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Biophysical Vulnerability of Fish Farmers to Climate Variability and Extreme Events in Arid and Semi-Arid Lands of Kitui County, Kenya

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A B S T R A C T

The present study assessed the household-level biophysical vulnerability to climate variability and extreme events of fish farmers in Kitui East and Kitui Central Sub counties of Kitui County, Kenya. The study employed a descriptive survey design and a total of 60 farmers constituted the sample. Carefully selected indicators for exposure and sensitivity were used to operationalize vulnerability. Principal Component Analysis (PCA) was used to assign weights to the indicators. Biophysical vulnerability indices indicated that Kitui East fish farmers were more vulnerable (3.70) as compared to Kitui Central fish farmers (-0.80). In conclusion, the study revealed a high biophysical vulnerability of fish farmers to climate variability and extreme events in arid and semi-arid lands. Therefore, fish farmers' access to off-farm income and their adaptive capacity should be a primary target as fish farming stakeholders lack control over environmental factors that increase the biophysical vulnerability of fish farmers.

Introduction

Fish farmers form one of the most vulnerable groups to climate variation and extreme events as their production heavily relies on precipitation and temperature (Azra *et al.*, 2020; Allison *et al.*, 2009; Barange *et al.*, 2018). Moreover, fish farmers in ASALs are at major risk due to their poor adaptive capacity and these areas' inherent characteristics like inadequate precipitation, high temperatures, recurring droughts, and flash floods (Badjeck *et al.*, 2010; Adger, 2006). The effects of these environmental factors, however, vary from household to household due to varying environmental conditions, different socioeconomic statuses, and pre-existing stresses in the households in question (Jamir *et al.,* 2013), hence the need for a systematic vulnerability assessment (Deressa *et al.,* 2008).

Fish farmers in the study area predominantly carry out fish farming under rain-fed conditions which underline their vulnerability to climate variability and extreme events. The study area is prone to droughts the recent one being the2014-18, which was declared a national disaster in 2017 and severely affected fish farmers (Nduku, 2015). Further, changing precipitation onsets and high temperatures are present in the study area (Njoka *et al., 2*016). Fish farmers in the study area have reportedly moved from large-scale fish farming and opted for subsistence fish farming only and others have completely shifted to other forms of agriculture (Nzevu *et al.*, 2018), as a result of droughts, reducing rainfall, and increasing temperatures among other factors. As such, the sustainability of fish farming in the county has been a challenge. Therefore, there is an urgent need for policymakers and all fish farming stakeholders to understand specific areas and households that are vulnerable in the study area. Early identification of risks, factors, and areas that are vulnerable has previously been highlighted as important and can aid in timely adaptation measures and reduce vulnerability (Monterroso –Rivas *et al.*, 2018). The current study, therefore, sought to assess the biophysical vulnerability of fish farmers to climate variability and extreme events at a household level in arid and semi-arid areas of Kitui Central and Kitui East Sub Counties in Kitui, Kenya.

Materials and methods

Profile of the Study Area; Topography and Climate

The study was conducted in Kitui Central and Kitui East Sub Counties in Kitui County, Kenya (Figure 1). Kitui County is located in the Southern part of Kenya and has an altitude ranging between 400m and 1800m above sea level. The general landscape of Kitui County is flat but gently rolls down to the East and North East, where altitudes are as low as 400m. The County's lowest annual average temperature is 14°C, while the highest annual average temperature is 32°C (ROK, 2010), slightly different from the 20°C to 30°C requirement for fish to thrive.

Further, due to its semi-arid nature, the study area is vulnerable to droughts. Kitui Central, Sub-County, one of the study sites, exhibits a sub-humid climate and receives more precipitation attributed to its high altitude of 600m to 900m (Nzevu *et al.*, 2018) compared to Kitui East Sub County. Fish culture units are majorly stocked during rainy seasons when there is enough water for fish farming in both study sites. The most common fish farming practice in the study sites is pond fish farming. Additionally, both study sites have bi-modal precipitation patterns and have long rains that are mostly erratic and unreliable, increasing fish farmers' biophysical vulnerability in the study sites. However, short rains are relatively reliable and occur from October to December.

Population and economy

According to KCIDP (2018), Kitui Central Sub County, one of the study sites, has a human population of 131,715 and constitutes five wards, namely; Township, Miambani, Kyangwithya west, Kyangwithya East, and Mulango. Kitui East on the other hand has a human population of 123,239 and constitutes five wards, namely; Mutitu/Kaliku, Endau/Malalani, voo/Kyamatu, Nzambani, and Zombe/Mwitika. In general, Kitui County has a human growth rate of 1.16% from the previous census in 2009 (GOK, 2019). Further, Food insecurity is also prevalent in the County, with 50% of the population unable to access food and improved water sources (KCEAP, 2018). The rapid human growth rate coupled with food insecurity calls for sustainable food systems to eradicate food insecurity in the County. Agriculture in the County is primarily rain-fed, with the inhabitants practicing; crop farming, livestock keeping, beekeeping, poultry farming, and fish farming (ROK, 2005).

Research Design, Data Collection, and Data Analysis

This study employed the descriptive survey design and focused on individual fish farmers' households as the unit of analysis. The Purposive sampling technique was used to select the two study sites, Kitui Central Sub-County and Kitui East Sub-County. The households interviewed were selected by the use of simple random sampling and had to have existed in the study area for a period of ten years before the data collection exercise. Primary data was collected through participant observation and a household survey interview schedule. Secondary data was collected through the analysis of literature. However, meteorological data on average annual maximum temperature, average annual minimum temperature, and average annual precipitation for 30 years (1989 to 2019) was collected from the nearest metrological station. Statistical Package for Social Sciences (SPSS) version 22 and Ms Excel were used to analyze the data.

Biophysical Vulnerability Assessment

The biophysical vulnerability was operationalized as a function of exposure and sensitivity following the IPCC definition (IPCC, 2014). An indicator approach was used to operationalize exposure and sensitivity.

Exposure of the fish farmers

In the present study, exposure indicators used to measure the vulnerability of fish farmers in the study area included historical changes in climate variables and the frequency of extreme events as perceived by the fish farmers in a period of ten years. The coefficients of trend in annual maximum temperature, average annual minimum temperature, and total annual precipitation for a 30-year period (1989-2019) represented the historical climate variables. The coefficients of the trend for historical climate variables were done at the Sub-County level and extrapolated to the household level. A higher rate of change in the historical climate variables and a higher frequency in the occurrences of extreme events would denote a higher exposure of the fish farmers to climate variability and extreme events.

Sensitivity of the fish farmers

The effects of extreme events on fish fatalities, fish culture units, water resources, and the household income structure of the fish farmers in the study area were used as indicators for the sensitivity of the fish farmers. A higher impact of extreme events on the sensitivity indicators would increase the biophysical vulnerability of the fish farmers and vice-versa. Regarding the household income, natural resources-based income included (crop farming, sale of forestry products, honey sales, sand harvesting, livestock production, and aquaculture) while non-natural resource-based income included (remittances, salaried jobs, skilled non-farm jobs, and small business returns). A higher share of non-natural resources-based-income as compared to the share of natural resources-based-income would reduce the household's sensitivity as non-natural resource-based-income is remunerative and less reliant on climate and vice versa (Luni *et al.,* 2012).

Construction of biophysical vulnerability index

After selecting the indicators for exposure and sensitivity of the fish farmers in the study area and defining their relationship with vulnerability, normalization of the indicators was done as per the UNDPs' Human Development Index (HDI) (UNDP, 2006). Normalization was done for standardization purposes of various indicators with different units such that all normalized values lie between 0 and 1 using the formulae;

$$Normalized\ value = \frac{Observed\ value - Mean}{Standard\ deviation}$$

The next step involved the assignment of weights to the indicators. Weights were assigned using the Principal Component Analysis (PCA) following Filmer and Pritchett (2001). PCA was run on the indicators for exposure and sensitivity separately in

SPSS. Loadings from PCA that were highly correlated to the indicators were used as the weights of the indicators. Multiplication of the normalized their weights was done to generate the indices for exposure and sensitivity, respectively. The steps are summarized by the following formulae.

$$I_j = \sum_{i=1}^{k} b_i [\frac{a_{ji-x_i}}{si}]$$

Whereby;

I is the respective index value for the j^{th} household

b is the weighted value for the i^{th} indicator

a is the i^{th} indicator value for j^{th} household

x is the mean value for the i^{th} indicator

and S is the standard deviation for the i^{th} indicator value

The final biophysical vulnerability index for the fish farmers was calculated by using the formulae;

$$V = E + S$$

Whereby;

V represented the biophysical vulnerability index, E represented the Exposure index and S represented the sensitivity index of the fish farmers in the study area.

Results and Discussion

Annual Precipitation Trend in the Study Area

Linear regression analysis results for the 30-year period of annual precipitation showed that the amount of precipitation decreased with time in Kitui Central (y=-1.8173x+990.37) and Kitui East (y=-2.5715x+863.66) as illustrated in Figure 2 below. Rainfall is the primary source of water for fish farmers in the study area. Therefore, its decrease affected fish farming operations and water levels in fish culture units. Most fish species require specific water levels in culture units and therefore any significant reduction in rainfall call for manual maintenance of water levels in fish culture units, which is an extra cost, hence, fish farmers' vulnerability. The results however indicated that the variation in the amount of precipitation with time (R^2) in the study area was very small in both Kitui Central (R^2= 0.0027) and Kitui East (R^2= 0.0081). The results are corroborated by Marigi *et al.,* (2016) who reported a significant decreasing trend in annual rainfall in South Eastern parts of Kenya.

Temperature trends in the study area

Annual maximum temperature trend in the study area

The findings of the study indicated an increase in the trend of average annual maximum temperature with time in Kitui Central(y=0.0252x+29.909) and Kitui East (y=0.025x+29.916) as illustrated in Figure 3 below. Additionally, the variation in maximum temperature with time R^2 was high in both Kitui Central (R^2= 0.4666) and Kitui East (R^2= 0.4652). A rise in temperature leads to water loss in culture units through evapotranspiration which can directly affect fish well-being. Further, high temperatures can also affect the level of dissolved oxygen, hence fish fatalities. The results are in agreement with results from a similar study by Marigi *et al.,* (2016) who reported a significant increasing temperature trend in South Eastern Kenya.

Annual minimum temperature trends and variability in the study area

The results indicated a significant increase with time in the annual minimum temperature trend in Kitui Central(y=0.0158x+18.135) and Kitui East (y=0.0286x+17.865) (Figure 4). Consequently, the minimum temperature trend variation, R^2 increased with time in both Kitui Central (R^2= 0.2119) and Kitui East (R^2= 0,2371). The higher minimum temperature may have contributed to the few cases of fish diseases in the study area, which increased veterinary costs to the fish farmers, further increasing their biophysical vulnerability. The results align with Luck *et al.*, (2011), who noted that higher minimum temperatures encouraged the proliferation of fish diseases.

Mean temperatures in the study area

The results indicated that there was a statistically significant increasing trend in the average annual mean temperature with time in Kitui Central (y=0.0205x+24.025) and Kitui East (y=0.0267x+23.896) (Figure 5). The variation in mean temperature trend with time was high in both Kitui Central (R^2=0.4915) and Kitui East (R^2=0.4384).

Exposure of fish farmers in the study area

Examination of results indicated that the weights for the exposure indicators as illustrated in Table 1 were positive hence a positive relationship with the exposure index. The possible explanation for this is that fish farming is a climate-sensitive venture, and therefore, any slight variations in these environmental factors increased the exposure of fish farmers. Similar findings by Islam *et al.,* (2019) indicated that variation in past maximum and minimum temperatures, rainfall variation, storm surges, and past sea-level change contributed positively to fish farmers' exposure index in Bangladesh. Further, Dzoga *et al.*, (2018) found that temperature and rainfall indicators positively correlated with the exposure index in a study on ecological vulnerability to climate variability of coastal fishing communities in Ungwana bay and lower Tana estuary in Kenya.

The results also revealed that the rate of change in average annual precipitation (0.99) had the highest contribution towards the exposure index as compared to other indicators. The high contribution is attributed to rainfall being a prime input and requirement in fish farming in the study area. Therefore, any changes in precipitation would increase the exposure of fish farmers in the study area. The results corroborate similar studies by Cochrane *et al.*, (2009) and Ciseneros *et al.*, (2014), who indicated that inland fisheries were highly impacted by changing precipitations and runoff due to climate change. On the contrary, Cochrane *et al.*, (2009) noted a likelihood of increased fish production in areas like The Ganges basin in South Asia, which was characterized by high runoff and discharge rates. Similar studies by Allison *et al.*, (2005) also indicated that flooding increased yields in fish farming in Bangladesh. However, most studies agree that unfavorable impacts of climate change on fisheries outweighed the favorable outcomes, more so in developing countries where adaptive capacity is typically weakest.

Conversely, historical climate variables contributed more to the fish farmers' exposure as compared to extreme events in the study area. This can be ascribed to the low frequency of extreme events in the study area, with droughts and heavy precipitation reportedly being the most experienced events. The results are in line with findings by Luni *et al.*, (2012) who found out that absolute values of weights of historical climate variables contributed more to the exposure index as compared to the occurrence of extreme events in Nepal.

The results also revealed that the coefficient of variation in average annual maximum temperature for 30 years (1989-2019) was slightly higher in Kitui Central (1.06) compared to Kitui East (1.05). The current trend of results is attributed to the semi-humid nature of Kitui Central compared to the dry Kitui East Sub County. Higher maximum temperatures result in more significant risks of droughts and water shortages which can affect the productivity of fish farming, increasing the exposure of fish farmers. Brander (2007) and Azra *et al.*, (2020) uphold this finding by noting that higher temperatures affected fish farming directly and indirectly, with other reports having shown rising temperatures across Kenya (Mutunga *et al.*, 2017; Klisch *et al.*, 2015).

Results of the independent-samples T-test on mean values for the indicators of exposure revealed a statistically significant difference between the study sites in the mean values for all the exposure indicators except for the estimated number of occurrences of droughts. The number of droughts recorded in Kitui Central had a mean value of (6.90) slightly lower than Kitui East (6.10) which implied that both study sites experienced similar drought occurrences. The difference in exposure levels between the two Sub Counties could be due to variations in rainfall distribution and temperature. The finding is in tandem with studies by Cochrane *et al.*, (2009) and Hoque *et al.*, (2019), who noted that climate change would have uneven effects on different geographical areas, nations, social groupings, and individuals. Further, the study results revealed that there was indeed climate variation in the study area, which is corroborated by findings by Mutunga *et al.,* (2017); Khisa *et al.,* (2014), who noted an increase in climate variability in Kenya.

Sensitivity indicators in the study area

The sensitivity of the fish farmers in the study area was calculated using a 2-step PCA, whereby the first step PCA was run separately on indicators of the components of the overall sensitivity index. In the second step, PCA was run on the sub-composite indices to generate weights for calculating the overall sensitivity index.

Fish fatalities Sub-Composite index

The first step PCA was run on indicators of fish fatalities as presented in Table 2. All the indicators had positive weights hence positively impacted the fish fatalities sub-composite index. The fish stock lost to high precipitation had the highest weight (0.76). Further, mean values for fatalities due to heavy precipitation indicated that fish farmers in Kitui Central (12.17) experienced more fish fatalities compared to fish farmers in Kitui East (3.00). The possible explanation is that active and large-scale fish farming was reported in Kitui Central compared to Kitui East. Therefore, more fatalities were recorded in Kitui Central in heavy precipitation events. In addition, Nzevu *et al.*, (2018) also noted that 66.6% of fish farmers in Kitui Central had no expertise in fish pond management. Therefore, any occurrence of an extreme event would result in many fatalities of fish.

The results further indicated that the weight of fish stock lost due to droughts (0.67) was the second in regards to the contribution towards the fish fatalities sub-composite index. Droughts translate into a lack of adequate water for fish which is crucial for their growth, increasing fish fatalities. Fish fatalities resulting from droughts were higher in Kitui East (115.93) compared to Kitui Central (27.67), resulting from a lack of adequate water for fish farming and poor water quality due to the severity of droughts in Kitui East compared to Kitui Central. The finding of the present study is corroborated by Adebo and Ayelari (2011), who reported that 80% of fish farmers in their study area had experienced droughts and countered it by stocking culture units only in rainy seasons to reduce fatalities due to a lack of adequate water.

In addition, results indicated that mean values for fish stock lost due to diseases were higher in Kitui East (5.97) compared to Kitui Central (1.67). The lack of adequate water for fish farming operations in Kitui East could have encouraged poor water quality, hence, the growth of fish diseases. Again, the higher temperatures in Kitui East compared to Kitui Central could also have promoted the growth of fish diseases hence the many mortalities. Similar studies by FAO (2018) indicated that freshwater fish species are susceptible to high water temperatures. Further, due to the shallowness of fish ponds, increased air temperatures would exacerbate problems like water quality in areas with increased anthropogenic loading of nutrients.

Moreover, the mean values for fish stock lost to conflicts with other resource users were higher in Kitui East (25.23) compared to Kitui Central (15.33). Fish farmers in the study area reported the destruction of culture units by unknown people, resulting in a total loss of fish stocks after the attacks. The destructions reportedly resulted from the scarcity of resources like water, which fueled more conflicts between fish farmers and residents using water for other agricultural activities. Similar findings by Mwikali and Wafula (2019) highlighted water resource-based conflicts in Kitui East Sub County.

Water resources Sub- Composite index

The estimated number of times water resources in close proximity to households had dried up in a period of ten years was used as an indicator for the sensitivity of water resources as tabulated in Table 3. The results showed that the weights for all the water sources sub-composite index indicators were positive, implying a positive influence on the water resources sub-composite index. The results further revealed that the estimated number of times shallow wells (0.80), boreholes (0.78), and rivers/streams (0.70) had dried up in a period of ten years had the highest contribution to the water resources sub-composite index. The possible explanation for this high contribution to the water resources sub-composite index is that the study area is part of ASAL. Therefore, these three sources are the main water sources as they are more resilient to droughts and rainfall variations, more reliable than the rest, and distribute water evenly across the ASALs. Similar findings were indicated by Marshall (2011), who noted that droughts resulting from climate change affected water resources, thereby interrupting the livelihoods of many in the drylands of Kenya.

In addition, the mean values for water resources sub-composite index indicators were statistically different ($p < 0.05$) between the two study sites. Therefore, the sensitivity levels of the various water resources between the two Sub Counties were different. Water resources in Kitui East Sub County dried more than water resources in Kitui Central which was attributed to the difference in climatic conditions. For instance, water resources in Kitui East Sub County, which is drier, are subject to higher evaporation rates, hence likely to dry up compared to water resources in Kitui Central Sub County, which is semi-humid. The current trend of results is concurrent with Obiero *et al.*, (2012) and Lake Victoria Basin Commission (2011), which indicated a significant but different drop in water levels of Kenyas' natural water bodies.

Moreover, the results indicated that the number of times all water resources had dried up was higher in Kitui East compared to Kitui Central. This phenomenon was possible due to higher temperatures and frequent droughts in Kitui East compared to Kitui Central, resulting in fast-drying up of surface waters and reduced groundwater. Further, the study area witnessed increased human population growth and development; hence, higher water demand was likely to occur, drying up water resources in dry months. The results are in agreement with FAO (2018) study, which indicated that high water demand is likely to increase due to the high population growth and unless remedial actions are taken, there will be severe impacts on inland fish farming. Similar studies also indicated that groundwater in Bangladesh's north and north-western districts had been affected by high temperatures and high rainfall variability which affected fish farmers (Shahid and Hazarika, 2010; Shahid and Behrawan, 2008; Ramamasy and Baas, 2007).

Weights and mean values for indicators of overall sensitivity in the study area

Weights and mean values of the indicators of overall sensitivity in the study area are indicated in Table 4. Results indicated that all the sensitivity indicators had a positive relationship with the sensitivity index except non-natural resources-based income (-0.98), which had a negative relationship. Usually, non-natural resources-based income is remunerative and aids in reducing the sensitivity of an area as it is more consistent and less reliant on the status of the climate.

Table.1 Weights and mean values for indicators of exposure in the study area

Indicator	Weight	Sub-County		*P*-Value
		Kitui Central n=30	Kitui East n=30	
Rate of change in average annual maximum temperature (1989-2019)	0.98	1.06(0.00)	1.05(0.00)	.00***
Rate of change in average annual minimum temperature (1989-2019)	0.00	1.62(0.00)	2.78(0.00)	.00***
Rate of change in average annual precipitation (1989-2019)	0.99	31.31(0.00)	30.38(0.00)	.00***
Estimated no. of occurrence of droughts in the last ten years	0.83	6.90(2.12)	6.10(2.52)	.19
Estimated no. of occurrence of heavy precipitation in last ten years	0.63	1.00(1.08)	1.67(1.03)	.02**

Note: Figures in parenthesis indicate standard deviation
***, and **indicate significant at 1% and 5% level of significance, respectively

Table.2 Weights and mean values for indicators of fish fatalities due to climate extreme events and disasters in the last ten years in the study areas

Indicator	Weight	Sub – counties		*P*-value
		Kitui Central n=30	Kitui East n=30	
The fish stock lost due to drought	0.67	27.67(50.08)	115.93 (215.80)	.04**
The fish stock lost due to high precipitation	0.76	12.17(20.79)	3.00(7.14)	.03**
The fish stock lost due to fish diseases	0.19	1.67(5.31)	5.97(10.91)	.06*
The fish stock lost due to conflict with other resource users	0.07	15.33(41.33)	25.23(61.65)	.47

Note: Figures in parenthesis indicate standard deviation
**and *indicate significant at 5% and 10% level of significance, respectively

Table.3 Weights and mean values for indicators of water resources sensitivity to climate extreme events and disasters in the study areas

Indicator	Weight	Sub – counties		*P*-value
		Kitui Central	Kitui East	
The estimated number of times rivers/streams had dried up in the last ten years	0.77	0.27(0.69)	3.70(4.00)	.00***
The estimated number of times boreholes had dried up in the last ten years	0.78	0.33(0.84)	3.87(4.02)	.00***
The estimated number of times shallow wells had dried up in the last ten years	0.80	2.03(3.22)	3.77(3.88)	.07*
The estimated number of times sand dams had dried up in the last ten years	0.60	1.17(1.90)	2.43(3.53)	.09*
The estimated number of times water pans had dried up in the last ten years	0.46	3.03(3.36)	5.33(4.44)	.03**
The estimated number of times springs had dried up in the last ten years	0.60	1.47(1.17)	2.47(2.42)	.05**
The estimated number of times other water resources had dried up in the last ten years	0.65	1.83(1.93)	3.80(3.60)	.01**

Note: Figures in parenthesis indicate standard deviation
*****, **** and ***** indicate significant at 1%, 5% and 10% level of significance

Table.4 Weights and mean values for indicators of overall sensitivity in the study area

Indicator	Weight	Sub-County		*P*-Value
		Kitui Central n=30	Kitui East n=30	
Fish fatalities due to climate extreme events and disasters in last ten years	0.71	-0.02(0.99)	0.02(1.03)	.88
Culture units destroyed by climate extreme events and disasters in last ten years	0.02	-2.29(0.98)	0.23(1.13)	.09*
The estimated number of times water resources have dried up in the last ten years	0.76	-1.62(1.02)	1.62(2.79)	.00***
Percentage share of natural resources based income	0.98	0.49(0.35)	0.69(0.29)	.02**
Percentage share of non-natural resources based income/ Percentage share of remunerative income	-0.98	0.51(0.35)	0.31(0.29)	.02**

Note: Figures in parenthesis indicate standard deviation
*****, **** and * indicate significant at 5%, 1% and 10% level of significance respectively

Table.5 Biophysical vulnerability indices in the study area

Index	Sub-County		*P*-Value
	Kitui Central n=30	Kitui East n=30	
Exposure index	-0.10(2.74)	1.02(2.62)	.11
Sensitivity index	-0.91(1.71)	2.67(3.20)	.00***
Biophysical Vulnerability	-0.80(2.93)	3.70(2.75)	.00***

Note: Figures in parenthesis indicate standard deviation
*** indicate significant at 5%, level of significance

Fig.1 The study area (Source, ILRIS GIS Database)

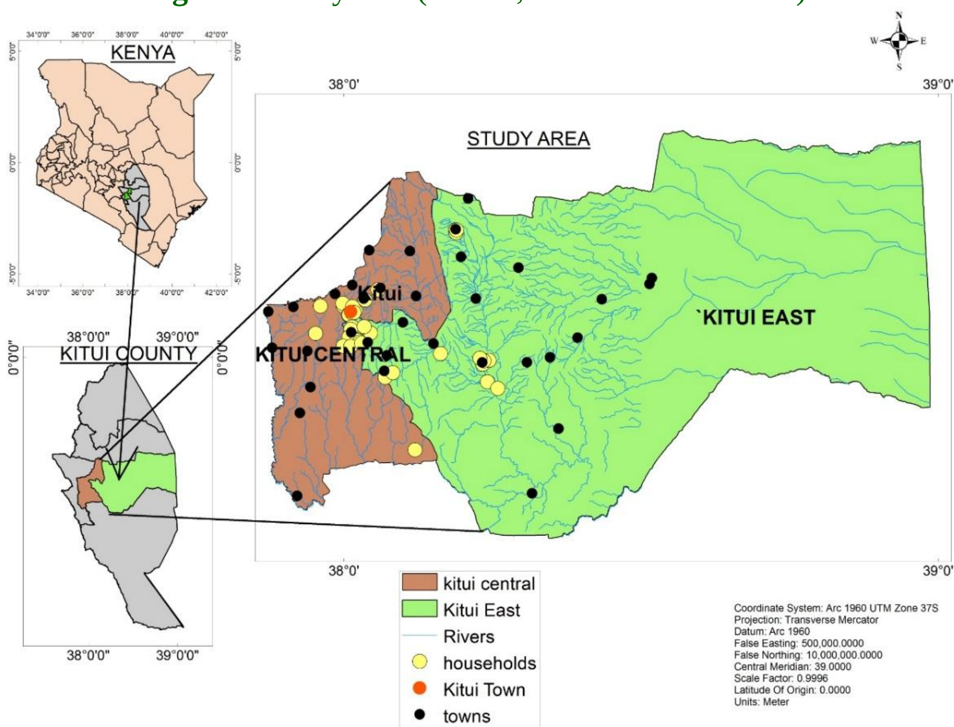


Fig.2 Average annual precipitation variation with time in the study area

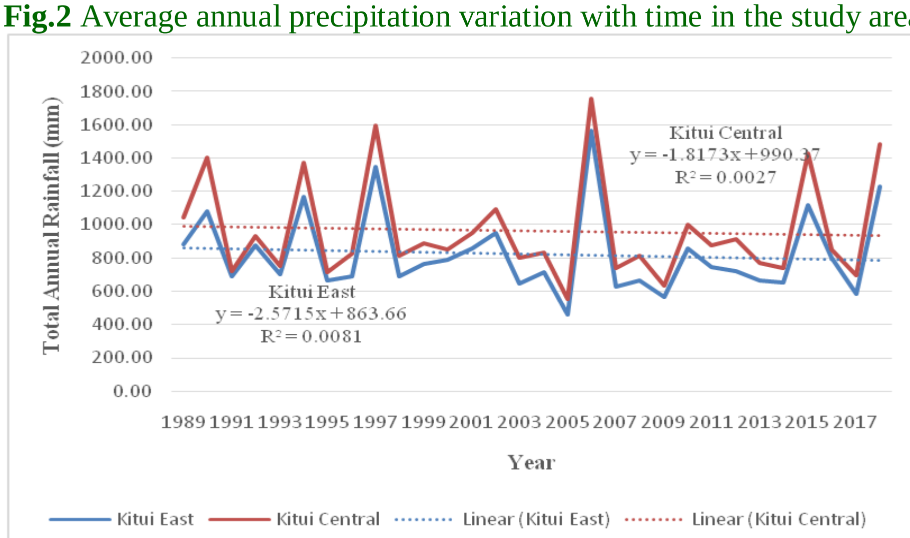


Fig.3 Average annual maximum temperature variation with time in the study area

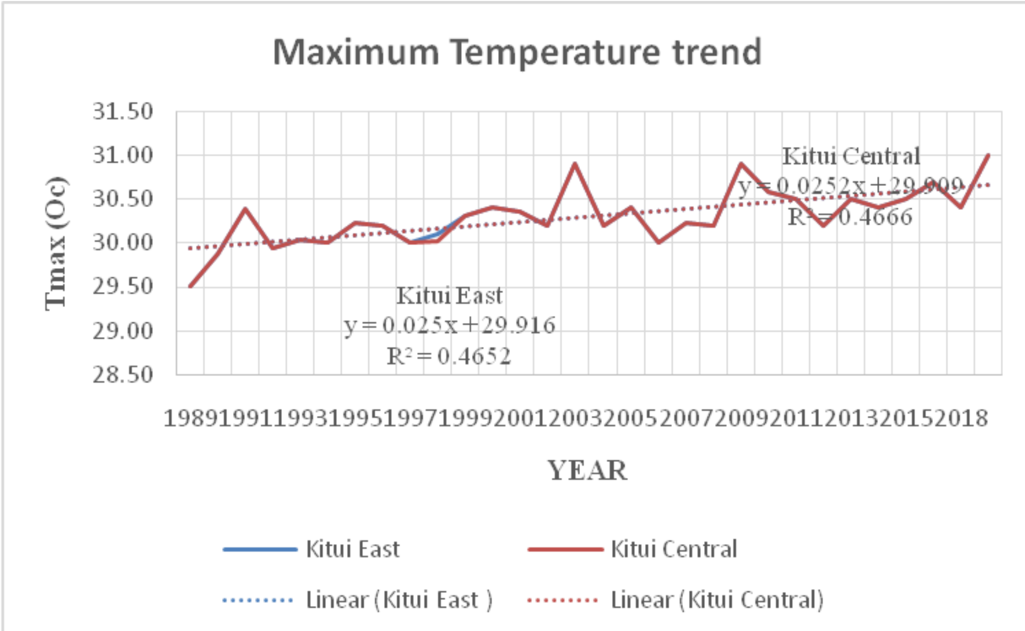


Fig.4 Average annual minimum temperature variation with time in the study area

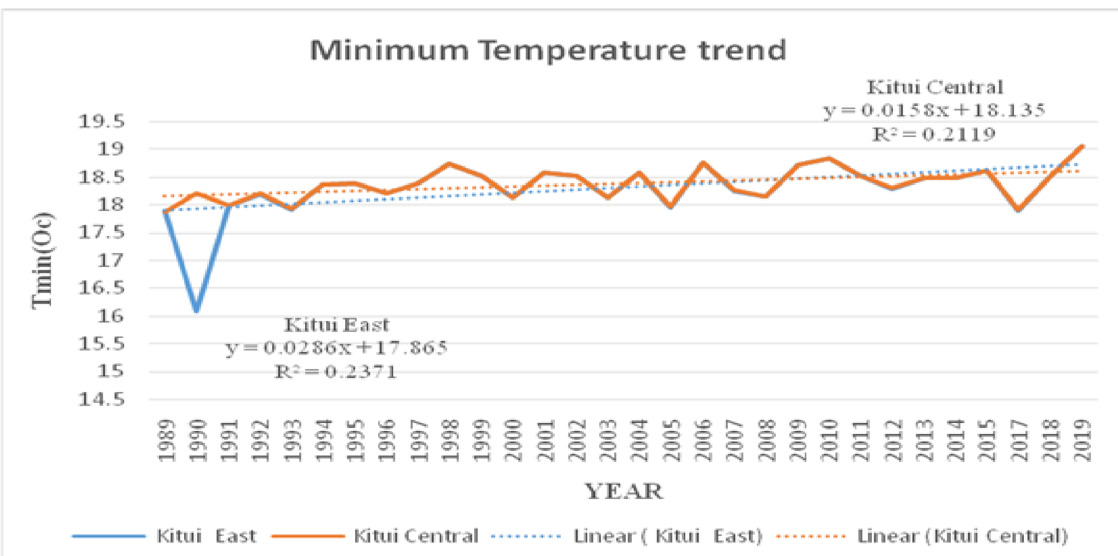
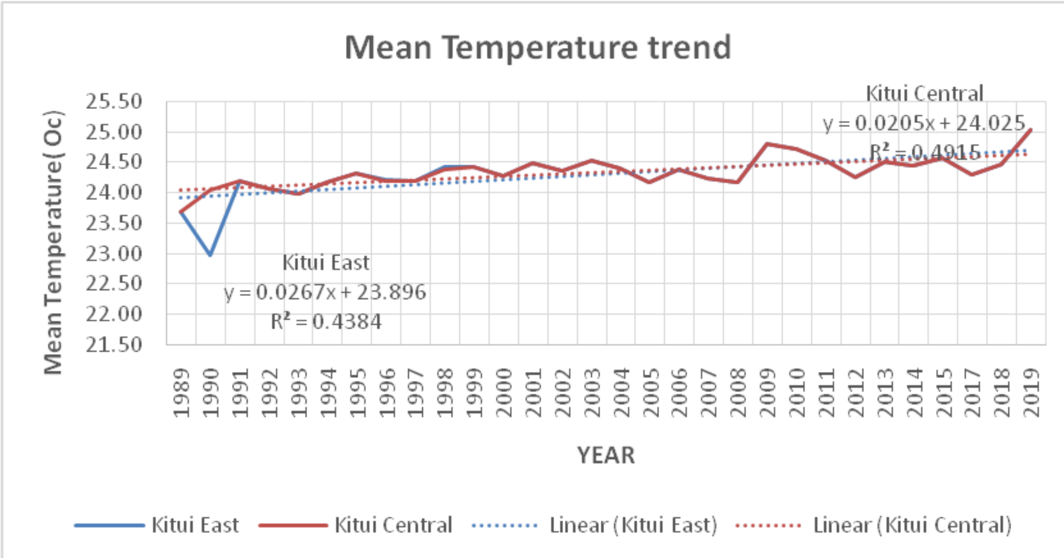


Fig.5 Mean temperature trend in the study area



Non-natural resources-based income in the study area ranged from salaried jobs, remittances, skilled non-farm jobs, and small business returns, which are less sensitive to climate variation and extreme events. The finding corroborates similar studies that indicated that the share of remunerative income helped reduce the overall sensitivity of households (Luni *et al.*, 2012; Opiyo *et al.*, 2014).

The results further indicated that the percentage share of natural resources-based income had the highest weight (0.98), contributing more to the sensitivity index as compared to the other indicators. A higher share of natural resources-based income of the fish farmers in the study area shows that most households highly depended on natural resources-based income which increases their vulnerability to the effects of climate variability and extreme events. The natural resource-based income in the study area ranged from aquaculture, crop farming, livestock production, honey sales, sale of forestry products, and sand harvesting. The results are in agreement with the findings of Opiyo *et al.*, (2014), who noted that households with over-reliance on natural resources like pastoralism and dryland cropping were at a higher risk of being affected by climate variability and extreme events.

Further examination of the results indicated that the weights of both natural and non-natural resources based income (income structure) towards the overall sensitivity index in the study area had a higher contribution to the overall sensitivity index compared to other indicators in the study area. Income structure is crucial in controlling households' sensitivity, which explains its high contribution to the study area's sensitivity index. The results corroborate findings of similar work by Ndungu *et al.*, (2015), who found out that the weights of natural resources-based income and non-natural resources-based income contributed more to the overall sensitivity index as compared to the other sensitivity indicators amongst rural communities in Himachal Pradesh, India. In contrast, findings by Luni *et al.*, (2012) indicated that the weights of all indicators used to measure the sensitivity of households in Chepang, Nepal, livelihood impacts due to natural calamities contributed more to the overall sensitivity index compared to the income structure of the households.

The number of culture units destroyed by climate extreme events and disasters and the number of times water resources dried up in a period of ten years was higher in Kitui East compared to Kitui Central. The phenomenon resulted from prolonged droughts and high temperatures during dry seasons in the Kitui East Sub County, which destroyed pond liners used in earthen ponds, the most modern type of culture units used in the study area. The prolonged droughts and varying precipitation rates also contributed to the drying up of water resources due to increased evaporation from water bodies. An increase in the number of culture units destroyed by extreme climate events and the number of water resources drying up increased the overall sensitivity of the fish farmers. Similar results were reported by the Lake Victoria. Basin Commission (2011), whereby, declining water levels due to less rainfall and more precipitation, increased the sensitivity of the ecosystems and communities that derive their livelihoods directly or indirectly from the basin.

In addition, the percentage share of natural resources-based income was noted to be higher in Kitui East (0.69) compared to Kitui Central (0.49). The high dependence on natural resources increased the sensitivity of the fish farmers in Kitui East since natural resources based-income is climate-sensitive, and any extreme event would render most households vulnerable. Regarding the percentage share of non-natural resources-based income, results revealed that Kitui Central possessed a higher share (0.51) compared to Kitui East (0.31). The observation is attributed to parts of the Kitui Central Sub County being within and near the County headquarters; hence, household members could find off-farm income streams. Therefore, to minimize their sensitivity to climate variability and extreme events, multiple income streams (both natural and non-natural-based) for all fish farmers in the study area should be considered.

Biophysical Vulnerability index

Kitui East registered a higher exposure index (1.02) compared to Kitui Central (-0.10) as illustrated in Table 5. The observation can be ascribed to the higher occurrences of extreme events coupled with the high rate of change in both maximum and minimum temperatures and low precipitation amounts in Kitui East compared to Kitui Central. The current trend of results is in consonance with findings by Mwangi *et al.,* (2020), who reported that the Eastern parts of Kitui County experienced comparatively higher exposure to climate change vulnerability than the western and central parts of the County.

Further, the results revealed that the sensitivity index was higher in Kitui East (2.67) compared to Kitui Central (-0.91). The finding can be attributed to the higher fish fatalities, the higher rate at which water resources dried up, and the higher number in which culture units got destroyed by extreme events. In addition, Kitui East fish farmers over-relied on natural resources-based income more than non-natural resources-based income compared to fish farmers in Kitui Central, which further increased their sensitivity.

Additionally, results indicated that the mean values for biophysical vulnerability to climate variability and extreme events were higher in Kitui East (3.70) compared to Kitui Central (-0.80). The results are ascribed to the high exposure levels of the fish farmers in Kitui East, coupled with their high sensitivity levels compared to Kitui Central fish farmers. Further, fish farmers in Kitui East are in a rural set up which further exacerbates their biophysical vulnerability compared to fish farmers in Kitui central who are in and around an urban set up hence better mitigation, response, and recovery capacity to effects of climate variability and extreme events. Consequently, independent samples T-test performed to compare the biophysical vulnerability of fish farmers in both study sites revealed that the sensitivity index and overall biophysical vulnerability index were statistically significant (p<.01). However, the mean values of the exposure index were not statistically significant at a 95% confidence level. The findings, therefore, imply a variation in biophysical vulnerability to climate variability and extreme events in both study sites. Similar results were reported by Lee (2017) who reported that biophysical vulnerability affected rural and urban study sites differently in Taiwan.

The study established that fish farmers in the study area are affected by climate variability and extreme events and should adequately adapt to survive in the future. Higher exposure and sensitivity to the climate variables and extreme events were reported in Kitui East compared to Kitui Central which was attributed to overreliance on natural resources-based income and the changing climate. Therefore, it is evident that fish farmers in marginalized areas are more vulnerable hence the need for improvement in their access to off-farm income opportunities which are less inclined to changing climate. Consequently, poorer and less empowered individuals are more vulnerable to climate change impacts. The biophysical vulnerability of fish farmers varies between localities and communities, and between demographic groups within a society. The study recommends future research on the vulnerability to climate change and extremes of various subsectors of fish farming such as pond fishing and artisanal fishing

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Conflict of interest

The authors declare no conflict of interest

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