Economic Impact of Climate Variability Cycles on Aquaculture Development in the Upper East Region of Ghana

GEORGE FRIMPONG ENCHILL[1], FRANCIS AFORVE[2], BUAH ANTOINETTE[3]
[1]*Department of Environmental Management, University of Energy and Natural Resources- Sunyani, Ghana.*
[2]*Department of Basic and Applied Sciences, Centre for Climate Change and Sustainability Studies, University of Ghana, Legon.*
[3]*Department of Environmental Science, Hungarian University of Agriculture and Life Science- Godollo, Hungary*

Abstract- ***This study examines the economic implications of recurring climate variability cycles on aquaculture development in Ghana's Upper East Region, a semi-arid area characterized by erratic rainfall patterns and increasing climate variability. The study was conducted in the Kasena Nankana municipal area in the Upper East region of Ghana. within which the catchment of the Tono irrigation project is located, covering an estimated land mass of 1,674 square kilometres. 80 percent of the land. The research employed a descriptive and statistical approach in analysing both the secondary and primary data. Questionnaire, interview, and observation were used to assess the effect of climate variability on fishers and fishermen, where MS Excel and Statistical Package for Social Sciences (SPSS). 150 populations were sampled within the Kasena Nankana municipal in which 80 fishermen and 70 food vendors (fish mongers, kenkey sellers, rice sellers and fried yam seller) were used respectively. The research reveals that fishermen face a complex web of interconnected problems, with climate conditions (42.5% of respondents) and financial constraints (41.3% of respondents) being the most significant issues. These problems reinforce each other - climate variability reduces fish catches, which in turn limits income and the ability to invest in better equipment. The interconnected nature of these problems suggests that effective interventions must address multiple issues simultaneously climate adaptation strategies, financial support mechanisms, and equipment modernization programs would likely be more effective than addressing any single challenge in isolation.***

Indexed-Terms: ***Aquaculture, Climate Adaptation, Fishermen activities, Economic Impact, Food Security***

I. INTRODUCTION

Ghana's Upper East Region represents one of the country's most climate-vulnerable areas, experiencing recurrent drought cycles that significantly impact agricultural productivity and rural livelihoods (Akudugu, Dittoh, & Mahama, 2012). As traditional rain-fed agriculture faces increasing uncertainties due to climate variability, aquaculture has emerged as a potential alternative livelihood strategy that could provide both food security and income generation opportunities for rural communities (Dankwa et al., 2004). However, the extent to which drought cycles affect aquaculture development and the economic implications of these impacts remain poorly understood. Climate change projections indicate an intensification of drought frequency and severity in the West African Sahel, including northern Ghana, with potential temperature increases of 2-4°C and rainfall reductions of 10-20% by 2050 (IPCC, 2021). These climatic shifts pose substantial challenges to water-dependent sectors like aquaculture, necessitating a comprehensive understanding of economic impacts and adaptive responses.

The development of aquaculture in the Upper East Region has gained momentum since the early 2000s, supported by government initiatives and international development programs aimed at enhancing food security and rural livelihoods (Ministry of Fisheries and Aquaculture Development, 2021). However, the sector's growth trajectory has been significantly impacted by recurring drought episodes that affect water availability, pond management, and overall production systems (Nunoo et al., 2020).

The Upper East Region, spanning approximately 8,842 square kilometers in northern Ghana, is characterized by a Guinea savanna ecosystem with a single rainy season that lasts from May to October (Ghana Statistical Service, 2013). The region

experiences high temperature variations and irregular rainfall patterns, with annual precipitation ranging from 900mm to 1,100mm (Limantol et al., 2016). These climatic conditions, combined with high poverty rates and dependence on subsistence agriculture, make the region particularly vulnerable to climate-related shocks. Aquaculture in Ghana has grown steadily over the past two decades, with production increasing from 3,800 tons in 2000 to approximately 55,000 tons in 2020 (Food and Agriculture Organization, 2022).

However, this growth has been concentrated primarily in the southern and middle belt regions, with northern regions like the Upper East contributing minimally to national production. Understanding the barriers to aquaculture development in northern Ghana, particularly the role of drought cycles, is crucial for informing policy decisions and investment strategies. Despite the potential of aquaculture to contribute to food security and economic development in the Upper East Region, the sector remains underdeveloped. Preliminary observations suggest that recurrent drought cycles significantly constrain aquaculture development by affecting water availability, increasing production costs, and limiting market access. However, a comprehensive economic analysis of these impacts is lacking, hindering the development of appropriate adaptation strategies and policy interventions.

Aquaculture in sub-Saharan Africa has experienced rapid growth over the past decade, with production increasing by over 300% between 2010 and 2020 (WorldFish, 2021). This growth has been driven by increasing demand for fish protein, declining capture fisheries, and government policies promoting aquaculture development. However, growth has been uneven across regions, with significant variations in production systems, species cultured, and market access. In Ghana specifically, aquaculture development has been supported by various government initiatives, including the Ghana Aquaculture Development Action Plan and the Fisheries Development Plan (Anane-Taabeah et al., 2016). These policies have focused on promoting tilapia and catfish culture, improving seed supply, and enhancing technical capacity. However, implementation has been challenging, particularly in northern regions where infrastructure, technical knowledge, and access to inputs remain limited.

II. LITERATURE REVIEW

Ghana's aquaculture sector has experienced rapid growth since the 1990s, driven by increasing domestic demand for fish, declining marine catches, and supportive government policies (Bostock et al., 2010). The sector contributes approximately 4% to national fish production and employs over 50,000 people across the value chain (FAO, 2020). Major species cultured include tilapia (Oreochromis niloticus), catfish (Clarias gariepinus), and increasingly, indigenous species adapted to local conditions (Asmah et al., 2019).

In northern Ghana, aquaculture development has been promoted as a climate adaptation strategy and livelihood diversification option for communities facing agricultural challenges (Cobbinah et al., 2013). The government's Aquaculture for Food and Jobs program, launched in 2018, specifically targets northern regions for pond construction, farmer training, and input support (Ministry of Fisheries and Aquaculture Development, 2019).

However, aquaculture growth in northern Ghana faces several constraints, including limited water availability, inadequate technical knowledge, poor market linkages, and climate-related risks (Nunoo & Asiedu, 2013). These challenges are particularly acute in the Upper East Region, where traditional extensive systems dominate and productivity remains below potential (Asmah, 2019).

Drought affects aquaculture through multiple pathways, including direct impacts on water availability and quality, and indirect effects on feed supply, market access, and farmer capacity (Kumar et al., 2018). In pond-based systems common in Ghana, drought reduces water levels, concentrates pollutants, elevates temperatures, and depletes dissolved oxygen, leading to fish stress, disease outbreaks, and mortality (Naylor et al., 2021).

International studies demonstrate significant economic losses from drought-induced aquaculture disruptions. In Australia, the Millennium Drought (1997-2009) reduced freshwater aquaculture production by 30% with estimated losses exceeding AUD 200 million (Productivity Commission, 2016). Similarly, drought episodes in Southeast Asia have caused production declines of 20-50% in affected

regions, with disproportionate impacts on smallholder farmers (Belton et al., 2018).

West Africa faces significant challenges from climate change, with increasing temperatures, changing precipitation patterns, and more frequent extreme weather events (Sultan & Gaetani, 2016). The Sahel region, which includes northern Ghana, is particularly vulnerable to these changes, with studies projecting increased drought frequency and intensity (Sylla et al., 2016). These climatic changes have profound implications for agricultural systems, food security, and rural livelihoods. Drought in West Africa is not merely a meteorological phenomenon but a complex interaction of climatic, hydrological, agricultural, and socioeconomic factors (Naumann et al., 2014). The region experiences multi-year drought cycles that can persist for several seasons, causing severe economic and social disruptions. Historical analysis shows that major droughts in the 1970s, 1980s, and early 2000s led to significant agricultural losses and rural-urban migration (Nicholson, 2013).

The economic analysis of climate impacts on aquaculture requires consideration of multiple pathways through which climate variables affect production systems. Temperature changes affect fish growth rates, feed conversion efficiency, and disease susceptibility (Handisyde et al., 2017). Water availability influences pond management, stocking densities, and production cycles. Extreme weather events can cause direct losses through fish kills, infrastructure damage, and market disruption. Previous studies have used various methodological approaches to assess climate-aquaculture interactions. Simulation models have been employed to project future production under different climate scenarios (Barange et al., 2018). Econometric analyses have examined historical relationships between climate variables and aquaculture productivity (Froehlich et al., 2018). Case study approaches have provided detailed insights into farmer adaptation strategies and policy responses (Oyinbo et al., 2020).

Drought affects aquaculture through multiple pathways. Direct impacts include reduced water availability for pond filling and water exchange, concentrated pollutants due to reduced dilution, and increased water temperatures that stress fish populations (Daw et al., 2009). Indirect impacts include increased feed costs due to agricultural drought, reduced market access due to infrastructure limitations, and competing demands for scarce water resources.

The severity of drought impacts depends on the type of aquaculture system, species cultured, and adaptive capacity of producers. Extensive pond systems that rely on rainfall and seasonal flooding are more vulnerable than intensive recirculating systems. Indigenous species with higher temperature tolerance may be more resilient than exotic species. Farmers with access to alternative water sources, financial resources, and technical knowledge are better positioned to adapt to drought conditions.

III. METHODOLOGY

Study Area and Description

This research was carried out in the Kasena Nankana municipal area, situated in Ghana's Upper East region, where the Tono irrigation project's watershed is found. The area encompasses approximately 1,674 square kilometers, with 80 percent consisting of cultivable land and the remaining 20 percent comprising forests, waterways, elevated terrain, and degraded landscapes. Fish farming in the Upper East Region operates predominantly at a small scale, featuring earthen pond systems that measure between 200-2,000 m² in area. This industry provides livelihoods for roughly 3,500 farmers distributed across 180 communities, with cultivation primarily centered on Nile tilapia and African catfish species intended for domestic markets (Regional Directorate of Fisheries, 2022).

Climate and Vegetation

The Kasena Nankana Municipality experiences distinct dry and rainy seasons, shaped primarily by two air masses: the North-East Trade winds and the South-Westerly (Tropical Maritime) systems (Aquastat, 2005). The harmattan winds (North-East Trade Winds) bring dry, dust-laden conditions as they originate from the Sahara Desert (Gordon 2009). These periods feature minimal precipitation due to low humidity levels that seldom surpass 20 percent, combined with vapor pressure below 10mb. Daytime temperatures reach extreme highs of 42° Celsius (particularly during February and March), while nighttime temperatures may drop to 18° Celsius (IPCC 2007). From May through October, the Municipality is influenced by tropical maritime air masses. Annual precipitation averages 950mm (IPCC

2007). The study region's vegetation falls under the Guinea Savannah Woodland classification. This ecosystem features scattered short deciduous trees with sparse distribution and ground-level vegetation comprising various shrub species of different heights. Notable exceptions include the Red Volta Forest Reserve, which provides habitat for wildlife. Additionally, the Kasena Nankana Municipal area contains several forest reserves including the Sissile and Asibelika watersheds, as well as the Kolgo and Naga Forest Reserves (KNMA, 2010).

Research Design & Sample Population

The study utilized a mixed-methods research design that integrated quantitative analysis of climate and economic data with qualitative evaluation of stakeholder perspectives and adaptive strategies. Population sampling involves selecting a representative subset from the entire population, typically employed when testing every individual is impractical and to optimize time and resources during research execution. The study sampled approximately 150 participants from the Kasena Nankana municipality, comprising 80 fishermen and 70 food vendors (including fish traders, kenkey vendors, rice sellers, and fried yam vendors).

Data Collection Tools

The research employed three primary data collection methods: questionnaires, interviews, and observational techniques. The study targeted fishermen, fish traders, kenkey vendors, fish processors, and fisheries commission officials as key respondents.

Questionnaire Method: This served as a primary tool for collecting original data, utilizing both structured and unstructured questionnaire formats. Data collection occurred across selected communities including Navrongo central (Tono dam), Pungu, Maayoro, Wuru, Vunania, Kologo, and Navrongo east (Kasanongo) within the Kasena Nankana municipality. The research focused on 80 fishermen and 70 food vendors, including fish importers/exporters, kenkey sellers, fish mongers, rice vendors, fried yam sellers, and other fish-related business operators. A total of 150 questionnaires, each containing 18 straightforward questions, were distributed and completed.

Interview and Observation Method: The study implemented unstructured interviews to gather respondent perspectives, with all interviews recorded verbatim for subsequent analysis. Field observations documented fishermen's work practices and responsibilities within their operational areas. During interviews, additional spontaneous questions emerged to provide deeper insights into specific topics that arose during discussions. Key informants included the chief fisherman of the municipality, with a snowball sampling technique used to identify additional stakeholders for interviews. The approach incorporated structured, unstructured, and semi-structured interview formats, with a predominant use of unstructured interviews to facilitate the spontaneous exploration of specific topics in greater depth. Participant observation was also employed, where the researcher's role was transparent to participants in the study area.

Data Analysis Methods

The study utilized descriptive and statistical analytical techniques to examine both secondary and primary data sources. Primary data collection involved questionnaires, interviews, and observational methods to evaluate how climate variability impacts fishing communities and individual fishers. The quantitative data from questionnaires was processed using Microsoft Excel and the Statistical Package for Social Sciences (SPSS). Through SPSS, the researchers calculated descriptive statistics including frequency distributions and percentage analyses. For the qualitative information, descriptive statistical methods were applied to systematically organize and interpret the data, with results presented through tabular formats and graphical representations when appropriate.

IV. RESULTS AND DISCUSSION

Temperature Range impacts on Fish catch

This study examined how temperature conditions and seasonal timing affect fishing success based on fishermen's experiences and observations. The research gathered opinions from local fishermen about optimal environmental conditions for fish catches. The findings revealed divided opinions on ideal temperature conditions. The largest group (40%) favoured moderate temperatures, believing that neither extremely hot nor cold conditions provide the best fishing environment. Meanwhile, opinions were split between those preferring warmer conditions (28.7%) and cooler conditions (31.3%).

Regarding optimal fishing months, fishermen showed strong preferences for specific time periods. Nearly half (45%) identified April through June as the most productive fishing season. About one-third (33.7%) preferred July through September, while smaller groups favored January-March (11.3%) and October-December (10%). Fishermen noted that different months bring varying environmental challenges, including intense heat periods and heavy rainfall seasons, which influence their fishing strategies and preparation.

The preference for moderate temperatures by the plurality suggests that extreme weather conditions may negatively impact fish behavior or fishing operations. This could relate to fish metabolism, feeding patterns, or practical fishing conditions. The strong preference for April-September (78.7% combined) indicates these months likely offer optimal conditions - possibly related to fish breeding cycles, water temperature stability, or favorable weather for fishing operations. The research highlights that experienced fishermen use environmental patterns to plan their activities, suggesting that traditional ecological knowledge plays a crucial role in fishing success. The acknowledgment of different monthly challenges (heat vs. rainfall) demonstrates fishermen's awareness of complex environmental factors affecting their livelihood. This data could inform fishing community planning, seasonal fishing regulations, and climate adaptation strategies for local fisheries. The split opinions on temperature preferences might also reflect different fishing methods, target species, or local microclimate variations.

Table 1 Fishermen perception on month range and temperature

Month Range	Frequency	Percentage
January- March	9	11.3
April- June	36	45.0
July –September	27	33.7
October- December	8	10.0
Total	80	100
Temperature type		
Lower temperature	25	31.3
Medium temperature	32	40
Higher temperature	23	28.7
Total	80	100

Source: Field survey May 2024

Fishing Industry Challenges

Fishermen in the Kasena Nankana municipality face multiple interconnected challenges that significantly impact their livelihoods. The survey revealed three primary concerns affecting their fishing operations.

Financial constraints emerged as a major obstacle, with 41.3% of respondents (33 fishermen) identifying lack of funding as their primary challenge. Many struggle to afford essential fishing equipment and tools, which directly limits their fishing capacity and ability to support their families adequately. Climate-related issues were cited by the largest group of respondents, with 42.5% (34 fishermen) expressing serious concerns about changing climatic conditions. Irregular rainfall patterns and temperature fluctuations significantly reduce fish populations and catch rates, creating uncertainty in their income and food security.

Equipment inadequacy affected 16.2% of respondents (13 fishermen), who reported using outdated or insufficient fishing tools. Many rely on basic hook-and-line methods, while others struggle with malfunctioning equipment like broken canoes, limiting their fishing effectiveness. The study found that virtually all fishermen experienced at least one of these challenges, indicating widespread difficulties across the fishing community. These interconnected problems create a cycle where financial limitations prevent equipment upgrades, inadequate tools reduce catch efficiency, and climate impacts further diminish already limited returns, ultimately threatening the sustainability of fishing

livelihoods in the region. According to an interview with one fisherman at Tono dam this is what he said:

Box 1 Fishermen Challenges: The Voice of a fisherman

I don't get enough money from fishing nowadays. I am a family man with five children, fish catch has reduced off late if you compare this time to the previous years, I don't get enough money from fishing anymore to take care of my family, I don't know why. Fish catch has reduced. All our equipment and tools for fishing are outmoded. We are pleading with the government and various NGOs to come to our aid.

Source: Field Survey, May 2024

Fishermen Earning.

Some fishermen outlined what they usually earn per day and some of them were not sure of what they earn a month 's whiles others were unwilling to give this information from this research conducted it was realized that most of them do not usually earn much money from it, the amount earned ranged from 5 to over 200 Ghana cedis a day depending on the climatic condition.

Table 2 Fishermen Earning Per day.

Earning per day	Frequency	Percent
10 Ghana cedis	36	45.0
5 Ghana cedis	23	29
15 Ghana cedis	13	16
200 Ghana cedis and above	8	10
Total	80	100.0

Source: Field survey May 2024

Perceptions on Fishing Activities by Food Vendors

Most of the vendors were complaining that they do not get enough fish to buy when the (whether) condition change. 32 women, representing 45.7% said they do not get enough fish to buy from the fishermen, 35.7% said they get fish to buy, and also 13 women representing 18.6% were complaining bitterly that for the past two months they do not get fish to buy. Most of the fishermen and fish mongers and other vendors depend on Tono dam for fish.

According to most vendors especially kenkey sellers and fish mongers, they usually buy different kind of fish because most customers usually have different taste and prefer either tilapia, salmon, red fish etc. Most of the kenkey sellers in Bongo and Kasena Nankana municipals usually use tilapia whiles most fishmonger 's uses salmon. 35 women representing 50% from the survey uses tilapia whiles 14 women representing 20% depended on salmon, 10% uses red fish whiles 20% usually sells other fishes. Nevertheless, from the vendors most customers also have their own preference about 48.6% customers prefers to buy tilapia, in upper east region especially Navrongo is regarded as a safe haven for tilapia. 25.7% customers also buy salmon, 14.3% opted for red fish whiles 11.4% customers like to buy other fishes.

Table 3 Vendors perception on type of fish and how often they buy

Activity	Frequency	Percentage
Do you often get fish to buy		
Often	25	35.7
Not often	32	45.7
Not at all	13	18.6
The kind of fish vendors buy		
Tilapia	35	50.0
Salmon	14	20.0
Red fish	7	10.0
Others	14	20.0
Total	70	100

Source: Field survey May 2015

Food Vendors' Views on Seasonal Fish Availability and Pricing Trends

When vendors were asked about the months when fish is most readily available for purchase, responses varied across seasonal periods. Nearly half of the women surveyed (33 respondents, 47.1%) identified April through June as the peak availability period. They attributed this to increased rainfall during these months, which raises dam water levels and creates better conditions for fishing. Another significant group (27 women, 38.6%) selected July to September, citing similar rainfall-related benefits for fish availability. A smaller portion chose January to March (6 women, 8.6%) and October to December (5.7%), with the latter group explaining that higher temperatures during this period actually enhance fishing conditions. Regarding fish pricing trends, vendors expressed strong concerns about rising costs. The vast majority (57 women, 81.4%) confirmed that fish prices are increasing and spoke with notable concern about this trend. Only 13 women (18.6%) disagreed, explaining that prices tend to decrease during periods of heavy rainfall when fish supply is abundant. However, these vendors noted that adequate rainfall has become inconsistent, affecting this natural price regulation mechanism.

Relationship between maximum Temperature and fish catch

Table 4 Correlation for the relationship between maximum temperature and fish catch.

		Fish	Maximum Temperature
Pearson Correlation	Fish	1.000	-0.655
	Temp	-0.655	1.000
Sig. (1-tailed)	Fish		0 .000
	Temp	0 .000	.
N	Fish	76	76
	Temp	76	76

Pearson correlation (General rule:$|r| < 0.50 = weak$, $|r| > 0.50 = strong$, $sig(a < 0.05)$. In the table above, it indicates that, the correlation (-0.655) between maximum temperature and fish is strong which indicate that both parameters depend on each other. (-0.655) shows that it is inversely proportional; whiles the significance level (1.000) also depicts there is strong relationship between the variables indicating that the variables are compactible.

The equation for the linear regression is in the form $Y = \alpha + \beta X$, where α is the intercept and β, the regression coefficient, and X is the independent variable (maximum annual temperature), and Y is the dependent variable (annual quantity of fish catch). The slope of the line shows that an increase in the average maximum annual temperature will decrease the annual quantity of fish catch Thus, there is a slight negative relationship between maximum temperature and the fish catch produced. This is in agreement with (Kwajosse, 2009). When temperature is high fish metabolism accelerates feeding and respiration

increases It also affect the productivity of the fish, most fish become weak and die and with this it makes fish catch very difficult for fishermen.

CONCLUSION

The research reveals that fishermen face a complex web of interconnected problems, with climate conditions (42.5% of respondents) and financial constraints (41.3% of respondents) being the most significant issues. These problems reinforce each other thus climate variability reduces fish catches, which in turn limits income and the ability to invest in better equipment.

The interconnected nature of these problems suggests that effective interventions must address multiple issues simultaneously climate adaptation strategies, financial support mechanisms, and equipment modernization programs would likely be more effective than addressing any single challenge in isolation.

The fishing community shows divided opinions on optimal temperature conditions, with no clear consensus. Medium temperatures (40%) have a slight edge over lower temperatures (31.3%) and higher temperatures (28.7%). This suggests that moderate thermal conditions may provide the most consistent fishing opportunities, though significant portions of fishermen find success in both cooler and warmer waters. There's a strong preference for the April-June period (45%), followed by July-September (33.7%). Together, these two periods (April-September) account for nearly 79% of fishermen preferred fishing months. This indicates that the warmer half of the year, likely corresponding to spring and summer months, provides the most favorable fishing conditions.

It was revealed that maximum temperature significantly influences fish catch quantities, with higher temperatures leading to reduced catches. This relationship is statistically robust and practically meaningful for fisheries management.

The negative correlation aligns with established biological principles. Elevated temperatures accelerate fish metabolism, increasing energy demands for feeding and respiration while simultaneously stressing fish populations, leading to increased mortality and reduced catchability.

RECOMMENDATION

1. The Ministry of Fisheries and Aquaculture, in collaboration with the district and municipal assembly, should help to organize workshops to train and educate fishermen on climate variability, since most of the fishermen do not have enough knowledge of climate change.
2. There should be an encouragement of afforestation around water bodies and dams in Kasena Nankana Municipal. If more trees are planted, it will help provide shade and avoid direct contact with the sun's rays on dams and river bodies, which will reduce high temperatures and can improve fish catch.
3. Various non-governmental organizations (NGO) and the government should help fishermen in this region with enough fishing equipment and tools since most of their equipment is worn out and outmoded, which usually affects fishing.

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