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Management practices, farmers' perceptions and coping strategies and challenges to climate change in integrated fish farms in Kenya

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Abstract

Climate change continues to threaten the sustainability of aquaculture systems due to the dependence of this sector on water resources which are threatened in a changing climate. There is therefore need to continually assess the current farm level practices with a view to developing the right policies and to make the necessary changes. A study was done to assess the management practices, perceptions, coping strategies and challenges of coping with climate change on integrated fish farms in Kajiado and Machakos Counties in Kenya. Data were collected from 51 and 186 integrated fish farms in Kajiado and Machakos Counties, respectively. A cross-sectional household survey was done using semi-structured questionnaires to collect the data. The data were validated using meteorological data, four key informants' interviews and a focus group discussion with 17 farmers in each County. Most of the household heads were males (80.4% in Kajiado County and 80.1% in Machakos County) and *Oreochromis niloticus* was the main fish species cultured by 78.4% and 79% of households in Kajiado and Machakos Counties, respectively. The integrated fish farms were able to outsource manure and crop residues from neighbouring farms for their potential use in compost heat recovery as a coping strategy to climate change. Most of the respondents reported the occurrence of extreme changes in precipitation (rainfall and hailstorms) and temperature. Only 11.8% and 9.14% of respondents in Kajiado and Machakos Counties, respectively, reported a decrease in ambient night temperature. The farmers adopted climate change coping strategies such as topping up fishpond water and covering the fishponds with a shade net. The challenges faced by fish farmers with regard to coping with climate change were inadequate funds, skills, and water resources. It is recommended that further training of fish farmers on potential coping strategies such as compost heat recovery should be carried out.

Keywords: *Aquaculture; compost; crop residues; manure; sustainability*

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Introduction

Climate change is mainly caused by greenhouse gas emissions emanating from human activities such as burning of fossil fuels (UNFCCC, 2011). This has led to the increased frequency of precipitation and temperature extremes which are highest in the tropics, where most developing countries are located. Despite the fact that they have the least contribution to anthropogenic causes of climate change (Robinson et al., 2021), developing countries have been severely affected by these changes. The continuous rise in global temperatures prompted the nations of the world to come up with the Paris Agreement of 2015 that proposed to limit it to a 2°C rise above pre-industrial levels (1850-1900) and make efforts to reduce it to a 1.5°C rise (Gao et al., 2017). The 1.5°C cap was affirmed as a better target by the Intergovernmental Panel on Climate Change (IPCC) special report of 2018 (Masson-Delmotte et al., 2019). This can be achieved through the reduction in the use of fossil fuels, capturing and sequestering carbon dioxide from the atmosphere, and using geoengineering to stabilize global temperatures (Fawzy et al., 2020). However, those who support these strategies have contradicting views, such as suggesting the adjustment of the pre-industrial level to be between 1940 and 1970 (Lüning and Vahrenholt, 2017), while others cite economic, infrastructure and operational barriers (Kumar et al., 2023). Some countries totally oppose the strategies due to the implied political and economic consequences (Rhodes, 2019). This has slowed down the implementation of these strategies despite the documented increase in global temperature (Horton et al., 2016; van der Wiel and Bintanja, 2021), and the consequences on precipitation (O'Gorman, 2015), human health, the economy, and the environment (Butler, 2018; Fawzy et al., 2020; Marx et al., 2021).

The increased occurrence of harsh climatic conditions in Kenya, such as droughts and varying ambient temperatures, have been attributed to climate change (Government of Kenya, GoK, 2016). Therefore, climate change needs to be addressed urgently worldwide thus the Food and Agriculture Organization of the United Nations (FAO) came up with the concept of Climate Smart Agriculture (CSA) in 2010 which seeks to address both climate change and food security issues (GoK, 2017). It is a concept based on three main pillars (triple wins): sustainable increase of productivity and incomes from agriculture; building resilience and adapting agriculture to climate change; reducing greenhouse gas emissions where possible (Newell et al., 2019). This concept was adopted by the World Bank, which funded the Kenya Climate Smart Agriculture Project (KCSAP) that aimed to promote climate smart agriculture practices in crop, livestock, fisheries (inclusive of aquaculture) and forestry sectors, and their integration on farms in Kenya (GoK, 2017).

Air temperatures have a direct effect on the temperature of water bodies such as seas, oceans, lakes, rivers, streams, and even fishponds, but the relationship is complex and several prediction models have been tried with varying results (Zhu et al., 2018). A study on the relationship between Lake Surface Water Temperature (LSWT) and air temperature reported that the LSWT increased with increase in air temperature (Brkić, 2023). Another study reported that the changes in water body temperature due to changes in air temperature can be direct/equal, or water temperature can rise at a slower rate (due to the high specific heat capacity of water), or the water temperature can fall at a slower rate (due to hysteresis effect) (Yu et al., 2021).

The increased occurrence of extremely high temperatures has been attributed to climate change (Clarke et al., 2022). High water temperature has been found to increase fish metabolism and activity, and expose the fish to hypoxia (Li et al., 2023). There is an inverse relationship between dissolved oxygen level and water/environmental temperatures. As the temperature of water increases, there is a reduction in dissolved oxygen saturation level in water. A study in India found that for every 1°C rise in river water temperature, there was a 2.3% decrease in dissolved oxygen saturation in the river water (Rajesh and Rehana, 2022). This has a negative impact on fish because they rely on dissolved oxygen in the water for their metabolism and growth (Volkoff and Rønnestad, 2020). However, quantifying this negative impact on different fish species is difficult because of differences in their morphological characteristics, feeding habits, habitats, the environmental variables considered, and the relationship between these variables and fish growth (Wang et al., 2020; Huang et al., 2021).

On the other hand, the frequency of occurrence of cold temperature extremes has declined, but they still exist (Clarke et al., 2022). Low water temperatures are caused by the normal diurnal changes, seasonal changes, or temperature shocks due to climate change and it causes cold stress, particularly in warm water fish species, resulting in impairment in their biochemical and physiological processes (Panase et al., 2018). The main coping strategies for low temperature that have been tried in Kenya are aquaponics and Recirculating Aquaculture Systems (RAS): However, these strategies have low adoption rates due to high technical skills requirement and high capital and operational costs (Munguti et al., 2022). Therefore, there is a need to come up with adaptive strategies to low fishpond water temperatures that require low technical skills, low capital, low operation costs and are sustainable.

Climate change coping strategies by fish farmers vary a lot in different regions. On the western shores of Lake Malawi, small scale fisher folk have adopted to climate change by opening small businesses and looking for work as casual laborers to supplement their income, putting more land under crop cultivation, using more efficient but illegal fishing nets and increasing fishing time (Limuwa et al., 2018). A study by Nguyen et al. (2015) of Striped catfish farmers in Vietnam reported that the farmers adapted to climate change by either changing their farming practices, changing the fish species cultured, or abandoning aquaculture altogether.

Integrated farming involves the use of waste products from one farming enterprise as inputs for another enterprise thus increasing the overall efficiency of the whole farm due to synergism of the farming enterprises (Edwards et al., 1988). The main form of aquaculture practiced in Kenya is the farming of warm water fish species, especially Nile Tilapia (*Oreochromis niloticus*) and African Catfish (*Clarias gariepinus*) under semi intensive culture (Munguti et al., 2021a). This culture system also involves the addition of livestock manure to fishponds to enhance growth of phytoplanktons, zooplanktons, and aquatic insects which are natural feeds for some fish species. However, untreated (raw) livestock manure poses risks to fish health, food safety and public health due to the presence of pathogens such as *Aeromonas hydrophila*, *Escherichia coli*, and *Salmonella* spp. that can be transmitted from livestock manure to fish and humans (Dang and Dalsgaard, 2012; Olgunoğlu, 2012). It is therefore important to process the livestock manure before use in fishponds through common manure treatment methods such as sun-drying, aerobic composting or anaerobic digestion (Ndambi et al., 2019).

Kajiado and Machakos Counties were selected for this study because of their vulnerability and exposure to extremes of climate, being in the semi-arid agro-ecological zone (Irungu et al., 2016; Nunow et al., 2019). In addition, they are close to Nairobi city, one of the main fish market outlets in Kenya (Awuor et al., 2019), and therefore, a possible destination for fish produced in these Counties. The current study assessed fish farmers' observations of two indicators of climate change, namely precipitation and temperature changes, their coping strategies, and challenges faced when adopting the coping strategies. This is important because the perception of climate change is the starting point for adoption of coping strategies because it changes the attitude of the farmers and makes them more willing to adopt strategies to safeguard their livelihoods now and in the future (Prokopy et al., 2015; Zhai et al., 2018). Therefore, the objective of this study was to assess the management practices on integrated fish farms, the perceptions of the fish farmers towards climate change, their adopted coping strategies, and their adoption challenges in Kajiado and Machakos Counties in Kenya.

Materials and Methods

Study sites

This study was carried out in four Sub-Counties in Kajiado County and four Sub-Counties in Machakos County in Kenya. In Kajiado County, the number of households interviewed in each Subcounty were 9 (Kajiado Central), 9 (Kajiado West), 7 (Kajiado East) and 26 (Kajiado South). The number of households interviewed in each Subcounty in Machakos County were 19 (Kangundo), 40 (Matungulu), 57 (Masinga), and 70 (Yatta). The number of fish farmers in Kajiado County was lower than those in Machakos County because the majority of people living in Kajiado County practice pastoralism (County Government of Kajiado, 2018) compared to those in Machakos County who mainly practice sedentary agriculture (County Government of Machakos, 2018).

Sampling frame and sampling procedure

The sampling frame was identified using secondary data on active fish farmers in each County. This was obtained from the Fisheries departments of the Counties. There was a total of 85 and 911 active fish farmers in Kajiado and Machakos Counties, respectively. These numbers (small population sizes) were used in the Yamane formula of 1967 (Equation (Eq.) 1) for sample size determination.

$$n = \frac{N}{(1+N(e^2))}$$

Eq. (1)

Where n= sample size, N= Active fish farmers, e= precision level of 0.05

Kajiado County: $n = \frac{85}{(1+85(0.05^2))}$ = 71 active fish farmers targeted

Machakos County: $n = \frac{911}{(1+911(0.05^2))}$ = 278 active fish farmers targeted

The calculated sample size of active fish farmers was 71 and 278 in Kajiado and Machakos Counties, respectively. Out of these, the farmers who practiced integrated fish farming (either crop-fish farming, livestock-fish farming or crop-livestock-fish farming) and had at least 10 years' experience in any one of their farming enterprises were purposively selected from the calculated sample size of active fish farmers during the farm visits: the only available secondary data was on active fish farmers and not farmers practicing integrated fish farming and having more than 10 years of farming experience (in order to validate their perception of climate change). Therefore, the calculated sample size helped to give the maximum acceptable number of respondents to be purposively selected for the study. As a result, data were collected from 51 and 186 fish farmers in Kajiado and Machakos Counties respectively who were identified as the household heads. The main information collected during the household survey were the fish management practices, the perceived changes in climate, the adopted coping strategies, the encountered coping challenges and the availability and uses of crop residues and animal manures on the farms.

The data obtained were validated using key informant interviews and focus group discussions. Four key informants in each County were interviewed, consisting of the County Directors of Fisheries, Agriculture, Livestock, and Meteorological Department. They were interviewed before the household survey. The main information collected during the key informant interviews were the common fish species kept in the area and the number of active fish farmers, the major crops grown in the area and the uses of crop residues, the major livestock species kept and the uses of their manure, and the main climate change effects observed in the area.

Focus group discussions with 17 participants (fish farmers) were held in each County after the household survey. The discussants were identified and recruited after the household survey in each Sub-County by the researcher and the Fisheries extension officer in charge of the Sub-County. This selection was done after the household survey because of the lack of secondary data based on the selection criteria of being a successful fish farmer who actively practiced integrated fish farming and had at least 10 years' farming experience. The participants were also selected based on different income levels, ages, professions and education level. The selection ensured that male and female farmers were represented (12 male and five female participants in Kajiado County and 11 male and six female participants in Machakos County). The questions were made simple and open ended and the sessions were moderated by the researcher assisted by the Sub-County Fisheries extension officer in order to avoid individual and group bias. The main information collected during the focus group discussions were the major fish species kept, the common fish management practices in the area, the main crops grown and livestock kept in the area and the perceptions of climate change and their coping strategies and challenges. The focus group discussions were located at a convenient central farm of one of the participants and they lasted for approximately 90 minutes each.

Methods and tools for data collection

The data collection tool used in the study was a semi structured questionnaire. Eight and 15 trained enumerators from Kajiado and Machakos Counties, respectively, were trained on the aim of the study and the proper administration of the tool in order to reduce enumerator bias and to standardize the data collection. Each of them then pretested the questionnaire on a fish farmer and the researcher subjected the responses to a language test that yielded a cronbach alpha coefficient of 0.7 which is within the acceptable range as described by Ngo et al. (2022) and Zobeidi et al. (2022). The questionnaire was then administered in the household survey through face-to-face interviews by the enumerators. The data were collected for three months between June and August, 2021. This was a cross-sectional survey conducted in purposively selected administrative wards having high numbers of fish farms in 4 Sub-Counties in each of the two Counties.

Data handling and analysis

The collected data were cleaned, sorted, entered into a Microsoft excel worksheet and exported to the Statistical Package for Social Sciences (SPSS) Version 25 for analysis. Descriptive statistics were generated from qualitative and quantitative data. Chi square $\chi 2$ analysis was carried out to assess the significance of the differences between counties in terms of gender of respondents and fish species cultured. Assumptions made were that the samples were randomly collected, the observations made were independent of each other and all cell entries had frequencies greater than five. The number of ponds per farmer, gross profit and farm size failed the normality test and were therefore analyzed using the Mann-Whitney U test. All outputs were considered significant at $p<0.05$.

Validation of perceptions of climate change using meteorological data

Annual average minimum and maximum temperature and rainfall data for a thirty-year period (1990-2020) were obtained from the Kenya Meteorological Department (2021) data set and entered into a Microsoft excel worksheet. The data were then plotted on graphs. The relationship between time and temperature or precipitation were investigated using Pearson product-moment correlation analysis for parametric data and Spearman rank-order correlation analysis for non-parametric data. Linear regression analysis was also carried out on the parametric data (maximum temperature) for Kajiado and Machakos Counties. Assumptions that all the variables are continuous, have a linear relationship, lack significant outliers, are normally distributed (for Pearson correlation analysis), and have homoscedasticity (cigar shaped uniform distribution) were met. All data was considered significant at $p<0.05$. The analysis results of the meteorological data were then compared with the findings of the household survey on farmer perceptions of changes in precipitation and temperature.

Limitations of the study

The low number of farmers with more than 10 years' experience in fish farming (in order to justify perception of climate change) resulted in the use of farmers with more than 10 years' experience in either crop or livestock farming on their integrated fish farms. Also, the main focus of the current study was integrated fish farms, therefore, integrated farms that had recently abandoned fish farming were left out of the study.

Results

Socio-economic characteristics of farmers in Kajiado and Machakos Counties

Most of the household heads interviewed in the current study were male with almost equal percentages in Kajiado and Machakos Counties (80.4% in Kajiado County and 80.1% in Machakos County) as shown in Table 1. A Chi-square test for independence indicated no significant ($p>0.05$) association between County and gender of respondents, χ^2 (degrees of freedom = 1, n= 237) = 0.002, p value = 0.964. In contrast, the few female household heads involved in fish farming had a higher average number of fish ponds: Female household heads had on average 1.5 ponds with a median of 1, minimum of 1 and maximum of 18 ponds compared to male-headed households who had an average of 1.1 ponds, median of 1, minimum of 1 and maximum of 5 ponds. Female household heads also reported higher gross profit (average KSH. 30346, median KSH. 3900, minimum KSH. -807600 and maximum KSH. 616700) compared to male household heads (average KSH. 8111, median KSH. -5750, minimum KSH. -374100 and maximum KSH. 563000). In addition, male farmers had larger land sizes (average 9.4 acres, median 5 acres, minimum 0.24 acres and maximum 200 acres) than female farmers (average 5.5 acres, median 4 acres, minimum 0.5 acres, maximum 35 acres). Land size values were given by the farmers themselves. The number of ponds per farmer, gross profit and land size were not significantly (p>0.05) different between female-headed and male-headed households when tested using the Mann-Whitney U test.

Table 1

Socioeconomic Characteristics of Farmers in Kajiado and Machakos Counties

No.	Dependent variable	N	%	Independent variable	N	%	χ^2	p value
1.	Female	10	19.6	Kajiado	51	21.5	0.002	0.964
	Male	41	80.4					
	Female	37	19.9	Machakos	186	78.5		
	Male	149	80.1					
2.	Nile Tilapia (*O. niloticus*)	187	78.9	Kajiado	40	78.4	0.009	0.926
				Machakos	147	79.0		
3.	African Catfish (*C. gariepinus*)	38	16.0	Kajiado	14	27.5	5.258	0.017
				Machakos	24	12.9		
4.	Tilapia and catfish	21	8.9	Kajiado	3	5.9	0.321	0.579
				Machakos	18	9.7		
5.	Ornamental fish	1	0.4	Kajiado	1	2	0.482	0.215
				Machakos	0	0		
6.	Nile Tilapia (*O. niloticus*)	187	78.9	Female	39	83.0	0.319	0.551
				Male	148	77.9		
7.	African Catfish (*C. gariepinus*)	38	16.0	Female	5	10.6	0.817	0.374
				Male	33	17.4		
8.	Tilapia and catfish	21	8.9	Female	4	8.5	0.009	0.925
				Male	17	8.9		
9.	Ornamental fish	1	0.4	Female	1	2.1	0.575	0.198
				Male	0	0		
No.	**Dependent Variable**	**Independent variable**	**N**	**%**	**Mean**	**Md**	**U**	**p value**
10.	Farm size (acres)	Female	47	19.8	5.5	4		
		Male	190	80.2	9.4	5	3813.5	0.120
11.	Number of ponds per farmer	Female	47	19.8	1.5	1		
		Male	190	80.2	1.1	1	4387.5	0.530
12.	Gross Profit (KSH.)	Female	45	19.8	30346	3900		
		Male	182	80.2	8111	-5750	3829.0	0.500

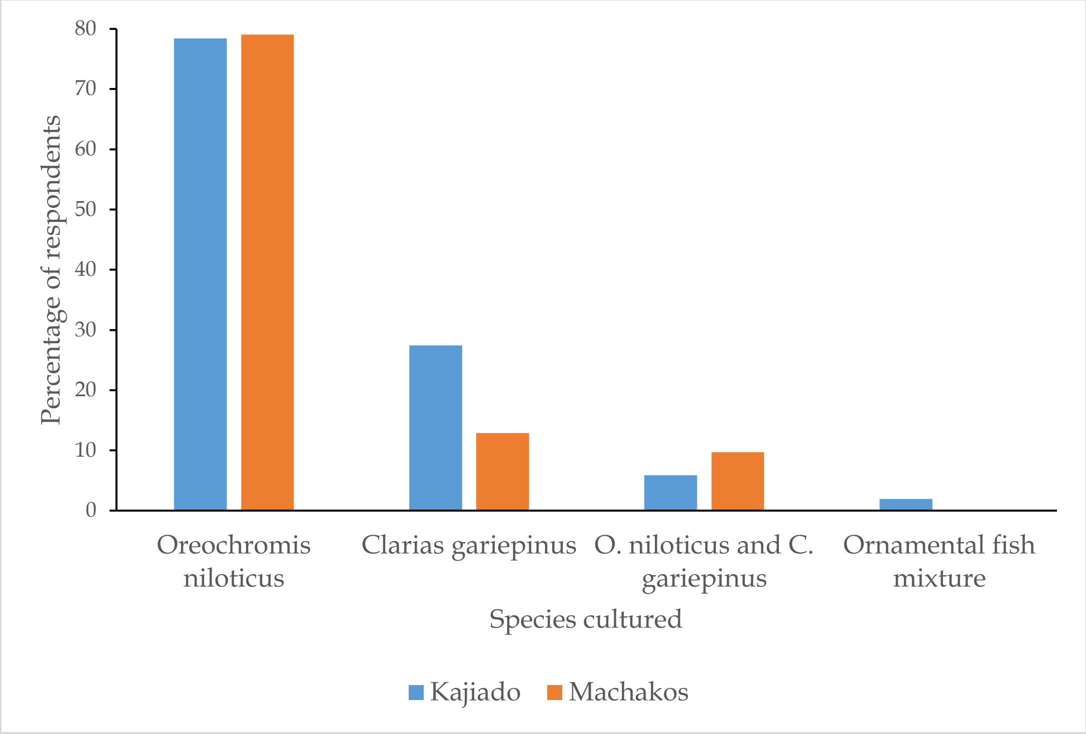
N = Number of respondents. Md = Median. U = Mann Whitney U test. Gross Profit = Revenue - (Total Variable Costs + Total Fixed Costs). 1USD = 134.75KSH.

Cultured fish in Kajiado and Machakos Counties

Nile Tilapia (*Oreochromis niloticus*) was the main fish species cultured (in monoculture) by farmers practicing integrated fish farming in Kajiado County (78.4%) and Machakos County (79%) (Table 1 and Figure 1). This was followed by African Catfish (*Clarias gariepinus*) under monoculture (27.5% in Kajiado County and 12.9% in Machakos County as a percentage of respondents in each County). The culture of catfish under monoculture was higher in Kajiado County compared to Machakos County when considered as a proportion of the total respondents in the respective Counties. A Chi-square test for independence indicated a significant ($p<0.05$) association between the County and the fish species cultured, χ^2 (degree of freedom= 1, n= 237) = 5.258, p value= 0.017. That is, the culture of African Catfish (*Clarias gariepinus*) was significantly ($p<0.05$) higher in Kajiado County compared to Machakos County. A few farmers kept Tilapia and catfish in polyculture (5.9% in Kajiado County and 9.7% in Machakos County) and ornamental fish (2% in Kajiado County only). The proportions add up to more than 100% due to multiple responses (the farmers cultured more than one fish species on the farm). Female-headed households kept more Nile Tilapia (*Oreochromis niloticus*) in monoculture (83%) and ornamental fish (2.1%) compared to male-headed households (77.9% *O. niloticus* and 0% ornamental fish). On the other hand, male-headed households kept more African Catfish (*Clarias gariepinus*) in monoculture (17.4%) and Tilapia and catfish in polyculture (8.9%) compared to female-headed households (10.6% *C. gariepinus* and 8.5% Tilapia and catfish in polyculture).

Figure 1

Fish Cultured in Integrated Fish Farms in Kajiado and Machakos Counties

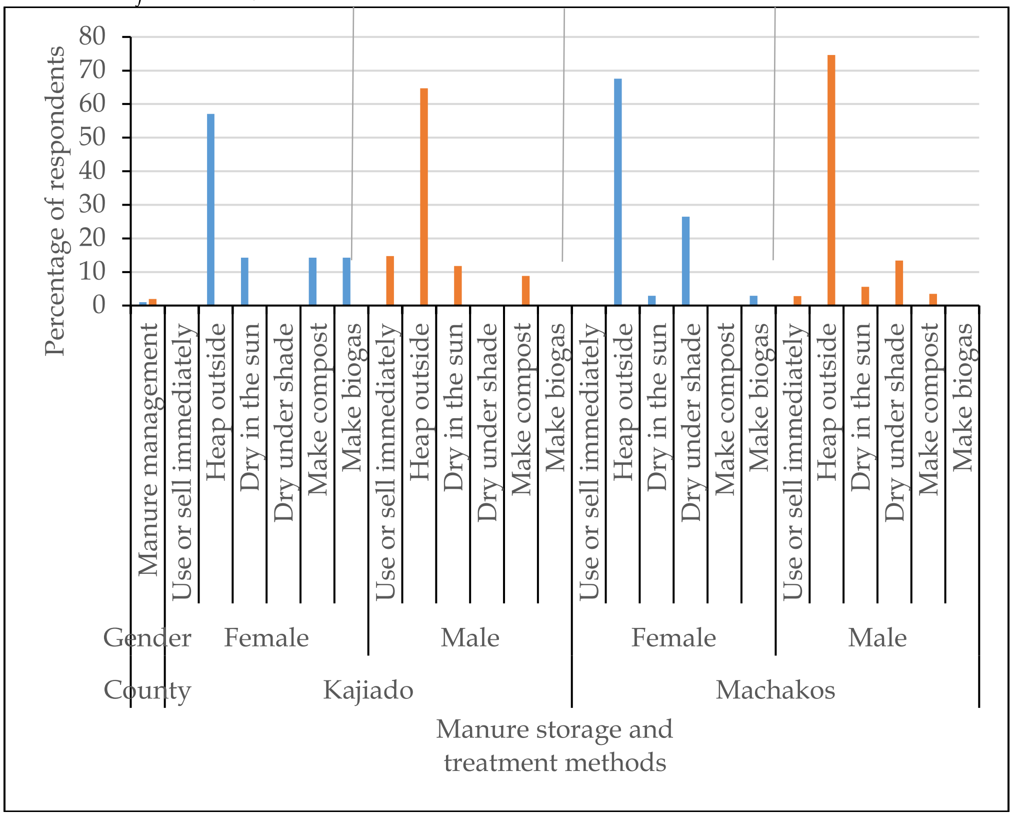


Manure storage and treatment practices in Kajiado and Machakos Counties

This study found that the fish farmers who kept livestock (cattle, sheep, goats, pigs, rabbits and chicken) mainly stored the manure in heaps outside the livestock houses (Figure 2). This was practiced more in male headed households (64.7% in Kajiado and 74.6% in Machakos) compared to female headed households (57.1% in Kajiado and 67.6% in Machakos). A few farmers treated the manure by drying it in the sun, drying under shade, composting or producing biogas.

Figure 2

Cattle, Sheep, Goats, Pigs, Rabbits and Chicken Manure Storage and Treatment Methods Practiced in Integrated Fish Farms in Kajiado and Machakos Counties

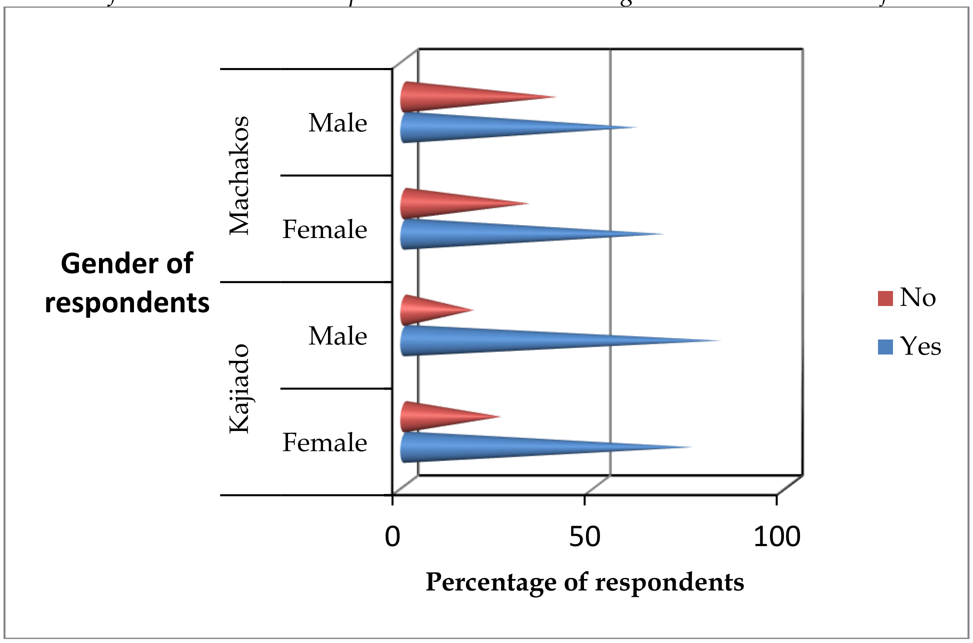


Use of raw manure to fertilize fishponds in Kajiado and Machakos Counties

All the integrated fish farms practiced semi-intensive culture of fish which involves input of animal manure or inorganic fertilizer into the pond water to increase primary productivity of the pond (phytoplankton and zooplankton) which are consumed by the fish and supplementary (formulated) feed is also given to the fish. Most of the farmers in Kajiado County (75% females and 82.1% males) and Machakos County (67.6% females and 60.4% males) fertilized their fishponds using raw manure (Figure 3).

Figure 3

The Use of Raw Manure in Fishpond Fertilization in Integrated Fish Farms in Kajiado and Machakos Counties



Manure availability in Kajiado and Machakos Counties

Most respondents reported that the manure produced on the farms was not sufficient for the current on-farm uses (Table 2). This assertion was more frequent in female headed households (71.4%) compared to male headed households (47.2%) in Kajiado County while in Machakos County the difference in opinion between female (57.1%) and male (59.4%) headed households was more subtle.

Majority of the household heads who reported having insufficient amounts of manure on their farms were able to outsource the same from neighboring farms in order to cover the deficit. This was more common in female headed households (80%) compared to male headed households (58.8%) in Kajiado County. The female (50%) and male (52.9%) headed households in Machakos County had almost similar responses for outsourcing of manure.

The household heads also reported that the crop residues produced in their farms were not sufficient for the current on-farm uses (Table 2). This was more common in female headed households (87.5%) compared to male headed households (57.1%) in Kajiado County, but in Machakos County the female (59.5%) and male (60.3%) household heads had almost similar views. A positive finding was that most of the household heads who reported insufficient amounts of crop residues on their farms were able to outsource crop residues from neighboring farms in order to satisfy their demand. This was more common in female headed households in both Kajiado (71.4%) and Machakos (81.8%) Counties compared to male headed households (56.3% for Kajiado and 61.4% for Machakos).

Table 2

Sufficiency of Manure and Crop Residues for On-Farm Uses and their Outsourcing in Kajiado and Machakos Counties

Materials availability	Kajiado County				Machakos County			
	Females		Males		Females		Males	
	N	Percentage (%)	N	Percentage (%)	N	Percentage (%)	N	Percentage (%)
Insufficient manure	5	71.4	17	47.2	20	57.1	85	59.4
Outsource manure	4	80	10	58.8	10	50	45	52.9
Insufficient crop residues	7	87.5	16	57.1	22	59.5	88	60.3
Outsource crop residues	5	71.4	9	56.3	18	81.8	54	61.4

N = Frequency.

Perceptions of change in precipitation due to climate change in Kajiado and Machakos Counties

All the respondents in Kajiado and Machakos Counties reported observing a change in the amount of precipitation (rainfall and hailstorms) received over a ten-year period, and increased frequency of floods and droughts (Table 3), which they attributed to climate change. A higher percentage of the respondents in Kajiado County reported the increased frequency of floods (80% female and 85.4% male) and droughts (100% female and 97.6% male) compared to respondents in Machakos County.

Table 3

Perceptions of Farmers on Increased Frequency of Floods and Droughts in Kajiado and Machakos Counties

County	Gender	Response	Floods		Droughts	
			N	Percentage (%)	N	Percentage (%)
Kajiado	Female	No	2	20	0	0
		Yes	8	80	10	100
	Male	No	6	14.6	1	2.4
		Yes	35	85.4	40	97.6
Machakos	Female	No	34	91.9	13	35.1
		Yes	3	8.1	24	64.9
	Male	No	134	89.9	30	20.1
		Yes	15	10.1	119	79.9

N = Frequency

Perceptions of change in temperature due to climate change in Kajiado and Machakos Counties

All the respondents in Kajiado and Machakos Counties reported a change in temperature which they attributed to climate change. The respondents reported increased day temperature and decreased night temperature (Table 4). All the respondents (100%) in Kajiado County (both male and female) reported an increase in day-time temperature while in Machakos County, 91.9% female and 89.9% male respondents reported day-time temperature increase. The percentage of those who reported a decrease in night temperature were also higher in Kajiado County (20% female and 9.8% male) compared to Machakos County (10.8% female and 8.7% male).

Table 4

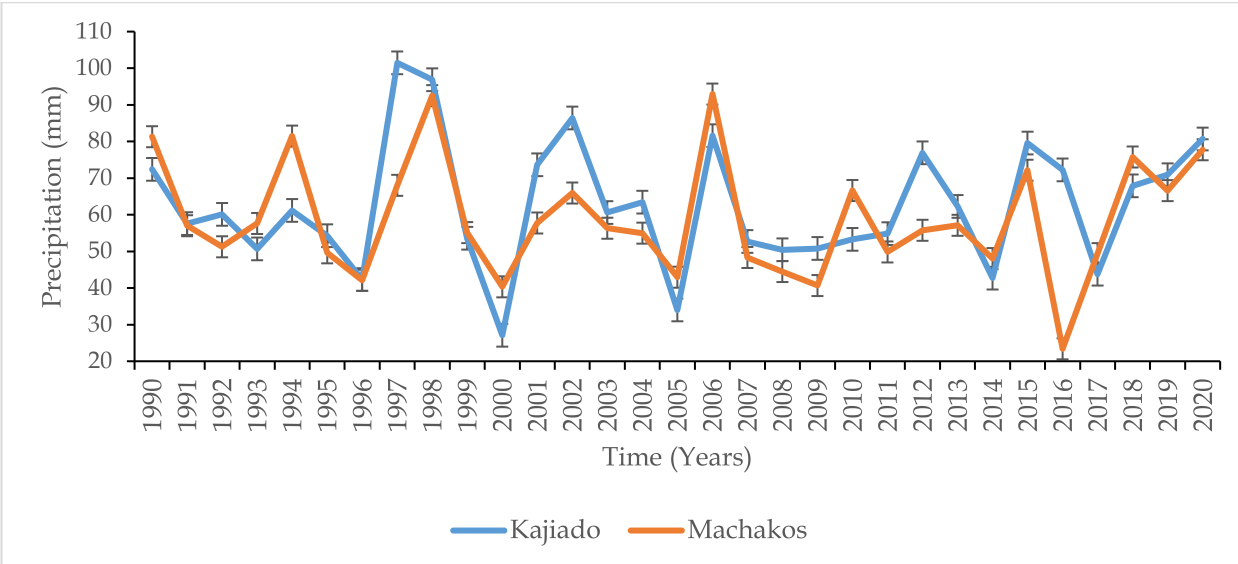
Perceptions of farmers on Increased Day Temperature and Decreased Night Temperature in Kajiado and Machakos Counties

County	Gender	Response	Day temperature rise		Night temperature fall	
			N	%	N	%
Kajiado	Female	No	0	0	8	80
		Yes	10	100	2	20
	Male	No	0	0	37	90.2
		Yes	41	100	4	9.8
Machakos	Female	No	3	8.1	33	89.2
		Yes	34	91.9	4	10.8
	Male	No	15	10.1	136	91.3
		Yes	134	89.9	13	8.7

N = Frequency.

Figure 4

Comparison of Precipitation Reported in Kajiado and Machakos Counties between 1990 and 2020



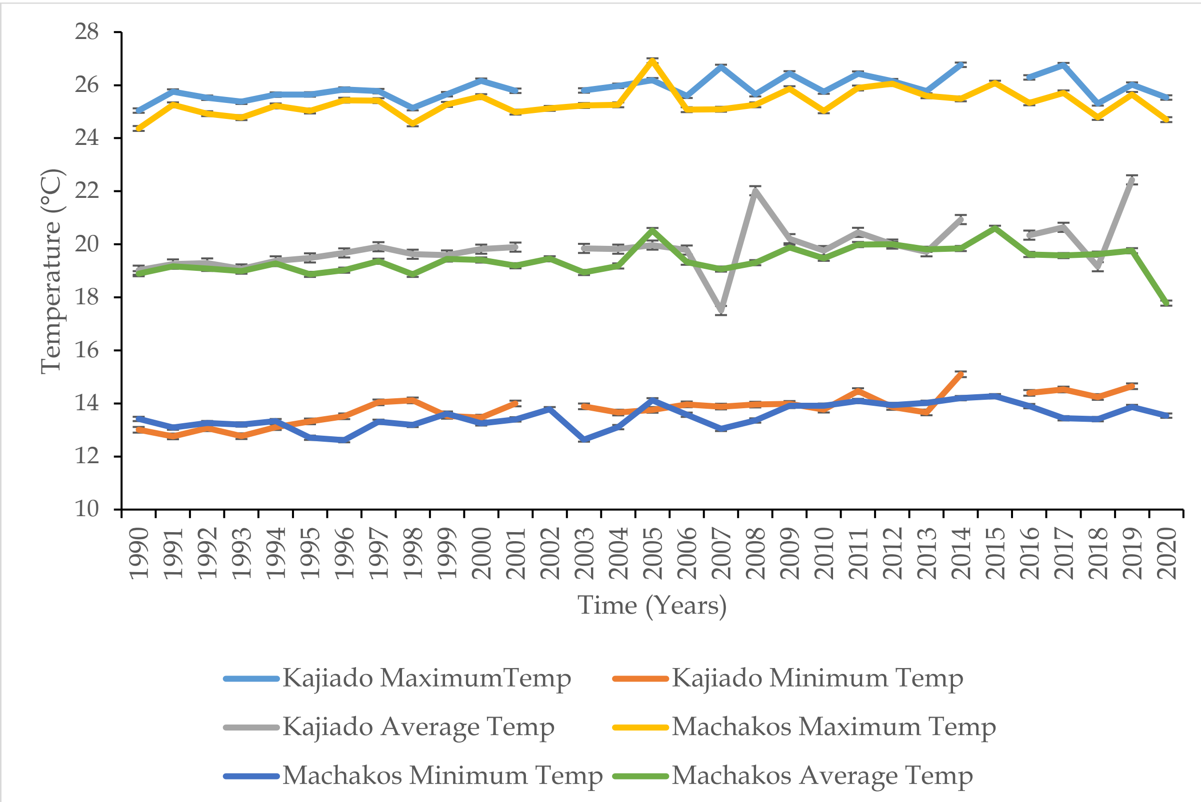
Note. Error bars represent standard error. Raw data was sourced from the Kenya Meteorological Department (2021).

Validation of findings using meteorological data

The observations of changes in precipitation and temperature by farmers practicing integrated fish farming in Kajiado and Machakos Counties were supported by the findings from the analysis of precipitation and temperature data obtained from the Kenya Meteorological Department for the past 30 years (1990 to 2020). The data showed lots of fluctuations in the recorded amounts of precipitation (Figure 4). A comparison of temperatures recorded in the same time period show an overall rising trend in both minimum and maximum temperatures (Figure 5).

Figure 5

Comparison of Minimum, Maximum and Average Temperature Reported in Kajiado and Machakos Counties between 1990 and 2020



Note. Error bars represent standard error. Raw data was sourced from the Kenya Meteorological Department (2021).

A Pearson product-moment correlation analysis for parametric data showed there was a small, positive correlation between time and maximum temperature in Kajiado County, which was statistically significant ($p<0.05$), $r = 0.132$, $n = 372$, $p<0.011$. There was also a very small, positive correlation between time and maximum temperature in Machakos County, which was not statistically significant ($p>0.05$), $r = 0.096$, $n = 372$, $p<0.064$.

A Spearman's rank-order correlation analysis that was run to determine the relationship between non-parametric data had a medium, positive correlation between time and minimum temperature in Kajiado County, which was statistically significant ($p<0.05$), rho = 0.371, $n = 372$, $p<0.001$. There was also a small, positive correlation between time and minimum temperature in Machakos County, which was statistically significant ($p<0.05$), rho = 0.179, $n = 372$, $p<0.001$.

Linear regression analysis of parametric data showed that time could statistically significantly ($p<0.05$) predict maximum temperature in Kajiado county $F(1,370) = 6.553$, $p=0.011$ and time accounted for 1.5% of the explained variability in maximum temperature in Kajiado County. The regression equation was: Maximum temperature = -26.4+0.026(time). Also, linear regression

Table 5

Coping Strategies of Fish Farmers to Perceived Changes in Precipitation and Temperature in Kajiado and Machakos Counties

Coping strategies	Kajiado County				Machakos County			
	Females		Males		Females		Males	
	N	Percentage (%)	N	Percentage (%)	N	Percentage (%)	N	Percentage (%)
1.Rain water harvesting	1	10	7	17.1	1	2.7	23	15.4
2. Conservation of water catchment areas	0	0	1	2.4	0	0	0	0
3. Water recirculation	0	0	0	0	0	0	1	0.7
4. Pond water top up	4	40	7	17.1	3	8.1	23	15.4
5. Cover fishpond with shade net	0	0	0	0	6	16.2	12	8.1
6. Change pond water	1	10	3	7.3	3	8.1	9	6
7. Plant grass on embankment	0	0	1	2.4	0	0	3	2
8. Monitoring fishpond water quality	2	20	0	0	4	10.8	18	12.1
9. Plant trees around fishpond	1	10	0	0	0	0	3	2

N = Frequency.

analysis showed that time could not statistically significantly ($p>0.05$) predict maximum temperature in Machakos County $F(1,370) = 3.462$, $p=0.064$ and time accounted for 0.7% of the explained variability in maximum temperature in Machakos County. The regression equation was: Maximum temperature = -12.7+0.019(time).

A Spearman's rank-order correlation analysis that was run to determine the relationship between non-parametric data had a very small, positive correlation between time and precipitation in Kajiado County, which was not statistically significant ($p>0.05$), $r_s = 0.037$, $n = 372$, $p=0.483$. There was also a very small, negative correlation between time and precipitation in Machakos County, which was not statistically significant ($p>0.05$), $r_s = -0.031$, $n = 372$, $p=0.547$.

Coping strategies to perceived changes in precipitation and temperature

The farmers practicing integrated fish farming in Kajiado and Machakos Counties adopted multiple strategies to cope with changes in precipitation and temperature (Table 5). In Kajiado County, most of the female household heads (40%) topped up fishpond water while most of the male household heads (17.1%) either topped up fishpond water or harvested rain water. In Machakos County, most of the female household heads (16.2%) covered the fishponds with a shade net to reduce evaporation, while most of the male household heads (15.4%) either topped up fishpond water or harvested rain water.

Challenges faced when coping with perceived changes in precipitation and temperature

The three main challenges faced by the fish farmers in both Kajiado and Machakos Counties were inadequate funds (53.3% in Kajiado and 50% in Machakos Counties), inadequate knowledge and skills (33.3% in Kajiado and 22.2% in Machakos Counties) and inadequate water (13.3% in Kajiado and 27.8% in Machakos Counties).

Discussion

Socio-economic characteristics of farmers in Kajiado and Machakos Counties

Most of the household heads interviewed in the current study were males. A similar trend was observed in a gender study of fish farmers in Nigeria (Olanike and Gbenga, 2013). The reason for this disparity between the number of male and female fish farmers was investigated in a study in Madagascar, which suggested that gender norms and decision-making ability in the society favor the involvement of more males than females in aquaculture (Miarisoa et al., 2019). This could be the reason for the higher number of male-headed households engaged in fish farming in the current study. In contrast, the few female household heads involved in fish farming had a higher average number of fishponds and higher average gross profit compared to male-headed households. This could be due to women's better ability to make financial security investments (Cyrus Chu et al., 2023). Women also take up fish farming more than men because they are usually involved in the decision making of the household's nutrition security and therefore view fish as a source of food and income (Quddus et al., 2016; Rahman et al., 2019).

On average, all the farmers in Kajiado County had larger land sizes than those in Machakos County, with male farmers having larger average land sizes than female farmers. A study of gender inequality in 47 countries worldwide found that, on average, men owned 303% more agricultural land than women (Fisher and Naidoo, 2016) and this can be attributed to parental preference and assistance in land acquisition for male children (Cyrus Chu et al., 2023).

Cultured fish in Kajiado and Machakos Counties

Nile Tilapia (*Oreochromis niloticus*) was the main fish species cultured (in monoculture) by farmers practicing integrated fish farming in Kajiado and Machakos Counties. This was followed by African Catfish (*Clarias gariepinus*) under monoculture, tilapia and catfish polyculture, and ornamental fish culture. Tilapia and catfish are two of the most popular cultured fish species in Kenya (Opiyo et al., 2018). Tilapia is more popular in the country and this is influenced by consumer preference based on price, quality, perceived health benefits from consuming the fish and nutritional value (Githukia et al., 2014). In contrast, the African catfish (*Clarias gariepinus*) has been found to have better growth performance than Nile Tilapia (*Oreochromis niloticus*) under aquaculture production (Shaw et al., 2022). However, Nile Tilapia is considered tastier and more readily available in the market place and this influences its pond culture (Obiero et al., 2014).

Manure storage and treatment in Kajiado and Machakos Counties

This study found that the fish farmers who kept livestock stored the manure mainly in heaps outside the livestock houses. A study done in Central Kenya on zero grazing systems of dairy cattle found that more than 80% of the farms stored the manure in heaps (Paul et al., 2009). Such heaps create anaerobic conditions which increase the production of methane, a greenhouse gas (Dong et al., 2020). A few of the farmers in the current study treated the manure by drying it in the sun, drying under shade, composting or producing biogas. These are the main methods of manure treatment practiced in Sub-Saharan Africa (Ndambi et al., 2019). A study in Western Kenya identified fresh or composted manure as a major avenue for nutrient cycling of nitrogen and carbon to the soil on smallholder crop-livestock systems, but the manure management practices in the farms can lead to nutrient losses before the manure is applied to crop fields (Castellanos-Navarrete et al., 2015). The current study explored the possibility of adoption of farm/home level composting as a manure treatment method because it makes the manure easier to handle, easier to apply on the land (Raza and Ahmad, 2016), safer than raw manure (Hruby et al., 2018), and has low methane emissions (Ermolaev et al., 2014), among other benefits. However, very few farmers in the current study make compost on their farms and they attribute this to lack of energy (drudgery work), time, skills and consistent supply of materials for successful compost production.

Use of raw manure to fertilize fishponds in Kajiado and Machakos Counties

Most of the farmers in the current study fertilized their fishponds using raw manure. Raw manure is usually used in aquaculture to increase the primary productivity of the pond, thus increasing fish growth through a prebiotic effect (Minich et al., 2018). However, the use of fresh manure can also lead to pathogen infections, which can cause fish mortality (Wanja et al., 2020). This poses a possible public health risk from the consumption of fish from these systems due to transmission of pathogens from the manure to the fish and finally to the end consumers (Elsaidy et al., 2015; Hruby et al., 2018). Fortunately, this risk can be reduced through continuous composting at thermophilic temperatures (Qian et al., 2016). Observations from this study showed that farmers were not aware of the benefits of compost heat and the dangers of using raw manure in the farms.

Manure availability in Kajiado and Machakos Counties

According to their own assessments, most of the respondents said that the manure produced in their farms was not sufficient for the current on-farm uses. Fortunately, the majority of household heads who reported having insufficient amounts of manure in their farms were able to outsource the same from neighboring farms in order to cover the deficit. The utilization of manure from livestock to grow crops (integrated farming) is a climate smart strategy that is on the rise as a way of coping with climate change (Muriithi et al., 2021). Climate smart agriculture has three main pillars: sustainable increase of productivity; building resilience; reducing greenhouse gas emissions (Newell et al., 2019). Integrated crop-livestock farming has been identified as a climate smart strategy because it has been found to increase productivity and sustainability, and reduce greenhouse gas emissions from both crop and livestock enterprises (Swarnam et al., 2024). The practice of integrated farming can improve the resilience of both crop (through improved soil health and water retention) and livestock (through increased low-cost fodder productivity and subsequent profitability) enterprises in the face of climate change compared to specialized farming systems (Gil et al., 2017). The integrated farming of fish is the combination of fish farming with either crop farming, or livestock farming, or both, and all these combinations have been reported to be climate smart (Lundeba et al., 2023). This is the strategy that was assessed in the current study where crop residues from crop farming and animal manures from livestock farming were checked for availability and potential for composting for use in fish farming.

A recent assessment of the suitability of the soils in Kajiado and Machakos Counties for capsicum production found that the soils in these two counties were deficient in organic carbon and nitrogen and recommended manure application as one of the remedies (Otieno et al., 2022). In Machakos County, manure application has already proven to improve technical efficiency in the production of sorghum (Chepng'Etich et al., 2015). The current study assessed the availability of manure and crop residues as potential substrates for use in composting because this has been found to increase the fertilizer value of the manure (Vandecasteele et al., 2014) and will therefore have a multiplier effect on the benefits of manure application in their farms. The current study reported insufficient amounts of crop residues and manure available for composting but the farmers were able to outsource them from neighbouring farms. In addition, very few farmers in the current study were actively composting because of the drudgery involved, the knowledge and time requirement and the inconsistency of crop residue and manure supply.

Crop residues availability in Kajiado and Machakos Counties

The household heads also reported that even though the crop residues produced on their farms were not sufficient for the current on-farm uses, they were able to outsource crop residues from neighboring farms in order to satisfy their demand. The main crop residues reported were maize stalks, maize cobs (without seeds), bean haulms, vegetable waste and banana stems. The main competing uses for crop residues in Kenya are their use as either soil mulch or as livestock feed, especially in mixed crop-livestock farms as outlined in a study done by Jaleta et al. (2013). The study found that the more the number of livestock in the farm, the more the use of crop residues as livestock feed. A study in Western Kenya found that farmers preferred feeding crop residues to cattle and using the manure produced to fertilize their crops. However, the direct use of the crop residues in crop fields is a cheaper source of nutrients to the crops compared to the manure (Castellanos-Navarrete et al., 2015). A study in Kajiado County found significantly higher arthropod richness and diversity in organic farms that fertilized soil using crop residues compared to non-organic farms (Wanjiku Kamau et al., 2019). The crop residues have also been found to conserve soil moisture in the root zone of crops in Machakos County (Tuure et al., 2021).

Manures usually have high levels of nitrogen, while crop residues usually have high levels of carbon, and these two materials are mixed during compost production to achieve a carbon: nitrogen ratio ranging between 25:1 and 35:1 (Román et al., 2015). This ratio is vital for decomposition of material by micro-organisms as they utilize the carbon and nitrogen, in the presence of oxygen, to build their own biomass. During this process, a lot of heat is generated and this heat can be harnessed to do useful work, a process called compost heat recovery (Smith et al., 2017). This offers a potential coping strategy for low water temperature fishponds caused by diurnal and seasonal changes and in some cases extremely low environmental temperature caused by climate change. In the current study, crop residues were mainly used for feeding livestock, and manure was mainly used directly in crop farming or fertilizing fishponds. The farmers did not combine these two materials to make compost because they lacked the knowledge, time, physical energy and sufficient amounts of these materials. There is little published information on compost heat recovery and how it can be used as a major coping strategy for low water temperatures fishponds. Therefore, this was a preliminary study to design compost heat recovery as a coping strategy to climate change in integrated fish farms.

Perceptions of changes in precipitation due to climate change in Kajiado and Machakos Counties

All the respondents in Kajiado and Machakos Counties reported a decrease in the total amount of precipitation received and the increased frequency of floods and droughts which they attributed to climate change. This has also been observed by Opiyo et al. (2014) in Turkana County, Kenya, and Sagero (2019) in a Kenyan countrywide study. Floods and droughts are natural hydrological events caused by yearly cycles of rainfall excesses and deficiencies, but their increased frequency and intensity in the recent years has been attributed to climate change (Marengo and Espinoza, 2016; Kreibich et al., 2022). Data from meteorological stations confirmed sharper changes in precipitation recorded in the past 30 years as observed by the farmers.

Perceptions of change in temperature due to climate change in Kajiado and Machakos Counties

All the respondents in Kajiado and Machakos Counties reported a change in the temperature which they attributed to climate change with more respondents reporting increased temperature than decreased temperature. The high level of awareness of increased temperature due to climate change is a positive finding as this will increase support for climate change mitigation measures taken by the government (Brooks et al., 2014). However, the low level of awareness about low temperature occurrence due to climate change is a worrying finding because awareness of its occurrence is the first step to searching for coping strategies to alleviate it (Prokopy et al., 2015). Low ambient air temperature results in low water temperature in fishponds (Zhu et al., 2018) and this directly affects fish metabolism and activity (fish are ectotherms) resulting in reduced fish growth and productivity and will therefore impact food security in the country (Thornton et al., 2014). Data from meteorological stations in the two Counties confirmed the farmers' observation of temperature increase with time but it also showed the continued occurrence of low temperatures.

Validation of findings using meteorological data
The meteorological data showed sharper changes in precipitation and a rising temperature trend with time, and this confirmed the observations of the farmers. The comparison of research findings with meteorological data helps to confirm the research findings (Ayanlade et al., 2017).

There was a small (Cohen, 1988), positive correlation between time and maximum temperature in Kajiado County, which was statistically significant ($p<0.05$). There was a very small (Cohen, 1988), positive correlation between time and maximum temperature in Machakos County, which was not statistically significant ($p>0.05$). There was a medium (Cohen, 1988), positive correlation between time and minimum temperature in Kajiado County, which was statistically significant ($p<0.05$). There was also a small (Cohen, 1988), positive correlation between time and minimum temperature in Machakos County, which was statistically significant ($p<0.05$). All the correlation coefficients indicated a rising trend of temperature associated with the passage of time. Similar rising trends of temperature rise with time were reported in studies of other Counties of Kenya such as Turkana (Opiyo et al., 2014), Kiambu (Macharia and Raude, 2017), Lamu (Maingey et al., 2020), Kisii (Samwel et al., 2021) and Kenya in general (Sagero, 2019).

Linear regression analysis of parametric data showed that time could statistically predict maximum temperature in Kajiado ($p<0.05$) and Machakos ($p>0.05$) Counties. The regression equations for maximum temperature had positive slopes in Kajiado (0.026) and Machakos (0.019) Counties indicating a rise in temperature with time. These slopes closely resemble 0.018 for Kiambu County (Macharia and Raude, 2017), 0.036 for Lamu County (Maingey et al., 2020), and 0.012-0.048 for Kenya in general (Sagero, 2019).
The average minimum temperatures reported were 13.8°C and 13.5°C in Kajiado and Machakos Counties respectively. The average maximum temperatures reported in that period were 25.9°C and 25.3°C in Kajiado and Machakos Counties respectively. The main fish species cultured in Kenya are Nile tilapia (*Oreochromis niloticus*) and African catfish (*Clarias gariepinus*) (Munguti et al., 2021a) and their optimum culture temperature is approximately 28°C (FAO, 2018). This shows that the average minimum reported temperatures were below the optimum temperature for culture of these fish species. Low fishpond water temperatures, caused by low ambient temperatures, directly affect fish growth (Bregnballe, 2015). This is due to reduced fish activities, feed intake, and fish metabolism, eventually impeding growth (Eriegha and Ekokotu, 2017).

A Spearman's rank order correlation that was run to determine the relationship between non-parametric data had a very small, positive correlation between time and precipitation in Kajiado County, which was not statistically significant ($p>0.05$). There was also a very small, negative correlation between time and precipitation in Machakos County, which was not statistically significant ($p>0.05$). This shows that time could not be used to predict precipitation, hence confirming the perception by fish farmers in the current study of precipitation variability. A study by Sagero (2019) that assessed various prediction models of climate variability in Kenya shows that precipitation variability will continue to rise while the total annual precipitation in the country will continue to fall. Discrepancies can occur between the research findings and the meteorological data (Ndamani and Watanabe, 2015) and this could be because the respondents are using memory recall instead of the actual measurements. In the current study, the farmers' observations were in line with the meteorological data.

Coping strategies to perceived changes in precipitation and temperature
The farmers practicing integrated fish farming in Kajiado and Machakos Counties adopted multiple strategies to cope with changes in precipitation and temperature. These included rain water harvesting, conservation of water catchment areas, water recirculation, pond water top up, covering the fishpond with a shade net, changing pond water, planting grass on the embankment, monitoring water quality of fishponds and planting trees around the fishponds. A study of the coping strategies to

climate change in Ghana reported that in order to avoid flood damage, fish farmers constructed high pond embankments, while during droughts they adjusted stocking times, sited fishponds close to water bodies, dug new boreholes, or improved their water management (Asiedu et al., 2017). Some of the reported coping strategies to climate change in India during droughts were using oxygen tablets to increase dissolved oxygen level in the fishpond water during hot days, adding fresh water to cool down fishpond water, pumping water from boreholes, or harvesting fish early (Ajit Keshav et al., 2018). During floods, the farmers used nets around the ponds to prevent fish from escaping or pumped excess water out of the ponds. Coping strategies implemented in various parts of the world are very varied because climate change impacts are location-specific thus, the coping strategies have local perspectives (Galappaththi et al., 2020).

Challenges faced when coping with perceived changes in precipitation and temperature

The three main challenges faced by the fish farmers in both Kajiado and Machakos Counties were inadequate funds, inadequate knowledge and skills of how to cope with climate change, and inadequate water. A study done in a neighbouring Makueni County, reported the lack of finances and water, among other challenges, as impediments that led to abandonment of fish farming in the County (Musyoka and Mutia, 2016). A review of the Kenyan fish feed industry and feeding management by fish farmers (Munguti et al., 2021b) found that some of the major challenges faced by farmers are the lack of finance and technical knowledge and skills in feed processing and formulation: This would enable them to reduce their production costs in the face of climate change. Government and Non-Government Organizations' (NGOs) interventions through subsidized farm inputs, provision of grants, infrastructure development in the water industry and farmer trainings are likely to offset these challenges, thus improving adaptation to extremely high temperature. These collaborations have had a positive impact on fish farming in the neighbouring Makueni County (Maina et al., 2017).

Conclusions

Most of the farmers practicing integrated fish farming in Kajiado and Machakos Counties are male, they keep Nile Tilapia (*Oreochromis niloticus*) in monoculture, and they can outsource manure and crop residues from neighbouring farms for their potential use in compost heat recovery. Also, majority of the fish farmers in Kajiado and Machakos Counties who perceive changes in precipitation and temperature, validated by meteorological data, have adopted coping strategies such as topping up fishpond water, but they face challenges like inadequate funds.

Recommendations

It was recommended that further training of fish farmers on climate change coping strategies such as compost heat recovery should be carried out.

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