

Assessing the Role of Climate Variability and its Perceptions on Aquaculture growth among stakeholders in Ghana

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ABSTRACT

This research assesses the role of climate variability in aquaculture development and its growth among stakeholders in Ghana's Upper East Region, a dry zone marked by unpredictable precipitation and growing climate instability. Conducted within the Kasena Nankana Municipal Area, the study focused on the Tono irrigation project's catchment area, which spans approximately 1,674 square kilometres, with 80 percent of the area being terrestrial. The investigation utilized descriptive and statistical methods to analyse both secondary and primary datasets. Data collection involved questionnaires, interviews, and direct observation to evaluate how climate fluctuations impact those engaged in fishing activities, with analysis performed using MS Excel and SPSS software. The sample consisted of 150 participants from the Kasena Nankana municipality, comprising 80 fishing practitioners and 70 food vendors (including fish traders, kenkey vendors, rice sellers, and fried yam vendors). Findings indicate that fishing practitioners encounter multiple interrelated challenges, with climatic conditions (identified by 42.5% of participants) and economic limitations (noted by 41.3% of participants) representing the primary concerns. These challenges are mutually reinforcing - variable climate patterns decrease fish yields, subsequently diminishing earnings and restricting capacity for equipment upgrades. The interconnected character of these challenges indicates that successful interventions require comprehensive approaches addressing multiple dimensions concurrently. Combining climate adaptation measures, economic assistance programs, and equipment modernization initiatives would prove more beneficial than tackling individual challenges separately.

Keywords: Aquaculture Growth, Climate Adaptation, Climate Variability, Drought, Fishermen Activities, Food Security.

INTRODUCTION

Ghana is recognized as one of the most susceptible areas to climate-related challenges, facing repeated drought patterns that substantially affect farming output and the economic well-being of rural populations (Akudugu, Dittoh, & Mahama, 2012). With conventional rain-dependent farming becoming increasingly unpredictable due to changing climate patterns, fish farming has been identified as a viable alternative means of livelihood that could enhance both nutritional security and income-earning potential for communities in rural areas (Dankwa et

al., 2004). Nevertheless, there remains a limited understanding regarding how drought patterns influence the growth of aquaculture and the financial consequences of these effects.

Forecasts related to climate change suggest that droughts will become more frequent and intense across the West African Sahel region, encompassing northern Ghana, with anticipated temperature rises of 2-4°C and precipitation declines of 10-20% by the year 2050 (IPCC, 2021). These environmental transformations create considerable obstacles for water-reliant industries such as fish farming, highlighting the need for thorough examination of economic ramifications and adaptation strategies.

Fish farming expansion has accelerated from the early 2000s onward, bolstered by governmental programs and international development initiatives focused on improving nutritional security and rural economic conditions (Ministry of Fisheries and Aquaculture Development, 2021). Despite this progress, the industry's development path has experienced substantial disruption from ongoing drought events that influence water access, pond maintenance, and comprehensive production operations (Nunoo et al., 2020). 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.

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).

Climate change adaptation through aquaculture has gained attention in northern Ghana as a way to support communities experiencing farming difficulties and to provide alternative income sources (Cobbinah et al., 2013). In 2018, the government introduced the Aquaculture for Food and Jobs initiative, which focuses on northern areas by providing pond infrastructure, training opportunities for farmers, and necessary production inputs (Ministry of Fisheries and Aquaculture Development, 2019). Despite these efforts, aquaculture expansion in northern Ghana encounters numerous obstacles, such as water scarcity, insufficient technical expertise, weak market connections, and climate vulnerability (Nunoo & Asiedu, 2013). The Upper East Region experiences

these difficulties particularly intensely, where basic production methods prevail and output falls short of achievable levels (Asmah, 2019).

Water scarcity impacts aquaculture operations through both direct and indirect mechanisms, affecting water resources and quality while also influencing feed availability, market accessibility, and farmer capabilities (Kumar et al., 2018). For pond-based fish farming typical in Ghana, insufficient rainfall decreases water volumes, increases pollutant concentrations, raises water temperatures, and reduces oxygen levels, resulting in fish stress, disease prevalence, and death (Naylor et al., 2021).

Global evidence reveals substantial financial damages from drought-related aquaculture interruptions. During Australia's Millennium Drought spanning 1997 to 2009, freshwater fish production dropped by 30 percent, with financial damages surpassing AUD 200 million (Productivity Commission, 2016). In Southeast Asia, drought periods have similarly caused production reductions ranging from 20 to 50 percent in impacted areas, with small-scale farmers bearing the greatest burden (Belton et al., 2018).

West Africa confronts considerable climate change pressures, including rising temperatures, altered rainfall distributions, and increased extreme weather frequency (Sultan & Gaetani, 2016). The Sahel zone, encompassing northern Ghana, shows heightened susceptibility to these shifts, with research indicating more frequent and severe dry periods ahead (Sylla et al., 2016). These environmental transformations carry serious consequences for farming systems, food availability, and rural livelihoods.

In West Africa, water scarcity represents more than just weather patterns; it involves interconnected climatic, water-related, agricultural, and socioeconomic elements (Naumann et al., 2014). The area experiences extended dry periods lasting multiple seasons that generate severe economic and social challenges. Historical records indicate that major dry periods during the 1970s, 1980s, and early 2000s resulted in substantial crop losses and population movement from rural to urban areas (Nicholson, 2013).

Evaluating climate effects on fish farming economically demands examination of various mechanisms through which environmental factors influence production operations. Temperature variations impact fish development rates, feed utilization efficiency, and disease resistance (Handisyde et al., 2017). Water supply affects pond operations, fish population density decisions, and production timing. Severe weather can generate immediate losses through fish deaths, facility damage, and market interruptions. Earlier research has applied diverse analytical methods to examine climate-aquaculture relationships. Computer modelling has been used to forecast future production under alternative climate conditions (Barange et al., 2018). Statistical economic analyses have investigated past connections between environmental variables and fish farming output (Froehlich et al., 2018). Detailed case examinations have offered a comprehensive understanding of how farmers adjust their practices and how policies respond to challenges (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 the 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.

MATERIALS AND METHODS

Study Area

The study was conducted in the Kasena Nankana municipal area, located in Ghana's Upper East region, which contains the watershed of the Tono irrigation project. This region covers roughly 1,674 square kilometres, where 80 percent of the land is suitable for cultivation, while the other 20 percent includes forests, water bodies, high-

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 and Analysis

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.

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 were 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.

RESULTS AND DISCUSSION

Temperature Range Impacts on Fish Production

This research investigated the relationship between environmental conditions, specifically temperature and seasonal patterns, and fishing productivity through the perspectives of experienced fishermen. The study collected local fishermen's views regarding the most favourable conditions for successful catches. Results showed fishermen held varying perspectives on temperature preferences. The plurality (40%) advocated for temperate conditions, arguing that extremes in either direction were suboptimal for fishing. The remaining respondents were nearly evenly divided between those who preferred warmer waters (28.7%) and those favouring cooler conditions (31.3%).

Seasonal preferences demonstrated clearer patterns. The spring-to-early-summer period of April-June emerged as the top choice, selected by nearly half the participants (45%). The summer-to-early-fall months of July-

September were the second most popular choice at 33.7%. The winter and late fall periods received notably less support, with January-March at 11.3% and October-December at just 10%. Fishermen recognised that each season presents distinct environmental obstacles, from extreme heat to heavy precipitation, requiring adapted approaches and equipment.

The widespread preference for moderate temperatures indicates that weather extremes may disrupt fish activity or complicate fishing logistics. This could stem from effects on fish physiology, food-seeking behaviour, or practical operational constraints. The overwhelming preference for the April-September window (totalling 78.7%) suggests these months provide ideal circumstances, potentially linked to reproductive cycles, consistent water temperatures, or more manageable weather for conducting operations. The findings underscore how seasoned fishermen rely on environmental patterns for strategic planning, emphasising the value of traditional ecological expertise in achieving successful outcomes. Recognition of season-specific challenges, whether heat or precipitation, reveals fishermen's sophisticated understanding of the multiple environmental variables that impact their profession. These insights could support fishing community resource management, guide seasonal regulatory frameworks, and inform climate resilience strategies for local fishing industries. The divergent temperature preferences may reflect variations in fishing techniques, targeted fish species, or localised climatic conditions across different areas.

Table 1: Fishermen's perception of the month range and temperature ranges

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

Challenges in Aquaculture Industries by fish farmers

Fishing communities in the Kasena Nankana municipality confront several interrelated difficulties that substantially threaten their economic well-being. Research identified three main issues affecting their fishing activities. Economic limitations represented a significant barrier, with 41.3% of participants (33 fishermen) pointing to insufficient capital as their chief concern. Many cannot purchase necessary fishing gear and implements, which directly restricts their fishing productivity and their capacity to provide adequately for their households.

Weather-related challenges were reported by the highest proportion of participants, with 42.5% (34 fishermen) voicing substantial worries about shifting weather patterns. Unpredictable precipitation and temperature variations considerably decrease fish stocks and harvest yields, generating instability in their earnings and nutritional security. Inadequate equipment troubled 16.2% of participants (13 fishermen), who described working with obsolete or substandard fishing implements. Many depend on simple hook-and-line techniques, while others contend with defective equipment, such as damaged boats, constraining their fishing productivity. The research determined that nearly every fisherman encountered at least one of these difficulties, suggesting pervasive hardships throughout the fishing population.

These linked challenges generate a recurring pattern where economic constraints hinder equipment improvements, poor tools diminish harvest efficiency, and weather effects further reduce already meagre yields, consequently endangering the long-term viability of fishing as a livelihood in the area. According to an interview with one fisherman at Tono dam, this is what he said: *I don't get enough money from fishing nowadays. I am a family man with five children; fish catch has reduced of 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.*

Perceptions on Fishing Activities by Food Vendors

The research reveals significant supply chain vulnerabilities affecting fish vendors in the region. Nearly half of the women vendors surveyed (45.7%, n=32) reported inadequate fish supplies from fishermen, particularly during periods of changing weather conditions. While just over one-third (35.7%) indicated they could obtain sufficient stock, a concerning portion (18.6%, n=13) experienced severe shortages, reporting a complete inability to purchase fish over the preceding two-month period. This supply instability appears closely tied to the Tono Dam, which serves as the primary fish source for the local fishing economy, affecting fishermen, fishmongers, and associated vendors alike. The heavy reliance on a single water body makes the fishing industry highly vulnerable to environmental fluctuations. Weather changes can affect water levels, fish breeding patterns, and fishing conditions, creating cascading effects throughout the supply chain. The two-month shortage reported by some vendors suggests potential seasonal variations or environmental stresses that could threaten livelihoods and food security in the region.

Vendor purchasing patterns reflect diverse customer preferences across the region. Half of the surveyed vendors (50%, n=35) primarily stock tilapia, making it the dominant fish type in local markets. Salmon accounts for one-fifth of vendor inventories (20%, n=14), while red fish and other varieties each represent 10% and 20%, respectively. This distribution varies by vendor type: kenkey sellers in Bongo and Kasena Nankana municipalities show a strong preference for tilapia, while fish mongers tend to favour salmon for their operations. Consumer preferences largely mirror these supply patterns, with tilapia emerging as the clear favorite among 48.6% of customers a preference particularly pronounced in Navrongo, where tilapia has established itself as the trusted, go to fish variety. Salmon attracts approximately one-quarter of customers (25.7%), followed by red fish (14.3%) and other fish varieties (11.4%). The strong preference for tilapia in the Upper East Region, especially in Navrongo, likely reflects factors such as affordability, cultural familiarity, availability, and taste preferences developed over time. The characterization of Navrongo as a "haven for tilapia" suggests both a reliable supply and established consumer trust in this fish type. The diversity in fish preferences indicates market segmentation opportunities, though vendors must balance inventory diversity against the risk of spoilage and the challenges of inconsistent supply from their primary source.

Table 2: 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
Total	70	100
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

Food Vendors' Views on Seasonal Fish Availability

When food vendors were questioned about optimal fish purchasing periods, their responses reflected distinct seasonal patterns. Just under half the vendors (47.1%, n=33) reported April-June as the prime availability window, linking this to rainfall increases that elevate dam water levels and improve fishing conditions. Over one-third (38.6%, n=27) favoured July-September, citing comparable rainfall advantages. Smaller groups selected January-March (8.6%, n=6) and October-December (5.7%, n=4), with the latter connecting higher temperatures to enhanced fishing productivity. On pricing dynamics, vendors demonstrated significant apprehension about cost escalation. An overwhelming majority (81.4%, n=57) confirmed upward price trajectories and voiced considerable worry about this pattern. A minority (18.6%, n=13) observed opposite trends, noting that prices decline when heavy rainfall boosts fish supply.

However, these vendors emphasized that reliable rainfall has become increasingly sporadic, undermining this traditional price stabilization mechanism.

The concentration of responses around April-September (85.7% combined) suggests a shared understanding among vendors that mid-year months offer superior fish availability, predominantly tied to rainfall patterns and their hydrological effects on fishing grounds. Vendors demonstrate acute awareness of the rainfall-fishing productivity relationship, recognizing both direct effects (water levels) and indirect consequences (fishing success rates).

The minority mentioning temperature effects indicates some regional or species-specific variation in environmental influences. The pronounced concern among 81.4% of vendors about rising prices suggests this isn't merely an observation but a significant business stressor, potentially affecting their profit margins, purchasing power, and customer relationships. The acknowledgment that rainfall has become "inconsistent"

points to vendors experiencing broader climate disruption, which undermines the traditional seasonal predictability they've historically relied upon for business planning.

The combination of rising prices and inconsistent supply creates double pressure on vendors, as they face higher procurement costs while losing the reliability of seasonal price fluctuations that previously allowed for strategic purchasing.

This squeeze likely reduces profit margins and increases business risk. The vendors' observations about inconsistent rainfall align with documented climate change effects in many regions. Their lived experience provides ground level evidence of how environmental shifts translate into economic consequences for informal sector workers. That 81.4% report rising prices despite seasonal availability suggests vendors have limited bargaining power; they're price-takers rather than price-setters. This vulnerability is compounded when environmental unpredictability disrupts their ability to anticipate and plan for supply fluctuations. As women vendors in what appears to be an informal economy context, these respondents represent a particularly vulnerable economic group. Their detailed environmental knowledge demonstrates expertise, yet their concern about pricing suggests this knowledge alone cannot buffer them against larger market and environmental forces. While vendors clearly understand the environmental drivers of fish availability, their expressed worry indicates limited capacity to adapt to changing conditions. They recognize problems, but may lack resources or alternatives to mitigate impacts on their livelihoods. The findings suggest that supporting these vendors requires addressing both immediate economic pressures (price volatility, access to credit) and longer-term environmental challenges (climate adaptation, sustainable fisheries management).

Analysis and Interpretation of Temperature and Fish Catch Relationship

The Pearson correlation coefficient of -0.655 demonstrates a moderately strong inverse relationship between maximum temperature and fish catch. This negative correlation suggests that as maximum temperatures rise, fish catch quantities tend to decline. The strength of this relationship ($|r| > 0.50$) indicates that temperature is a meaningful predictor of fish catch variability, though other factors likely also contribute to catch outcomes. However, there appears to be an error in reporting the significance level as 1.000. Significance values (p-values) range from 0 to 1, where values below 0.05 typically indicate statistical significance. A p-value of 1.000 would actually suggest no statistical significance, contradicting the claim of a strong relationship. This may be a reporting error that should be verified with the original statistical output. The linear regression model ($Y = \alpha + \beta X$) quantifies how maximum annual temperature (X) predicts annual fish catch (Y). The negative regression coefficient (β) confirms the inverse relationship: higher temperatures correspond to lower catch volumes.

This mathematical relationship provides a predictive tool for estimating how temperature changes might impact future fish catches. The observed negative relationship aligns with established ecological principles. Elevated water temperatures trigger multiple physiological stressors in fish populations. Accelerated metabolism increases energy demands, requiring more food intake while simultaneously depleting oxygen levels in warmer water. This creates a metabolic squeeze where fish expend more energy but have reduced capacity to meet those needs. These stresses can lead to increased mortality, reduced reproductive success, and behavioural changes such as migration to cooler waters all of which minimize local fish availability for capture. For fishing communities, rising temperatures present a significant challenge. Weakened fish populations become harder to locate and catch, potentially reducing both catch efficiency and economic viability for fishermen. This finding highlights the vulnerability of fishing-dependent livelihoods to climate change, underscoring the need for adaptive management strategies.

Table 3 Correlation for the relationship between maximum temperature and fish catch.

		Fish	Maximum Temperature
Pearson	Fish	1.000	-0.655

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

CONCLUSION

The study found that fishermen encounter multiple interrelated challenges, with weather patterns (42.5%) and economic difficulties (41.3%) emerging as the primary concerns among survey participants. These challenges create a cycle where unpredictable climate patterns diminish fish yields, subsequently reducing fishermen's earnings and their capacity to upgrade their tools and equipment. Because these issues are interconnected, solutions need to tackle several problems at once. Combining climate resilience measures, economic assistance programs, and equipment upgrade initiatives would prove more beneficial than focusing on individual challenges separately. Fishermen hold varying views on the ideal water temperature, without reaching a clear consensus. Moderate temperatures (40%) received slightly more favour compared to cooler (31.3%) or warmer (28.7%) conditions. This pattern implies that temperate water conditions might offer the most reliable fishing prospects, although substantial numbers of fishermen also achieve success in both colder and warmer environments.

The April-June timeframe (45%) emerged as the most preferred fishing period, with July-September (33.7%) ranking second. Combined, these periods, spanning April through September, represent nearly 79% of the fishermen's favoured fishing months. This demonstrates that the warmer portion of the year, corresponding to spring and summer seasons, offers the most advantageous fishing conditions. The analysis showed that peak temperatures have a substantial impact on catch volumes, with elevated temperatures resulting in smaller catches. This relationship demonstrates both statistical strength and practical importance for managing fisheries. The inverse relationship corresponds with established biological concepts: rising temperatures speed up fish metabolism, heightening their nutritional and oxygen requirements while simultaneously creating stress conditions that increase death rates and make fish harder to catch. The study proposed several recommendations: The Ministry of Fisheries and Aquaculture should partner with district and municipal authorities to conduct educational workshops for fishermen about climate fluctuations, as many lack sufficient understanding of climate-related changes. Additionally, tree-planting initiatives should be promoted near water sources and reservoirs in Kasena Nankana Municipal. Increasing tree coverage would create shade and minimize direct sunlight exposure on water bodies, thereby lowering water temperatures and potentially enhancing fish populations. Lastly, government agencies and non-governmental organizations should provide fishermen in the area with modern fishing gear and equipment, as their current tools are deteriorated and outdated, negatively impacting their fishing outcomes.

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Conflict of Interest Statement

The author declares that there is no conflict of interest related to this research.

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