ARTICLE | OPEN ACCESS

Discovery Agriculture

Fish farmers' perception of climate change and its impact on fish production in Sokoto metropolis, Nigeria. A preliminary study

Ibitoye EB[1]*, Yusuf N[1], Ajanaku D[2], Iriobe T[3], Gosa R[4], Gwimi BP[5], Ishola OD[6], Oladele OO[7], Tanimomo BK[8], Jimoh AA[1]

To Cite:
Ibitoye EB, Yusuf N, Ajanaku D, Iriobe T, Gosa R, Gwimi BP, Ishola OD, Oladele OO, Tanimomo BK, Jimoh AA. Fish farmers' perception of climate change and its impact on fish production in Sokoto metropolis, Nigeria. A preliminary study. *Discovery Agriculture* 2026; 12: e5da3190
doi:

Author Affiliation:
[1]Department of Theriogenology and Animal Production, Faculty of Veterinary Medicine, Usmanu Danfodiyo University Sokoto, Nigeria.
[2]Ministry of Agriculture and Food Security, Ogun State, Nigeria.
[3]Department of Forestry and Fisheries, Abdullahi Fodio University of Science and Technology Aliero, Kebbi state, Nigeria.
[4]Zonal Veterinary Clinic Argungu, Opposite Kara Market, Kebbi State, Nigeria.
[5]Department of Veterinary Public Health and Preventive Medicine, College of Veterinary Medicine, Federal University of Agriculture Zuru, Kebbi State, Nigeria.
[6]Olam Hatcheries Limited, Kaduna, Nigeria.
[7]Department of Medicine, Surgery and Radiology, Faculty of Veterinary Medicine, University of Jos, Nigeria.
[8]Department of Animal Health and Production, Faculty of Veterinary Medicine, University of Abuja, Nigeria.

***Corresponding author:**
Ibitoye, E.B.: Department of Theriogenology and Animal Production, Faculty of Veterinary Medicine, Usmanu Danfodiyo University Sokoto, Nigeria. Tel: +2347038228200, Email: eb.ibitoye@gmail.com

Peer-Review History
Received: 18 October 2025
Reviewed & Revised: 15/November/2025 to 21/April/2026
Accepted: 30 April 2026
Published: 09 May 2026

Peer-Review Model
External peer-review was done through double-blind method.

Discovery Agriculture
pISSN 2347-3819; eISSN 2347-386X

DISCOVERY SCIENTIFIC SOCIETY

ABSTRACT

The Nigerian aquaculture industry is growing, but it is being affected by changes in the global climate, particularly in the semi-arid Sudano-Sahelian zone. In Sokoto Metropolis, where the "Blue Economy" is vital for bridging the animal protein supply-demand gap, erratic weather patterns and rising temperatures challenge the viability of fish production. This study assessed fish farmers' knowledge of climate change, their opinions of its effects on productivity, and the farm-level adaptation tactics they used. An exploratory approach was used to gather data from 24 fish farmers recruited via convenience and snowball sampling methods. Structured questionnaire was used to collect information on fish farmers' demography, awareness levels, environmental observations, and coping mechanisms and descriptive statistics was used to analyze data generated using Microsoft Excel (Version 2023). Our results revealed that fish farmers in Sokoto metropolis are predominantly male (75%), with 50% of them aged 20–30 years. Findings of this study also revealed that most of the farmers (75%) had tertiary educational qualifications. Awareness of climate change is high where 95.8% of the farmers had observed a significant change in temperature and water levels. Some of the farmers reported a decline in production due to increased mortality (25%), stunted growth (20.8%), and overall yield reduction (83.3%). Although 45.8% of the farmers utilized self-governing adaptation measures such as pond shading and improved water management. Institutional support is low; only 12.5% of the farmers had received governmental assistance in the form of training with no report of financial aid or climate-resilient breeds. Fish farmers in Sokoto are aware of risks associated with climate change, but they lack the capital-intensive infrastructure to achieve full resilience. The study recommends increased governmental support by subsidizing capital-intensive infrastructures, promoting the development of thermo-tolerant fish strains, and the integration of digital extension services to bridge the gap between scientific climate data and pond-side application.

Keywords: Climate change, Fish farming, Institutionalized resilience, Sokoto metropolis, Thermo-tolerance

1. INTRODUCTION

The global aquaculture industry is becoming more widely acknowledged as a crucial part of the "Blue Economy," which is necessary to close the gap between supply and demand for premium animal protein. While the estimated current and future fish demands are about 3.32 and 4.37 million metric tons, respectively (Eti-Ukwu *et al.*, 2024; Esin *et al.*, 2025), the fish sub-sector in the Nigerian agriculture suffers a severe challenge and it is worsened by the unpredictable, erratic and often uncontrollable changes in the natural environment. Fish production has evolved from subsistence to vital component of food security and economic resilience in the semi-arid region of Nigeria (Odozi, 2025; Sulaiman *et al.*, 2025; Ajayi *et al.*, 2026). However, the challenges elicited by global climate change are threat to the viability of the fish sub-sector, as reported by Ahmed and Solomon (2017) and Jibrillah *et al.* (2025). In the semi-arid corridor of Sokoto metropolis, the challenge pose by climate change is worsened by both the direct and indirect impacts of climate change, a phenomenon characterized by long-term shifts in temperatures and unpredictable weather patterns (IPCC, 2021). The climate of semi-arid city of Sokoto in the Northwestern Nigeria is represented by long-term shifts in temperature and erratic weather patterns.

Climate change exacts its impact in the form of increased heat stress, unpredictable rainfall patterns, and an increase in the frequency of natural disasters such as devastating floods and protracted dry seasons (Enwa and Achoja, 2023; Ogunkalu, 2025). These changes are not just weather-related for aquaculture practitioners, but they also pose psychological, physiological, and financial challenges. According to a previous study, the metabolic rates of poikilothermic organisms like *Clarias gariepinus* are drastically altered by rising water temperatures (Dawood *et al.*, 2022). An increase in water temperatures leads to hypoxia, increased morbidity to organisms like *Aeromonas hydrophila*, and higher mortality in fish (Semwal *et al.*, 2023). More over, the whole of the fish production setting is under threat from the rising occurrence of "extreme weathers," which could be in the form of catastrophic flash floods that easily destroys pond embankments or severe droughts that deplete key water sources (Enwa and Achoja, 2023; Umechukwu *et al.*, 2025).

Scientific data alone, however, provides an incomplete picture of this crisis. In order to develop effective Climate-Smart Aquaculture strategies, the farmers' perceptions must be given top priority. However, there is limited empirical evidence on how fish farmers in Sokoto metropolis perceive climate change and how their perceptions influence their adaptation decisions. This is due to the fact that farmers' perceptions and awareness have a major role in how effective any adaptation strategy operates. Farmers respond to climate threats based on their subjective assessment of environmental cues rather than on evidence-based scientific data. It has been earlier reported that fish farmers in Sokoto are aware of unsteady harmattan cycles with intense but shorter durations (Atedhor, 2015; Jibrillah *et al.*, 2018; Dogondaji and Magawata, 2024). The opinions and native knowledge among fish farmers in Sokoto metropolis serve as a primary driver of adaptation. The reaction and response of farmers to low productivity is a function of what they perceived was the cause. If they perceived the loss was due to climate change and not just a natural occurrence, they are more likely to invest in solutions such as using of heat resistant strains of fish, shading their ponds, drilling wells or boreholes, or constructing flood blockades (Adeleke and Omoboyeje, 2016; Aroyehun and Henri-Ukoha, 2025).

Despite the presence of the Sokoto-Rima river basin, the metropolis still faces unique urban microclimates and anthropogenic pressures that exacerbate climatic impacts. It is crucial to understand the gap between farmers' impressions of reality and scientific climate trends when developing policies. Therefore, this study seeks to evaluate how fish farmers in the Sokoto metropolis identify, interpret, and respond to the climatic shifts threatening their livelihoods. This provides a baseline for localized adaptation frameworks that ensure the "blue economy" of Northern Nigeria as it remains resilient in an increasingly warming world with unpredictable climatic conditions.

2. MATERIALS AND METHODS

This study was conducted within Sokoto metropolis, which is situated between latitudes 12°46'N to 13°08'N and longitudes 5°14'E to 5°30'E at an average elevation of 272 meters above sea level. It includes Sokoto South, Sokoto North, a portion of Kware, Dange Shuni, and Wamakko LGAs (Dankani, 2018). Usually, Sokoto state experiences a distinct climate characterized by a prolonged dry season and a relatively short wet season. The dry season extents from October to May, while March, April, and May are the hottest months. The wet season is between the months of June and September, having peak rainfalls in August (Dogondaji and Muhammed, 2014). The study area is in the Sudan Savannah Agro Ecological zone of Nigeria, with an average annual rainfall of between 500 mm and 1,300 (Ekoh, 2020). The study area experiences significant diurnal temperature fluctuations, with high daytime temperatures followed by a marked cooling at night. The annual temperature ranges from 28.4 to 42°C. A large proportion of the inhabitants of Sokoto are involved in various forms of agricultural activity (Sokoto State Government, 2025). Agricultural activity in Sokoto, especially aquaculture is

highly influence by climate change, since it depends on water availability and temperature stability. With an estimated 3 million cattle, 3 million sheep, 5 million goats, and 4,600 camels, the state has the second-highest livestock population in the nation (Bala *et al.*, 2018).

Data collection

A structured questionnaire was used to collect the needed data. To guarantee clarity and relevance, the questionnaire was pre-tested with ten farmers from the study area and contains both closed-ended and open-ended items. Before its administration, the questionnaire was modified in response to pre-test comments.

A total of 24 farmers, including farm owners, managers, and workers, were recruited through a combination of volunteer-based convenience sampling and snowball sampling methods. Oral consent was obtained from farmers before administering the questionnaire. Where necessary, oral interviews and/ or a brief explanation was provided to farmers, and one questionnaire was administered to each farm. Information collected comprised demographic characteristics of farmers, climate change awareness, the perceived effect of climate change on fish farming, as well as farmers' approach to adaptation and coping strategies.

Collected data were cleaned and analyzed using Microsoft Excel (Microsoft Excel, 2013). Farmers' socio-demographic traits, awareness of climate change, the perceived impact on fish farming, farmers' coping mechanisms, and adaptation methods were all summarised using descriptive statistics, such as frequencies and percentages.

3. RESULTS

The study comprises 24 fully completed responses. As illustrated in Figure 1, the sector is predominantly male-dominated (75%). Age, and involvement in fish farming were shown to be inversely related; half of the farmers (50%) were between the ages of 20 and 30, whilst only 4.2% were over 50 and none were younger than 20. Information on educational status shows that 75% of farmers had tertiary education, 20.8% of them only had secondary school education, while 4.2% had no form of education. Regarding experience, 41.7% of farmers had 1–5 years of involvement, indicating a relatively new but educated workforce in the Sokoto metropolis, 20.8% had 1 year and 6-10 years of experience, and 12.5% had been farming fish for over 10 years.

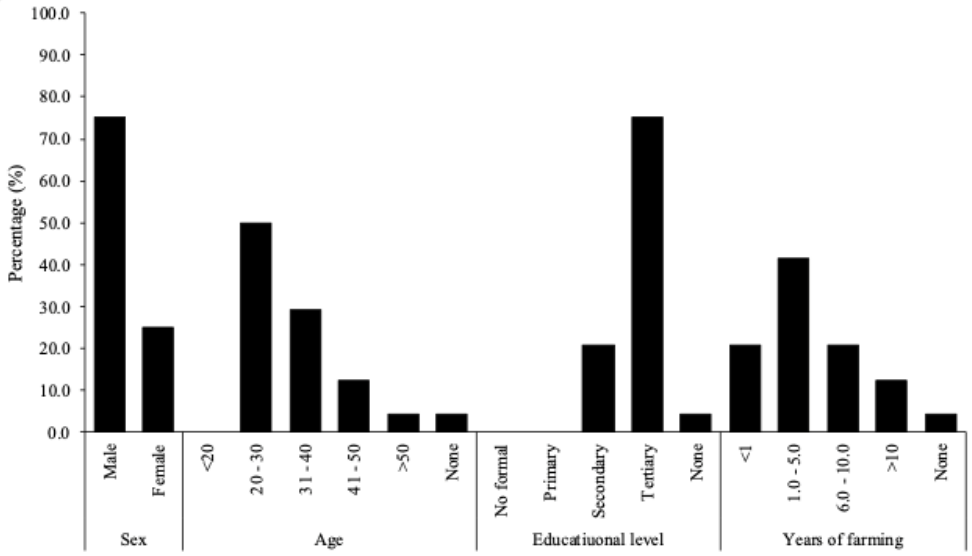

Figure 1. Socio-demographic characteristics of fish farmers in Sokoto metropolis

Awareness level was high, where 91.7% of farmers acknowledged that they had previously heard of climate change (Figure 2). Half (50%) of the farmers got informed about climate change through multiple channels, such as Radio/TV, the internet, and peer network. Out of the farmers, 87.5% had observed the direct impact of climatic shifts on aquaculture operations.

Perceptual data in Figure 3 shows that 95.8% of farmers observed significant shifts in temperature, rainfall, and water levels. The primary challenges identified were synergistic; 79.2% experienced a combination of increased water temperature, disease outbreaks, and stunted growth. The observed increased in mortality (25%), retarded growth (20.8%), increased cost of production (8.3%), and

overall decline in fish yield (83.3%) are indications that environmental stressors have resulted in huge economic losses, attributable to climate change.

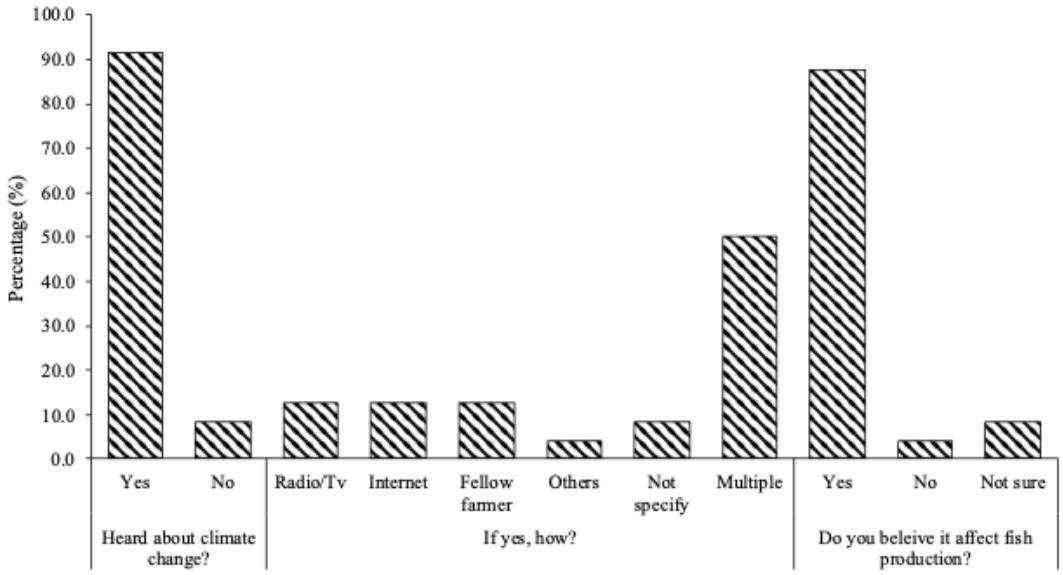

Figure 2. Fish farmers' awareness of climate change in Sokoto metropolis

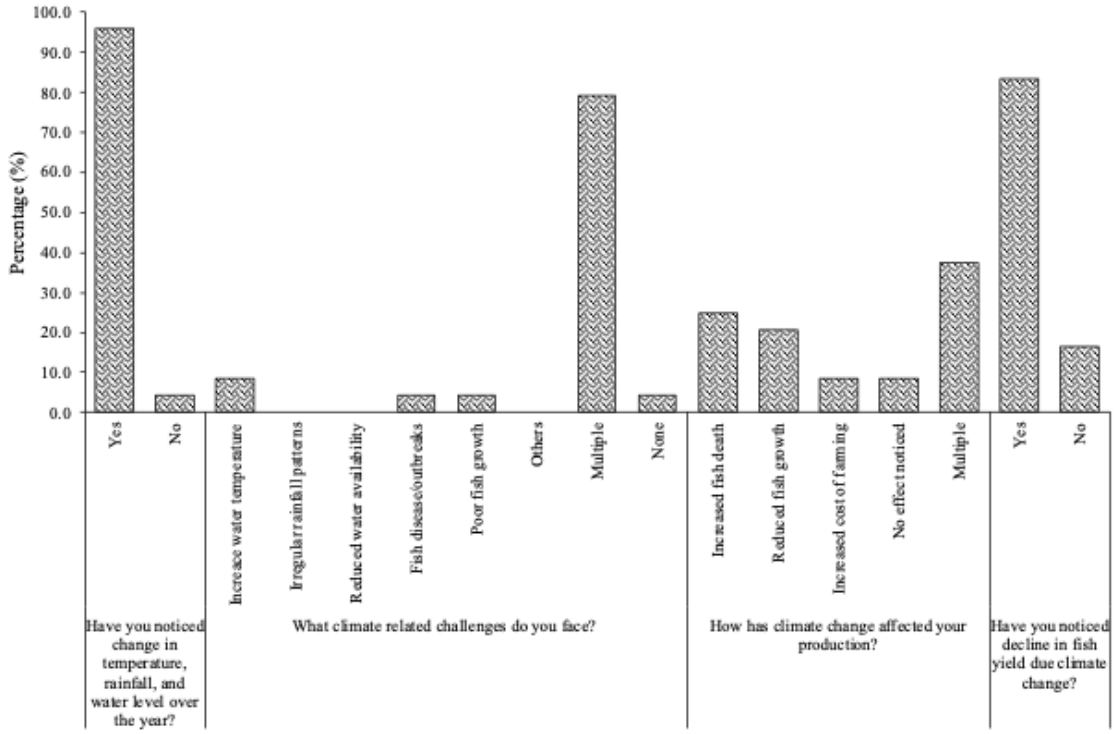

Figure 3. Farmers' perception of the effect of climate change on fish farming in Sokoto metropolis

Farmers employed various autonomous adaptation measures (Figure 4). It was recorded that 29.2% focused on water management, 8.3% utilized shading, 4.2% deeper ponds, while 45.8% utilized a combination of techniques. However, the study found that institutional support remains low, where only 12.5% received government assistance, which was limited to training. No farmers

reported receiving financial aid or improved, climate-resilient fish breeds. It was recorded that 20.8% and 16.7% of the farmers opined that the government should support the farmer with finance and awareness campaign, respectively to help the famers cope with climate change.

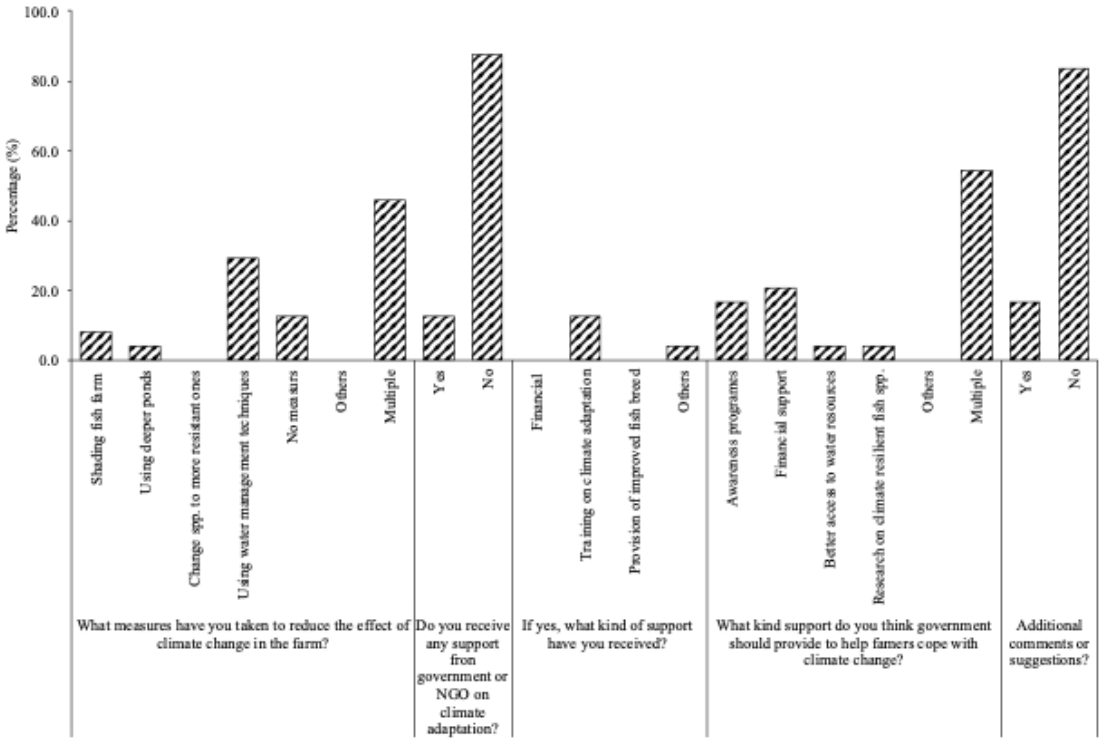

Figure 4. Adaptation and coping strategies adopted by fish farmers in Sokoto metropolis

4. DISCUSSION

This study provides a snapshot of the connection between climate change and the emerging aquaculture sector in the semi-arid region of Northwestern Nigeria. It is evident from the study that Sokoto fish industry is dominated by a young-educated workforce, however the prevailing environmental condition pose a significant threat to productivity.

The high concentration of males and young farmers suggests that fish farming in Sokoto metropolis is becoming a modern entrepreneurial venture rather than a traditional subsistence activity. Also, this study indicates that male gender dominated fish farming in the study area, which corroborates previous reports by Olaoye *et al.* (2024), Badaru *et al.* (2022), and Ibrahim *et al.* (2016) who reported 88, 90, and 74% involvement of males in fish farming in Ogun, Sokoto, and Borno states, respectively. The higher involvement of the male gender in fish farming may be due to the fact that the male gender of household typically possesses superior financial autonomy than their female counterparts (National Bureau of Statistics, 2020; Damong and Perez, 2024). Also, increasing household financial demands usually make men to find additional source of income which may enable them to venture into farming activity. Furthermore, men typically have easier access to the large sums of money needed to start and run a fish farm (Eze *et al.* 2026). There is an indication that younger individuals are more likely to be involved in fish farming as evidenced by a drop in involvement with age. These findings is consistent with those of Avery *et al.* (2007) that job performance and productivity are higher among younger workforces when compared with older workers.

Findings of this study imply that a high percentage of fish farmers in Sokoto holds tertiary education qualifications, which suggests that most of the fish farmers are literate and can easily adapt innovation. Ibrahim *et al.* (2016) and Umar *et al.* (2019) had earlier reported that 71 and 68%, respectively, of their studied farmers had obtained a tertiary educational qualification. Perhaps this is an indication that farmers who has achieved a tertiary level of education can easily understand and adopt technical climate adaptation strategies, since they are more informed about fish farming compared to those with lower levels of education (Raufu *et al.*, 2009). In line with the reports of Petros *et al.* (2024), Katya Kule *et al.* (2025), and Oli *et al.* (2025), individuals with higher educational level are better in terms

of accessing information and are more likely to quickly adopt innovation technologies. Likewise, our findings showed that fish farmers who have attained a tertiary education displayed a higher level of awareness of fish farming practices than those with lower educational levels (Raufu *et al.,* 2009). This assertion is at variance with the findings of Adewuyi *et al.* (2010), who reported a higher (82.9%) percentage of secondary school students engaged in fish farming.

The higher level of awareness and recognition of climate change consequences indicates that farmers within the Sokoto metropolis are well attuned to global environmental shifts. Data from this study suggests that there is an increase in the awareness level of climate change when compared to previous findings of Enete and Amusa (2010). This might be because, since climate change awareness is a process (Efut *et al.,* 2025) this study indicated that the awareness of climate change has improved over time, and this is in line with the observations of Efut *et al.* (2025), who also reported that awareness of climate change is higher among farmers and fishermen. Getting information from different sources such as TV, radio, and the internet explains a shift toward a digitalized agricultural extension system. Receiving information from multiple sources, suggests that the traditional extension services within Sokoto metropolis requires a change to digital platforms so as to remain relevant to the majority younger farmers. Notwithstanding, since only a few farmers obtain information from fellow farmers indicate a poor farmer to farmer extension systems, which is a vital for indigenous adaptation approaches in sub-Saharan Africa. The changes in the temperature and water levels observed by farmers in this study corroborate the meteorological information for the Sudano-Sahelian zone, depicted by a stable climbing course in temperatures and increasingly irregular precipitation patterns over the past four decades (Jidauna *et al.,* 2011; Ati *et al.,* 2022).

The semi-arid climate of Sokoto, characterized by extreme thermal peaks (Abdullahi *et al.,* 2014; Musa and Ogbe, 2025), poses a physiological challenge to fish health. Findings of this study suggested that there could be an association between climate change and increase mortality and decline yield in fish farming, and this may be attributed to synergistic stress model. In aquaculture, as water temperature rises, the dissolved oxygen concentration decreases while the metabolic demand of the fish increases (Cheng *et al.,* 2019; Volkoff and Rønnestad, 2020). This leads to chronic hypoxia and thermal stress, as previously documented by Umar *et al.* (2019), and Volkoff and Rønnestad (2020). Hypoxia is detrimental to fish physiology, metabolism, antioxidant capacity, immune function, and growth, as reported by Roman *et al.* (2019) and Zhao *et al.* (2020). Hypoxia has been reported as a trigger for the release of catecholamines, cortisol, and other hormones in fish (Xiao, 2015), leading to oxidative stress (Zhao *et al.,* 2020). A strong positive correlation has been reported between bacterial pathogens, temperature, growth, and virulence, leading to increase disease morbidity and susceptibility to opportunistic pathogens like *Aeromonas* spp., according to Liu *et al.* (2022), and Jadhav *et al.* (2026).

Perhaps the most significant finding is the support gap. Despite adopting some mitigation strategies, for example, pond shading, water management, and deeper ponds, the lack of financial support and/ or genetically improved strains has limited the resilience of fish and farmers to the effects of climate change. Only a few farmers received governmental support in the form of training alone, calls for closer attention. The lack of financial support and/ or provision of improved, heat-resilient fish breeds (e.g., genetically improved farmed tilapia or heat-tolerant catfish strains) highlights a policy gap in Nigeria's National Adaptation Provider framework. While the majority of fish farmers in Sokoto metropolis are highly aware and educated, they lack the capital-intensive infrastructure needed to to protect production from fluctuating ambient temperatures fully. This problem is worsened by the lack of institutional financial support and research into climate-resilient species.

5. CONCLUSION

Fish farmers within Sokoto metropolis are aware of climate change and its impact on production. To address these impacts, the industry must move beyond just awareness toward institutionalized climate resilience. Hence, technical assistance in the form of selective breeding programs that emphasize thermotolerance is crucial for the Sahelian environment. Government subsidies on deep well or boreholes and pond shading materials are needed to mitigate the higher evaporation rates typical of the Sokoto environment. Also, extension services must be enriched in order to connect the researchers and farmers with the aim to translating data on climate change into actionable pond-side effect. More studies should employ larger sample size and probability sampling methods to enhance generalizability.

Acknowledgments

We would like to express my sincere gratitude to all those who supported me throughout the course of this research.

Author Contributions

Ibitoye EB, Yusuf N, Gosa R, Gwimi BP: Collected and sorted data, conducted the field studies, and also prepared the first draft of the manuscript, covering the primary analysis and results interpretation.
Ajanaku D, Iriobe T, Ishola OD, Oladele OO, Tanimomo BK: Major editing, minor editing, proof reading and criticize the manuscript.
Ibitoye EB, Tanimomo BK, Jimoh AA: Monitored the research process and progress, provided guidance, ensured the project aligned with the research ethics, and reviewed and edited the manuscript.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or nonprofit sectors.

Conflict of interest

The authors declare that they have no conflicts of interest, competing financial interests or personal relationships that could have influenced the work reported in this paper.

Ethical approval

The study was done in conformity with ethical guidelines. Participation was entirely voluntary, and all respondents provided informed consent. The participants' anonymity and confidentiality were ensured, and the data obtained were utilized purely for the study. The ethical guidelines for Human Subjects are followed in the study.

Informed consent

Oral informed consent was obtained from individual participants included in the study.

Data availability

All data supporting the findings of this study are embedded within the manuscript.

REFERENCES

1. Abdullahi SA, Muhammad MM, Adeogun BK, Mohammed IU. Assessment of Water Availability in the Sokoto Rima River Basin. Resources and Environment, 2014; 4, 220-233.
2. Adeleke ML, Omoboyeje VO. Effects of climate change on aquaculture production and management in Akure Metropolis, Ondo State, Nigeria. Academia Journal of Agricultural Research, 2016; 4(6), 319-325. doi: 10.15413/ajar.2016.0113
3. Adewuyi A, Phillips BB, Ayinde IA, Akerele D. Analysis of Profitability of Fish farming in Ogun state. Nigeria. J. Hum. Ecol. 2010; 3(3): 179-184.
4. Ahmed OO, Solomon OO. Climate Smart Aquaculture: A Sustainable Approach to Increasing Fish Production in the Face of Climate Change in Nigeria. International Journal of Weather, Climate Change and Conservation Research, 2017; 3(1), 8-27.
5. Ajayi O, Myo A, Cheng Y, Li J. Rice–Fish Integration as a Pathway to Sustainable Livelihoods Among Smallholder Farmers: Evidence from DPSIR-Informed Analysis in Sub-Saharan Africa. Sustainability, 2026; 18(1), 498. doi: 10.3390/su18010498
6. Aroyehun AR, Henri-Ukoha A. The impact of climate change on aquaculture and fisheries production in Nigeria. Discovery Agriculture, 2025; 11: e8da3119. doi: doi: 10.54905/disssi.v11i23.e8da3119
7. Asin SE, Umoh AA, Akpan UE. Trend Analysis of Mean Annual Temperature in Sokoto Metropolis Between 1971 And 2020 Using Man-Kendall and Sen's Slope Estimator. International Journal of Latest Technology in Engineering, Management & Applied Science, 2025; doi. 10.51583/IJLTEMAS
8. Atedhor GO. Agricultural vulnerability to climate change in Sokoto State, Nigeria. African Journal of Food, Agriculture, Nutrition and Development, 2015; 15(2), 9855-9871. doi: 10.18697/ajfand.69.15220
9. Ati OF, Aremu K, Olatunde AF, Iliya B, Abaje IB, Oladipo EO. Meteorological Drought and Temperature in Sudano-Sahelian Region of Nigeria under Increasing Global Warming. In The Nature, Causes, Effects and Mitigation of Climate Change on the Environment. IntechOpen. 2022; doi: 10.5772/intechopen.100108
10. Avery DR, McKay PF, Wilson DC. Engaging the aging workforce: The relationship between perceived age similarity,

satisfaction with coworkers, and employee engagement. Journal of Applied Psychology, 2007; 92(6), 1542–1556. doi: 10.1037/0021-9010.92.6.1542.

11. Badaru AA, Abubakar Y, Ibrahim B. Survey on the recent advances in fish hatchery operations around Sokoto metropolis. J Aqua Fish, 2022; 2(7):1-5.
12. Bala A, Junaidu AU, Salihu MD, Agaie BM, Saulawa MA, Musawa AI, Ahmad KH. Determination of heavy metal residues in slaughtered camels at Sokoto and Gusau modern abattoirs, Nigeria. Journal of Health and Pollution, 2018, doi.10.5696/2156-9614-8.20.181204.
13. Cheng L, Abraham J, Hausfather Z, Trenberth KE. How fast are the oceans warming? Science, 2019; 363, 128–129.
14. Damong GC, Perez C. Financial behavior between male and female: a systematic literature review. Journal of Social Sciences and Management Studies, 2024; 3(3):23-34. doi: 10.56556/jssms.v3i4.1051
15. Dankani IM. Assessment of perception and attitude of city dwellers on Urban forestry in Sokoto Metropolis. Journal of Agriculture and Environment, 2018; 14(2): 233-243.
16. Dawood MAO, Noreldin AE, Sewilam H. Blood biochemical variables, antioxidative status, and histological features of intestinal, gill, and liver tissues of African catfish (Clarias gariepinus) exposed to high salinity and high-temperature stress. Environmental Science and Pollution Research International, 2022; 29(37), 56357–56369. doi: 10.1007/s11356-022-19702-0
17. Dogondaji MB, Magawata D. Rainfall Variability and Its Implications On Crop Production In Sokoto State. International Journal of Innovative Environmental Studies Research, 2024; 12(3), 89-103
18. Dogondaji MB, Muhammed A. Analysis of meteorological drought in Sokoto State for the past four decades (1970-2009). International Letters of Natural Sciences, 2014; doi.10.56431/p-lv7o5l
19. Efut EN, Eldosouky AM, Akpan NA. Climate change awareness and adaptation strategies of farmers fishermen and teachers in Southeastern Nigeria. Discover Geoscience, 2025; 3:162, doi: 10.1007/s44288-025-00254-y.
20. Ekoh HC. Analysis of Rainfall Trend in Sokoto State, Nigeria (1987-2016). World News of Natural Sciences, 2020; 28: 171-186.
21. Enete AA, Amusa TA. Challenge of agricultural adaptation to climate change in Nigeria: a Synthesis form the Literature. The Journal of Field Actions Science Reports, 2010; 4(Special Issue 2): http://factsreports.revues.org/index678.html.
22. Enwa S, Achoja FO. Impact of Flooding Disaster on Economic Returns of Fish Farmers in Rivers State Nigeria. World Journal of Environmental Biosciences, 2023; 12(4), 18-24. doi: 10.51847/wYBB1Pdfv4
23. Esin JO, Evans UF, Ndekhedehe AI. Blue Economy and the Fisheries Sector in Nigeria: Analysis of the Performance of Capture and Aquaculture Fisheries to Fish Production and Implication on Economic Growth. International Journal of Research and Innovation in Applied Science (IJRIAS), 2015; X(III): 723-737. doi: 10.51584/IJRIAS.2025.10030053
24. Eti-Ukwu AI, Oyibo FO, Abdullahi S. Influence of climate change on fish production in Nigeria: A co-integration approach (2000-2022). International Journal of Agricultural Economics, Management and Development (IJAEMD) 2024; 12(1), 96-112.
25. Eze AA, Muogbo KA, Edeh GI, Obika AG. Gender-credit constraints on sectorial firm performance in Nigeria: An empirical analysis using PSM approach. Economy, 2026; 13(1), 1–11. 10.20448/economy.v13i1.8017
26. Ibrahim UI, Shamaki BU, Lawal JR, Grema HA, Ibrahim A, Majama YB, Badau SJ, Kushi CD. Demographic distribution of fish farmers in Maiduguri, NorthEastern Nigeria. Direct Research Journal of Agriculture and Food Sceince, 2016; 4(1): 1-4.
27. IPCC. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, In press, 2021; doi: 10.1017/9781009157896.
28. Jadhav S, Rani N, Srinath E, Rai PK, Manam VK, Chandravanshi S. From heat stress to health collapse: A global review of temperature-mediated disease risk in fish. International Journal of Advanced Biochemistry Research, 2026; 10(2): 428-435. doi: 10.33545/26174693.2026.v10.i2f.7620
29. Jibrillah AM, Choy LK, Jaafar M. Climate Change Manifestations and Impacts in The Sokoto Close-Settled Zone, Northwestern Nigeria. Akademika, 2018; 88(2), 21-34. doi: 10.17576/akad-2018-8802-02
30. Jibrillah AM, Shamaki MA, Hamisu I. Ecosystem Distress Syndrome (EDS) and its Impacts across Sokoto State, Northwestern Nigeria: A Geospatial Analysis. Journal of Geography, Environment and Earth Science International, 2025; 29(5), 39–51. doi: 10.9734/jgeesi/2025/v29i5893
31. Jidauna GG, Dabi DD, Dia RZ. The effect of climate change on agricultural activities in selected settlements in the Sudano-

Sahelian Region of Nigeria. Archives of Applied Science Research, 2011; 3(6):154-165.
32. Katya Kule E, Kyohangirwe A, Midamba DC, Byakatonda J. Determinants of adoption of climate-smart agricultural technologies among smallholder coffee farmers in Western Uganda. Cogent Social Sciences, 2025; 11(1). doi: 10.1080/23311886.2025.2588856
33. Liu H, Yu H, Yu YY, Bao XX, Zhou JH, Zeng WW, Peng ZQ, Yang Y, Duan N. miRNA and mRNA expression analysis reveals the effects of continuous heat stress on antibacterial responses to Aeromonas hydrophila lipopolysaccharide (LPS) in grass carp (Ctenopharyngodon idella). Fish & Shellfish Immunology, 2022; 130: 332-341. doi: 10.1016/j.fsi.2022.09.014
34. Musa YF, Ogbe JA. Assessing the spatiotemporal dynamics of PM2.5 concentrations during the harmattan season in Sokoto State, Nigeria, 1980-2024. Journal of Research in Forestry, Wildlife & Environment, 2025; 17(1): March 2025.
35. National Bureau of Statistics (NBS). 2019 Poverty and Inequality in Nigeria: Executive Summary. 2020; (May):1–27.
36. Odozi JC. Quantifying the Economic Contribution of Aquaculture Production Within a Rural Livelihood System: A Decomposition and Quasi-Experimental Approach. Review of Economic Assessment, 2025; 4(1), 46. doi:10.58567/rea04010004
37. Ogunkalu OA. Negative Effects of Climate Change on Aquaculture Production in Nigeria. Eurasian Journal of Agricultural Research, 2025; 9(2), 159-167.
38. Olaoye OJ, Ojebiyi WG, Adenika OF. Assessment of Socio-demographic Predictors of Fish Farmers' Access to Formal Credit Sources in Ogun West Senatorial District, Nigeria. The Philippine Journal of Fisheries 2024; 31(1). doi: 10.31398/tpjf/31.1.2021-0029.
39. Oli D, Gyawali B, Acharya S, Oshikoya S. Factors influencing learning attitude of farmers regarding adoption of farming technologies in farms of Kentucky, USA. Smart Agricultural Technology, 2025; 10(2025) 100801, doi: 10.1016/j.atech.2025.100801
40. Petros C, Feyissa S, Sileshi M, Shepande C. Factors Influencing Climate-Smart Agriculture Practices Adoption and Crop Productivity among Smallholder Farmers in Nyimba District, Zambia. F1000Research, 2024; 13:815, doi: 10.12688/f1000research.144332.2
41. Raufu MO, Adepoju AA, Salau AS, Adebiyi OA. Determination of Yield Performance in Small Scale Fish Farming in Alimosho Local Government Area Lagos State. International Journal of Agriculture and Rural Development, 2009; 2(1): 9-14.
42. Roman MR, Brandt SB, Houde ED, Pierson JJ. Interactive effects of hypoxia and temperature on coastal pelagic zooplankton and fish. Frontiers in Marine Science, 2019; 6(139): doi: 10.3389/fmars.2019.00139
43. Semwal A, Kumar A, Kumar N. A review on pathogenicity of Aeromonas hydrophila and their mitigation through medicinal herbs in aquaculture. Heliyon, 2023; 9(3), e14088. doi: 10.1016/j.heliyon.2023.e14088
44. Sokoto State Government. The Economy - Official Website of Sokoto State Government. 2025; https://sokotostate.gov.ng/history-of-sokoto/the-economy, retrieved 20-12-2025.
45. Sulaiman M, Man A, Alhaji A, Rilwan B. Economic Analysis of the Effect of Integrated Farming Systems on the Livelihood Strategies of Farmers in North-West Nigeria. International Journal of Intellectual Discourse, 2025; 8(1), Retrieved from https://ijidjournal.org/index.php/ijid/article/view/879
46. Umar HM, Modu BM, Mohammed ZB, Yagana A. Analysis of socio-economic and practices of fish farmers towards fish health management in Maiduguri and its environment. FUDMA Journal of Sciences (FJS), 2019; 3(2): 232 – 236.
47. Umechukwu JN, Sarpong DB, Mensah-Bonsu A, Ama Ahene-Codjoe A, Kim T. Effects of flooding-induced migration on farm technical efficiency in Rivers State, Nigeria. Journal of Agriculture and Food Research, 2025; 23, 102189
48. Volkoff H, Rønnestad I. Effects of temperature on feeding and digestive processes in fish. Temperature (Austin, Tex.), 2020; 7(4), 307–320. doi: 10.1080/23328940.2020.1765950
49. Xiao W. The hypoxia signaling pathway and hypoxic adaptation in fishes. Science China. Life Sciences, 2015; 58(2): 148–155. doi: 10.1007/s11427-015-4801-z
50. Zhao L, Cui C, Liu Q, Sun J, He K, Adam AA, Luo J, Li Z, Wang Y, Yang S. Combined exposure to hypoxia and ammonia aggravated biological effects on glucose metabolism, oxidative stress, inflammation and apoptosis in largemouth bass (Micropterus salmoides). Aquatic toxicology (Amsterdam, Netherlands), 2020; 224(105514): doi: 10.1016/j.aquatox.2020.105514