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Impacts of Climate Change on Small Pelagic Fish Catches in the Coastal Artisanal Fishers Communities of Tanzania

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Abstract

Climate-related effects occur across all regions in Tanzania, affecting primary sectors such as agriculture and fishing. This study investigated the impacts of climatic change on small pelagic catches in fishers in Kilindoni, Kipumbwi and Kilwa Kivinje villages along the Tanzanian coast. We studied how changes in rainfall, sea surface temperature, wind speed and chlorophyll *a* affect small pelagic fisheries using primary and secondary data. Qualitative and quantitative methods were applied. Primary data collection involved questionnaires, focus group discussions and key informant interviews. Secondary data was obtained from Tanzania Meteorological Agency and remote sensing from Modi's sensor. Results showed an increase in sea surface temperature (tau = 0.0151, 0.0121, 0.0238 for Kilindoni, Kilwa Kivinje and Kipumbwi, respectively) and unpredictable changes in rainfall patterns which affected small pelagic fisheries. The average rainfall was 284.6, 97.5 and 56.4 mm in Kilindoni, Kilwa Kivinje and Kipumbwi, respectively. In recent years, rain has been unreliable compared to the past 20 years. Unpredictable rainfall, increased sea surface temperature, wind speed and chlorophyll *a* had negatively impacted the small pelagic fishery. There was a strong relationship between the decline of small pelagic catches and climatic variables. The findings of this study have implications for coastal fisher's livelihood, income and food security.

Keywords: Coastal communities; small pelagic fishery; climate change; fisheries; livelihood.

Introduction

Climate change and variabilities such as sea surface temperature, rainfall, and extreme events are global issues with severe impacts at national and local levels (Bates et al. 2008). Global marine fisheries are not performing economically due to overfishing, pollution, and habitat degradation (Sumaila et al. 2011). Brander (2010) observed that climate change poses significant threats to fisheries and other concurrent pressures such as overfishing, pollution and habitat degradation. These have increased the threats to coastal and marine fisheries due to climate change and have been identified as the latest threats to the world's fast-declining fish stocks (Sumaila et al. 2011). It has been documented that marine fisheries will be exposed to increasing sea surface temperatures. Ocean acidification, sea-level rise, increasing storm intensity, altered ocean circulation and rainfall patterns will affect target species through direct and indirect mechanisms (Bates et al. 2008). Bertrand et al. (2020) explained that extreme *El-Niño* was characterised by a mean deficit, approximated when considering the ENSO types 480,000 tonnes of marine capture fisheries. Substantial evidence of climate change in Tanzania includes the disappearance of ice on Mount Kilimanjaro, the submergence of Maziwe Island, and the interruption of freshwater by saltwater in shallow wells in Bagamoyo District (Mwandosya et al. 1998). High temperatures in Tanzania have interrupted coastal and marine ecosystems, increased evaporation, transpiration rate, and heat stress, reducing crop production (Agrawala et al. 2003). More studies have indicated that saltwater intrusion and sea-level rise interfere with water supplies, damage ecosystems, accelerate the loss of land, and weaken agriculture (Mwandosya et al. 1998, Shemsanga et al. 2010). Climate-related impacts are occurring across regions of Tanzania, and primary sectors such as farming and fishing are more vulnerable (Yusuf et al. 2015). Despite the gaps in understanding climate change effects on fisheries in Tanzania, sufficient scientific information highlights the need to implement climate change mitigation and adaptation policies to reduce the impacts of climate (URT 2003). This study aimed to evaluate the potential effects of climate change and met-ocean conditions (wind speed, sea surface temperature and rainfall) on small pelagic fisheries. The study explores how met-ocean conditions caused by climate change affect small pelagic fishery and the resulting catch of artisanal fishers in the study area.

Materials and Methods

Description of the study area

The study was conducted at three landing sites: Kilindoni in Mafia Island, Kipumbwi in Pangani District, and Kilwa Kivinje in Kilwa District (Figure 1). Kilindoni site is located at latitude 7º 50' S and longitude 39º 45' E. Kilwa Kivinje is located at latitude 8º 45' S and longitude 39º 24' E. Kilindoni is essential for its conservation value. Its habitat harbours' the highest coral and marine biodiversity. In 2013, the population of Kilindoni was 14,221, Kilwa Kivinje was 19,376, - and Kipumbwi was 5,333 housing censuses of the Government of Tanzania (NBS 2013). Most of the population depends on coastal and marine fisheries resources for their income, employment and food security.

Sampling procedure and sample size

In this study, we sampled 20% of the total population, which is considered appropriate according to Gay et al. (2009). A systematic stratified random sampling was used in the selection of samples. At Kilindoni, 20 active fishing vessels were sampled, while at Kipumbwi, 10%, and at Kilwa Kivinje, 10% of active sardines (dagaa) fishing vessels were sampled. During the sampling period, the total number of active fishing vessels at Kilindoni was 20, as Kipumbwi and Kilwa Kivinje, with approximately 100 active fishing vessels. One type of small pelagic (dagaa) fishing vessel was sampled.

Data collection techniques

Data were collected between January and November 2019; this involved nine monthly sampling periods. This study collected primary data from questionnaires, focus group discussions and key informant interviews. Secondary data (rainfall, sea surface temperature (SST), wind speed and direction) were obtained from Tanzania Meteorological Agency (TMA). Small pelagic catch Clupeidae (*Sardinella neglecta*) and Engraulidae (Anchovy) species (Bianchi 1985) locally known as "dagaa" (monthly total weight in metric tons caught by ring net or purse fishing gears in 2010–2019 for Kilindoni and Kilwa Kivinje were obtained from the Ministry of Livestock and Fisheries Development–Tanzania government (URT 2019). However, there were no small pelagic "dagaa" catch data records for Kipumbwi. Concerning this, Kipumbwi were not included in the analysis.

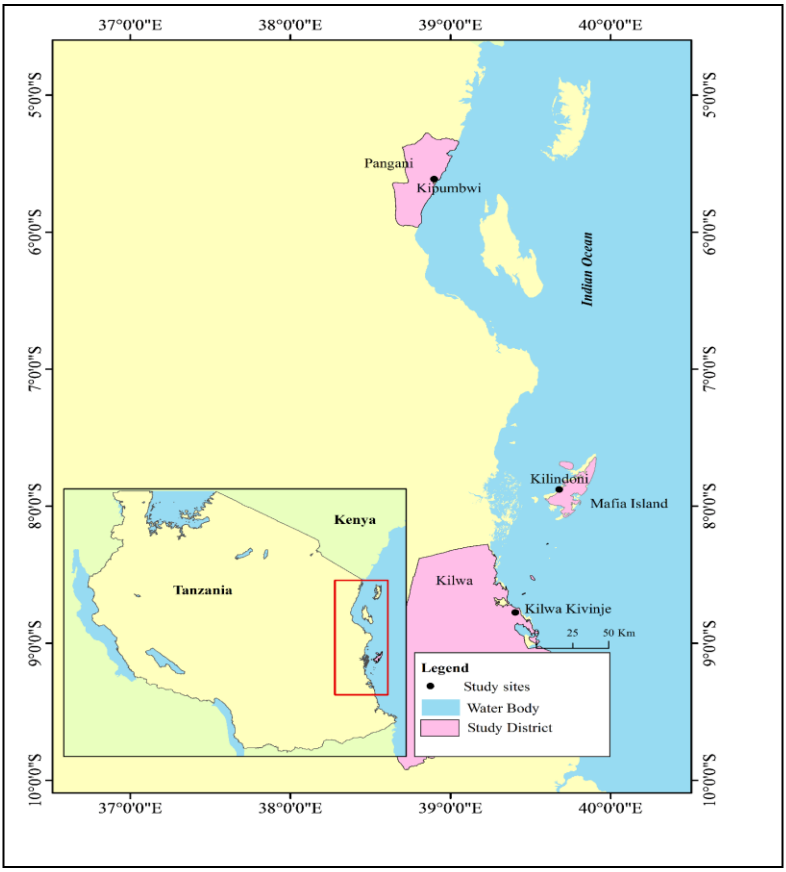

Figure 1: Map of Tanzania showing the location of Kilindoni, Kipumbwi and Kilwa Kivinje.

The fish catch data for small pelagic 'dagaa" was available for two sites. The remote sensing was obtained from Modis Sensor (chlorophyll *a* (2000-2019)) and sea surface temperature (SST) (2010–2019). Rainfall data for Kilindoni (1983–2020) and Kilwa Kivinje (1999–2019) landing sites (TMA 2019).

A maximum variation in wind speed data for 10 years was used to determine wind patterns along the coast of Tanzania. The average wind speed data for the coastal stations of Tanga, Kibaha and Kilwa for ten years (from 2010–2019) were obtained from Tanzania Meteorological Agency (TMA) and recorded at three-hourly intervals at the height of 10 meters. Land-based station data represent wind fields in the nearshore coastal area (study area). Tanga station represents Kipumbwi in Pangani District, Kibaha station represents Kilindoni in Mafia District and Kilwa station for Kilwa Kivinje.

Focus group discussion and key informant interview

A total of 8 focus group discussions (FGD) with 6–10 participants per group, conducted for 1–1.45 hours, were organised per study site giving a total of 126 participants; Kilindoni had 40, Kipumbwi 46, and Kilwa Kivinje with 40. At least 26 key informants' interviews (KIIs) were carried out with beach management unit (BMUs) leaders, District Fisheries Officers and village officials at Kilindoni (12), Kipumbwi, and Kilwa Kivinje, each with 7. We used multiple data sources to address data validity problems during data collection. Thus, individual interviews were sometimes cross-checked with group discussions where contentious issues were resolved by agreeing with the answers or rejecting them. Structured questionnaires were used to collect information. In total, 414 respondents were interviewed, comprising fishers (n = 217) small pelagic fish (dagaa) traders (n = 95), small pelagic fish (dagaa) porters (n = 39), and dagaa processors (n = 63). The interview lasted for 20–30 minutes per respondent.

Data analysis

Mann Kendall test and time series plots were used to analyse trend data on sea surface temperature (SST), rainfall, chlorophyll *a*, and fish catch from 2000–2019. Correlation between SST (°C), precipitation (mm), and fish catches (Mt) (independent of their time) was performed using Pearson's Product-Moment Correlation test. Multiple linear regressions were carried out to investigate if SST, rainfall, and chlorophyll *a* influenced catch. R-Software (Version 4.1.2 2021) and Origin software (Version 8.5) were used for statistical analysis.

Results

Rainfall variations

Rainfall data from Kilindoni meteorological station was used to predict climate change. Any significant variations in years indicated a possible climate change. Data showed rainfall decreased between 1983 and 2020, with the lowest rainfall recorded at 1075 mm in 1987 and the highest at 2,664 mm in 2002 (Figure 2). The annual mean rainfall was 1751 mm. However, the decrease in rainfall was not statistically significant (Mann-Kendal test = -1.897, $p < 0.100$). During the focus group discussion, participants explained that recent rain patterns have been unreliable compared to 10 or 20 years ago. There have been delays in the onset of rainfall. A prolonged dry season in May and June 2019 corresponded with reduced fish catches and agricultural produce.

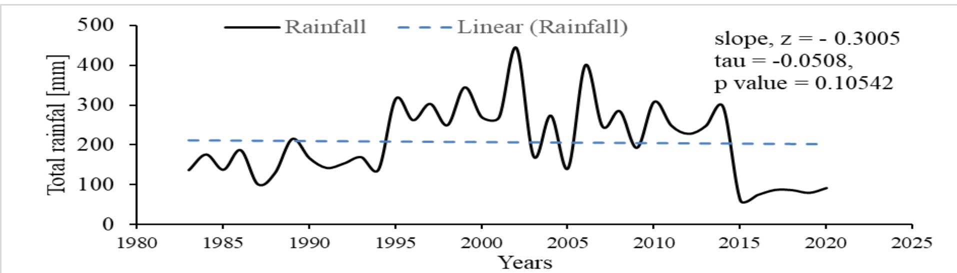

Figure 2: Rainfall trend in Kilindoni, 1983–2020 (Source: Tanzania Meteorological Agency. (TMA) 2021)

In 2014, there was more rainfall in Kilindoni than Kilwa Kivinje (Figure 3). Results showed that Kilindoni had a decreasing trend, while Kilwa Kivinje and Kipumbwi had an increasing trend from 2010 to 2020.

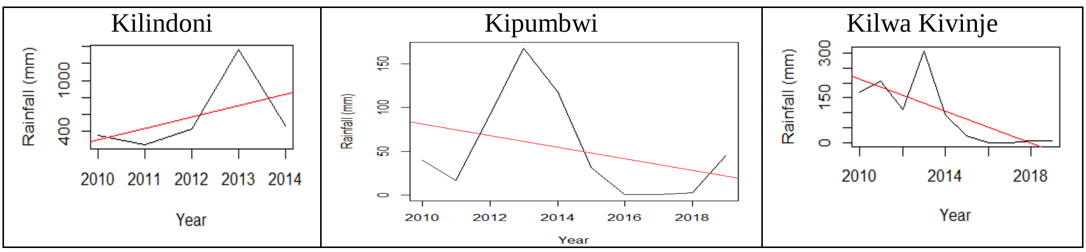

Figure 3: Annual rainfall in Kilindoni (1995–2014) (left), Kipumbwi (middle), and Kilwa Kivinje landing sites (right) (Source: Tanzania Meteorological Agency (TMA) 2021).

Results on variations in rainfall among the landing sites are shown in Figure 4A. The average values for rainfall were 284.6, 97.5 and 56.4 mm for Kilindoni, Kilwa Kivinje and Kipumbwi, respectively. Kilindoni landing site had the highest rain (2010 to 2014) compared to other landing sites.

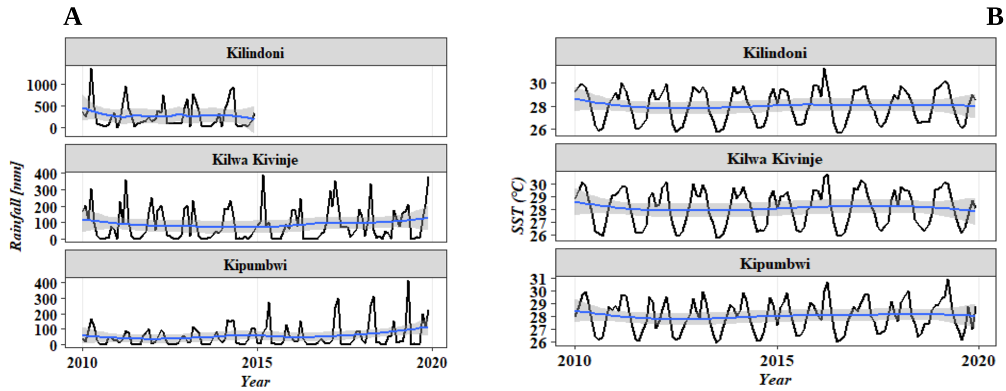

Figure 4: A: Variations in rainfall trends in Kilindoni, Kilwa Kivinje and Kipumbwi. B: Variations in sea surface temperature in Kilindoni, Kilwa Kivinje and Kipumbwi. (**Source**: Tanzania Meteorological Agency (TMA) 2021 and Modi's sensor 2020).

Sea surface temperature

The results showed that the daily average sea surface temperature (SST) negatively correlated with catch except for 2014 and 2016 in Kilindoni. As SST increased, catches decreased (Figure 6). There was a significant variation in small pelagic catches between Kilwa Kivinje and Kilindoni landing sites (W = 0; p = 0.001). There was also a significant negative correlation between catches and sea surface temperature at Kilindoni (r = - 0.73; p = 0.05) and Kilwa Kivinje (r = - 0.99; p < 0.01), and a variation in small pelagic fish catches between Kilwa Kivinje and Kilindoni landing sites (W = 0, p-value < 2.2e -16) (Table 2). The current study indicated SST correlated negatively with small pelagic fish catches in Kilwa Kivinje and Kilindoni landing sites. In comparison, the Kilwa Kivinje landing site correlated more negatively with the catch than the Kilindoni landing site (Table 1). Sea surface temperatures varied across the study sites (Figure 4B). SST did not differ significantly; 28.01 °C, 28.08 °C, and 28.01 °C for Kilindoni, Kilwa Kivinje, and Kipumbwi, respectively (p = 0.490668).

Correlation between SST, rainfall and catch

Results on catch and rainfall at Kilindoni showed a significant negative trend (-0.348**) (Table 1) (Mann Kendall test = -0.0149; p = 0.858). Catches and rainfall at Kilwa Kivinje showed a similar trend (negative trend but not significant (Mann Kendall test = - 0.0204; p = 0.823) (Figure 5). Rainfall varied across the years in Kilwa Kivinje and Kilindoni. Observations showed a decreasing rainfall and increasing SST trends from 2012–2017 in Kilwa Kivinje (Table 1).

Table 1: Correlation between sea surface temperature (SST), rainfall, chlorophyll *a*, and catch in Kilindoni and Kilwa Kivinje

	SST (°C)	Catch (Mt)	Rainfall (mm)
Catch (Mt)	Overall r = – 1.44* Kilindoni r = – 0.188* Kilwa Kivinje r = 0.405**		
Rainfall (mm)	Overall r = 0.459*** Kilindoni r.= 0.572*** Kilwa Kivinje = 0.644***	Overall r.= - 0.442 Kilindoni r = - 0.348** Kilwa Kivinje = 0.313**	
Chl *a*	Overall = – 0.210** Kilindoni = - 0.230* Kilwa Kivinje = - 0.190*	Overall r = 0.025 Kilindoni r.= - 0.098 Kilwa Kivinje r = 0. 093	Overall r = 0.037 Kilindoni r. = 0.226 Kilwa Kivinje r.= 0.045

(= Correlation is significant at the 0.01 level, ** = correlation is more significant at 0.01 level, *** = correlation is more strongly significant at 0.01 level).*

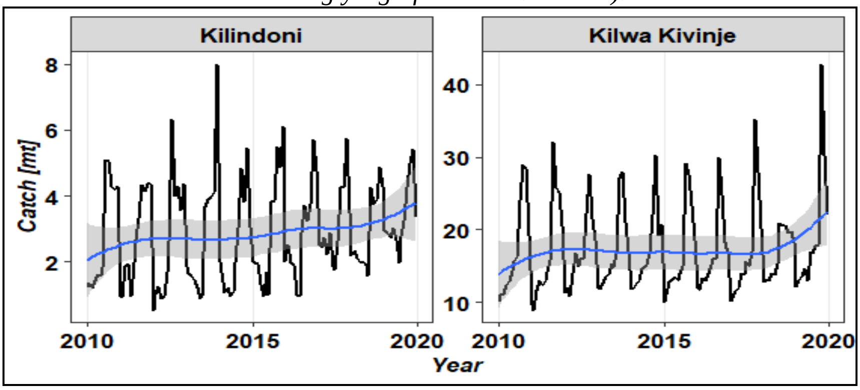

Figure 5: Correlation between small pelagic catch and rainfall at Kilindoni (left) and Kilwa Kivinje (right) from 2010–2019 (Source**:** URT-Fisheries Department 2019, Tanzania Meteorological Agency (TMA) 2019).

Table 2: Kendall's tau statistic from the Mann-Kendall trend test (*p* values in brackets; Data sources: Tanzania Meteorological Agency (TMA), 2021, 2019; Modi's sensor, URT (2019)

Attributes	**Kilindoni**	**Kilwa Kivinje**	**Kipumbwi**
Rainfall	- 0.0771 (0.38907)	0.0396 (0.84711)	0.042 (0.70146)
SST	0.0151 (0.80823)	0.0121 (0.84711)	0.0238 (0.70146)
Catch	0.17 (0.006)	0.119 (0.0543)	-
Chlorophyll *a*	0.0585 (0.34422)	0.0849 (0.16997)	0.165 (0.0074)
Wind speed	0.203 (0.0019)	0.258 (0.0020)	- 0.0542 (0.4281)

Influences of sea surface temperature and rainfall on catches

A multiple linear regression model was performed to explore the influence of sea surface temperature (SST) and rainfall on fish catches. The regression model had a significant coefficient of determination (Adjusted $r^2 = 0.76$, $p < 0.001$). Both SST and rainfall correlated negatively with the amount of catch (Table 3). However, only the correlation between SST and catch was statistically significant. A significant decrease in catch by 1.365617 Mt was found for each increase in SST. The results showed that the interaction between SST and rainfall had no significant influence on the amount of catch (*p* = 0.277). Besides SST, the catch amount significantly depended on the site ($p < 0.001$). The mean fish catch at Kilwa Kivinje was 13.51 Mt, significantly higher than that recorded at Kilindoni at 2.84 Mt (t = -18.07, df = 67.282, $p < 0.001$). (tau = 0.17 , *p* = 0.00592 and tau = 0.119, *p* = 0.05438) for Kilindoni and Kilwa Kivinje, respectively. The overall equation expressing the regression relationship between catch and SST, rainfall and site can be presented as follows: Catch = 41.889-1.366*(SST)–0.041*(rainfall) + 13.513*(site) + 0.001(SST*rainfall) (Table 3).

Table 3: Multiple linear regression results for the influence of SST, rainfall and site on catch

Coefficients	Estimate	Std. Error	t value	Pr (> t)
(Intercept)	41.888550	10.671315	3.925	<0.001
SST	-1.365617	0.382957	-3.566	<0.001
Rainfall	-0.040567	0.034787	-1.166	0.246
Site Kilwa Kivinje	13.513094	0.872847	15.482	<0.001
SST: Rainfall	0.001353	0.001240	1.091	0.278

Chlorophyll *a* variation in the study area

The trend data showed a significant negative correlation with SST (- 0.426 ***). SST and chlorophyll *a* also negatively correlated with fish catches (r = - 0.144*) and (r = - 0.569***), respectively. However, rainfall correlated with chlorophyll *a* (r = 0.329 *** (Figure 6), while wind speed correlated negatively with SST and rainfall. The standardised values of SST and rainfall showed a negative correlation between SST and rainfall (Figure 6).

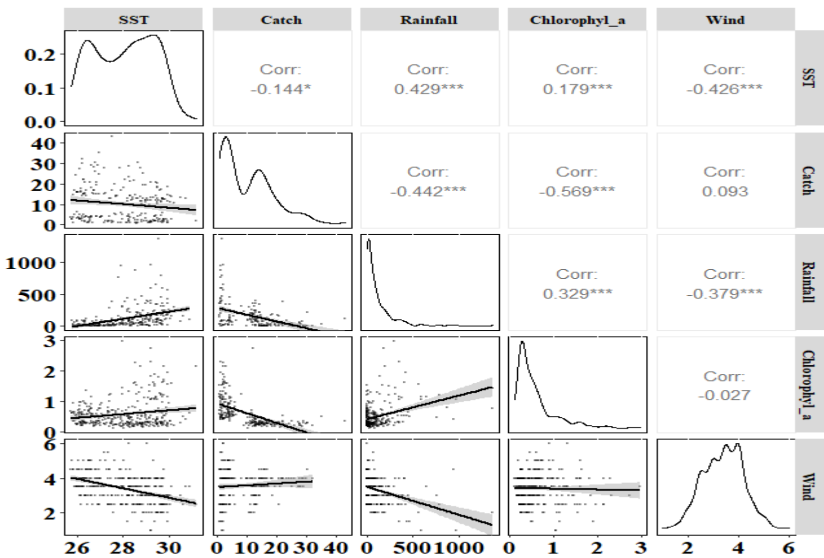

Figure 6: Correlation between (wind speed), SST, rainfall, catch and chlorophyll *a*. (*Correlation is significant at 0.01 level, ** = the correlation is more significant at 0.01 level, *** = the correlation is more strongly significant at 0.01 level).*

Influence of rainfall on chlorophyll *a* and small pelagic fish catches

Kilindoni received less rainfall than Kilwa Kivinje (r = - 0.313**), favouring the increase in chlorophyll *a* and increasing small pelagic fish catches. SST negatively correlated with chlorophyll *a*. As chlorophyll *a* decreased, it resulted in a more significant negative correlation with SST (r = - 0.210**). The correlation was negative (r = - 0.230* and - 0.190*) in Kilindoni and Kilwa Kivinje, respectively (Table 1). Variations of chlorophyll *a* in the study sites showed that Kilindoni had the highest chlorophyll *a*, followed by Kipumbwi and Kilwa Kivinje. In all the study sites, chlorophyll *a* showed an increasing trend (Figure 7A).

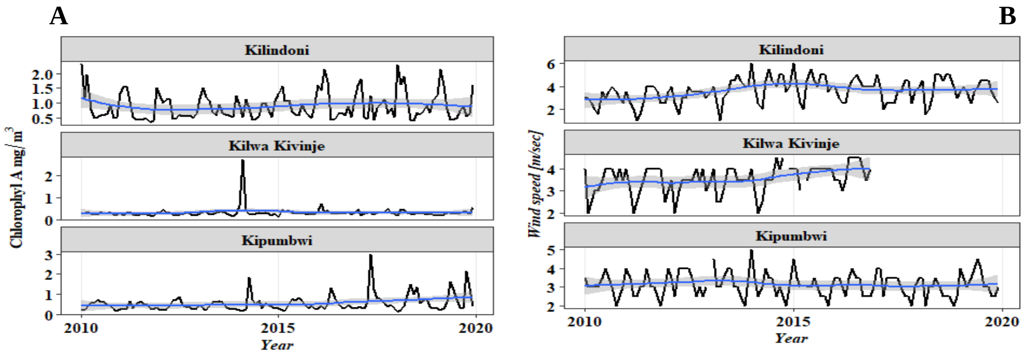

Figure 7: A: Variation in chlorophyll ***a***, B: Variations in wind speed at Kilindoni, Kilwa Kivinje and Kipumbwi landing sites (data Sources: Modi's sensor 2020, Tanzania Meteorological Agency (TMA) 2021).

Variation in wind speed

The average values for wind speed were 3.55, 3.54, and 3.13 ms^{-1} for Kilindoni, Kilwa Kivinje and Kipumbwi, respectively, with Kilindoni having the highest wind speed (maximum six ms^{-1} compared to other sites (p = 0.000 or 3.35e-07 (Figure 7B).

Fishers' perceptions of the effects of climate change on small pelagic fisheries

Most respondents were 29 years old and above (70%). The gender ratio indicated that among all the respondents (n = 414), 65.5% were males, whereas 34.4% were females. The focus group discussion (FGD) participants explained that fishers reported a temperature increase during the 1999–2019 period. They also reported a decline in catches and an increase in fishing time. Fishing used to be nearshore, closer to landing sites. However, recently fishers have to go far offshore to catch the same types of fish, which increases operation costs/fuel consumption. During the FGD, participants explained a distinct seasonal change in small pelagic fish catches with low catches during strong winds (South-East Monsoon) (May to August) when the sea becomes rough with turbid waters, thus limiting fishing activities. High catches during calm weather North-East Monsoons (NEM) occur between December and March; a calm sea with clear water good for fishing. The analysed climatic data concurred with the respondents' perceptions. For example, Kilwa Kivinje experienced increased sea surface temperatures and decreased rainfall from 2012 to 2018. Results are similar to those reported by IPCC (2007), which indicated that the global average temperature has increased since 1861. Earth's temperature has risen by 0.14 F (0.08 °C) per decade since 1880.

Discussion

The fishery system's sensitivity to various factors includes nutrient availability, circulation, water column stability and environmental variables such as increased sea surface temperature and rainfall changes that affect primary productivity (chlorophyll *a* and phytoplankton) (Diankha et al. 2013, Semba et al. 2016). During unreliable rainfall, increased SST reduces fish catches (Gordon et al. 2000). Temperature influences fish during the spawning season, development, and survival of the eggs, and larvae tend to control distribution, aggregation, migration, and schooling behaviour of juveniles and adult fish (Gordon et al. 2000, Yona et al. 2016). With the decrease in fish catches, fisher communities also lost their core sources of income. Studies, such as those by Cinner et al. (2012), noted increased trends in sea surface temperature in the Indian Ocean; IPCC (2013) have also reported that an Indian Ocean basin model (IOBM) has strong warming trends significant at 1% since the middle of 20th century. Therefore, there is no doubt that the currently observed ocean productivity is going downward. In this present study, there were noted differences in landings of small pelagic fish in Kilindoni and Kilwa Kivinje, which are discussed below.

Impacts of climatic variables on the fishery ecosystem

The important climatic drivers in fish production systems include water temperature, precipitation, wind, and wave action (Brander 2010, Barange et al. 2014). It has been documented that changes in these climate variables affect fish populations (Drinkwater et al. 2010). The differences in wind speed between different landing sites are probably due to the differences in the geographical locations on the recording. Small pelagic fish have been susceptible to their marine environment throughout history (Alheit et al. 2009). They have specific tolerance windows for their environmental conditions (temperature, salinity, oxygen, and pH), which define their bioclimatic envelopes (Pearson and Dawson 2003). Pauly (2019) found that oxygen levels influence the maximum size of fish and growth. This author added that as the pelagic environment gets warmer, the oxygen demand of the fish for metabolic needs will rise and force fish to migrate to cooler waters or die. These findings agree with fishers' claims that these days they need to go very far offshore to catch the same type of fish they used to catch nearshore during the 1980s. The current distant fishing is related to the depletion of fish near shore due to overfishing, change in temperature, or both noted in the present study.

Relationship between sea surface temperature (SST) and rainfall

The present study found that as SST increased, catches subsequently decreased (Figure 6). Gordon et al. (2000) reported that climate change threatens fish migration and productivity. Increased temperatures and sea-level rise, associated with ocean acidification, could also reduce fish stocks, destroy habitats and affect the migrations of different fish species (Pauly 2019). It was projected that the temperature would increase between 3–5 °C under a doubling of carbon dioxide by 2075 (Agrawala et al. 2003). Localised variations of sea surface temperature (SST) for a short period to a few weeks could influence the distribution sub-population of adult small pelagic fish. It has been shown that longer-term abundance follows decadal oscillations of SST and primary production (Peck et al. 2013). However, the correlation between rainfall and SST was not significant. Therefore, other factors besides SST may influence rainfall in the study area.

Climate change and the fishing environment

At a national level, climate change variables such as temperature will rise by 2-4 °C by 2075 (URT 2003). In general, the country will experience a decrease in precipitation by between 0–20% inland. However, in the coastal areas where the study sites are located, rainfall is predicted to increase by 20–50% (Nkonya et al. 2017). Seasonal variation in rainfall observed in this study might have resulted in reduced small pelagic fish catches and decreased production, given the dependence on significant sectors such as agriculture and fisheries. These sectors are susceptible to slight changes in climatic variables (Shemsanga et al. 2010). It was predicted that changes in precipitation and temperature would lead to an annual average loss of USD 200,000 in agricultural production in Tanzania alone (Nkonya et al. 2017).

Similarly, global coastal and marine fish production has suffered a mean deficit of approximately 480 000 tons during the *El-Niño* Southern Oscillation (ENSO) (Bertrand et al. 2020). Although ENSO has significantly affected the global coastal and marine catches, its development has recorded a minimal effect on the Indian Ocean fisheries' landings (Bertrand et al. 2020). Cinner et al. (2012) have noted that increased temperatures combined with frequent *El-Niño* events have caused thermal stress in the coral reef, leading to coral bleaching and causing a shift in fish communities. Findings of focus group discussion (FGD) revealed that the reduction in rainfall has led to a decrease in agricultural produce; thus, many farmers joined fishing activities. Subsequently leading to an increase in illegal fishing techniques and changes in fishing gear.

The effects of chlorophyll *a* variations on the coastal and marine ecosystem

Surface stratification increases plankton in illuminated surface waters at higher latitudes (light-limited) in the global oceans. The opposite occurs at mid-latitudes, where reducing nutrient supplies decreases phytoplankton (Semba et al. 2016). Tsiaras et al. (2012) reported that positive SST trends reduce the vertical mixing of the water column, leading to nutrient-depleted surface areas. Consequently, primary production and phytoplankton biomass may affect fisheries. Differences in the geographical location of the two sites have influenced the reproductive potential of small pelagic fishes (*dagaa*). Kilwa Kivinje seems to be more productive than Kilindoni landing sites due to its location. Kilwa Kivinje is also favoured by strong ocean currents that enhance nutrient circulation and primary productivity, resulting in more catches than Kilindoni (Table 1). Semba et al. (2016) noted that the area around the Rufiji delta (Western side of Mafia–Rufiji channel had a higher content of chlorophyll *a* than around Mafia Island's eastern side (Kilindoni), where high chlorophyll *a* concentration was observed enhanced by ocean currents upwelling and mixing nutrients. Chlorophyll (Chl *a*) availability in surface water has been used to indicate the primary production and ecological functioning of freshwater and marine ecosystems (Boyce et al. 2010).

Assessment of long-term changes in phytoplankton (chlorophyll *a*) and ecosystem conditions is paramount because chlorophyll *a* is linked to a decline in marine fisheries resources (Boyce et al. 2010). The present study indicates that an increase in sea surface temperature and a decrease in rainfall influenced chlorophyll *a*, which might have affected the production of small pelagic fisheries and catches. Kilwa Kivinje was more productive with a higher chlorophyll *a* concentration and had more small pelagic catches than the Kilindoni landing site. These findings also conquered with Brander (2010), who showed that satellite observations of the ocean indicated that global ocean annual primary production (chlorophyll *a* has declined by more than 6%, influencing the fishery ecosystem. Semba et al. (2016) noted that the mean annual SST has increased from 27.17 °C in 2002 to 28.66 °C in 2014, indicating a 1.49 °C increase in temperature. Therefore, the decrease in phytoplankton productivity (using chlorophyll *a* as a proxy of primary productivity) in the study area might affect the recruitment and reproduction of small pelagic fishes. Semba et al. (2016) documented that chlorophyll *α* positively correlated with catches. The present study showed an overall correlation ($r = 0.025$). However, chlorophyll *a* showed negative correlation with catch at Kilindoni landing site ($r = - 0.098$); and rainfall $r = - 0.348^{**}$ Table 1).

Influence of rainfall variability on small pelagic fish catches

The current study observed a similar rainfall pattern significantly impacting livelihood, agriculture, and small pelagic fisheries and catches (Figure 2 and Figure 4 A). As noted in this study, rainfall was decreasing, accompanied by prolonged dry seasons and delays in the onset of rains affecting the livelihood activities such as agriculture, livestock, and fishing. Currently, rainfall has decreased compared to the 1980s.

In the 90s, central, western, southwestern, southern, and eastern parts of Tanzania had reduced rain by 10% to 15%, as previously reported by Agrawala et al. (2003).

Influences of sea surface temperature on fisheries

Climate variability can affect fisheries in multiple ways (Drinkwater et al. 2010). Changes in water temperature, precipitation, and aquatic variables such as wind velocity, wave action and rise in water level bring significant ecological and biological changes to marine ecosystems and the resultant fish population (Brander 2010). This study found that any difference in climate variables such as SST and rainfall influences chlorophyll *α*, which impacts fish catches, affecting the fishers' livelihoods, primarily dependent on fisheries resources. An increase in sea surface temperature affects fish stock, changing physiology and sex ratio and altering the timing of spawning, migrations, and peak abundance (Diankha et al. 2013). Modis remote sensing data showed that increased SST adversely affects chlorophyll *a* and small pelagic fishery and catches.

In the Mediterranean Sea, fisheries landings variations showed a 70% negative gain annually associated with changes in SST (Tzanatos et al. 2014). An increase in sea surface temperature reported in this study might have negatively impacted small pelagic catches. The decline in the catch in Kilwa Kivinje from 2012–2017 was possibly attributed to increased sea surface temperature and a decrease in rainfall. However, other factors, such as the increase in fishing efforts and illegal fishing practices, might have contributed to the decline in catches, as previously noted by Alheit et al. (2009). The fishery ecosystem on which these communities depend is affected by climate changes (sea surface temperature and reduced rainfall). The consequence to fisher communities has been a decline in fish catches and un-matching changes in fish prices that do not enable communities to balance the fall with their expenses, thus affecting their local economy. Climate change was shown clearly in the study area, and there was an increase in rainfall, which increased chlorophyll α and consequently increased catches at Kilindoni only; and not observed in the other sites. The decline in rainfall led to reduced agricultural production, reducing livelihood diversification. Thus, many coastal communities found themselves in the fishery, influx of fishing vessels and fishers, ultimately impacting fish resources.

The current study recorded variations in climate change over 20 years, fishing, and seasonal changes in livelihood activities such as agriculture. Catches were significant determinants influencing fishers' perceptions. The study showed that fishers had adopted various coping strategies to adapt to climate change and variability, such as food vendors and eating a single meal daily. However, some respondents cited coping strategies such as engaging in illegal fishing and beach seining *'kukwega'*, which hinder the sustainability of marine resources.

Conclusion

The collected data on climatic variables; rainfall, SST, wind speed, and chlorophyll *a*, and the analysis of relationships of the variables with catches of small pelagic fish in Kilindoni, Kilwa Kivinje and Kipumbwi explain the decline in small pelagic fish catches to change in the climate. Further research into environmental factors such as carbon dioxide concentration, current ocean variations and fishing efforts are recommended to determine the fluctuations in fisheries populations. Fluctuations in fisheries in the population might also be influenced by several factors, including changes in fishing efforts (fishing boats, gears, and fishers) and fleet dynamics.

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Competing interest

The authors declare that no competing interest is associated with this publication.

Ethical considerations were observed. This research was done under the University of Dar-es-Salaam moral regulation; a research clearance permit Ref No: AB3/12(B) was obtained.

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