Status and outlook for climate-resilient aquaculture in Kenya: Stakeholders' perspectives

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Abstract

The impact of climate change on the aquaculture sector, which both supports livelihoods and is a source of nutrition in Kenya, is of concern. This study seeks to assess how stakeholders understand the impact of climate change on the aquaculture sector in Kenya, to highlight the steps needed towards enhancing the adaptation of aquaculture infrastructure to climate change. The study adopts a complementary mix of data collection methods (workshops, interviews, questionnaires, and field visits) implemented in four case study sites (Kakamega, Kajiado, Nairobi, and Kiambu). The findings of this study indicate that the most important climate hazard impacting aquaculture in Kenya is drought. It is estimated that about 40% of the potential growth of the sub-sector is lost due to the direct and indirect impacts of climate change. However, only a handful of farmers have opted for adaptation measures mainly because they are considered expensive. Facilitating the adequate adaptation of aquaculture practice to climate change will require a focus on improving the fish production infrastructure, improved aquaculture feeds, and policy changes. Overall, this study shows that for the sector in Kenya to overcome the impacts of climate hazards and be resilient to future climate change, there is also a need to prioritise economic incentives and capacity building. The findings are timely and should serve as a crucial stimulus for critical stakeholders towards developing infrastructures in tackling the present climate change challenges confronting the aquaculture sector in Kenya.

Keywords: Adaptation, Climate hazards, Fish production, SDG, Stakeholders

Case Study Questions

- What are the main climatic related hazards and their impacts on aquaculture in Kenya?
- How are fish farmers in Kenya adapting to climatic hazards?
- What is needed to promote resilience of the aquaculture sector in Kenya to climate change?

1. Introduction

The increase in global demand for fish, resulting in overfishing, has led to diminished wild fish stocks globally. This has enhanced the significance of the aquaculture sector in providing millions of people with healthy, high-protein food while reducing pressure on wild fish stocks. Aquaculture is important for health, livelihoods, and social empowerment, as well as contributing to several Sustainable Development Goals (SDGs), including reducing hunger and poverty. Farmed fish account for over half of all fish consumed directly by humans (1); aquaculture is already growing, experiencing a twenty-fold production increase from 1995 to 2018 (2) and is further expected to expand by up to 48 per cent (3). Globally, the aquaculture sector employs an estimated 20.5 million people, most of whom are in developing countries and are small-scale fish farmers (3-5). In Africa alone, as of 2014, the aquaculture sector employed over a million people (6).

Over the last decade, aquaculture has played an important role in growing fish production and making fish available and affordable in Africa, especially to the poor (7). However, recent estimates suggest that per capita fish consumption is expected to decrease in Africa (3).

Currently responsible factors include local production lagging behind consumption due to Africa's population outpacing the supply growth, as well as a lack of technical knowledge in seed and feed production (8, 9). Beyond these, climate change is an increasingly major issue threatening the viability of the aquaculture system in Africa (10-12). Akezua (13) reports how floods destroyed fish farms worth millions of naira in a Nigerian community. Likewise, Nkala (14) details how fish farmers on Lake Kariba (Zambia and Zimbabwe) are suffering in the face of drought. In a study of the aquaculture sector in Ghana, Asiedu, Adetola (15) identified floods and storms as being significant climate hazards threatening the aquaculture sector. Despite Africa being a climate risk hotspot and with the impact of this on aquaculture likely to affect wellbeing, few studies have explored how fish farmers are adapting and building resilience to climate hazards. As such, Badjeck, Katikiro (16) called for better understanding of the impacts of climate change on aquaculture in Africa. This paper contributes to filling this gap with an assessment of stakeholders perspective on the impact of climate change on aquaculture in Kenya.

Although African aquaculture is subject to multiple climatic hazards, research related to risk perception and adaptation measures is still lacking. This lack of appropriate understanding of fish farmers' experiences, perceptions, and interests, alongside the barriers and enablers to promoting adaptation in the sector, has led to unanswered questions around how to build resilience to climate change in the sector. This in turn has led to recommendations of adaptation measures that have failed to take account of specific local peculiarities (17). More evidence is needed on establishing effective adaptation measures tailored to local factors and cultural norms. Therefore, this study considers the questions of 'what are the main impacts of climate-related hazards on the aquaculture sector in Kenya and what are the adaptation measures currently being used and needed to promote resilience of the sector to climate change?' The overall aim of this paper is to appreciate stakeholders' understanding of climate change's impact on aquaculture and the effects this has on fish farmers and to suggest potential steps towards the adaptation of aquaculture infrastructure to climate change.

2. Literature review

2.1. Aquaculture and climate change in Africa

Aquatic animals are generally cold-blooded, with their metabolic rates strongly affected by climatic conditions. Occurrences of extreme climatic changes can trigger both direct and indirect influences on the aquaculture system. Direct impacts are those that affect the physiology and behaviour of the fish, impacting their growth, reproduction, mortality, and distribution (18). For example, extreme changes in temperature can affect the reproductive cycles of fish, including the speed at which they reach sexual maturity, the timing of spawning, and the size of the eggs they lay. On the other hand, the indirect impacts affect the productivity, structure, and composition of the ecosystem which the fish depend upon for sustenance (19). This is experienced through increased temperature a factor to the spread of farmed fish diseases and other opportunistic infections, while floods and prolonged drought have been documented to cause damage to fisheries and aquaculture infrastructure, growing the risks of farmed species escapees and mortalities. The production and distribution chain can also be impacted by changes in the frequency, distribution, or intensity of weather events leading to increased losses (20, 21). In addition, climate change can influence people's choices in their use of aquatic resources, such as changes in governance structures, input and output prices, technological change, emergencies, and cultural contexts that have unplanned consequences within the aquatic food production systems (22).

Over the last decade, there has been a significant increase in the number of emerging studies focusing on climate change and aquaculture. A number of these have suggested that climate change implications for aquaculture will result in winners and losers (22-25). Although this is a global challenge, the African continent is more vulnerable to climate change than other regions (26) because most practices there are small-scale and rely on natural environmental factors. The region has several different climate types: (i) Arid and semi-arid (the Sahel region, Kalahari, and Namib deserts); (ii) Tropical Savanna grasslands (Sub-Saharan Africa and Central Southern Africa); (iii) Equatorial (the forested Congo region and the East African highlands); (iv) Temperate (the South Eastern tip of South Africa) (27). Current projections under various climate change scenarios suggest impacts on the continent's fisheries and aquaculture will be grave (11, 16, 28). This is because climate change would worsen aquaculture growing conditions in large parts of Africa, especially in coastal East Africa, that would threaten human health and safety, food and water security, and socio-economic development (29). For most of Africa, studies have predicted yield losses (15, 30, 31). The study by Asiedu, Adetola (15) showed over 80% of fish farmers in the Ghanaian aquaculture sector have experienced one climate-related hazard or the other, the most common of these being flooding, erosion, and drought.

2.2. Aquaculture in Kenya

Kenya is located in the tropics along the equator, with various agro-ecological zones that include several freshwater lakes, rivers, and permanent dams (Figure 1). Thus, the country has great potential to grow its aquaculture sector locally. However, farmed fish production is not uniform across all Kenyan counties, as a result of disparities in soil type and water availability (32). Among aquaculture producing counties Kakamega, Bugoma, Busia, Kisii, Meru, and Nyeri are leading, while those lagging behind are Kitui, Lamu, and Elgeyo Marakwet.

Fig 1 about here. Map of Kenya indicating areas suitable for freshwater aquaculture (based on (32)
Green = High suitability; Pink = Medium suitability; Yellow = Low suitability

In Kenya, capture fisheries can be traced to the precolonial era when the focus was mainly on haplochromine cichlids fishing in Lake Victoria and Lake Turkana (33, 34). Trout fishing was such an important venture that in 1928 the law protected trout in the country (35). Static water earthen ponds emerged in the 1920s in Sagana mainly on the Tilapine culture; soon after, the farming of other fish species (such as the Common carp (*Cyprinus carpio*) and African catfish (*Clarias gariepinus*)) began to emerge (36). To ensure a continued supply of fingerlings for ponds and of trout for stocking in rivers, the British colonial government put up two fish farms: the Kiganjo trout (*Oncoryhnchus mykiss*) fish farm for cold-water fish and the Sagana fish farm for warm freshwater fish (37). The same fish species are still cultured today with the inclusion of a variety of ornamental fish species such as the Goldfish (*Carassius auratus*) and Koi carp (*Cyprinus rubrofuscus)*.

The freshwater aquaculture subsector's growth was sluggish, until the colonial government rolled out the "Eat More Fish" campaign in 1960 (25) which popularised aquaculture. Beyond this, the Kenyan government put in place the Economic Stimulus Project (ESP) in 2009 (38). The ESP programme was geared towards reducing poverty, reviving the economy, and inducing regional development (26). It propelled aquaculture in the country, moving it from prolonged stagnation to being at the forefront of the African continent 27). Today, Kenyan fisheries and its aquaculture sector contribute about 0.8% to the GDP, an equivalent of 461m USD, to the Kenyan economy, supporting the livelihoods of over four million people directly and indirectly (39). With the rapidly increasing demand for fish in Kenya, the Government is actively promoting the development of the aquaculture (fish farming) sector, especially through the design of aquaculture and aquaculture-related policy and legal documents such as the National Aquaculture Strategy and Development Plan - NASDP (2010–2015); the Fisheries Bill (2012) and National Aquaculture Policy (November 2011), Ministry of Fisheries Development (40)

The fish consumpton rate increased from one kilogram per capita per year to five kilograms per capita per year between 2009 and 2018, leaving a considerable gap in the Kenyan fish market (22). In 2018 alone, Kenya spent 1.7 billion Kenyan shillings (about 20 million USD) on 22,362 tons of fish imports to cater for its growing fish demand, marking an 11.8% increase from the previous year's 11.5 billion (19,127 tons) (41, 42). The imported fish is crucial to servicing the 500,000 tonnes of demand on fish, compared to the 135,000 tonnes that the country produces (43). This goes to show the great potential the Kenyan fish market has for cultured and captured fish stocks, although Kenyan farmers have to compete against the cheap fish coming from China currently have in the market (44). At the same time, climate change is becoming a major challenge to the sector (45, 46). It is therefore imperative that resilient and sustainable approaches to aquaculture will allow for sufficient locally produced aquaculture products that guarantee traceability and protect human and environmental health.

To come up with strategies to curb climate change impacts on the agricultural sector (including fisheries and aquaculture), the government came up with the 'Kenya Climate Smart Agriculture Implementetion Framework-2018-2027' in 2018 (47). This framework is aimed at "promoting climate resilient and low carbon growth sustainable agriculture to ensure food security and contribute to national development goals in line with Kenya Vision 2030." According to the framework, the government intends to: improve accessibility to and the use of climate change adaptive technologies; promote the use of integrated fish farming systems to reduce pollution; upscale climate smart fish culture technologies; improve value addition processes to limit wastage; and create gene banks to safeguard future fish populations.

3. Methods

The data for this study was collected in four case study sites purposively selected to account for different climatic zones in Kenya, hence the various climate-related hazards. The four locations are Kakamega, Kajiado, Nairobi, and Kiambu. Kakamega is known for its tropical climate with year-round rain and an average temperature of 20.8°C. Kajiado has a bi-modal rainfall pattern. The short rains fall between October and December while the long rains fall between March and May. Nairobi and Kiambu experience a bimodal type of rainfall. The long rains fall between Mid-March to May followed by a cold season usually with drizzles and frost from June to August and the short rains between mid-October to November. The average rainfall received by the county is 1,200 mm and a mean temperature of 26°C (48, 49). This study adopted a complementary mix of data collection methods including workshops, interviews, questionnaires, steering group meetings, and field visits. Full ethical approval was sought and granted for this study.

Two stakeholder workshops held in Nairobi provided a useful platform enabling different individuals and groups to interact, discuss, and learn about the issue. The workshops aimed to raise awareness about the project, build capacity and understand and draw on a range of narratives and actions related to climate-resilient aquaculture in Kenya. The workshops served as an opportunity to engage key stakeholders, briefing them about the research programme. The second workshop also served as an opportunity for feedback and the validation of project outcomes. The stakeholders were engaged in identifying key climate-related hazards facing the aquaculture sector, identifying local adaptation and coping strategies, and as well as highlighting the interests and perspectives regarding addressing climate-related hazards. Workshop participants represented different stakeholder groups, including fish farmers, aquaculture associations, businesses, researchers, government representatives, non-governmental organisations, and academia. This includes some of the major stakeholders in Kenya's aquaculture sector, such as the Kenya Marine and Fisheries Research Institute, State Department of Fisheries, Kenyan universities, International Livestock Research Institute, Kenya Fish Processors and Exporters Association, and Aquaculture Association of Kenya (AAK). The first stakeholder workshop was held on 12th June 2019 and the second workshop was held on 11th October 2019.

Field visits to the four case study towns were conducted, during which informal interviews were held with twelve purposively selected fish farmers to interphase with stakeholders in-situ, thereby providing greater opportunities to directly observe key issues. Care was taken to ensure gender balance was achieved, alongside different types of farms (small to large), schools, businesses, etc. The interviews provided an opportunity for in-depth conversation, discussing issues highlighted during the workshop with farmers in the field. A questionnaire was designed to obtain the views of fish farmers not at the stakeholders' workshop. The questionnaires were distributed to fish farmers in the four case study locations and comprised two main sections. The first dealt with demographic data while the second sought to understand respondents' experiences of and views about climate adaptation practices. The survey was randomly distributed to be completed either by farm managers or farm owners. The questionnaires were designed in simple English language that could be easily understood by respondents.

4. **Results**

4.1. Characteristics of Questionnaire Survey Respondents

A total of 84 questionnaires were completed. The majority (86%) of respondents to the questionnaire were male (Table 1). This could merely be a reflection of male dominance within production activities in Kenyan society. The average age of respondents to the questionnaire was 52 years and the majority (71.4%) of respondents had either primary or secondary education. The average household had size 6 members with an average household income of $2,863. It was estimated that about 35% of this came from aquaculture farming.

The majority (78.6%) of respondents indicated that they had another occupation besides aquaculture to serve as a source of income.

Table 1: About here Socio-demographic profile of survey respondents

All questionnaire respondents indicated that they, or a farmer they knew, had been directly affected by a climate-related issue in the last five years. Specifically, 50% of respondents had experienced an extreme weather event in the last five years.

4.2. Stakeholders' Perceptions of the Impacts of Climate Change on Aquaculture

Based on the data, it was found that the impacts of climate change on Kenyan aquaculture manifests were diverse. These include rising temperatures, prolonged droughts, floods due to changes in rain patterns and windstorms. All respondents to the interviews and questionnaires expressed some level of concern about at least one climate hazard. This suggests that climate change is perceived as a real threat to the sector by the stakeholders. The results obtained from the questionnaire showed that the main hazard of concern is drought, followed by an increase in temperature, flood, and windstorm respectively (Figure 2). During workshop discussions, the main indirect concerns identified were how climate-related events impact the cost of aquaculture inputs, feeds, and water scarcity. However, evidence from the field visits suggests that issues of concern can be location-specific. For example, the majority of the farmers who visited in Nairobi, Kiambu and Kajiado emphasised the impacts of extreme heat, while those in Kakamega were more concerned about the impacts of flooding. One of the farmers in Nairobi was so concerned about a possible connection between increased theft of their fish and climate change. According to them "it [climate change] has impacted this area such that most of the agricultural lands are dry and less fertile … such that some of the farmers now resort to stealing our fish to feed themselves".

Figure 2 about here: Survey respondents' assessment of climatic hazards

To further gauge the impacts of climate hazards on aquaculture, respondents were asked to rank some potential impacts of climate change that had been mentioned either during the workshop or interview on a scale of 1 (not at all concerned) to 5 (extremely concerned). The overall results (Figure 3), using the mean response, showed that the direct impact of climate change affecting production and yield was of the most concern (4.36). This is followed by loss of income (4.30), impact on market-leading to closure (3.97) and water availability (3.93).

Figure 3 about here: Survey respondents' assessment of impacts of climatic hazards on aquaculture

Of the respondents who had experienced impacts of climate hazards, 56 put this in economic terms, stating an average loss of $785 per incidence. From the data gathered, it is estimated that this represents a loss of about 40% of the potential growth of the subsector because of direct and indirect climate change impacts. The loss was estimated to be between 10% of their fish to everything. Some of the ways this was found to affect farmers include an inability to raise enough funds to pay their children's school fees, as well as reduced production and profit. Only a handful of the respondents (10%) indicated that they had a coping strategy in place as indicated in the matrix below;

Table 1: Coping mechanisms identified by respondents

Impact	Coping Mechanism
Prolonged drought	Climate smart technologies (re-circulative aquaculture systems-RAS) / weather updates/ hired water pumps
Floods	Site selection/ weather updates / built embankment
Effluent contamination	Reservoir management/ integrated agriculture
Evasive species (Escapees)	Biosafety measures (screening)

This implies that most of those taking action generally look to structural adaptation strategies, overlooking or not knowing enough about other strategies i.e. institutional and societal approaches (50). There were reports of farmers who had left the business and abandoned their fishponds due to an inability to cope (Figure 4).

Figure 4 about here: An abandoned fishpond because the owner couldn't cope with the impacts of climate related hazard.

71% of the respondents had received information about how to adapt their infrastructure to climate-related hazards. The main source of this information came from businesses with 56% of respondents indicating they had received information from this source. 44% of respondents indicated they had received climate resilient aquaculture information from NGO/CBO, while 24% and 20% stated individuals and governments respectively.

The need for technology (i.e., green houses, raised tanks, aerated ponds, etc.), government policies, programmes and services, and educational approaches (through trainings) appeared highest in stakeholders' suggestion as to ways to manage climate-related hazards in the Kenyan aquaculture sector. Participants identified the need to provide additional support to help farmers understand climate risks, train them to identify climate hazard warnings, understand how those warnings are used, and what should be done in case of incidences such as flood and/or drought. Other training needs identified included alternative livelihoods, production of quality fingerlings, water management, pond construction, feeding formulation, and site selection. Furthermore, there is need to sensitise farmers and build their capacity to understand how to manage the environment, especially when it comes to water management through responsible/sustainable abstraction as well as effluent management. Framers visited in the field appear to be less concerned about the destruction of ecosystems to construct aquaculture farms, however they show concern for the environmental impacts of the effluents on the ecosystems. There was a recognition that climate related issues have made the risk facing aquaculture farmers more complex. It was suggested that having a system whereby farmers can easily share knowledge and pool resources together would be helpful. There is also a need for institutions that will regulate, manage, and provide support for aquaculture farmers, especially when they are affected by climate hazards.

4.3 Key areas of focus

Based on workshop discussions and informal field interactions with fish farmers, respondents identified key areas of focus for the sector to be climate-resilient. In the Kenyan context, the resilience of the aquaculture system to climatic hazard was linked to three broad issues, namely fish production, aquaculture feeds and policy. Overall, it was suggested that for success, the sector in Kenya must find innovative solutions in technological design and policies to ensure a robust and resilient aquaculture sector.

4.3.1. Fish production

Three major factors need to be addressed to enhance the adaptation of the fish production system to climate change. These are site selection, unit design, and water management.

Site selection practice to be climate-resilient: Participants pointed out that the success or failure of the Kenyan aquaculture venture largely depends on the right site selection. However, over 85% of inland aquaculture ponds in Kenya are thought to be poorly sited by the riverside, exposing them to climatic hazards including flooding, nutrient loads, diseases, invasion by non-target species, and easy unregulated effluent discharge to rivers by farmers. Participants emphasised that it is essential that alongside socioeconomic, political, and legal considerations, farmers must give heed to climatic and environmental factors in site selection. One of the suggestions given during this study was to have to initiate a real-time aquaculture stakeholder's platform to take care of all value chain needs including fish marketing, input sourcing and capacity building.

Improved aquaculture production unit and design: The importance of proper design and construction when setting up aquaculture production units was also identified as paramount. In Kenya, over 80% of fish culture facilities are earthen ponds which are entirely constructed from clay soil material. These units are exposed to sudden changes in temperature and are easily overwhelmed by both floods and drought, resulting in fast drying due to prolonged drought or loss of fish through flooding. In addition, these ponds face the challenges of predation, theft, low or high stocking densities, unregulated water volumes, and exposure to invasive species and diseases. Participants suggested that fish production would be improved if farmers were able to diversify to climate-resilient species which are currently not very common in the Kenyan market. Investment in making secondary products, such as drying fish if they are at risk of spoiling and storage facilities, was also highlighted.

Improved management of water quantity and quality: Kenya is a water scarce country with a fast-growing population, 41% of whom rely on unimproved water sources. Water is a key factor affecting fish health and performance in aquaculture production systems. As such, most farmers depend on either the scarce water resources from unpredictable rains, drying rivers and streams, or declining water levels in lakes and reservoirs for aquaculture. Unpredictable rain patterns have a direct effect on water sources, and thus permanent water abstraction and discharge associated with low stocking densities and poor feeding will not be a sustainable climate-resilient approach to food security and safety. Aquaculture in Kenya is concentrated in high rainfall areas, and therefore there is a need for farmers to adopt rain harvesting approaches which will serve during the dry spell. One issue identified was different farmers digging boreholes which has further reduced and affected groundwater availability. This is based on the belief that the extensive water abstraction from groundwater will cause a big drain on already depleting water resources in the country. Some suggestions from participants included corporative or network of fish farmers pooling resources and reducing the need for each farmer to drill a personal/individual borehole.

4.3.2. Aquaculture feeds, waste management and policy

Feed infrastructure not resilient against climate: Feed accounts for between 50 and 60% of aquaculture production costs and contributes over 70% of greenhouse gas emissions in the aquaculture value chain. This could be much higher in Kenya where feeds and ingredients are imported into the country. This also has the potential to introduce invasive species and diseases into the country. Growing feed industry players in Kenya have recently enabled the feed prices to drop by an estimated 50%. However, local feed manufacturers are likely to be faced with the challenge of a lack of availability of ingredients due to climate change, as well as unsupportive agricultural policies, infrastructure, and ingredients production costs which will directly affect the production of major ingredients required in fish feed production. The cotton industry is at its lowest, and soybean and sunflower production have each in the recent past experienced major declines, among other crops critical to aquaculture development. There is a need to review agricultural policies to ensure they are farmer supportive in view of technologies that promote new climate-resilient feeds and/or fish production in Kenya's aquaculture subsector.

Poor aquaculture effluent management: Many aquaculture farmers in Kenya typically discharge effluents from their ponds into the natural environment (i.e., wetlands or rivers and streams). These effluents are enriched with nitrogen, phosphorus, organic matter, and suspended solids because fertilisers and feeds are used to enhance production. This practice has implications not just on the ecosystem, goods, and services, but is also potential source of resource use conflicts especially in downstream communities and operators in the livestock, horticulture, and industrial sectors. The integrated aquaculture approaches such as aquaponics has resulted in both economic and environmental value by converting pollution and waste in one production process to serve as an input in another production process (51).

Policy suggestions/direction: The sustainability of the aquaculture subsector in Kenya is highly dependent on sound climate-resilient infrastructure and policies. This therefore demands a review of existing policies to ensure that they support climate-resilient aquaculture by addressing the issues highlighted earlier. While other agricultural policies are very good, there is a need to further review fisheries and aquaculture policies to promote food and nutrition security, economic growth, and more critically environmental management. Kenya's aquaculture subsector believes that surviving future climate change effects depends on the adoption and adaptation of climate-resilient technologies and innovations across the value chain. There is an urgent need to create climate-resilient aquaculture awareness among the value chain stakeholders, focusing on climate hazard dimensions and their impacts on productivity, economic empowerment, food security, and safety. The future of Kenya's food sufficiency equally lies in the sustainability of the aquaculture subsector. It is important to adequately build the capacity of current and future actors in the sector to manage climate change-related challenges. This requires a critical inventory of the aquaculture value chain, identifying all potential areas of climate impact and develop local expertise that will ensure each issue is resilient to climate change. To achieve this, it is essential to "catch them young," meaning that climate-resilient topics should be embedded early within the school curriculum. If Kenya's aquaculture subsector is to achieve its potential and be resilient to climate change, it must be far more sustainable than its current practice. This means finding ways to boost yield with less land and inputs. The current yield per hectare using an earthen pond is approximately 250kg/0.03 hectares, yet this can be tripled with more climate-resilient and environmentally-friendly technologies and innovations, such as solar-powered aeration and recirculation aquaculture systems. There is the potential for farmers to form networks and groups to come up with water harvesting and storage facilities at cluster levels. This would minimise the endless investment on boreholes drilling and water abstraction from the aquifer. To address issues raised, there is need for the convocation of a group of experts to develop helpful manuals specific to the aquaculture sector and enhance extension services to help operators in the sector.

5. Discussion

This study provides important insights into the perception and understanding of climate impacts and adaptation measures that reflect Kenyan fish farmers. The aquaculture systems in Kenya are highly dependent on the natural environment and so are highly vulnerable to climate change. Kenya is experiencing increasingly harsh climatic conditions, leading to extreme drought (52-54), which was found to be the major climate hazard of concern for the aquaculture sector. Flooding due to increased precipitation, increased evaporative demand, and reduced availability of water also threatens the aquaculture system in Kenya. This is somewhat different from the findings of Asiedu, Adetola (15) in Ghana, which establishes that flooding and storms are the most critical climatic factors, with drought, low rainfall, and high temperature seen as less important. This disparity reflects that while most regions and sectors are exposed to the impacts of climate hazards, the dominant event causing concern may not be the same. However, our study found that the over 40% of fish yield could be lost due to climate change, thereby confirming suggestions about yield losses made by (15, 30, 31).

Climate change-induced extreme events that impact directly and indirectly on the aquaculture in Kenya are expected to continue (55). This underscores the importance of adaptation strategies. Farmers currently do not have many strategies to draw upon to reduce the impact of climatic hazards on their farms. Only a handful of study participants indicated that they used an adaptation procedure, most of which focused on structural strategies and neglect institutional and economic strategies. These structural adaptation practices are regarded as capital intensive, one that farmers are not able to bear alone without the support of the government, and tend to be implemented only after some effects have been witnessed. Studies have pointed at problems connected with too much dependence on structural approaches to climate adaptation (56) which ignores the underlying barriers and limits to climate adaptation. As such, there has been calls for practitioners to be aware of the limitations of structural adaptation measures and give other paths, namely institutional and economic approaches due consideration (57). Generally, the adaptation responses of fish farmers to climate change impacts are scarce (58). As such, adaptation to climate hazards must be improved, with policies that advocate financial support and market opportunities for market-based activities introduced, including the subsidising of aquaculture inputs and machinery. This would present an opportunity for the local design of infrastructure. Therefore, the sector in Kenya more than ever before can be positioned to develop innovative solutions in technological design and policies that will ensure a robust and resilient aquaculture sector.

In the absence of resilient aquaculture practices in Kenya, impacts can be felt at the household, community, and national levels. At the household level, reduced income can affect children's school attendance, and at the national level because of the over 40% lost due to climate. This means potentially more use of foreign exchange for importation of fish. The direct and indirect impacts of climate change on the aquaculture system in Kenya are multifaceted and include impacts on feed, cost of inputs, and effluent management. This presents both a challenge and an opportunity. A challenge in the sense that addressing all issues can be complex and requiring a holistic approach. However, it also presents an opportunity in the sense that there are multiple entry points to make a change.

In addition to the need to focus on fish production, aquaculture feeds, and policy to build a climate-resilient aquaculture system in Kenya, the need for training on climate resilience, the adoption of technology, and management of effluents are priorities. For such training to have maximum impact, it should be sensitive to gender and age. There is also a need to improve on information availability as about 30% of fish farmers do not have information on how they could adapt.

Overall, there are similarities in the views, perceptions, and interests of the various stakeholders, barring the fact that government emphasised the need for farmers to take more responsibility while farmers demanded more support from the government. Such synergy is important for planning purposes and in managing the issues.

6. Conclusion

This study finds that fish farmers in Kenya have some knowledge and experience of climate impacts on their practice. There is a good understanding of the direct and indirect threats posed to fish production by climate change in Kenya, with the problem being responsible for up to 40% of fish production. Despite strong experience and awareness of the need to adapt and be resilient, uptake of adaptation strategies has been low due to financial constraints. The main adaptation method required is to address the challenge of water quality and quantity which is essential to aquaculture in a country that is already water stressed. The lack of financial incentive and training in climate smart technology is a critical barrier to the adoption of climate-resilient aquaculture practices. On the other hand, the seeming awareness and synergy among stakeholders and willingness to work together can be important in building a climate-resilient sector for Kenya. There are opportunities to engage key stakeholders in the sector to facilitate and adopt policy and technological changes effectively. This can be leveraged to provide a strong financial base and develop training with inputs from multiple stakeholders. To effectively achieve this, there is need to build an aquaculture platform that will facilitate the co-designing of fish production, aquaculture feeds, and policy.

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CRediT authorship contribution statement

Olalekan Adekola: Conceptualization, Methodology, Formal analysis, Writing - Original Draft, Writing - Review & Editing, Supervision. **Margaret Gatonye**: Conceptualisation, Writing - Original Draft. **Paul Orina**: Writing - Original Draft, Writing - Review & Editing.

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