial environment means that changes in one system can have cascading impacts. Over the years, various factors, including anthropogenic activities, have exerted stress on freshwater and marine ecosystems. These stresses encompass pollution and physical environmental degradation. The release of pollutants from urban related activities and changes in land use, driven by high urbanization and the accumulation of debris and other forms of wastes, poses severe human-induced threats to freshwater and marine ecosystems [3,4].

Besides climate change, the COVID-19 pandemic wrought havoc on coastal tourism, fisheries, seafood production, and maritime transport globally, with developing nations like Kenya being particularly vulnerable due to limited resources and expertise. The perishable nature of fish products posted significant challenges for the fisheries and aquaculture sectors, which provides substantial employment opportunities worldwide with losses in income by small-scale fisheries. Furthermore, Kenya's fish productivity experiences fluctuations during election seasons, when political tensions disrupt the supply chains. Given the under-development of the sector, small-scale fishing communities are hard-hit by these shocks [5,6].

Despite the consensus among researchers regarding the threats posed by climate change, environmental pollution, COVID-19 pandemic, and national geopolitical instability to blue economy-based livelihoods, there remains a scarcity of studies that have specifically reviewed the impacts of these covariate shocks on blue economy-based livelihoods and businesses in Kenya. Moreover, the available studies have primarily focused on the impacts of sudden-onset disasters, such as earthquakes and tsunamis, on ocean-based businesses, leaving a significant gap in understanding the influences of slow-onset covariate shocks, such as droughts, floods, increasing sea surface temperatures, sea level rise, COVID-19 pandemic, and human-induced disasters like environmental pollution and national geopolitical instability on the blue economy [7,8].

To address the impacts of these shocks, community-based adaptation remains a widely recognized response strategy, especially in tackling the impacts of covariate shocks. While societies, including fishing communities, have traditionally adapted to various shocks, the specific community-based adaptive responses to climate change, the COVID-19 pandemic, environmental pollution and national geopolitical instability within the context of the blue economy remain insufficiently understood. These covariate shocks often cause vulnerabilities beyond the range of experience, necessitating additional adaptation measures among fishing communities. Therefore, the systematic review aims to delineate community adaptation and resilience strategies in response to the emerging covariate shocks. Additionally, the study proposes additional sustainable resilience strategies complementing the already practiced ones in the context of Kenyan fisheries and aquaculture sectors. These insights are intended to guide development partners, governments and policymakers in formulating sustainable and scalable programs that bolster the resilience of rural household's dependent on blue economy resources for livelihoods [9,10].

Conceptual framework

Resilience is the ability of people, households, communities, countries, and systems to anticipate, adapt to, and recover from shocks and stresses in a manner that reduces chronic vulnerability and facilitates inclusive growth (USAID 2018) as illustrated in figure 1.

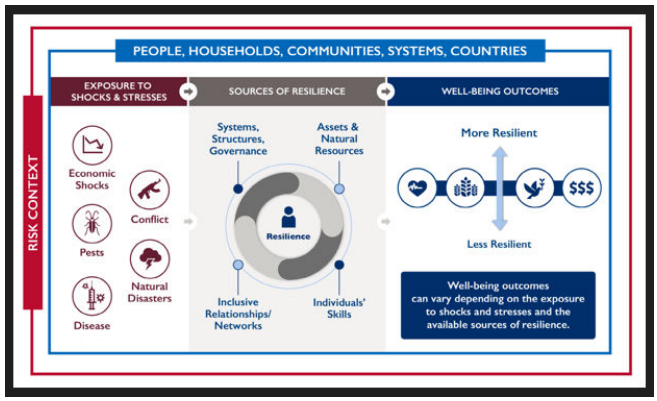

Figure 1: Resilience conceptual framework (adapted from TANGO International).

The conceptual framework of resilience, as depicted in Figure 1, elucidates the interplay between risk, resilience factors, and well-being outcomes. This framework serves as a blueprint for understanding resilience and shaping both programming and assessment efforts. The effectiveness of resilience factors, superimposed with the impacts of stressors, determines the spectrum of potential outcomes. A household or system is deemed resilient if it maintains or enhances desired well-being outcomes inspite of shocks and stresses. While the resilience conceptual framework can be customised to specific technical sectors or employed through a multisectoral lens, it's important to recognize that resilience factors often transcend sectoral boundaries. Enhancing resilience holds the key to achieving and sustaining well-being outcomes such as food security [11,12].

MATERIALS AND METHODS

The systematic review involved a comprehensive search of scientific databases, including PubMed, Web of Science, and

Google Scholar. The search targeted articles, reports, and studies concerning covariate shocks in Kenya's fisheries and aquaculture sectors. Key search terms comprised of 'climate change', 'marine pollution' 'freshwater pollution', 'COVID-19', 'geopolitical instability', 'Fisheries', 'Aquaculture', 'Kenya', and 'community-based', 'adaptive response'. Inclusion criteria encompassed relevance to the topic, full-text publication in peer-reviewed journals, and publications between the year 2000 and 2024. Articles not available in English were excluded [13,14].

Data extracted from the selected literature included information on the impacts of various covariate shocks on fishery and aquaculture-dependent livelihoods, as well as the community-based adaptive responses to these shocks. The collated data underwent further analysis to identify the principal impacts of covariate shocks on fishery and aquaculture-dependent livelihoods, along with community-adaptive responses aimed at enhancing resilience. Synthesizing key findings and trends from the literature enabled the provision of a comprehensive overview of the impacts of covariate shocks and adaptive responses in the Kenyan fisheries and aquaculture sector [15,16].

RESULTS AND DISCUSSION

Overview of climate change

The climate change refers to a long-term alteration in the state of the climate, identifiable through statistical tests by changes in mean and/or variability persisting over decades or more (IPCC, 2021). Unlike short-term weather changes, climate change involves substantial shifts in seasonal patterns. These alterations profoundly influence human economies and cultures reliant on natural ecosystems (Halbac-Cotoara-Zamfir) [17,18].

The escalating global concern about climate unpredictability is particularly concerning in the fisheries and aquaculture industries. Climate change indicators, such as floods, droughts, high temperatures, storms, acidification, and aquatic factors like wind speed, wave action, and water level rise, significantly impact the production ecology, fishing operations, communication, and livelihoods, thereby affecting broader society and the economy. These changes affect households relying on these ecosystems for their livelihoods, with extreme weather conditions disrupting fishing operations and land-based infrastructure [19,20].

The consequences of climate change on the ocean environment, especially in anticipated regions, continue to impact fisheries, carrying significant implications for coastal communities and ecological systems. Recent studies highlight the impacts of climate change on fisheries, aquaculture productivity, and coral reefs, resulting in coral bleaching and alterations in species diversity and composition. As these events are already affecting the aquaculture and fisheries sectors, particularly in the ocean and coastal areas, causing declines in fisheries stocks, understanding the impacts of extreme events like floods, droughts, increased temperature, and rise in sea levels becomes crucial for predicting and comprehending the dynamics of fish stocks and their implications for future food production systems (Figure 2).

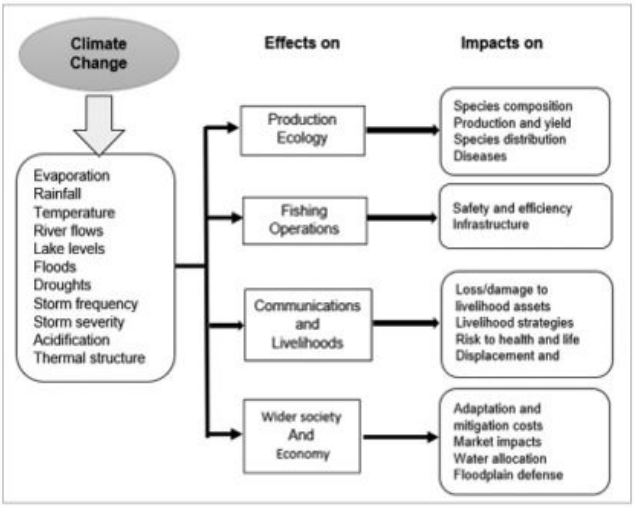

Figure 2: Impacts of climate change on the fisheries and aquaculture sector.

Drought: Prolonged droughts on aquaculture is particularly pronounced in facilities relying on surface freshwater sources. Fish ponds filled through overland flow experience a significant reduction in volume, limiting space for animal cultivation and accumulation of potentially harmful metabolites. Furthermore, drought-induced conditions contribute to nutrient concentration, causing excessive phytoplankton blooms and elevating dissolved and particulate organic matter concentrations, subsequently limiting oxygen concentration and circulation. Drought-related water stress, such as shortages and declines in water quality, can adversely affect aquaculture output. Impoverished small-scale pond farmers face a higher risks of water loss, resulting in shorter growing seasons, reduced yields, and limited cultivable species [21,22].

The fishing sector, dependent on natural water supplies, is also negatively impacted by drought, particularly in regions where fisheries rely on these water sources. In estuaries with limited connection to the ocean and inadequate tidal cleansing, drought reduces freshwater inflow, causing an anomalous increase in salinity due to evaporation. The rise in salinity can surpass the optimal range for aquatic species, leading to mortalities. Additionally, in most lakes, changes in water levels significantly influence fish stock sizes, with declining lake levels resulting in decreased capture rates. For example, Lake Victoria and its surroundings are threatened by declining water levels, with a decrease of more than 1.5 meters since 1998. Drought is believed to be a contributing factor, impacting wetlands that harbor fish breeding grounds [23,24].

The adverse effects of drought extend to production ecology, fishing operations, safety, and the efficiency of fishing infrastructure, influencing fish species composition, production, and yield. These effects pose risks to the health and life of fisher folk, contributing to the loss and damage of livelihood assets and exacerbating food insecurity in the region. Local communities near Lake Victoria, characterized by high population densities, widespread poverty, recurrent droughts, crop failures, and health challenges, are among the most food insecure in the region.

Drought, being a slow and progressively extreme climatic event, has been less anticipated in the wetland-filled Lake Victoria region. Consequently, its impacts are more severe than those of floods, given the inadequacy of existing coping mechanisms. In the wetlands surrounding the lake, essential ecological and provisioning services are significantly affected by drought, accentuating the severity of the situation. The repercussions of drought-induced stresses are manifold, leading to the destruction of wetlands for agricultural use. These anthropogenic activities not only contribute to the degradation of the wetland ecosystem but also escalate resource use conflicts among stakeholders [25,26].

In response, communities have diversified products for wider domestic markets. For instance, investing in alternative income activities like horticulture and ecotourism has been applied to alleviate pressure on fishing resources, offering producers diversified options for livelihoods and enhanced resilience against climate change impacts. Diversification extends to combining aquaculture production systems with other sectors, such as agriculture, either integrated or as separate systems. Successful diversification hinges on government policies incentivizing efficient resource utilization, equity, and environmental protection. Integrating indigenous knowledge with government interventions is essential for improving livelihood diversification among fish producers. In addition, incorporating climate variability and change into the modeling of fisheries and aquaculture activities is important to mitigate the impacts of climate change on livelihoods in these sectors [27,28].

Floods: Floods exert multifaceted effects on human capital, encompassing food security, maritime safety, and socioeconomic activities. Death, a significant outcome of adverse climatic events, not only affects surviving family members but also hampers broader social and economic activities. Flood-induced natural catastrophes are often linked to accidents at sea, jeopardizing fishermen's livelihoods. The repercussions extend to the cost and availability of food, negatively impacting family and community health.

Reduced catches due to flooding events pose a risk of hunger and undernutrition for populations heavily reliant on fish as a protein source, potentially leading to dietary changes. The economic ramifications of climatic fluctuations extend to fishery-dependent incomes, impacting the ability of communities to procure store-bought food during periods of natural resource scarcity. As noted reductions in fishery-dependent incomes create financial constraints that limit access to alternative food sources. This economic strain further exacerbates the vulnerability of communities reliant on fisheries for sustenance [29,30].

The health implications stemming from climatic phenomena, such as the El Nino cycle, are evident, where alterations in disease transmission dynamics have been observed. Similar studies reveal a notable association between the El Nino cycle and changes in the risk of mosquito-borne diseases, including malaria and dengue fever. In the African context, where a significant portion of small-scale fisher folk operates, the heightened sensitivity of malaria risk to El Nino events poses a direct threat to community well-being. The interconnectedness of climate variations and health outcomes becomes particularly pronounced, thereby emphasizing the need for a comprehensive understanding of these dynamics in the context of fisheries and aquaculture communities.

The unpredictable nature of flooding patterns threaten food security, particularly for low-income rural communities in the fisheries and aquaculture sectors. Lowland areas are at increased production risks with heightened precipitation. Risks include; pond destruction from infilling and wall erosion, fish loss, and introduction of invasive species into the ponds.

In Kenya, several regions face heightened vulnerability to perennial flooding, particularly during rainy seasons. For instance, in 2020, Kenya experienced devastating floods in the Nyanza and coastal region and rising water levels in Rift Valley lakes, severely affecting blue economy-based livelihoods. For instance, Lake Victoria experienced rising water levels, leading to widespread flooding that displaced lakeside communities and destroyed critical fishing infrastructure. Fishers and traders reported losses in homes, businesses, farmland, and the tragic loss of lives. In the same year, Lakes Turkana, Baringo, and Bogoria experienced heavy flooding, displacing thousands, disrupting livelihood activities, eroding farmlands, submerging businesses along the shores of the lakes, and posing a threat of cross-contamination between the two lakes (BBC News, 2020; Wambua-Soi, 2020; OCHA, 2023).

Climate warming over Africa, intensifying since the 1970s, is a contributor to the increased precipitation leading to these floods, necessitating the development of adaptation and mitigation measures to reduce their impact on resources and livelihoods (IPCC in 2013). The adaptation responses used by most communities have evolved, such as; knowledge of adaptation strategies, access to credit facilities, access to early-warning information. Early Warning Systems (EWS) for flood risk, such as those implemented in the Nzoia River in Western Kenya, have demonstrated effectiveness in reducing the impact of flood events. Other widely documented responses to flooding include; construction of pond dikes, netting and fencing around the low elevated ponds, community-based flood protection, and changing stocking dates.

Incorporating local and indigenous knowledge into adaptation strategies has proven effective, providing specific insights into the physical environment, infrastructure systems, livelihood status, behavior, governance organization, and other crucial attributes. Traditional methods and indicators aid in predicting changes in weather patterns, enabling producers to prepare for expected changes and build resilience. While the utilization of indigenous knowledge in fisheries and aquaculture production is not well-documented, its successful application in other sectors, like agriculture, suggests its potential value in adapting to climate change.

Increasing water surface temperature

Increasing water temperature is remains an environmental stressor affecting both inland and marine fisheries. The escalating warming trend in Africa over the past 27 years has

raised urgent concerns, emphasizing actions to mitigate its consequences and institute climate resilience strategies. Projections from the IPCC indicate an anticipated temperature surge of 2 to 4 °C in Africa by end of the century. The responses of aquatic species to the rising water temperatures vary, reflecting distinct processes in both marine and freshwater ecosystems. Poikilothermic animals, such as fish, adapt to warming temperatures through alterations in species distribution, population dynamics, and organismal physiology and phenology. Consequently, a significant migration pattern is observed, with fish species relocating from low tropics to higher latitudes, causing reduced fish landings in lower latitude communities and increased landings in higher latitude areas. These shifts in species' distribution contribute to conflicts among fishers within and between countries.

The timing of spawning, influenced by water temperature, further impacts fish productivity, affecting fishery-dependent communities and national economies. Optimal temperature ranges important for fish reproduction become disrupted by climate-induced temperature changes, influencing cueing, spawning periods, larval distribution, and survival. While effects vary among species, some studies demonstrate a positive correlation between temperature and fish larval mortality. For instance, a 1°C increase in water temperature results in a 0.01 increase in fish larval mortality. The connection between increasing sea surface temperature and marine and freshwater primary production emerges as a critical constraint on fish and fisheries production.

Studies suggest that changing water temperatures impact plankton productivity in African lakes and marine ecosystems, leading to diminishing primary productivity. The resulting declines in primary productivity pose detrimental consequences for fish stocks, human livelihoods, and food security. Warming water temperatures additionally induce vertical stratification, reducing Mixed Layer Depth (MLD) and nutrient flux into upper oceans. Stratification leads to low dissolved oxygen concentrations, negatively impacting fish growth and population. Recurring episodes of low oxygen levels in Lake Victoria have caused significant losses for aquaculture practitioners, linked to climate change and unregulated development.

In response to these challenges, fisher folks, particularly those around Lake Victoria, shifted to adopting technologies such as cage aquaculture and aquaculture parks. These technologies hold the potential to increase fish production, ensure food security, and mitigate fishing pressure on natural water bodies. Cage aquaculture, with its value chain linkages, becomes a crucial pillar for rural households, offering alternative livelihoods to fishing and utilizing understocked waters left behind by dwindling capture fisheries. Other measures include development of insurance schemes for small-scale producers, to build resilience in the face of climate change. However, the viability of fisheries and aquaculture insurance hinges on addressing risks beyond climate change, with high risks associated with the sector hindering insurance companies' involvement. Aquaculture producers are also enhancing resilience by shifting to species, techniques, or areas less vulnerable or more resilient to a changing environment. For instance, the adoption of the Integrated Multi Trophic Aquaculture (IMTA) system, combining finfish farming with other species, has emerged as an environmentally friendly, sustainable, and economically rewarding option for most communities. Shifting to or developing aquaculture species more resilient to climate change also presents a potential avenue for adaptation.

Sea level rise

Sea-level rise poses a significant threat to coastal fisheries, with varying impacts along African coastlines. The rate of sea-level increase is not uniform, but projections by the World Bank indicate a potential rise of approximately 10% along African coastlines by the end of the 2nd century, surpassing the global mean. Coastal ecosystems like mangroves and salt marshes, vital for maintaining wild fish stocks and supporting aquaculture, are adversely affected by rising sea levels. This negatively impacts aquaculture breeding programs and economic sustainability, particularly in lowland regions where saline water intrusion threatens production facilities such as ponds, cages, tanks, and pens. The salinization of groundwater further hampers aquaculture, freshwater fisheries, and agricultural production, leading to higher costs and reduced economic gains.

In specific regions like the Kenyan coast, sea-level rise brings about submergence, displacing coastal wetlands, causing shore erosion, increasing salinity, and infiltrating saline into coastal aquifers. Coastal development faces considerable risk, with projections indicating a rise of 0.17 m-0.59 m over the next century. Saltwater intrusion and salt wedge estuaries are already observed phenomena in places like Lamu, alongside coral reef bleaching linked to warming seas. Climate change predictions indicate potential threats to mangroves, with extreme droughts, flooding, and sedimentation leading to dieback, as witnessed in Mwache Creek in Mombasa (CORDIO, 2008). The vulnerability of the Kenyan coast to sea-level rise is evident, impacting low-lying developments in agriculture, infrastructure, and tourism.

To address these challenges, the Coast Development Authority, in collaboration with partners, implements adaptation mechanisms along the coastal region. Activities include the rehabilitation of mangrove ecosystems, coral reef protection, shoreline stabilization, and erosion and accretion control KEFRI. Kenya's Integrated Coastal Zone Management (ICZM) action plan and Shoreline Management Strategy provide a comprehensive framework for managing coastal and marine resources, guiding stakeholders, and offering policy recommendations (KEFRI).

Environmental pollution

Environmental pollution, induced by human activities is a significant stressor in freshwater ecosystems today. For instance,

in the Lake Victoria basin, population and economic growth are principal contributors to water resource pollution. This densely populated region, characterized by riparian communities, experiences a rapid increase in both population and economic activities, resulting in heightened demand for natural resources. This escalating demand surpasses the ecosystem's capacity, leading to adverse impacts on the ecological integrity of Lake Victoria. Land use changes, primarily driven by agricultural practices, urbanization, and industrialization, further exacerbate water quality degradation in the basin. Noteworthy, alterations in the physical, chemical, and biological components of the lake have been observed, signifying a substantial shift from conditions in the 1960s.

Physically, there is a discernible increase in water turbidity, evidenced by a reduction in Secchi transparencies over time. Nutrient enrichment is evident, with elevated nitrogen concentrations, particularly in inshore waters, indicating chemical changes. Biologically, the phytoplankton community has shifted persistently, with cyanobacteria dominating. This shift has led to increased algal biomass and common blooms dominated by cyanobacteria. Eutrophication has further degraded water quality, fostering excessive weed growth and increasing suspended organic material. These changes adversely impact the ecological, esthetic, and economic functions provided by the lake ecosystem, including fishing, transport, and tourism.

On the Kenyan coast, pollution challenges are escalating, driven by coastal county governments facing capacity constraints in waste management. Inadequate technical, human, and financial resources hinder effective waste management, and the absence of measures addressing non-point sources of pollution exposes the marine realm and dependent organisms to a high risk of pollution. Sewage pollution is manifested by elevated concentrations of inorganic nutrients, with phosphorus being a concern for freshwater systems, and excessive nitrogen causing eutrophication in estuaries and coastal waters. Population growth, poor land management, and changes in precipitation contribute to nutrient imbalances in coastal ecosystems, affecting fisheries production (Duarte and Krause-Jensen). This is a concern at the Kenyan coast, especially concerning food and nutrition security, as local communities along the Kenyan Coast heavily depend on artisanal fisheries for their livelihoods and affordable nutrition.

Additionally, microplastic pollution poses a significant threat to the fishery sector, affecting organisms at lower trophic levels that ingest microplastic with food particles. These contaminants propagate through food webs, accumulating toxic chemicals in higher trophic levels, including fish, leading to adverse effects on both capture fisheries and the aquaculture sector. This contamination results in economic losses due to reduced demand for contaminated fishery sources. For instance, a study in northern Lake Victoria revealed widespread occurrence of microplastic debris, primarily composed of polyethylene and polypropylene, originating from local activities. Fish landing beaches were identified as major hotspots for plastic pollution, adversely impacting the economic value of Lake Victoria. On the Kenyan coast, areas like Mombasa City, characterized by industrial plants, dense human settlements, and fishing and tourist activities, contribute significantly to plastic waste. Studies in Kenya's Exclusive Economic Zone (EEZ) recorded substantial plastic pollution, affecting marine biodiversity and jeopardizing seafood safety and availability. The economic impact is particularly severe in Kenya, where marine and coastal fishery resources are important for food security (FAO, 2016).

Plastic pollution's repercussions extend beyond the economic realm, affecting aesthetics, natural beauty, and the health of ecosystems in coastal and marine environments. This degradation diminishes the tourist appeal of these areas, leading to a reduction in the number of tourists. Activities such as coral watching, snorkeling, and scuba diving, dependent on healthy ecosystems, suffer due to plastic pollution's detrimental effects. The resulting decline in tourism has cascading effects, causing job losses for local communities dependent on tourism-related activities (GEF, 2012). The intricate dynamics of environmental pollution have demanded comprehensive adaptive strategies within the Kenyan fisheries and aquaculture sectors to ensure resilience in the face of emerging covariate shocks and stresses.

The establishment of Beach Management Units (BMUs) around Lake Victoria represents a significant and ambitious initiative to mitigate the impacts of environmental pollution. The BMUs, organized on a community basis, have become integral components of a fishery co-management program that extends beyond fisheries management. The deliberate inclusion of all fishermen in this co-management structure reflects a comprehensive approach to community involvement. Notably, the adaptive strategy extends to addressing environmental pollution within the lake, positioning BMUs as key players in controlling and mitigating the impacts of pollution.

Awareness and capacity-building campaigns among communities have been done to transform attitudes toward environmental conservation and sustainable management for marine and coastal ecosystem quality. Public awareness initiatives, disseminated through various channels, aim to educate communities on litter generation, removal, and the impact on marine environments. Mandatory actions, such as segregating recyclable plastic and strategically placing disposal bins, contribute to a cleaner environment. Social media, local media, printed materials, and public displays serve as effective mediums to disseminate information on marine debris accumulation and mitigation strategies. Involving stakeholders in beach cleaning and waste removal campaigns has also been utilized to enhance awareness and capacity-building within local communities.

COVID-19 pandemic-related disruptions

Disruptions stemming from the COVID-19 pandemic negatively impacted various functions within the value chain. A synthesis of documented news/papers reported notable disruptions that in fish transportation options during lockdown periods FAO. This market contraction resulted in increased live fish stock levels and prolonged fish culture periods, adversely affecting feed conversion ratios, restocking capabilities, and overall farm profitability. The consequential rise in the risk of fish mortality

and feeding expenditures added further strain to an already challenging scenario.

The stringent restrictions on movement, a consequence of the pandemic control measures, presented impediments for fishers and aquaculture producers. Access to important production inputs such as brood stock, fingerlings, feed, and labor became restricted, exacerbating challenges within the value chain. Additionally, the closure of markets, restaurants, and hotels disrupted fish trade and consumption patterns, contributed to a decline in overall fish production. The multifaceted impact extended to the livelihoods of diverse stakeholders, including fishers, farmers, and other actors in the fisheries and aquaculture value chain.

The challenges posed by the pandemic were manifold, encompassing reduced access to markets and services, shortages of inputs, food and nutrition insecurity as well as household, domestic and foreign income. These obstacles resulted in inadequate production, unexpected stock retention, and substantial financial losses. As the sector grappled with these challenges, the need for adaptive strategies at the community level became increasingly apparent.

Influence of the COVID-19 pandemic on access to markets and services

The ramifications of COVID-19 disruptions to various segments of the aquaculture value chain are well-documented, drawing from data derived from press sources, social media, government reports, and development partners. The initial brunt of the pandemic was felt by China and its trade partners, but the repercussions swiftly reverberated globally. The decline in market demand for fish and restricted transportation options during lockdowns posed challenges for fish farms in gathering and distributing their products. This inability to market goods resulted in lower fish stock levels, and extended fish culture periods, adversely affecting feed conversion ratios, restocking capacity, and, ultimately, farm profitability. Elevated fish mortality and increased feeding expenses ensued. International market restrictions and closures of hotels and restaurants further hindered fish trade and consumption, leading to decreased aquaculture productivity and significant impacts on stakeholders across the value chain. The pandemic's restrictive measures also curtailed meetings, limiting the implementation of fisheries and aquaculture-related interventions.

The perishable nature of fish products presented substantial challenges to the fisheries and aquaculture sectors (FAO, 2020). In Kenya, small-scale farmers, predominant in fish production, faced market closures during the pandemic, especially in open-air marketplaces. The closure of major markets led to a decline in fish prices and an oversupply in nearby markets. Fisheries-related occupations experienced significant losses, with fish traders and processors bearing a greater impact than fishers and BMU officials, primarily due to the impact of COVID-19 regulations on their operational markets. Transport constraints impeded fish delivery to markets, while concerns over COVID-19 spread led to reduced gatherings, potentially accelerating fish spoilage.

Aura et al. [8], reported that pandemic containment measures, including curfews, lockdowns, and sanitary regulations, impacted fishing and fish trade across freshwater lakes. Lake Victoria faced the highest impact from sanitary measures, while curfews affected the other lakes more significantly. The dusk-to- dawn curfew also resulted in reduced fishing time and trips per week, reducing from an average of seven to five due to the pandemic. Travel restrictions and lockdowns affected the movement of Nile perch and its products in and out of Kenya, impacting both internal and external markets (Rajeev and Nagendran). In Homa Bay County on Lake Victoria, the price of tilapia, a highly valued fish delicacy in Kenya, increased due to high demand and limited supply during the pandemic, while Siaya County experienced lower prices, possibly due to the availability of cage culture supplementing wild tilapia.

The closure of restaurants and lodging establishments led to decreased demand for fish and fish-based products. Nevertheless, anecdotal data suggests a potential growth in Kenyan demand for Lake Victoria tilapia, offsetting lower Chinese tilapia imports due to travel restrictions. The disruption in global fish demand significantly impacted pricing and small-scale fisheries. Transportation challenges hindered the aquaculture industry by impeding the transfer of finished goods, raw materials, fertilizer, and other essential resources. Low farm gate prices resulted from a shortage of local and international buyers, contributing to market instability and price decline, with fish producers unable to sell their catch.

A key response to the challenges posed by the COVID-19 pandemic on access to market and services was the implementation of community-based market linkages. In this strategic approach, fisher folk collaborated to establish direct connections with consumers and retailers, reducing their reliance on conventional market channels. An innovative manifestation of this adaptation involved the emergence of "social-network" e-commerce for food during the pandemic. This model enabled sales directly from farms to consumers, with volunteers leveraging social networks to aid farmers in reaching urban consumers. The integration of e-banking and payment applications played an important role in facilitating these transactions, allowing for seamless mobile person-to-person transfers of cash. Notably, the success of these community-based market linkages extended beyond the immediate challenges of the pandemic. Post-COVID lockdowns, these networks have persisted and evolved into a significant alternative for consumers, surpassing the convenience of traditional supermarkets and green groceries. Consumers, now accustomed to the perceived higher quality of produce obtained through these direct connections, have embraced this shift in their purchasing behavior.

Influence of the COVID-19 pandemic on access to inputs

The COVID-19 pandemic significantly disrupted the critical aspect of inputs within the aquaculture and fisheries sector. Due to lockdown and physical distancing, transport and travel restrictions, trade restrictions, and price fluctuation (Figure 3).

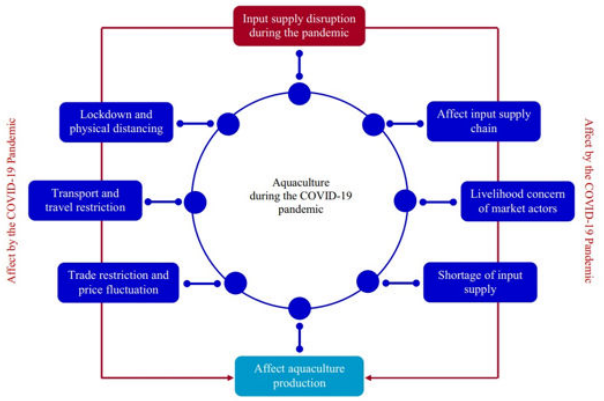

Figure 3: COVID-19 disruptions and impacts on input supply, which, in turn, affect aquaculture production.

Fish farmers faced challenges in accessing extension services and obtaining essential production inputs such as brood stock, fingerlings, fertilizer, and manpower. The impact on fish hatcheries resulted in a decline in fry prices, labor shortages, increased shipping costs, compliance expenses with health regulations, and social distancing measures. This scenario led to a drastic reduction in the market for fry/fingerlings, with fish remaining unclaimed in culture ponds. Lockdowns, curfews, and border blockades restricted mobility, making it challenging to transfer fingerlings across counties, hindering producers and/or dealers from shipping fingerlings across state and federal borders. The shortage of regular employees and rising labor costs posed challenges at hatcheries and feed mills.

The East African Community (EAC), regional markets, and other international markets serve as primary sources of micro-ingredients for fish feed in Kenya, including chemical preservatives, vitamins, antibiotics, and minerals. These ingredients, such as maize, wheat, rice by-products, soybean and its derivatives, sunflower, cotton, and fishmeal, faced a substantial impact from the pandemic. Feed industry companies were compelled to raise feed prices due to labor and raw material shortages, lower feed sales, increased transportation costs (20%-60%), and higher operational expenses to adhere to health regulations and social distancing measures. Moreover, the pandemic witnessed a notable decline in the average crew (fishing inputs) and boat fuel (consumable) used in fishing activities, resulting in an overarching decrease in catch quantities and prices. This significant reduction in fishing effort and inputs posed a considerable threat to the socio-economic status of small-scale fishers, particularly those already grappling with economic challenges.

In response to the challenges posed by the COVID-19 pandemic, there was the establishment of community seed and input banks within the sector. This innovative approach involved communities collaboratively pooling and managing critical inputs essential for their fishing and aquaculture activities. These inputs encompassed a range of vital resources, including fish fingerlings, aquaculture feeds, and seeds. The creation of these local repositories resulted in reducing their dependence on external supply chains, which were susceptible to disruptions during the pandemic. The process of establishing these community seed and input banks typically involved active participation and coordination among community members. Through collaborative efforts, communities developed mechanisms for collecting and storing key inputs in centralized locations, ensuring accessibility and management efficiency. This not only served as a proactive response to disruptions but also promoted a sense of collective resilience and self-reliance within the local fishing and aquaculture communities. As a result, community members could rely on these local repositories to secure a more stable supply of essential resources, safeguarding the continuity of their fish farming and aquaculture activities even in the face of external uncertainties caused by the ongoing health crisis.

Influence of COVID-19 on food and nutrition security

Despite the global pandemic, fish remains an important source of animal proteins, minerals, and omega-3 fatty acids (FAO, 2020). In underdeveloped nations, fishing plays a pivotal role in providing nourishment and sustenance for subsistence populations. According to the FAO, millions of people globally rely on fish not only for nourishment and sustenance but also as a livelihood. The nutritional consequences of the pandemic disproportionately affected smallholder fish producers and participants in the aquaculture value chain, given their susceptibility due to high rates of poverty, hunger, and food insecurity.

In Kenya, despite the potential of aquaculture to enhance food security, nutrition, livelihoods, and social capital, small and Medium-Sized Enterprises (SMEs) bore the brunt of COVID-19 restrictions. The resilience of these actors and their response to the disruptions played a pivotal role in their ability to withstand the challenges. COVID-19 preventive measures aimed at reducing human interactions posed a significant challenge to value chains dependent on such interactions. The aquaculture and fisheries value chain encompasses production, fishing, processing, input transportation, distribution, wholesale, and retail marketing. The pandemic-induced disruption of these sectors resulted in reduced job opportunities, and incomes, disrupted the food supply chain, increased price of necessities, and increased price of inputs, and the cumulative effects increased household food security vulnerability (Figure 4).

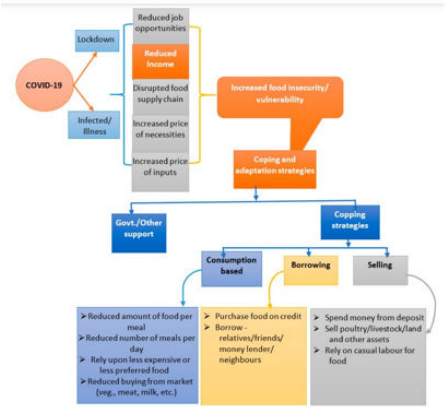

Figure 4: Impact of COVID-19 on food and nutrition security and adaptation strategies.

Further, the disruption resulted in a reduction in fish consumption which posed a severe threat to the nutritional well-being of many Kenyan families, especially newborns, who rely on the nutrients present in fish for growth and development. Changes in household access to various fish species and a decrease in the frequency of fish consumption were observed by Fiorella et al. [24], cheaper species like dagaa and cichlids gained popularity, reflecting economic constraints faced by families during the pandemic. Even low-value fish species were considered costly by some households, underscoring the challenges associated with rising costs and decreasing income during this period.

To safeguard vulnerable communities engaged in fishing and fish processing during the COVID-19 pandemic, most communities took decisive measures. A study conducted in Kilifi eplains on the varied experiences reported by respondents from five different communities regarding the receipt of aid and support. The findings of the study reveal diverse accounts among respondents, with some individuals, including a trader, reporting receipt of a modest portion of aid in the form of food. A community leader played a pivotal role in orchestrating contributions from various community organizations. This collaborative effort resulted in a one-time food aid package customised for fishers, encompassing essential items such as maize flour, beans, sugar, and soap.

Also report that resilience research should focus on components of the aquaculture and fisheries system crucial for populations highly dependent on fish for nourishment and supporting the food security of low-income value chain players. Developing an assessment framework and resilience indicators for the fish value chain, considering social, economic, and environmental factors, facilitates the identification of resilience "hot spots." Government collaboration with the commercial sector, international organizations, and local communities is imperative to secure sufficient supplies of wholesome food during pandemics. Transparent and honest communication between the government and the public builds confidence and support. Additionally, promoting community-based initiatives such as urban and peri-urban agriculture, home gardening, and community-supported agriculture can contribute to enhancing food resilience at the grassroots level.

CONCLUSION

The study emphasizes the critical need for community-based adaptive strategies to ensure the sustainability and resilience of Kenya's fisheries and aquaculture sectors. Facing escalating challenges from climate change, environmental pollution, the COVID-19 pandemic, and national geopolitical instability, it is imperative to address these issues comprehensively. Climate change has brought about a range of challenges, including diminished fisheries-dependent incomes, increased human diseases, aggravated food insecurity, and significant losses in fishery infrastructure and assets. To counter the impacts of climate change, communities have embraced diverse livelihood strategies. These include reducing dependence on fisheries by investing in alternative income sources, integrating indigenous knowledge with scientific expertise for sustainable resource management, developing climate-resilient aquaculture species, and enhancing infrastructure such as higher pond dikes, netting, and fencing around low-elevated ponds. Innovations like cage aquaculture and insurance schemes have also been adopted to alleviate fishing pressure and mitigate economic losses. Environmental pollution emerges as a pervasive stressor, leading to reduced fish productivity, marine life loss, economic downturns, and declining tourism. Community awareness and capacity-building campaigns have been crucial in transforming attitudes toward environmental conservation. Active community involvement in beach cleaning further contributes to environmental conservation efforts. The COVID-19 pandemic has exacerbated vulnerabilities, resulting in reduced fish prices, restricted access to essential inputs, decreased fish consumption, and elevated unemployment. Community-based market linkages, direct connections between fisher folks and consumers, and the establishment of community fish seed and input banks have proven effective in reducing reliance on conventional market channels. Additionally, the introduction of precision aquaculture technologies and the strengthening of local food systems are proposed as essential measures to adapt to future disruptions. National geopolitical instability poses additional challenges, impacting fish productivity, inflating fish prices, increasing production costs, and disrupting fish imports. Adaptation strategies encompass diversifying aquaculture systems, strengthening governance through transparent policies, investing in community-based training, implementing short-term genetic improvement programs, and establishing collaborative research initiatives. In light of these findings, it is recommended that policymakers and stakeholders prioritize the implementation of these adaptive strategies.

DATA AVAILABILITY STATEMENT

No data was used for the research described in the article.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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