frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 17 July 2024
DOI 10.3389/fsufs.2024.1348984

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EDITED BY
Andy Morse,
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Bangor University, United Kingdom

*CORRESPONDENCE
Sahya Maulu
✉ sahyamaulu@gmail.com
Oliver J. Hasimuna
✉ oliverhasimuna@gmail.com

RECEIVED 03 December 2023
ACCEPTED 28 June 2024
PUBLISHED 17 July 2024

CITATION
Maulu S, Hasimuna OJ, Chibesa M, Bbole I, Mphande J, Mwanachingwala M, Nawanzi K, Chibeya D, Siavwapa S, Mbewe J, Namukonda L, Balungu F, Mumbula I, Kabika M, Mweemba S, Sikanyenyene M, Siankwilimba E, Imbwae I and Mweetwa HM (2024) Perceived effects of climate change on aquaculture production in Zambia: status, vulnerability factors, and adaptation strategies. *Front. Sustain. Food Syst.* 8:1348984.
doi: 10.3389/fsufs.2024.1348984

Perceived effects of climate change on aquaculture production in Zambia: status, vulnerability factors, and adaptation strategies

Sahya Maulu[1,2]*, Oliver J. Hasimuna[3,4,5]*, Moses Chibesa[6], Ian Bbole[7], Joseph Mphande[5,8], Mazuba Mwanachingwala[9,10], Kundananji Nawanzi[5], Doubt Chibeya[11], Sillah Siavwapa[5], Joyce Mbewe[5], Lucy Namukonda[5], Friday Balungu[5], Inyambo Mumbula[12], Mwangala Kabika[13], Shimbetu Mweemba[14], Mwaanda Sikanyenyene[5], Enock Siankwilimba[15], Imikendu Imbwae[16,17] and Hansel M. Mweetwa[15]

[1]Department of Research and Development, Centre for Innovative Approach Zambia (CIAZ), Lusaka, Zambia, [2]Faculty of Science and Engineering, School of Biological and Marine Sciences, University of Plymouth, Plymouth, United Kingdom, [3]Department of Fisheries, National Aquaculture Research and Development Centre, Ministry of Fisheries and Livestock, Kitwe, Zambia, [4]Department of Geography and Environmental Sciences, School of Archaeology, Geography and Environmental Science (SAGES), University of Reading, Reading, United Kingdom, [5]Department of Agriculture and Aquatic Sciences, Kapasa Makasa University, Chinsali, Zambia, [6]Department of Zoology and Aquatic Sciences, School of Natural Resources, Copperbelt University, Kitwe, Zambia, [7]IBAN Aquafish Solutions and Consultancy Ltd., Lusaka, Zambia, [8]Department of Fisheries, Ministry of Fisheries and Livestock, Ndola, Zambia, [9]Fish for Food Security in Zambia Project, Agriculture and Food Cluster, GIZ Lusaka, Lusaka, Zambia, [10]Zambia Austarlia Alumni Association (ZAAA), Lusaka, Zambia, [11]Department of Physical Geography, Biogeography and Geomatics, Stockholm University, Stockholm, Sweden, [12]Department of Disease Control, School of Veterinary Medicine, University of Zambia, Lusaka, Zambia, [13]Department of Aquatic Bio-Source and Aquaculture, School of Fisheries and Natural Resource Management, Astrakhan State Technology University, Moscow, Russia, [14]Department of Fisheries, Ministry of Fisheries and Livestock, Chinsali, Muchinga, Zambia, [15]Graduate School of Business, University of Zambia, Lusaka, Zambia, [16]Department of Ichthyology and Fisheries Science (DIFS), Rhodes University, Makhanda, South Africa, [17]Department of Fisheries, Ministry of Fisheries and Livestock, Choma, Zambia

Aquaculture plays a critical role in Zambia's food and nutrition security. However, aquaculture is highly vulnerable to the effects of a changing climate which can lead to economic losses, and food and nutrition insecurity. In this study, we investigated the perceived effects of climate change on aquaculture production in Zambia, vulnerability factors, and adaptation strategies. We used semi-structured and structured questionnaires to collect data from aquaculture producers in all provinces across the country. Results revealed high (over 80%) awareness of climate change, primarily attributed to literacy levels and access to media. Producers perceived occurrence of climate-related changes such as rising temperature, altered rainfall patterns, cyclones frequency, and disease outbreaks, impacting production costs. Generally, the results indicate a high to medium perception of rising temperature and increased frequency of flooding and droughts across the country. Although rising temperature did not appear to affect aquaculture production cost, the frequency of droughts, floods, cyclones, and disease outbreaks showed a significant association with production costs. Identified vulnerability factors include reliance on a limited range of fish species, absence of insurance coverage, and low adoption of adaptation practices. Vulnerability levels vary across regions, with provinces in agroecological zone I (Eastern, Lusaka, Southern, and Western) showing higher vulnerability. Despite this, many producers aren't implementing adaptation measures due to financial limitations, species diversity constraints, and insufficient knowledge of alternative economic pursuits. Main adaptation strategies involve livelihood diversification and adjustments in fish cultivation periods and infrastructure. To foster aquaculture sustainability amid climate change, critical interventions such as farm insurance, research diversification in aquaculture species, and enhancing producer resilience are necessary.

KEYWORDS

adaptation, aquaculture, climate change, perception, vulnerability, Zambia, food security, sub-Saharan Africa

1 Introduction

Recent global population projections show that about 10 billion people will be living on the earth by 2050 (United Nations, 2019). More than half of this projected population will come from sub-Saharan countries (FAO et al., 2022). Furthermore, recent statistics suggest that the world will not be able to meet the goal of ending all forms of hunger and malnutrition by 2030 (FAO et al., 2022). Hence, food systems must be transformed to ensure the provision of adequate, nutritious, and healthy foods accessible to different sections of societies, including poor-resource communities, whilst also ensuring the preservation of natural resources (FAO, 2022). Fish, being highly nutritious and widely accessible, especially for those with limited economic resources, play a crucial role in this endeavor (Beveridge et al., 2013; Maulu et al., 2020, 2021c). Aquaculture is the largest supplier of global food fish and has remained the fastest-growing food production sector globally since the 2000s (Naylor et al., 2021; FAO et al., 2022). The sector's contribution to food and nutrition security is seen as a critical means to achieving the transformation of global food systems. In developing countries, the role of aquaculture is of greater value, particularly in providing accessible animal protein sources, employment opportunities, and gross domestic product (GDP).

In Zambia, fish's contribution to per capita protein intake was estimated at 30.6% of per capita protein intake, with a per capita fish consumption estimated at 13.1 kg/person/year in 2021 (FAO et al., 2022). The country's aquaculture industry is the leading producer of farmed fish in Southern Africa region and ranks fifth in Africa by volume (FAO et al., 2022). In 2021, its aquaculture production increased to 63,355 tons from 9,535 tons in 2011, reflecting a growth rate of 564.45% (Nsonga and Simbotwe, 2014; FAO et al., 2022). Furthermore, over the last decade, the gap in fish production between capture fisheries and aquaculture has decreased significantly in Zambia, from a difference of 60,000 tons in 2011 to 20,000 tons in 2021 (Nsonga and Simbotwe, 2014; FAO et al., 2022). This shift positions aquaculture as the primary source of food fish for nutrition and food security in Zambia. Despite this substantial growth, the sector still possesses significant potential, owing to the country's abundant resources, including land, freshwater, human capital, and until recently, weather conditions have been favorable for freshwater tropical fish species like tilapia (Maulu et al., 2019). Additionally, Zambia recently launched its inaugural Fisheries and Aquaculture Policy to further boost domestic fish production, with aquaculture expected to play a critical role in this effort.

The aquaculture industry in Zambia operates on two primary scales: small-scale and large-scale commercial production. However, the specific distinctions between these scales are not clearly defined (Zhang et al., 2023). Small-scale fish production predominantly relies on earthen ponds, typically lined with dam liners, and involves modest investments. In contrast, large-scale commercial aquaculture leans toward intensive methods like floating cages, requiring substantial investments and advanced management techniques (Genschick et al., 2017; Zhang et al., 2023). Historically, large-scale aquaculture dominated national production, constituting roughly 75%, with small-scale operations contributing the remaining 25% (Hasimuna et al., 2023). However, recent data from 2022 shows a significant shift: small-scale aquaculture now comprises ~62%, while large-scale commercial production makes up the remaining 38% (Zhang et al., 2023). This surge in small-scale production is attributed to heightened government backing, including input subsidies and startup loans facilitated by the Zambia Aquaculture Enterprise Development Project (ZAEDP), funded by the African Development Bank. Geographical distribution of aquaculture operations in Zambia is influenced by several factors such as abundant water resources, favorable climate, government support, and closeness to the market (Genschick et al., 2017; Zhang et al., 2023).

However, aquaculture like many other sectors, faces significant vulnerability to climate change impacts (De Silva and Soto, 2009; Ahmed et al., 2019; Maulu et al., 2021a), resulting in economic losses and a threat to global food production systems throughout the value chain (Barange et al., 2018). Developing countries, especially small-scale producers, are expected to suffer more due to limited knowledge of climate change, its causes, and its impacts, along with limited adaptive capacity [Intergovernmental Panel on Climate Change (IPCC), 2018; Maulu et al., 2021a]. Producers' geographical locations and economic status also play crucial roles in determining their vulnerability (Brugère and De Young, 2015), which highlights the importance of localized adaptation and mitigation measures. Governments can play a critical role at the national level in enhancing producers' adaptive capacity, reducing vulnerability, and providing adaptation options through strategic policy development, proactive awareness campaigns, and the promotion of financial instruments like loans and insurance programs (Troell et al., 2014). However, a lack of crucial information often hinders well-informed decisions and timely interventions, which are vital for developing climate-resilient producers and advancing sustainable aquaculture practices. This study was designed to investigate the perceived effects of climate change on aquaculture production in Zambia, vulnerability factors, and adaptation strategies. This information is essential for fostering climate-resilient aquaculture producers and ensuring sustainable food and nutrition security in Zambia.

2 Materials and methods

2.1 Study area

Zambia is a landlocked country situated in the southern Central of Africa with a total area of 752, 610 km^2 (Maulu et al., 2019). The country is divided into 10 provinces with a total of 116 districts. Temperature ranges from 10°C to 30°C, with an average of 25°C which is favorable for most tropical aquaculture species (Mulenga et al., 2017). This study covered all the 10 provinces of Zambia, with data collection conducted across 49 districts (Figure 1). According to long-term climatic data, Zambia is further categorized into three major agro-ecological zones: I (South), II (Central), and III (Northern), depending on rainfall distribution (Figure 2). Zone, I receive less than 800 mm of rainfall, accounting for around 12% of the total rainfall received in the country annually (Makondo et al., 2014). Zone II receives 800-1000 mm, representing about 42 %, and is further categorized into two zones IIa and region IIb. Region III receives 1000-1500 mm, representing about 46 % of the total rainfall received annually (Makondo et al., 2014). This geographical and climatic stratification suggest varied impacts of climate change across different regions of Zambia, which is likely to shape vulnerability and adaptation strategies needed in each agro-ecological zone.

2.2 Design and sampling techniques

The study was designed to collect data from aquaculture producers in all ten (10) provinces of Zambia. According to the latest census of aquaculture producers in Zambia, the total number of aquaculture producers is estimated at 9,615 [Ministry of Fisheries and Livestock (MFL, 2023)]. However, this figure is subject to yearly fluctuations as some producers lack consistency, while new producers join the industry. To mitigate these fluctuations, we engaged with local staffs from the Department of Fisheries, Ministry of Fisheries and Livestock in each province. Our aim was to identify producers who have maintained consistent aquaculture production for at least the past four years. The distribution of aquaculture producers per province and production facilities, based on the 2017 census, along with the number sampled in the current study, are presented in Table 1.

In each province, at least 30 % of all districts were randomly selected for data collection, except in Southern Province, where three districts (Siavonga, Gwembe, and Sinazongwe) were purposively selected because these are the districts with major aquaculture activities in the province, operating in cages on Lake Kariba. Within the districts, a purposive sampling technique was applied to select the aquaculture producers with the help of the respective District Fisheries Officers (DFOs) from the Department of Fisheries, MFL in Zambia. While the total number of aquaculture producers with at least four years of consistent practice in each district was not accurately known, we aimed to interview all the estimated aquaculture producers in the selected districts from Central, Copperbelt, Eastern, Lusaka, Southern, and Western Provinces, as their total numbers were comparatively few. In provinces with a larger number of aquaculture producers, particularly Luapula, Muchinga, Northern, and Northwestern Provinces, we randomly selected half of the estimated total number of producers in each district. The total number of aquaculture producers interviewed in each district by province are shown in the Supplementary File.

2.3 Data collection

A structured and semi-structured questionnaire was used to collect data from the aquaculture producers in each of the selected districts from November 2022 to August 2023. Before the actual interviews, the questionnaire was pretested with a few aquaculture producers in the Lusaka district, and necessary adjustments were made based on the results to ensure it was user-friendly. The questionnaire had four major sections. Section 1 comprised the socio-demographic characteristics of the respondents. Section 2 comprised questions on climate change knowledge and perceived changes in climate using the pathways described by Maulu et al. (2021a) with some modifications, considering the freshwater aquaculture subsector. Specifically, we focused on documented elements of climate change on aquaculture production (Barange et al., 2018; Maulu et al., 2021a). After careful consideration, we selected the elements relevant to freshwater aquaculture within a landlocked country context. These elements included rising temperatures, shifts in rainfall patterns (manifesting as either droughts or floods), occurrences of cyclones, and outbreaks of diseases. Perception questions required the respondents to answer "yes" or "no" to whether they had heard of climate change and to state what they knew or thought caused it. The respondents were given options: Neutral, Low, Medium, and High, and were asked to select in response to the extent of any change observed for each pathway of climate change. Section 3 included questions to collect information on strategies taken by the aquaculture producers to cope with perceived climatic changes. The respondents were given numerous options to select from and an option for additional input/remarks. Section 4 comprised questions on aquaculture production insurance and major assets owned by the producers. This section together with overall findings from other sections were used to identify factors that might increase the vulnerability of producers to climate change. A copy of the questionnaire used for data collection in the current study can be found in the Supplementary material.

2.4 Data analysis

The collected data was first cleaned and coded before being transferred to SPSS for analysis. Using SPSS version 25.0, a detailed

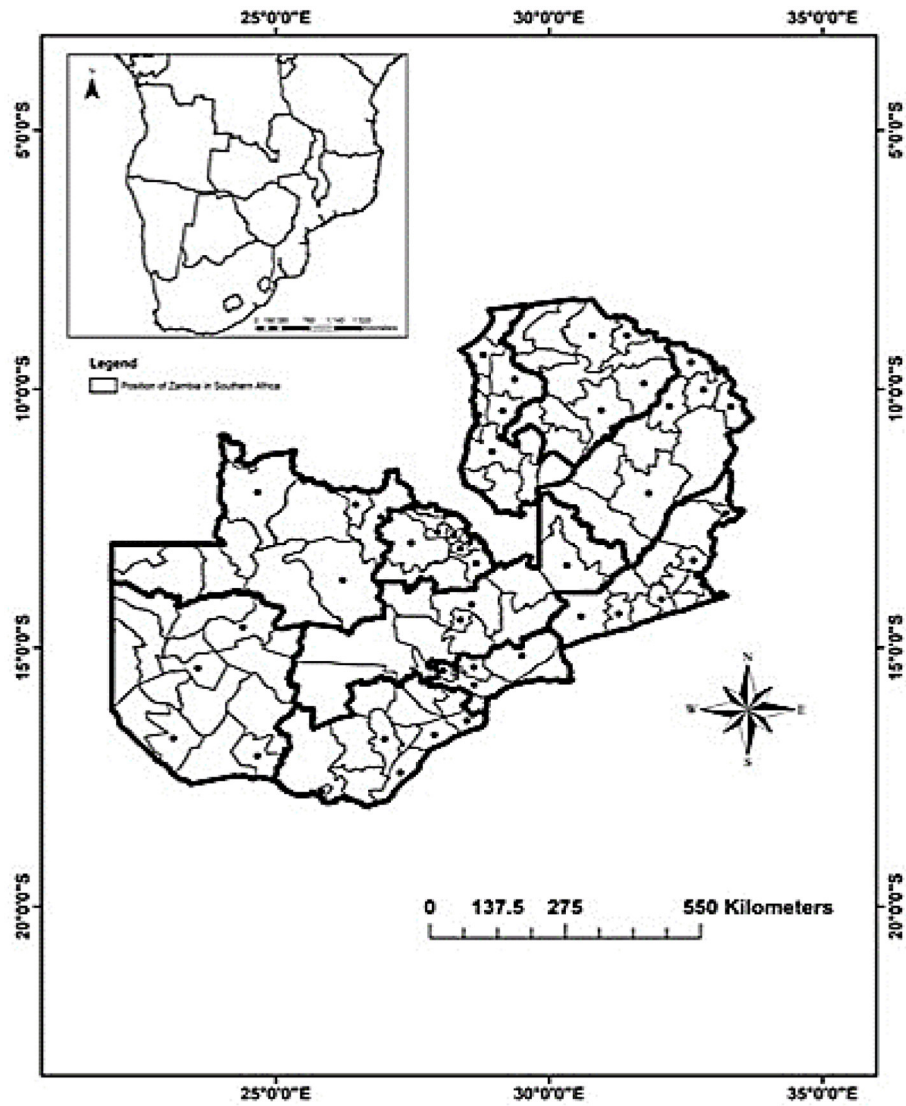

FIGURE 1
Map of Zambia showing sampling locations. The black dots represent the actual districts selected for data collection. Thick black lines represent provincial boundaries while thin lines represent district boundaries within each province.

analysis was conducted, employing basic descriptive statistics. The Pearson's chi-square test was used to analyze the association among key variables. Unless otherwise specified, data was presented as frequencies in percentages (%).

3 Results

3.1 Socio-demographic information of the respondents

The key socio-demographic information of the respondents in the current study is summarized in Table 2. Most respondents in Copperbelt, Lusaka, Northern, Southern, and Western provinces had attained up to tertiary level of education. While the majority in Central, Eastern, Muchinga and North-western provinces attained up to secondary education level. Primary education was the highest level attained by most respondents in Luapula province. In all provinces, most (over 40%) respondents had been practicing aquaculture for 4–7 years consecutively. Average monthly household income was low in all provinces with most getting <2,500 ZMW in Central and Lusaka provinces, 2,500-5,000 ZMW in Copperbelt, Luapula, Muchinga, Northern, and Western provinces, while most in Eastern and Southern provinces were earning 5,001–7,500 ZMW. Notably, all the respondents were also involved in other income generating activities with agriculture being the most prevalent across the country.

3.2 Perceived effects

3.2.1 Perception of causes of climate change

Nearly all the producers investigated in the present study were aware of climate change and the majority across the country

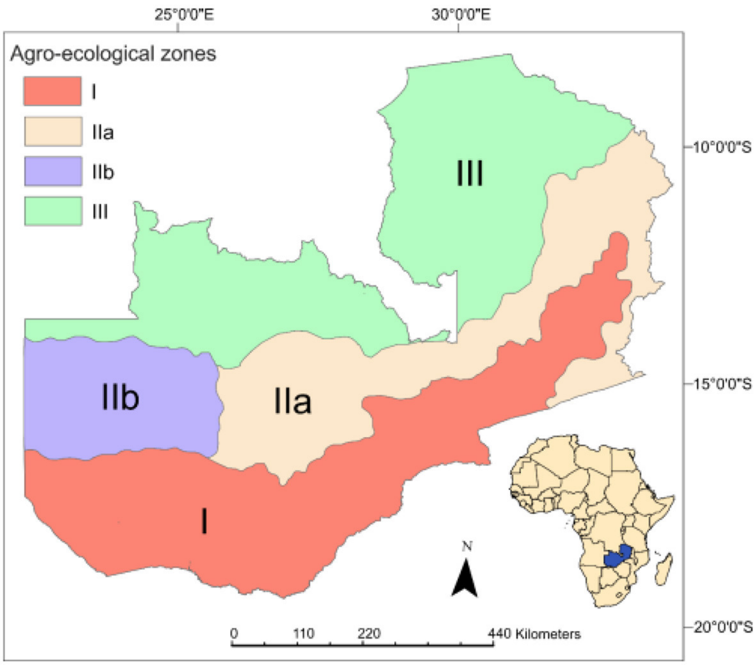

FIGURE 2
Map of Zambia showing agroecological zones. Zone I cover Lusaka, and parts of Western, Southern, and Eastern; Zone IIa covers Central, and part of Eastern, and Muchinga provinces; Zone IIb covers part of Western and North-Western provinces, while Zone III cover Luapula, Northern, and part of Copperbelt, Northwestern, and Muchinga province. Source: Phiri et al. (2021).

TABLE 1 Distribution of aquaculture production by province in Zambia and the number of producers interviewed in the current study (MFL, 2023).

Province	Number of producers	Production facilities						Production (Mt)	Number sampled
		Ponds	Cages	Tanks	Pen	Dam	Weir		
Central	463	522	18	8	4	104	4	238	109
Copperbelt	902	3,510	20	0	0	281	7	1,293	144
Eastern	499	655	10	0	0	2	0	31	98
Luapula	1,111	2,916	94	8	0	122	0	844	128
Lusaka	542	9,769	16	2,521	0	19	0	1,984	108
Muchinga	1,017	3,005	0	0	0	88	0	974	85
Northern	3,254	8,254	41	8	0	305	0	3,292	110
Northwestern	1,394	4,401	15	0	0	231	0	522	114
Southern	288	545	73	23	0	4	33	12,339	69
Western	145	254	0	0	0	10	2	51	61
Total	9,615	33,831	287	2,568	4	1,166	46	21,567	1,026

attributed it to human causes (Figure 3). Across various provinces in Zambia, the majority of aquaculture producers attributed climate change primarily to human activities. Central, Luapula, and Western provinces showed particularly high confidence in human causes, with over 84% in agreement. Conversely, Northern Province showed a substantial 38.18% of producers attributing climate change to natural causes. Some uncertainty existed, especially in Lusaka, where 14.81% of producers were unsure about the causes. While there was some recognition of both human and natural contributions, particularly in Copperbelt and Southern provinces, the predominant belief across most regions was that human activities are the main drivers of climate change. Using the Pearson chi-square test, we found that climate change knowledge was significantly associated with education of the respondents ($\chi^2 = 37.58$, $p < 0.05$).

3.2.2 Source of information

Aquaculture producers in Zambia mainly received climate information through radio and TV (Figure 4). Radio was most

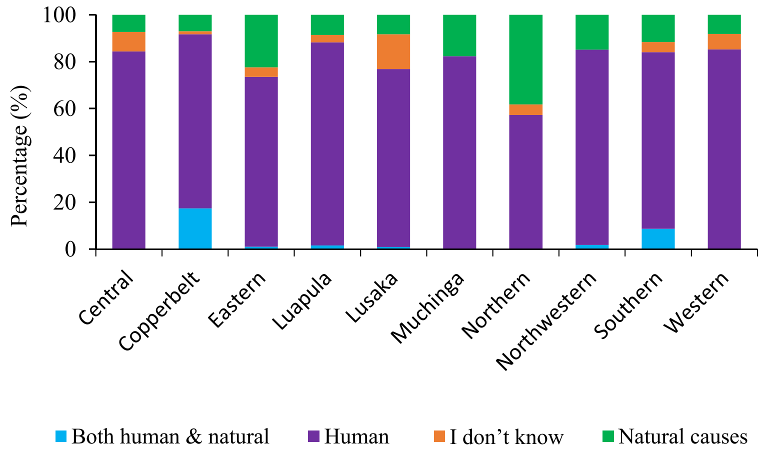

FIGURE 3
Perception of aquaculture producers on the causes of climate change.

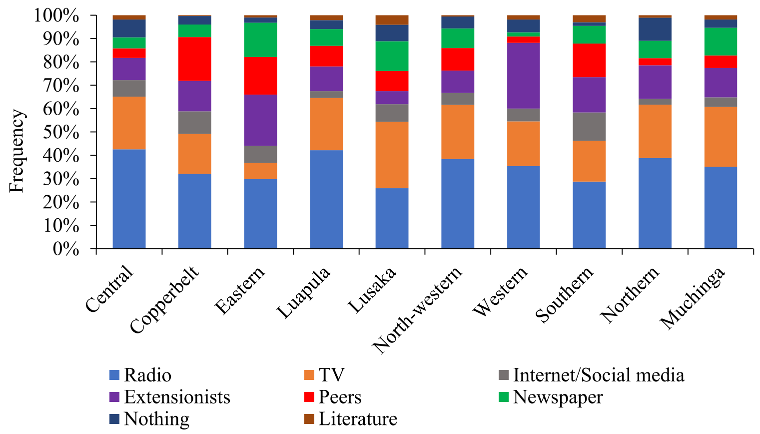

FIGURE 4
Sources of climate change-related information by the aquaculture producers in Zambia.

used in Luapula (78.13%) and Northern (70.91%), while TV was prominent in Lusaka (51.85%) and Muchinga (50.59%). Internet usage was highest in Southern (23.19%) and Copperbelt (20.14%), and extensionists were key in Eastern (48.98%) and Western (50.82%). Peer influence was significant in Copperbelt (38.89%) and Eastern (35.71%). Newspapers were moderately used, especially in Eastern (32.65%) and Muchinga (23.53%). Literature was the least used source overall.

3.2.3 Observed changes

The perception of climate related changes among the aquaculture producers in Zambia varied across provinces (Figure 5). Generally, the results indicate a high to medium perception of rising temperature and increased frequency of flooding and droughts across the country. Particularly, most aquaculture producers from Southern, Western, Eastern, and Lusaka provinces perceived a high rise in temperatures, while Copperbelt province had the lowest perception. Regarding increased frequency of droughts, Southern Province showed the highest perception, followed by Eastern, Lusaka, and Western provinces. Similarly, the perception of increased flooding frequency was highest in Southern Province, followed by Lusaka and Central provinces, with Copperbelt reporting the lowest. Notably, perceptions of increased cyclones and disease outbreaks were generally low (<50%) across the country, though Eastern province had the highest perception of increased cyclone frequency followed by Lusaka province. Additionally, the perception of high disease outbreak frequency was highest in Southern province and lowest in Luapula province.

3.2.4 Effect of observed changes on cost of aquaculture production

The analysis of the association between perceived climate change elements and the cost of aquaculture production in Zambia reveals that there are significant associations for most factors except rising temperatures (Table 3). As indicated in the table, significant

Province	Rise in temperature			
	High	Medium	Low	Neutral
Central	45	55	0	0
Copperbelt	38	19	13	31
Eastern	71	27	0	2
Luapula	45	50	2	3
Lusaka	67	28	6	0
Muchinga	55	39	2	4
Northern	48	45	4	4
Northwestern	54	20	11	14
Southern	77	22	0	1
Western	72	16	8	3

Province	Frequency of drought			
	High	Medium	Low	Neutral
Central	7	45	42	6
Copperbelt	23	29	16	32
Eastern	51	27	16	6
Luapula	30	35	27	7
Lusaka	49	35	8	7
Muchinga	28	49	14	8
Northern	26	41	13	20
Northwestern	28	45	12	15
Southern	55	42	3	0
Western	49	21	15	15

Province	Frequency in flooding			
	High	Medium	Low	Neutral
Central	53	20	12	15
Copperbelt	13	28	13	46
Eastern	43	28	18	11
Luapula	16	38	43	3
Lusaka	56	33	7	3
Muchinga	26	48	8	18
Northern	19	32	31	18
Northwestern	23	32	28	18
Southern	67	19	12	3
Western	44	28	20	8

Province	Frequency of cyclones			
	High	Medium	Low	Neutral
Central	0	6	52	41
Copperbelt	2	13	22	63
Eastern	42	29	11	18
Luapula	0	9	64	27
Lusaka	39	35	18	8
Muchinga	5	25	28	42
Northern	2	5	17	75
Northwestern	0	1	38	61
Southern	30	26	38	6
Western	10	3	51	36

Province	Frequency of disease outbreaks			
	High	Medium	Low	Neutral
Central	2	2	49	48
Copperbelt	10	13	27	51
Eastern	3	10	29	58
Luapula	2	13	63	23
Lusaka	4	16	51	30
Muchinga	7	15	29	48
Northern	5	10	16	68
Northwestern	7	4	38	52
Southern	36	42	20	1
Western	0	5	52	43

FIGURE 5
The degree of agreement to the occurrence of different climate change elements as observed by aquaculture producers in Zambia, presented as percentages. Values in each row represent the proportion (%) of respondents from each province who agreed to the occurrence of each climate change element.

relationships were found between increased costs and the frequency of droughts, flooding, cyclones, and disease outbreaks. In contrast, the perceived change in temperature did not show a significant impact on production costs, indicated by a low chi-square value and a $p > 0.05$. Thus, while temperature changes did not appear to significantly affect aquaculture costs, other climate change elements like droughts, floods, cyclones, and disease outbreaks did.

The perception of aquaculture producers across Zambia indicates a majority believe that climate change has increased production costs. The perceived extent of cost increases due to climate change among aquaculture producers across different provinces in Zambia is indicated in Figure 6.The increase in the cost of production attributed to climate change were estimated at 1–10% by most (>30%) respondents in all provinces except in Eastern and Southern provinces where most estimated it at 11–20% (Figure 6). Very few (<3%), particularly in Southern, Lusaka, Luapula, and Copperbelt provinces reportedly observed over 80% change.

3.3 Vulnerability factors

3.3.1 Aquaculture species

Aquaculture production was based entirely on finfish freshwater species with tilapia species being the most widely cultured across the country (Figure 7). The indigenous three spot

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TABLE 2 Social-demographic characteristics of the respondents.

Variable	Central ($n = 109$)	Copperbelt ($n = 144$)	Eastern ($n = 98$)	Luapula ($n = 128$)	Lusaka ($n = 108$)	Muchinga ($n = 85$)	Northern ($n = 110$)	North-western ($n = 114$)	Southern ($n = 69$)	Western ($n = 61$)	Total ($n =$ 1,026)
Highest education attained											
Primary	28.44	5.56	20.41	36.72	34.26	12.94	21.82	9.65	23.19	14.75	20.86
Secondary	34.86	31.94	46.94	35.16	18.52	40.00	35.45	42.98	17.39	37.70	34.31
Tertiary	29.36	61.11	24.49	26.56	36.11	29.41	35.55	41.23	59.42	47.54	38.79
None	3.67	0.00	4.08	1.56	5.56	8.24	0.00	2.63	0.00	0.00	2.53
Informal training	3.67	1.39	4.08	0.00	5.56	9.41	7.27	3.51	0.00	0.00	3.51
Years in production											
4–7 years	78.90	84.72	48.98	60.94	80.56	41.18	79.09	60.53	62.32	67.21	67.84
8–11 years	15.60	8.33	34.69	32.81	13.89	21.18	11.82	28.07	30.43	32.79	21.83
12–15 years	3.67	6.25	9.18	6.25	3.70	21.18	3.64	9.65	7.25	0.00	7.02
16–20 years	0.00	0.00	0.00	0.00	0.00	4.71	1.82	0.00	0.00	0.00	0.58
Over 20 years	1.83	0.69	7.14	0.00	1.85	11.76	3.64	1.75	0.00	0.00	2.73
Household monthly income (ZMW)											
$<$ 2,500	23.85	4.17	18.37	40.53	25.93	17.65	12.73	6.14	4.35	16.39	17.45
2,500–5,000	21.10	29.17	30.61	40.73	15.74	42.35	45.45	9.65	11.59	27.87	27.88
5,001–7,500	18.35	22.22	31.63	6.25	14.81	27.06	4.55	8.77	42.03	8.20	17.45
7,501–10,000	13.76	20.14	4.08	7.81	12.96	7.06	22.73	14.04	0.00	9.84	12.18
10,001–12,500	10.09	13.19	4.08	1.56	0.00	3.53	0.00	10.53	23.19	13.11	7.31
12,501–15,000	5.50	4.17	6.12	1.56	4.63	0.00	1.82	17.54	0.00	11.48	5.26
15,001–17,500	0.00	2.78	1.02	0.00	0.00	0.00	2.73	1.75	0.00	0.00	0.97
17,501–20,000	0.00	2.78	0.00	0.00	3.70	1.18	3.64	9.65	8.70	3.28	3.12
$>$ 20,000	7.34	1.39	4.08	1.56	22.22	1.18	6.36	21.93	10.14	9.84	8.32
Other livelihood sources (besides aquaculture)											
Agriculture	90.83	83.33	72.45	92.19	64.81	63.16	62.30	78.26	83.64	94.12	79.34
Livestock	66.06	59.72	55.10	84.38	43.52	58.77	55.74	42.03	44.55	69.41	58.97
Horticulture	50.46	56.25	39.80	80.47	37.96	40.35	50.82	56.52	17.27	57.65	49.03
Business	37.61	15.28	46.94	50.00	36.11	21.05	40.98	37.68	32.73	74.12	37.62
Formal salary	24.77	50.00	22.45	38.28	12.04	17.54	16.39	36.23	11.82	42.35	27.97

TABLE 3 Association between different elements of climate change and perceived increase in cost of aquaculture production observed by aquaculture producers in Zambia.

Perceived climate changes against cost of production	Level of agreement to observed change (%)				Pearson's chi-square (X^2)	*P*-value
	Neutral	Low	Medium	High		
Rising temperature						
No observed change	7	8	67	103	6.188	0.402
Cost has decreased	2	6	41	67		
Cost has increased	47	27	247	404		
Drought frequency						
No observed change	34	26	79	46	29.721	0.000
Cost has decreased	4	15	45	52		
Cost has increased	94	149	278	204		
Flooding frequency						
No observed change	44	46	50	45	27.003	0.000
Cost has decreased	6	23	37	50		
Cost has increased	128	168	234	195		
Cyclones						
No observed change	80	73	23	9	37.899	0.000
Cost has decreased	38	24	36	18		
Cost has increased	300	252	104	69		
Disease outbreak						
No observed change	86	73	18	8	14.305	0.026
Cost has decreased	38	51	23	4		
Cost has increased	321	266	88	50		

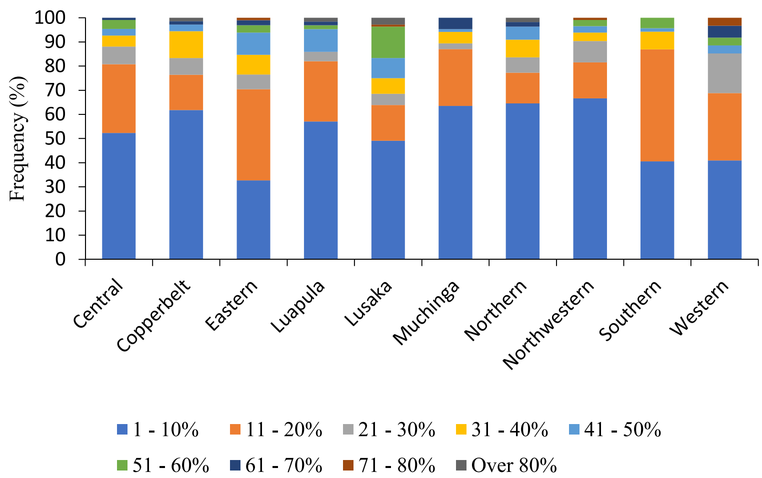

FIGURE 6
The estimated extent of changes in aquaculture production cost resulting from perceived climatic changes.

tilapia (*Oreochromis andersonii)* was the most abundantly cultured species in Central, Copperbelt, Eastern, Lusaka, Northwestern, and Western provinces. However, it was not reported in the Southern province where the invasive Nile tilapia was the only cultured species recorded. Other widely cultured species were the red breast tilapia (*Coptodon rendalli*) and the green head tilapia (*Oreochromis macrochir)*. Tanganyika tilapia (*Oreochromis tanganyicae)* was also an important species in Northern and to some extent in Muchinga province. Notably, the invasive Nile tilapia was reported in all provinces but by very few producers in

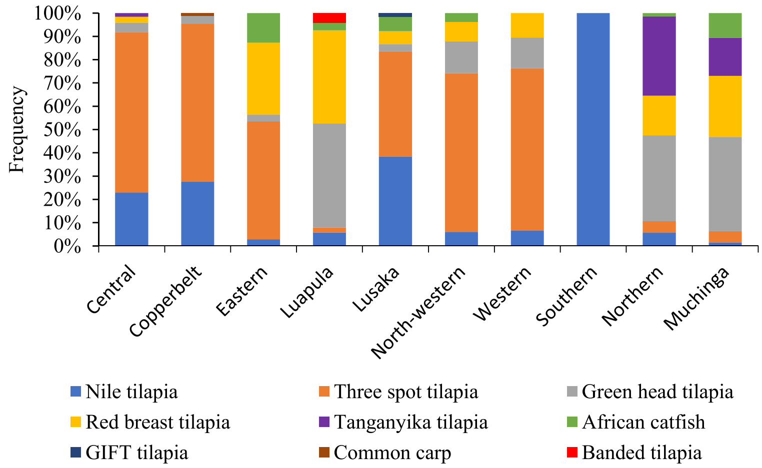

FIGURE 7
Aquaculture species reportedly cultured by the respondents in Zambia.

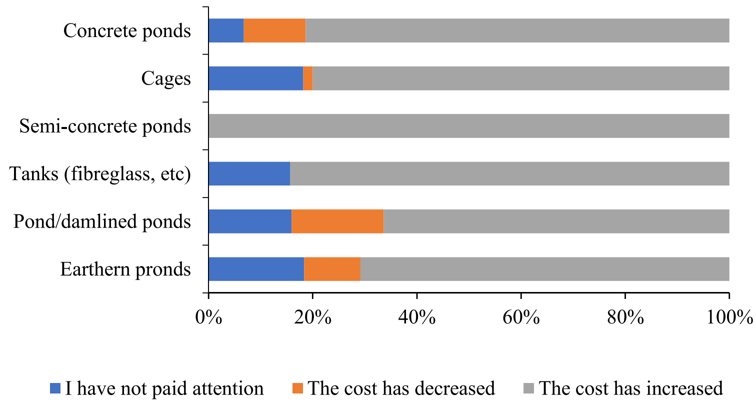

FIGURE 8
Effect of perceived climate-related changes on production costs against different aquaculture production systems used in Zambia.

most provinces such as Eastern, Northwestern, Western, Northern, and Muchinga provinces. Furthermore, the genetically improved farmed tilapia (GIFT, *O. niloticus*) was reported by very few producers in Lusaka province.

3.3.2 Production systems

Most respondents across the country associated climatic changes with increased cost of production in aquaculture (Figure 8). Notably, Lusaka province had the lowest number of respondents agreeing to this perception while higher numbers were reported in Western, Muchinga, and Luapula provinces. Interestingly, a higher number (31%) in Northwestern province did not agree that the cost of production had changed due to climate-related changes. Contrariwise, at least 20% of the respondents in Eastern and Lusaka provinces reported a decline in production costs due to climate change. Further analysis showed the increase in production costs due to climate change was lowest among those that used earthen ponds, whether dam/pond lined or not, and highest among those that used concrete, semi-concrete, and tanks as production systems.

3.3.3 Farm insurance

The present study showed that over 85% of the aquaculture producers in Zambia did not insure their aquaculture farms (Table 4). The highest number of insured farms were recorded in the Eastern province followed by the Southern province. However, most of the respondents in all provinces were willing to insure their farms. The major reasons for not insuring the farms across the country were a lack of knowledge of how insurance works and a lack of financial resources (Figure 9).

3.3.4 Producer assets

Different assets reportedly owned by the aquaculture producers in each province of Zambia are displayed in Figure 10. Generally, a variety of assets were owned by the aquaculture producers in all the provinces. Notably, bicycles, chicken, smart/cell phones, land, and radio were the major assets across the country.

3.4 Adaptation strategies

Different adaptation measures were employed by the aquaculture producers across the country (Figure 11). Notably, a substantial number of producers in Muchinga (34%), Northern (52%), North-western (35%), Lusaka (34%), Luapula (45%), and Copperbelt (45%) provinces were not taking any measures. Among those who were taking some measures, diversification was the most practiced measure in Muchinga (32%), Southern (29%), North-western (36%), Lusaka (22%), Eastern (41%), central (38%) and Copperbelt (22%) provinces. Except in Lusaka province, all provinces had respondents who abandoned their production facilities in some cases, and this was more (15%) frequent in the Eastern province.

The specific adaptation measures employed by aquaculture producers in Zambia are further detailed in Table 5. This table provides additional information on major adaptation strategies highlighted in Figure 11, focusing on those that are not self-explanatory, including diversification into other farming activities, adjusting growing periods, production facility adjustments, and improving resource use. As highlighted in the table, common strategies include diversifying into crop and livestock farming, adjusting growing periods by delaying stocking until rains start or floods recede, and making production facility adjustments such as building longer pond dykes and changing locations or types of production systems. To improve resource use, farmers across all provinces focus on water storage, rainwater harvesting, and enhancing water use efficiency.

TABLE 4 Insurance status of the aquaculture farms in different provinces of Zambia.

Province	Is your farm insured?		Would you be interested in insuring your farm?	
	No (%)	Yes (%)	No (%)	Yes (%)
Central ($n = 109$)	96.33	3.67	11.01	88.99
Copperbelt ($n = 144$)	100.00	0.00	6.94	93.06
Eastern ($n = 98$)	89.80	10.20	13.27	86.73
Luapula ($n = 128$)	96.88	3.13	21.09	78.91
Lusaka ($n = 108$)	96.30	3.70	39.81	60.19
Muchinga ($n = 85$)	100.00	0.00	21.18	78.82
Northern ($n = 110$)	95.45	4.55	16.36	83.64
Northwestern ($n = 114$)	92.98	7.02	20.18	79.82
Southern ($n = 69$)	92.75	7.25	17.39	82.61
Western ($n = 61$)	100.00	0.00	13.11	86.89

3.4.1 Barriers to adaptation

Several factors that hindered successful adaptation among the respondents are presented in the table below (Table 6). Most respondents in Central Province, Eastern Province, Luapula Province, Lusaka Province, Northern Province, Northwestern Province, Southern, and Western province indicated that inadequate financial resources were the major factor affecting adaptation. However, in Copperbelt province, the majority lacked adequate knowledge and information. A large proportion in most provinces also reported that the aquaculture species available were limited. Overall, inadequate financial resources, lack of adequate knowledge and information, and limited fish species were the major factors affecting adaptation to climate change in aquaculture in Zambia.

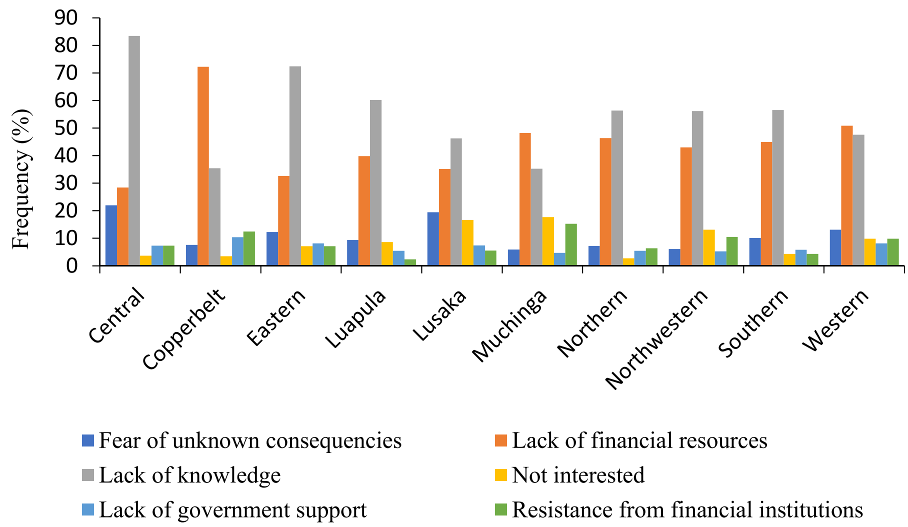

FIGURE 9
Reasons for not insuring aquaculture farms in different provinces of Zambia.

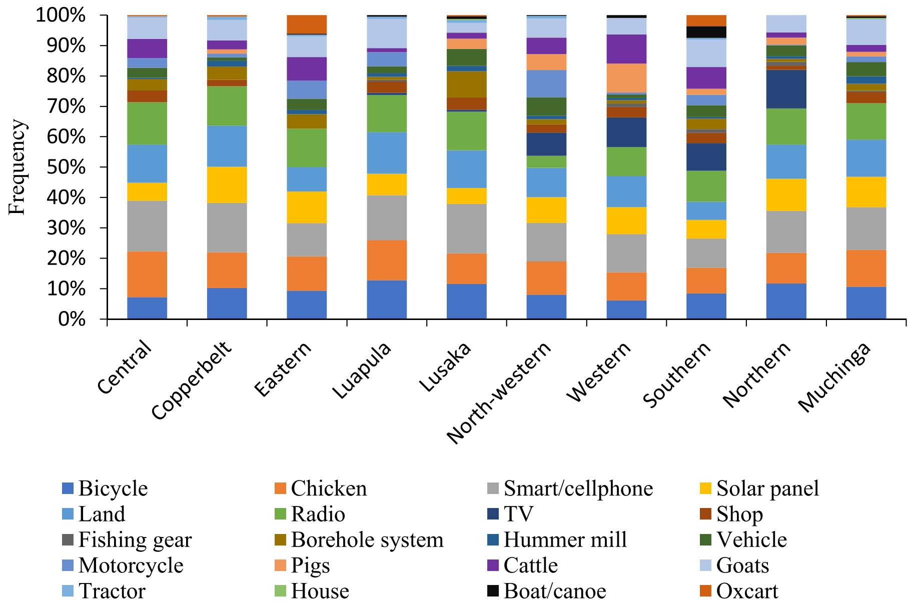

FIGURE 10
Main assets owned by the aquaculture producers in Zambia.

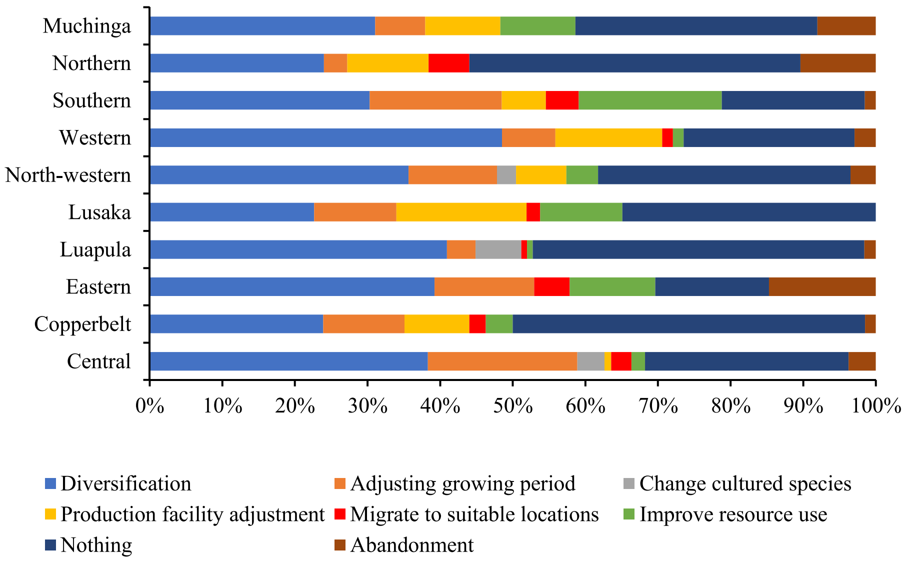

FIGURE 11
Adaptation strategies used by aquaculture producers in Zambia against perceived changes in climate.

4 Discussion

Aquaculture presents a promising solution to boost fish production amidst the stagnation and decline of wild fisheries production globally. However, the ongoing climate change, as noted by the Intergovernmental Panel on Climate Change (IPCC) (2018), threatens aquaculture production significantly. Therefore, understanding the varied impacts of climate change on aquaculture across different geographical contexts is crucial for creating a climate-resilient aquaculture sector. In this study, we conducted a nationwide survey to understand the perceived effects of climate change on aquaculture production in Zambia. We also explored the vulnerability factors and adaptation strategies employed by aquaculture producers.

4.1 Climate knowledge and perceived effects

The results of the current study revealed that most aquaculture producers across the country had knowledge of climate change and

TABLE 5 Selected adaptation measures to climate change in Zambian aquaculture by Province.

Province	Diversification	Adjusting growing period	Production facility adjustment	Improve resource use
Central	Crop farming; livestock farming,	Delay stocking until rains start, wait until floods recede.	Build longer pond dykes, change location of production facility	Rainwater harvest, water storage.
Copperbelt	Crop farming; livestock farming, horticulture	Delay stocking until rains start	Change location of production facility	Water storage
Eastern	Crop farming; livestock farming	Delay stocking until rains start, wait until floods recede	Change location of production facility, change type of production system	Rainwater harvest, water storage.
Luapula	Crop farming, livestock farming, Fishing	Delay stocking until rains start, wait until floods recede.	Change location of production facility	Water storage
Lusaka	Crop farming, livestock farming, Fishing, venture into business	Delay stocking until rains start, wait until floods recede.	Change type of production system, Change production size,	Rainwater harvest, water storage. water re-use
North-western	Crop farming; livestock farming, horticulture.	Wait until water is easily accessible	Build longer pond dykes, change type of production system.	Water storage, Improve water use efficiency, water storage.
Western	Crop farming, livestock farming, Fishing	Delay stocking until rains start, wait until floods recede.	Change type of production system, change location of production facility.	Water storage, improve water use efficiency.
Southern	Crop farming, livestock farming, Fishing	Delay stocking until rains start, wait until floods recede.	Change type of production system (i.e., use pond liners), Build longer pond dykes, Change location of production facility	Rainwater harvest, water storage. improve water use efficiency
Northern	Crop farming; livestock farming, horticulture.	wait until floods recede	Build longer pond dykes,	Improve water use efficiency
Muchinga	Crop farming; livestock farming, horticulture.	Wait until water is easily accessible	Change type of production system (i.e., use pond liners), change size of production unit.	Improve water use efficiency.

attributed it mainly to human activities. Although both human activities and natural causes are responsible for climate change, human activities are known to be the major contributor to climate change [Intergovernmental Panel on Climate Change (IPCC), 2018]. The high awareness of climate change and its causes in this study was due to the high literacy levels of the respondents which was also confirmed by a strong association between education level and climate change knowledge obtained in the present study. Thus, education is very crucial in successful aquaculture operations especially with emerging challenges like climate change (Adebo and Ayelari, 2011). Additionally, most aquaculture producers across the country owned radio and television sets that promoted their access to climate-related knowledge and information.

Various climate-related changes were including rising temperatures, changes in rainfall patterns either as droughts or flooding, cyclones, and disease outbreaks were reported by the aquaculture producers in the current study. Most respondents across the country strongly agreed to a rise in temperature and changes in rainfall patterns leading to prolonged periods of either drought or flooding. Similarly, studies by Tologbonse et al. (2010) and Aphunu and Nwabeze (2013) in Nigeria also reported these climate changes. These changes were further attributed to the rise in aquaculture production costs which can adversely affect aquaculture productivity. Rising temperature can negatively affect fish physiology particularly if it rises beyond the tolerance range of aquaculture species while changes in rainfall patterns can increase water resource use competition if low or destroy production facilities if high (Maulu et al., 2021a).

Although most aquaculture producers across the country strongly agreed to climate related temperature rise, there was no association with increased cost of aquaculture production probably because Zambia's aquaculture production relies on warm water fish species such as tilapia, catfish, and carp (Mphande et al., 2023; Zhang et al., 2023). These findings suggest that while temperature rise has been reported by the aquaculture producers in the country, it is still within the tolerance ranges of the cultured species. However, a rise in temperature may also compound the negative effects caused by other elements of climate change such as disease outbreaks if it increases the virulence of warm water pathogens (Maulu et al., 2021a). The present study revealed changes in rainfall patterns (rainfall or drought), frequency of cyclones and disease outbreaks were strongly associated with increased cost of production. The increased occurrence of droughts results in reduced water quantity and quality, often triggering conflicts over water usage across sectors like aquaculture, agriculture, construction, and domestic needs (Barange et al., 2018). This dynamic can adversely impact aquaculture production by driving up water demand, subsequently inflating production costs. Therefore, the profits of the aquaculture producers are likely to be reduced, consequently affecting food and nutrition security negatively in the country. It is important to note that, despite weak agreement on the increased frequency of cyclones and disease outbreaks, these factors are strongly associated with rising production costs. In Mozambique for instance, cyclones have been documented to cause significant destruction to aquaculture ponds, hatcheries, and farm infrastructure (Muhala et al., 2021). The medium agreement on the occurrence of disease outbreaks

TABLE 6 Factors affecting adaptation to climate change by the aquaculture producers in Zambia.

Province	Factors affecting adaptation						
	Fear of taking risks (%)	Low government support (%)	Limited culturable fish species (%)	Inaccess to assets, e.g., land (%)	Inadequate financial resources (%)	Lack of adequate knowledge (%)	None (%)
Central ($n = 109$)	3.00	2.00	30.00	0.00	71.00	23.00	2.00
Copperbelt ($n = 144$)	0.00	0.00	33.00	4.00	26.00	73.00	3.00
Eastern ($n = 98$)	9.00	0.00	42.00	6.00	50.00	32.00	0.00
Luapula ($n = 128$)	2.00	1.00	12.00	0.00	69.00	9.00	2.00
Lusaka ($n = 108$)	2.00	9.00	27.00	9.00	50.00	20.00	2.00
Muchinga ($n = 85$)	0.00	2.00	44.00	6.00	40.00	36.00	5.00
Northern ($n = 110$)	8.00	13.00	22.00	2.00	49.00	25.00	6.00
Northwestern ($n = 114$)	2.00	1.00	14.00	0.00	58.00	39.00	2.00
Southern ($n = 69$)	9.00	9.00	55.00	3.00	67.00	29.00	0.00
Western ($n = 61$)	0.00	5.00	36.00	5.00	52.00	38.00	0.00

in the Southern Province can be linked to the prevalence of respondents operating mainly on Lake Kariba, particularly in cages where potential bacterial pathogens have been identified (Bwalya et al., 2021; Ndashe et al., 2023). Although the mere presence of pathogens does not necessarily lead to disease outbreaks (Hasimuna et al., 2020; Maulu et al., 2021b), it is crucial to regularly monitor for disease outbreaks, as climate change is likely to increase the virulence of warm-water pathogens in aquaculture facilities (Maulu et al., 2021a).

Overall, the increase in aquaculture production associated with climate change was estimated to be up to 10% in most provinces, except in the Southern and Eastern provinces, where it was estimated at 11-20%. This increase could potentially cause adverse effects on aquaculture productivity, either directly or indirectly. It is important to note that the estimated changes in the cost of aquaculture production lacked supporting records and were based solely on producer estimates, which may not accurately reflect the impact. Nonetheless, it is essential to educate aquaculture producers about these climate-related changes and enhance their resilience, particularly in the more vulnerable provinces across the country.

4.2 Vulnerability factors

Various factors were identified that may increase the vulnerability of aquaculture producers and their production systems to climate change impacts in Zambia. The dependence of the Zambian aquaculture industry on closely related species, particularly tilapia species as also reported by previous studies (Maulu et al., 2019; Kaminski et al., 2022; Zhang et al., 2023) increases its vulnerability to climate change. Currently, tilapias account for at least 95 % of Zambia's aquaculture production by quantity, with the invasive Nile tilapia alone accounting for more than 60 % of the total production (FAO et al., 2022). This heavy reliance on a limited number of closely related species increases vulnerability to climate change. Diversifying the range of species, as suggested by Maulu et al. (2021a), is crucial for climate resilience in aquaculture. The current study also revealed that nearly all aquaculture farms were not insured, making aquaculture production in the country more vulnerable to climate-related risks (Maulu et al., 2021a).

Lack of financial resources to seek insurance schemes and lack of knowledge regarding insurance programs were the major factors attributed to very low farm insurance among the aquaculture producers in Zambia. Considering the high interest of the producers to insure their farms across the country, there is a need to address these challenges and promote policies that encourage insurance and specific aquaculture insurance packages are recommended. Moreover, while the aquaculture producers in Zambia possess a variety of assets, their low monetary value may limit resilience to climate change impacts in the long term. Moreover, the low uptake of adaptation measures among aquaculture producers, especially in provinces like Southern, Western, Lusaka, and Eastern that appear to be more vulnerable suggests a high susceptibility to climate change. These provinces may be more vulnerable due to factors such as prolonged droughts, flooding, and cyclones, as reflected in the reported 11–20% increase in production costs attributed to climate change. Furthermore, ponds were the primary culture facilities in Zambia, in line with previous research (Namonje-Kapembwa and Samboko, 2017; Hasimuna et al., 2020), likely due to relatively lower investment costs incurred in this system. Additionally, most producers using ponds either earthen or dam-lined reported lower climate-induced costs compared to those using other systems suggesting more resilience in these systems.

It is very important to note that the findings of this study suggest varying levels of vulnerability to climate change across the country. Some provinces particularly those within the agroecological zone I are likely to be more vulnerable to climate-induced changes. For instance, provinces like Western, Southern, Lusaka, and Eastern, generally represented the largest number of producers who reported the occurrence of all the elements of climate change discussed in this study. Within these provinces, vulnerability to the impacts of climate change may also vary based on production systems. In Southern province, for example, the effects of droughts are likely to be felt more by pond-based aquaculture producers compared to those practicing cage aquaculture. Conversely, in the Eastern region, where aquaculture is largely pond-based, drought will have devastating impacts on regional aquaculture production. Understanding the varying levels of vulnerability to climate change across the country is very crucial for developing a climate resilient aquaculture industry in Zambia.

4.3 Adaptation strategies

The knowledge of climate change and its impacts is crucial for the adoption of climate change adaption measures (Adimassu and Kessler, 2016; Lakhran et al., 2017; Sadiq et al., 2019; Abunyewah et al., 2023). Despite high awareness of climate change among producers in this study, the adoption of adaptation measures remained generally low across the country. Inadequate finances, few culturable fish species, and a lack of knowledge in alternative economic activities were the major factors hindering the adoption of adaptation measures. Nevertheless, some aquaculture producers in various provinces employed a range of adaptive strategies to enhance their resilience against environmental variability and optimize their production. Diversification of livelihoods and adjustments in fish growing periods and production facilities were the widely adopted adaptation strategies, agreeing with several other findings (Asiedu et al., 2017; Galappaththi et al., 2020; Abunyewah et al., 2023). Diversification into other income-generating activities such as crop farming, livestock farming, horticulture, and fishing provides financial stability and food security. The higher diversification in agriculture and livestock farming observed in the present study may be attributed to the fact that nearly all aquaculture producers were also engaged in these activities. Opportunities for improving livelihood diversification exist among aquaculture producers, who were already involved in additional income-generating activities like agriculture, livestock farming, horticulture, and fishing. However, these practices have historically been part of traditional livelihood systems rather than being specifically adapted to address changing climate conditions. This suggests that the observed diversification may represent a non-intentional adaptation strategy, primarily rooted in local traditions and cultural practices. Consequently, many producers may not recognize these actions as formal adaptation measures to climate change, which likely explains why the majority did not report any intentional adaptation strategies. Notably, fishing emerged as a widely embraced diversification strategy among aquaculture producers, especially those with farms situated near wild fishery resources, particularly in Southern, Luapula, and Western provinces. This may be attributed to lower investment costs in capture fisheries compared to aquaculture, considering that both systems face similar impacts of climate change (Barange et al., 2018; Muhala et al., 2021).

Due to changes in precipitation patterns, some aquaculture producers adapted by adjusting the growing period to match natural water availability and managing production facilities to mitigate risks associated with flooding and water scarcity. As observed by Srivastava et al. (2022), focusing on water management may be a critical measure for adapting to climate change in aquaculture production. Others adjusted their production facilities by building longer dikes and improved drainage systems to avoid flooding. Improving resource use through rainwater harvesting, water storage, and efficiency measures ensures sustainability and productivity in aquaculture operations across the country. However, these measures may also come with a cost, making it more challenging for small-scale producers and thereby increasing their vulnerability (Maulu et al., 2021a). The current study further revealed that producers in provinces in provinces that receive less annual rainfall are more likely to abandon production facilities, which emphasizes the critical role of water resources in aquaculture.

To address the low adoption of adaptation measures to climate change among the aquaculture producers in Zambia for sustainable aquaculture production, it is essential to tackle the identified hindrances. There is a need to promote increased access to support for aquaculture producers, especially the most vulnerable, to enhance income generation and food security. This includes promoting additional financial services that support diverse farm income-generating activities, along with providing appropriate training in multidisciplinary areas. Besides, enhancing research and development programs is crucial for diversifying aquaculture species in Zambia, moving beyond the current reliance on species from the same genus. Moreover, access to climate-related information through various widely covered media channels is crucial for aquaculture producers across diverse financial and social situations. However, successful adaptation must account for existing variations in producer vulnerability factors, which are often overlooked in mainstream programs. Therefore, enhancing producer-specific extension programs in the aquaculture industry is essential for effective climate change mitigation and adaptation.

5 Conclusion

This study investigated the perceived effects of climate change on aquaculture production in Zambia, vulnerability factors, and adaptation strategies. Climate change poses significant challenges to aquaculture production in Zambia, with observed impacts including rising temperatures, altered rainfall patterns, cyclones, and disease outbreaks, leading to increased production costs. Despite high awareness of climate change among aquaculture producers, the adoption of adaptation measures remains low due to financial constraints, limited fish species diversity, and insufficient knowledge of alternative economic activities. Livelihood diversification and adjustments in production facilities emerge as key adaptation strategies. Efforts to enhance aquaculture sustainability in Zambia amidst climate change should focus on promoting financial services supporting diverse income-generating activities, investing in research and development for exploring diverse aquaculture species, and strengthening producer-specific extension programs. Moreover, access to climate-related information through mass media channels plays a crucial role in preparing producers for climate change impacts. Addressing these challenges and promoting proactive adaptation measures are essential for building a climate-resilient aquaculture industry in Zambia and ensuring long-term food security and livelihood sustainability.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding authors.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the [patients/participants OR patients/participants legal guardian/next of kin] was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

SMa: Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing, Conceptualization. OH: Data curation, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – review & editing. MC: Data curation, Resources, Supervision, Validation, Writing – review & editing. IB: Data curation, Resources, Supervision, Validation, Writing – review & editing. JMp: Data curation, Methodology, Resources, Software, Writing – original draft, Writing – review & editing. MM: Data curation, Resources, Writing – review & editing. KN: Data curation, Resources, Writing – review & editing. DC: Data curation, Methodology, Resources, Validation, Writing – review & editing. SS: Data curation, Resources, Validation, Writing – review & editing. JMb: Data curation, Resources, Writing – review & editing. LN: Data curation, Resources, Writing – review & editing. FB: Data curation, Resources, Writing – review & editing. IM: Data curation, Methodology, Resources, Software, Writing – review & editing. MK: Data curation, Resources, Writing – review & editing. SMw: Data curation, Resources, Writing – review & editing. MS: Data curation, Resources, Writing – review & editing. ES: Data curation, Methodology, Resources, Validation, Writing – review & editing. II: Data curation, Resources, Writing – review & editing. HM: Data curation, Resources, Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Acknowledgments

The authors would like to acknowledge the strong support from the Zambian Department of Fisheries and, Ministry of Fisheries and Livestock at the National level and in all sampled districts across the country during data collection. Furthermore, the support of the aquaculture producers interviewed is greatly appreciated.

Conflict of interest

IB was employed by IBAN Aquafish Solutions and Consultancy Ltd.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2024.1348984/full#supplementary-material

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