Original Article

Effects of climate change on mangrove-dependent livelihoods in Lamu County, Kenya

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Abstract
The effects of climate change on mangrove-dependent livelihoods were examined in Lamu County, Kenya. Climatic instrumental, household survey, key informant interview, and focus group discussion data were collected from August to December 2021. Data analysis indicated a significantly increasing trend in annual air temperature between 1985 and 2020, with minimum and maximum temperatures increasing by 0.034 °C and 0.0281 °C, respectively. Rainfall during the seasonal long rains declined, but not significantly. In contrast, the seasonal 'short rains' increased significantly. The mean sea level rose significantly, from 7066 mm in 1985 to 7150 mm in 2020. The perception data showed an increasing effect of climate change on mangrove-dependent livelihoods in the last 10 years. Critical livelihood aspects that were affected included the destruction of property, displacement, the prevalence of waterborne infections, reduced mangrove products, increased salinity in underground waters, and destruction of fish habitats.

Keywords: climate, mangroves, temperature, rainfall, sea level, livelihood

Introduction
Climate change is a long-term change in the average weather patterns that define the Earth's global, regional, and local climates (Bruine de Bruin *et al.*, 2021). Climate change factors including sea level rise, increased storminess, altered precipitation regime, and increasing temperature impact mangroves at global, regional, and national scales. Mangrove-dependent livelihoods refer to people who live in the mangrove ecosystem (Youshao, 2021). The mangrove ecosystem provides a means of sustaining the lives of the population living around it. Mangroves sustain the lives of the coastal population through their products (i.e., mangrove trees for wood, fuel, and medicines), their preservation of the coastal ecosystem (i.e., protecting the coastline from strong waves), and their provision of habitat for fishes and seafood (Fongzossie *et al.*, 2022). Climate change is causing destructive impacts on mangrove ecosystems, leading to a reduction in the availability of mangrove products and the destruction of recreational sites and beaches (Mung'ong'a *et al.*, 2019). Mangrove-dependent societies are being affected by climate change impacts, and there is a need for community education on climate change impacts and livelihood diversification strategies.

Globally, the total surface area of mangroves has decreased by 1.04 million ha between 1990 and 2020 and thus livelihoods depending on mangroves have been at stake (Friess *et al.*, 2020). Empirical studies have closely linked variations in climate to mangrove biodiversity change (Rogers *et al.*, 2019; Cameron *et al.*, 2021). Indeed, livelihoods depending on mangrove ecosystems globally are exposed to a massive decline in mangroves and therefore their means of survival. Ward *et al.* (2016) established that sea level rise and storminess were likely to have a greater impact on mangroves in North and Central America, Asia, Australia, and East Africa than in West Africa and South America. Coastal communities in Pakistan, Bangladesh, and Sri Lanka that depend on the mangrove ecosystem for trade and fishery have negatively been exposed to climate change with the mangrove ecosystem deteriorating and associated mangrove products and fish reducing in supply (Salik *et al.*, 2016). In agreement with Salik *et al.* (2016), Wilson (2017) showed that sea level rise that causes saline intrusion, coastal erosion and destruction of primary habitat is currently the most immediate climate-related threat to mangroves in Caribbean Small Islands (SIDS).

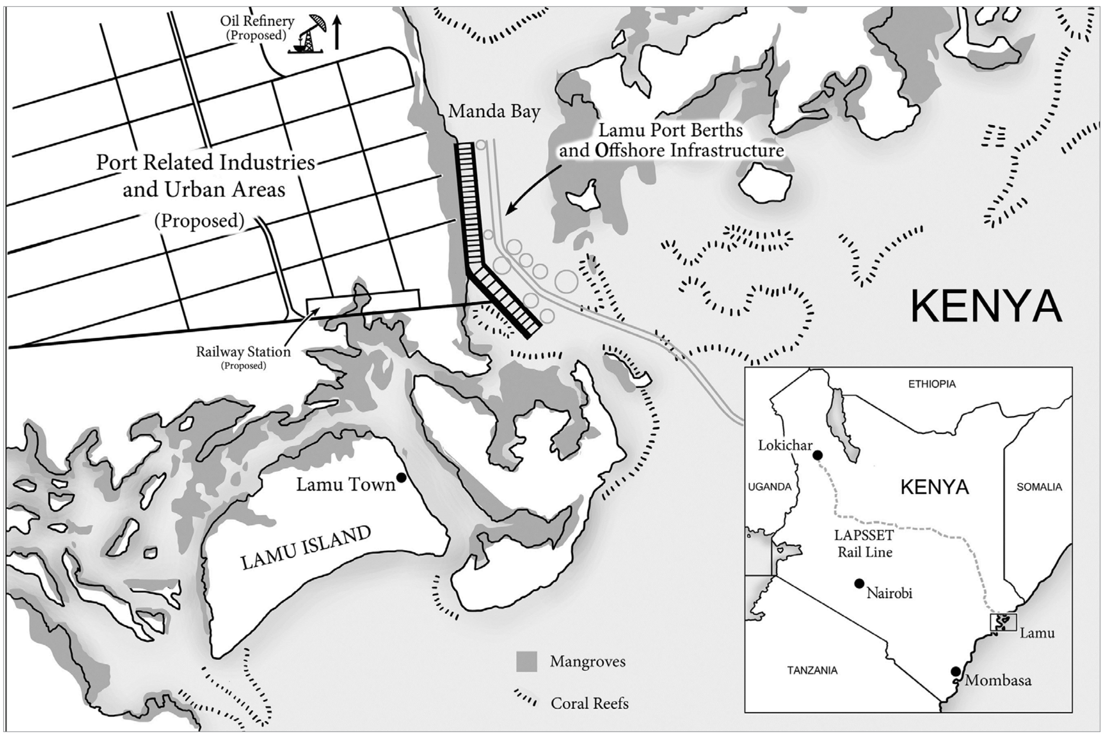

Figure 1. Lamu County Map (prepared by S. Njenga)

Climate change and its impacts on mangrove-dependent livelihoods are also apparent in Africa. Indeed, it is an emerging threat to mangrove ecosystems in Africa (Scales *et al.*, 2018). In Cameroon, Fongnzossie *et al.* (2022) found that irregular rainfall patterns and increasing temperature have left the households on Manoka Island vulnerable to the impacts of climate change such as floods, and rain storms that have destroyed mangroves supporting lives. In the East African mangrove ecoregion, climate change has also affected the mangrove-dependent communities across the coastlines of Mozambique, Tanzania, Kenya, and southern Somalia by undermining their capacity to access mangrove ecosystem resources (Bandeira *et al.*, 2018). Overall regional decline of mangrove surface area with a net loss of 984 sq. km between 1975 and 2013 has resulted in socio-economic vulnerability among the mangrove-dependent communities, with various mangrove ecosystem benefits being impaired, such as reduced catch of shrimp and fish (Bandeira *et al.*, 2018). Mung'ong'o *et al.* (2019) noted the vulnerability of fisher-mangrove-dependent communities in the Rufiji Delta in Tanzania climate change impacts with reduced catch from fisheries in the mangroves are experienced. Maina *et al.* (2021) identified sea level and macroclimate as the main drivers of the present-day ecological condition of mangroves in the Western Indian Ocean. Nicholson (2019) showed that rainfall seasonality is quite complex, changing within tens of kilometres showing strong links to the El Nino-Southern Oscillation (ENSO) phenomenon in the Eastern Africa Region.

In Kenya, climate change is negatively affecting the coastal regions with climate change variables such as sea level rise and flooding displacing coastal indigenous populations and destroying property (Kogo et al., 2020). Mangrove cover in Kenya is estimated at 50,000-60,000 hectares and has significantly declined by almost one-fifth between 1985 and 2020 (Maina *et al*., 2021). During the same period, climate variables have also become erratic with significant changes in climate being observed (Yvonne *et al*., 2020). Indeed, previous studies in Kenya have since established that climate variables such as rainfall, temperature, sea level rise, and sea storminess have severe consequences for ecosystem-dependent communities i.e., mangrove-dependent livelihoods (Okello *et al*., 2015; Yvonne *et al*., 2020). Given that over 70 % of Lamu's people partially depend on mangroves and fisheries for trade and livelihood (Wanderi, 2019), it is becoming clear that these livelihoods are now threatened by climate change. Even though the link between climate change and mangrove-dependent livelihoods has been well-studied elsewhere, few studies have been undertaken in the context of Lamu, Kenya. This study sought to fill this gap in information.

Materials and methods

The study area

Lamu is one of six coastal counties in Kenya. It is situated on the north coast with Lamu Town as the county capital. The county shares boundaries with Somalia to the northeast, Tana River County to the southwest, Garissa County to the north, and the Indian Ocean to the south. The Lamu Archipelago, which consists of more than 65 islands, and the county's mainland together make up the county's 6,273.1 km^2 (2,422.1 sq. mi) of territory. The coastline's overall length is 130 km (81 mi), while the total area of land and water is 308 km^2 (119 sq. mi) (Fig. 1). Lamu County's biophysical characteristics present a vulnerability to climate change impacts, given that it is generally flat and lies between 0 and 50 m above sea level (Gichenje *et al*., 2019). Further, the soils in Lamu are generally shallow and prone to water logging. The area is thus susceptible to flooding from excessive rains, sea level rise, and sea storminess (Zachary, 2023). Further, the mangroves that form a significant element of biodiversity in the area are vulnerable to erratic rainfall and sea level rise resulting in flooding suffocation, and death of mangroves (Andreetta *et al*., 2014). The death of mangroves from climatic factors implies that mangrove-dependent livelihoods are impaired, thus endogenous groups in Lamu such as the Boni that practice subsistence agriculture, hunting, and gathering of edible forest products are exposed to climate change variables (i.e., erratic rainfall, sea level rise, and increasing temperatures (Olsen *et al*., 2020). Further, a key economic activity in Lamu is tourism with visitors attracted by recreational beaches and sport fishing in the mangrove ecosystem. Climate change impacts the mangrove ecosystem which is a tourist attraction leading to a loss of income for livelihoods depending on tourism activities such as tour guiding (Njoroge *et al*., 2020). The findings from this study and the data generated are critical for climate change adaptation and mitigation efforts for the benefit of mangrove-dependent livelihoods in Lamu, and Kenya at large.

Conceptual framework

This study employed a conceptual framework as an analytical tool to evaluate the effect of climate change on mangrove-dependent livelihoods in Lamu County-Kenya (Fig. 2). The key independent variable was climate change. The sub-independent variables included rainfall, temperatures, and sea level rise. The temperature aspect captured was the annual minimum and maximum in degrees centigrade. The rainfall aspect captured was mean annual rainfall and mean seasonal rainfall in millilitres. The sea level rise aspect captured was the mean annual sea level in

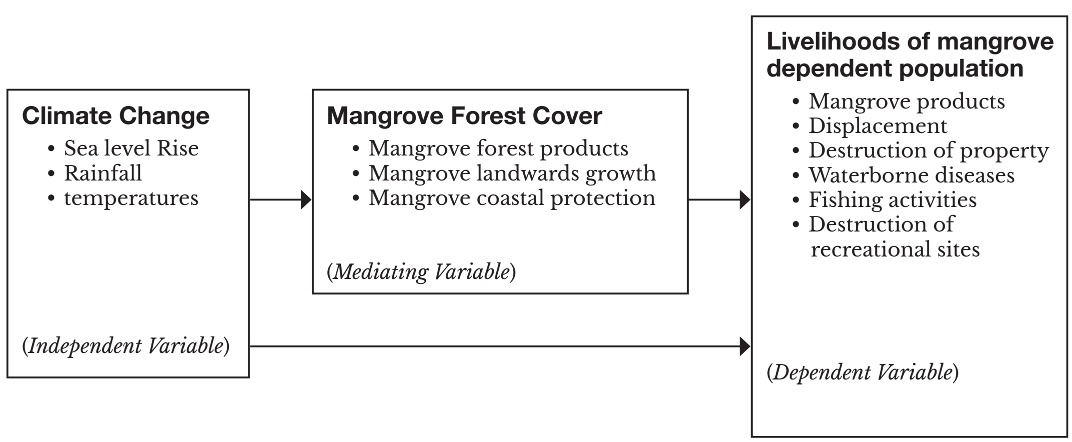

Figure 2. A conceptual framework for the study.

millimeters. The changes in climatic variables were conceptualized as directly and indirectly impacting mangrove-dependent livelihoods. The direct effect of climate change occurred without a mediating factor while the indirect effects occurred through mangrove forest cover as the mediating factor. The mangrove forest cover in Lamu County, a mediating variable, was captured in terms of mangrove products, its coastal protection feature, and its capacity to protect people and animals from flooding. The change in the mangrove forest cover due to the impact of climate change was expected to affect mangrove-dependent livelihoods. The dependent variable was therefore mangrove - mangrove-dependent livelihoods. The livelihoods affected included the supply of mangrove forest resources, human population displacement, destruction of property and infrastructure, destruction of recreational sites and beaches, the emergence of human and livestock diseases, and interference with fishing activities.

Data collection and analysis

The National Oceanic and Atmospheric Administration (NOAA) provided data on the atmospheric temperature (SST), while the Kenya Meteorological Department (KMD)-Lamu Station provided rainfall data, and KMFRI and the University of Hawaii Sea Level Centre (UHSLC) provided the sea level rise (SLR) data. These data were used to quantify climate change variables in Lamu. Further, key informant interviews (KII), household (hh) surveys, and focus group discussions (FGDs) were used to gather perception data. The household survey was employed among 380 hh sampled from the target population of 37,963 hh in Lamu County (Balaton-Chrimes, 2021). The hh were distributed over nine divisions (Witu, Amu, Hindi, Mkumbini, Mpeketoni, Basuba, Faza, Kiunga, and Kizingitini). The sample size was determined based on formulae proposed by Kothari, 2004)

$$\mathbf{n} = \frac{z2pqN}{e2(N-1) + z2pq}$$

Where e = error taken as 5 %; p= population reliability taken as p=0.5; q= (1-p), z is the normal distribution at 0.05 level of significance such that z =1.96, N is the target population and n is the sample size.

$$\mathbf{n} = \frac{1.96*1.96*0.5*0.5*37{,}963}{0.05*0.05\ (37963-1) + 1.96*1.96*0.5*0.5}$$

n = 380.32
n = 380

Further, using stratified random sampling, the sample size was stratified into sub-counties and then administrative divisions and then hh from each stratum were randomly selected from a list prepared for each administrative division. The head of the hh automatically participated in the study and in cases where they were absent, the representative of the head of the hh participated in the study. During the hh survey, questionnaires were administered to 380 sampled hh of which 353 filled the questionnaire, giving a return rate of 92.8 %. The majority of the hh heads that participated in the study were males with 227 (64.3 %) against 126 (35.7 %) females. The majority of the HH heads that participated in the study were aged 35 years and above and hence were old enough to answer questions on climate change and how it has impacted their livelihood. Most respondents in the survey had the highest education level between primary and Certificate/Diploma. Further, most (86.3 %) of hh heads had stayed in Lamu for over thirty years and hence had stayed long enough to answer questions on climate change within Lamu. The findings also showed that most respondents were fishermen, fisherfolk, and mangrove cutters/licensees who are presumably more susceptible to climate change (Yvonne *et al*., 2020).

The questionnaire sought information on how climate has changed in the last 10 years and how that change was impacting mangrove-dependent livelihoods in Lamu. The local research assistants involved in the administration of the hh survey questionnaire were identified and trained before the study date. The role of the researcher during the survey was that of monitoring the work of research assistants through phone calls and random visits to places where research assistants were collecting data. The survey questionnaire was in English and Kiswahili language with research assistants reading for those respondents who were illiterate. The data collected in the survey were recorded on survey forms filled out by the research assistants. Personal information such as names were not collected, with codes being adopted to represent the respondents.

Key informant interviews were conducted with a range of specialists and representatives from various institutions (including the Lamu County Government, Kenya Forest Service (KFS), Kenya Marine and Fishery Research Institute (KMFRI), National Environmental Management Authority (NEMA), grassroots and not-for-profit organizations, and the Lamu Division of Climate Change) selected purposively. The study interviewed twenty (20) respondents based on a prepared KII guide. The interview guide was administered in English language given that the respondents were conversant with English. The KII was undertaken at the place of work of respondents between 5th September 2021 – 10th October 2021. The researcher made short notes as the interview progressed. The names of the interviewees were not recorded, with codes being adopted to represent them. Finally, purposive sampling was used to choose the participants in FGDs drawn from various representatives including Save Lamu civil society organization, mangrove cutter license holders, Beach Management Units (BMUs) managers, women group members, youth group members and artisanal fishermen. Each FGD session lasted 60 minutes and had a total of ten (10) participants (excluding the principal investigator). There were five FGD sessions altogether undertaken between 11th September 2021 to 18th September 2021 in Shella, Mpeketoni, Faza, Kiunga and Kizingitini. Each FGD session had a mix of genders, ages, and groups represented. The FGDs were spearheaded by a trained local leader who acted as a research assistant. The FGD sessions were undertaken in English and Kiswahili language with a voice recorder being adopted to capture discussions and moderations. The role of the researcher during the FGD was that of taking short notes as the discussion progressed. Personal information such as the names of respondents were not captured during the FGD to protect their identity.

The study's quantitative data were analysed using the Statistical Package for Social Scientists (SPSS) version 23 and Microsoft Excel 2021. Mean, minimum, maximum, and graphs were among the descriptive statistics employed in the study. Regression analysis was used to determine whether time was a predictor of rainfall, temperature, and sea level. To investigate the significance of the slope of the trend of climatic variables such as rainfall, temperature, and sea level rise, a Mann-Kendall non-parametric test was used. The content analysis approach was used to transcribe and evaluate qualitative data. The analysis entailed identifying themes derived from study questions and story answers from FGD and KII participants. The synthesis was based on triangulation, in which data from quantitative and qualitative sources were combined. The study was approved by the Kenya National Council for Science and Technology (NACOSTI). Further, all participants in the study provided formal consent (written and verbal) before participating in the study which took place between September 2021 and March 2022.

Results

Temperature variation and trend analysis

The minimum values for the annual maximum and annual minimum temperatures in Lamu were 30.5 °C and 23.2 °C, respectively. Further, the maximum yearly maximum and minimum temperatures were 32 °C and 25 °C, respectively (Fig. 3). The regression analysis revealed that yearly minimum and maximum temperatures in Lamu were rising at the rate of 0.034 °C and 0.0281 °C respectively. The coefficient of determination (R^2) showed that time (in years) accounts for 62.6 % and 55.7 % of the total variation in the annual maximum and annual minimum temperature, respectively (Fig. 3). Further, the Mann-Kendall non-parametric test (Table 1) revealed that Kendall's tau_b was positive and statistically significant for the maximum annual and minimum annual temperature (Kendall's tau-b = 0.626, $p < 0.05$; Kendall's tau-b = 0.627, $p < 0.05$) respectively. These findings implied that the trend for annual maximum and minimum temperature from 1985-2020 in Lamu was rising and that time was a predictor for temperature experienced. Further, Kendall's tau_b was positive and statistically significant for the correlation between maximum and minimum annual temperature (Kendall's tau-b = 0.599, $p < 0.05$)

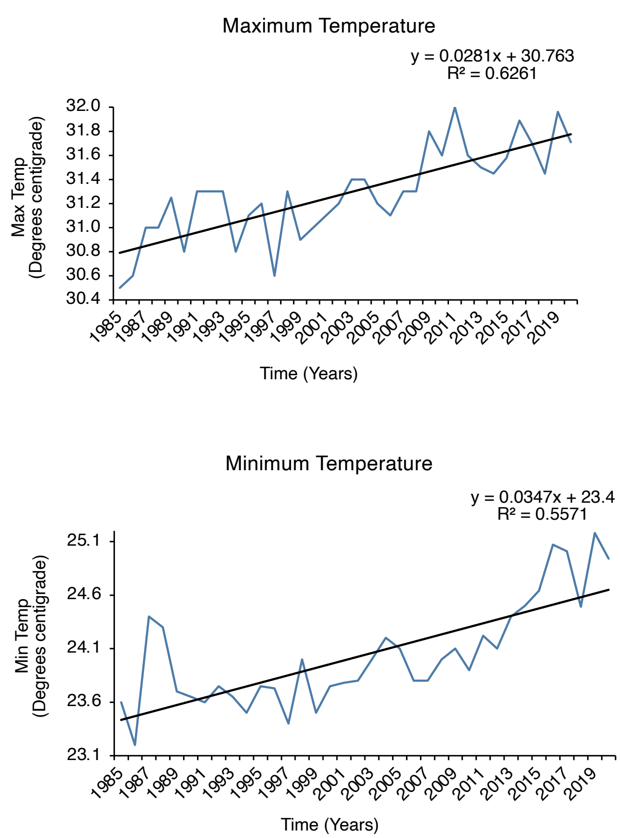

Figure 3. Annual maximum and minimum temperature (1985-2020) in Lamu (Climate Data Services, KMD, 2020).

Table 1. Mann-Kendall test for temperature trends in Lamu (1985-2020).

			Year	MaxTemp	MinTemp
Kendall's tau_b	Year	Correlation Coefficient	1.000	0.626**	0.627**
		Sig. (2-tailed)	0.0	0.000	0.000
	MaxTemp	Correlation Coefficient	0.626**	1.000	0.599**
		Sig. (2-tailed)	0.000	0.0	0.000
	MinTemp	Correlation Coefficient	0.627**	.599**	1.000
		Sig. (2-tailed)	0.000	0.000	0.0

**At the 2-tailed threshold of 0.01, the correlation is significant.

depicting that as the maximum temperature rises, so does the minimum temperature in Lamu.

Rainfall variation and trend analysis

Figure 4 presents the lowest and the highest annual rainfall at 600 mm and 2250 mm, respectively over the study period. The coefficient of determination showed that time in years explained 2.2 % of the trend in Lamu County's average annual rainfall. Furthermore, the Mann-Kendall non-parametric test showed that Kendall's tau_b was positive but not statistically significant (Kendall's tau-b =.147, $p > 0.05$) hence time (in years) and was not a significant predictor of the annual average rainfall in Lamu. Further, Figure 5 presents seasonal rainfall trends with Lamu receiving a bimodal rainfall distribution (long rain and short rain seasons) throughout the year. Long rain season is rainfall received between mid-April to the end of June (Naeku, 2020) while the short rain season comes in November and December, decreasing rapidly to a minimum in January and February (Kairo *et al*., 2021). The trend includes the minimum and maximum rainfall for the long rain season and short rain season from 1985 to 2020. Further, Kendall's tau_b (Table 3) showed that long rain seasons had a negative but not statistically significant trend (Kendall's tau_b = -0.048, $p > 0.05$). In contrast, the short rain season showed a positive and statistically significant trend (Kendall's tau-b =0.445, $p < 0.05$). Therefore, the finding suggests that the time factor accounted for more of the short rain season's rainfall than the long rain season's rainfall.

Seal level variation and trend analysis

Figure 6 shows the trend analysis for annual sea level including the minimum and maximum at 7 023 and 7 151 millimetres, respectively. The coefficient of determination (R^2) showed that time explained 49.07 % of the total change in mean sea level throughout the research period. The Mann-Kendall test (Table 4) revealed that Kendall's tau_b was positive and statistically significant (Kendall's tau-b = 0.577, $p < 0.05$), indicating that time in years described the trend for annual mean sea level at Lamu from 1995 to 2018 and these findings corroborates that of Guerry (2022). Time was therefore a predictor of Lamu's mean sea level.

People's perception of climate change

Perception of temperature

Figure 7 showed that 87.8 % of respondents in the hh survey perceived that the temperature was higher now than it had been in the previous ten years. This contrasted with only 12.2 % who perceived differently. In terms of temperature variance, 87.5 % of those surveyed said it had changed significantly during the preceding 10 years. The FGD also found a considerable temperature change, with participants showing that the temperature in Lamu has been rising for quite some time. A respondent [a tour guide from Kiunga] in the FGD revealed that,

> "Lamu temperatures have recently risen. The beach area becomes warm at 11 a.m. and stays so throughout the day. Most local tourists are afraid of the hot weather and would often rest until late in the day before returning to the beach. I have never seen temps climb this high in my 20 years on Lamu."

Table 2. Mann-Kendall test for average annual rainfall trends in Lamu (1985-2020).

			Year	Rainfall (mm)
Kendall's tau_b	Year	Correlation Coefficient	1.000	0.147
		Sig. (2-tailed)	0.0	0.218
	Rainfall (mm)	Correlation Coefficient	0.147	1.000
		Sig. (2-tailed)	0.218	.

Source: Kenya Meteorological Department, Lamu (2020)

Perception of Rainfall

Figure 8 shows the frequency distribution of respondents' opinions on the volume and distribution of rainfall (2010-2020). Most respondents (90.1 %) believed that recent rainfall was low compared to 10 years ago. In terms of rainfall distribution, most respondents (91.8 %) believed that rainfall was unequally distributed over the seasons as compared to 10 years ago. Indeed, a respondent [a farmer from the Faza area] in the FGD stated,

> "I have noticed that the long rains that used to start in April now arrive as late as June and often end earlier as well." There is presently little distinction between "long" and "short" showers…Rainfall has been irregular and inconsistent throughout the season, including in the Mkokoni and Ndau districts."

Perception of Sea Level Rise

Figure 9 shows that the sea level is higher currently than it was 10 years ago, as supported by 86.7 % of respondents. The finding suggests that the sea level in Lamu County has risen during the last 10 years. The respondents in the FGD from the Faza area of Lamu reported having experienced an increase in sea level. They noted floods and property devastation, disruption of fishing activities, loss of agriculture due to inundation, and increasing coastline erosion. One of the respondents [the beach leader in Faza] in the FGD stated,

> "The sea level has been rising for as long as I can remember, and most of the places where I used to play as a child have now been submerged by rising waters." Rising water levels have engulfed the majority of the neighbouring areas. The mangroves near the shore have also gotten inundated, with most mangrove trees standing deep in water and drying out."

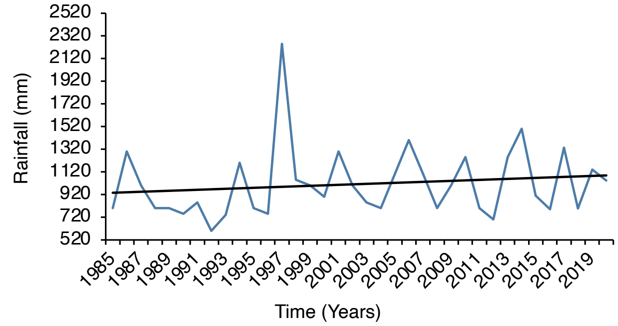

Figure 4. Average annual rainfall trend analysis for Lamu County [1985-2020] (Climate Data Services KMD, 2020).

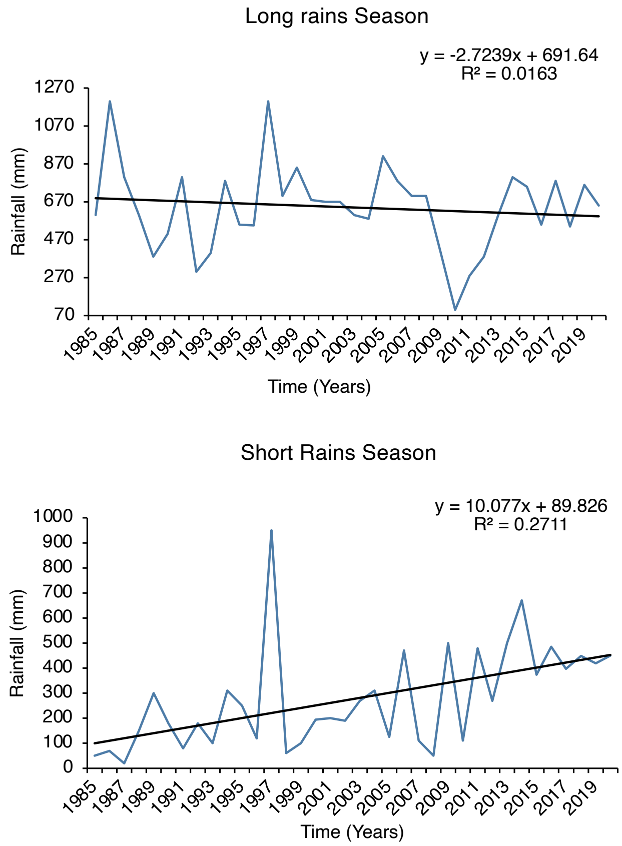

Figure 5. The trend in average season rainfall in Lamu County [1985–2020] (Climate Data Services, Kenya Meteorological Department, 2020).

Table 3. Mann-Kendall test for average seasonal rainfall trends in Lamu (1985-2020).

			Year	Long Rains	Short Rains
Kendall's tau_b	Year	Correlation Coefficient	1.000	-0.048	0.445**
		Sig. (2-tailed)	0.0	0.682	0.000
	Long Rains	Correlation Coefficient	-0.048	1.000	-0.063
		Sig. (2-tailed)	0.682	0.0	0.594
	Short Rains	Correlation Coefficient	0.445**	-0.063	1.000
		Sig. (2-tailed)	0.000	0.594	0.0

** At the two-tailed significance threshold of 0.01, the correlation is significant.

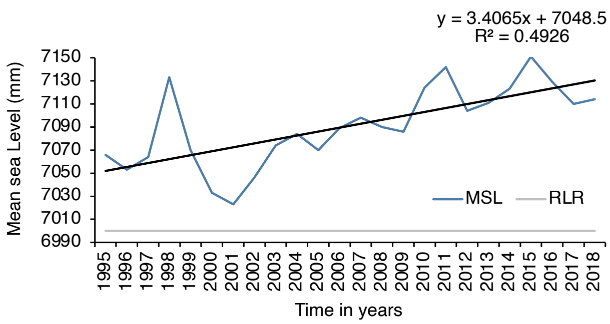

Figure 6. Annual mean sea level (1995-2020) for Lamu (Hawaii Sea Level Centre [UHSLC]) (Caldwell, 2020)

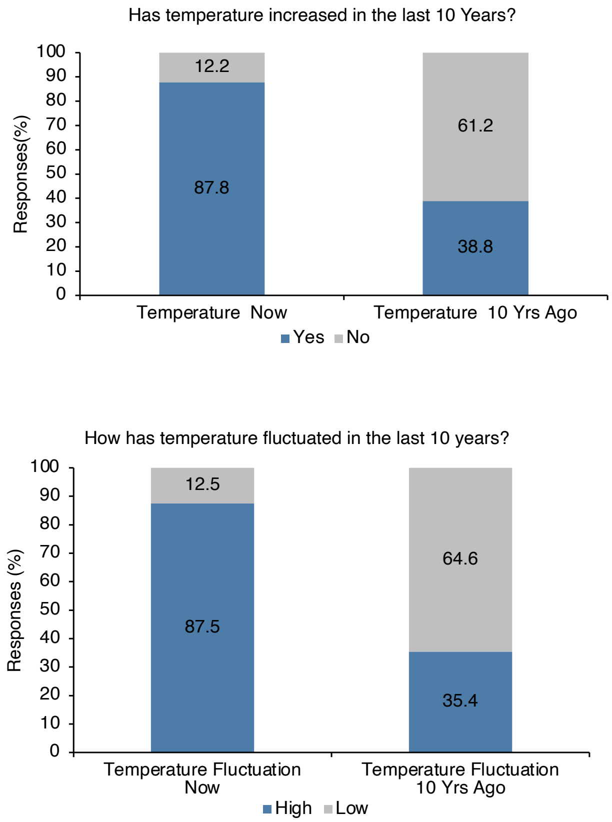

Figure 7. Perception of temperature.

Perceived impact of climate change on mangrove-dependent livelihoods in Lamu

The information in Table 5 reveals several impacts of climate change variables on mangrove-dependent livelihoods. Most (96 %, 95.8 %) of respondents in the hh survey were of the perception that rainfall and sea level rise have been destroying property and infrastructure respectively. The respondents in the FGD recalled the Tsunami event in 2004, during which the sea level in villages such as Faza and Mpeketoni rose significantly destroying homes, fishing boats, and nets. One respondent [resident of Mpeketoni] stated: "*Climate change has not been forgiving especially around here in Faza, the erratic rainfall has destroyed most of the marram roads built through CDF and County government, and even houses have never been spared in the wake of floods.*" Furthermore, most of the respondents in the survey revealed that rainfall (94.1 %) and sea level rise (100 %) were the major causes of displacement of populations from ancestral lands in Lamu. The KII with the respondent from KFS revealed, *"The heavy downpours are associated with increased soil erosion landwards and transported and deposited in the mangrove. The soil improves mangrove sediments inclination thereby leading to increased landwards growth of mangrove thereby displacing population from ancestral land."*

Most (94.6 % and 97.2 %) of the respondents in the survey were of the perception that climate change through erratic rainfall and sea level rise had resulted in a rise in waterborne infectious diseases respectively. In addition, respondents in the FGD stated most residents in the Faza and Mkokoni areas of Lamu depended on rainwater as the main source of drinking water. Once it is depleted, they are forced to beg for it or use stagnant water from nearby pools leading to a rise of water-borne diseases. The stored water also sometimes has been contaminated leading to waterborne diseases such as Bilharzia. One respondent [a member of Save Lamu] in the FGD stated, "*Children and adults in Lamu's terror-prone Boni forest are often affected by outbreaks of bilharzia and diarrhoea due to drinking contaminated water. The most affected families are those from Kiangwe, Mangai, Milimani, and Basuba villages inside the dense Boni forest....*"

Table 4. Mann-Kendall test for annual mean sea level trends in Lamu.

			Year	MSL (mm)
Kendall's tau_b	Year	Correlation Coefficient	1.000	0.577**
		Sig. (2-tailed)	0.0	0.000
	MSL (mm)	Correlation Coefficient	0.577**	1.000
		Sig. (2-tailed)	0.000	0.0

**Correlation is significant at the 0.01 level (2-tailed)

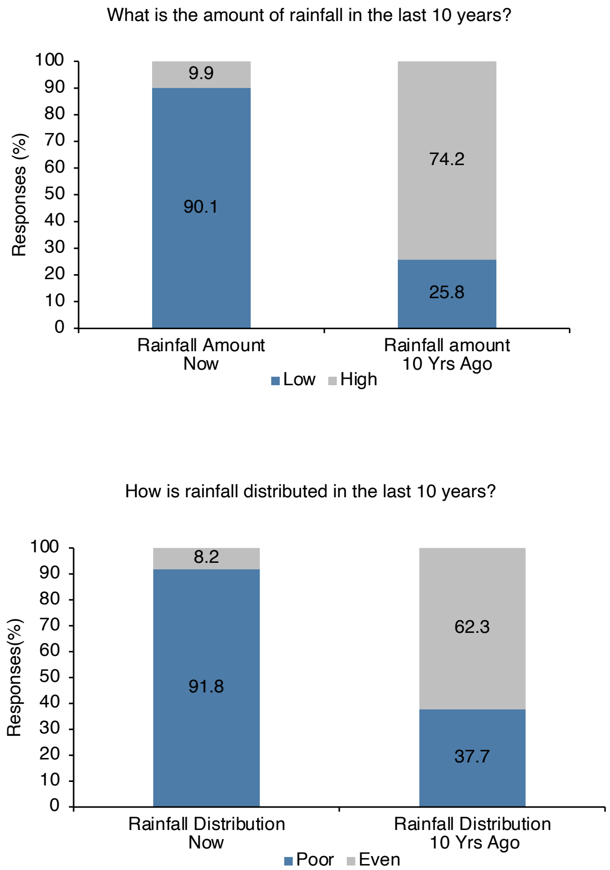

Figure 8. Perception of rainfall amount and distribution in the last 10 years.

The majority (100 %, 100 %, and 94.1 %) of the respondents in the hh survey noted that rainfall, temperature, and sea level rise respectively were contributing to reduced availability of mangrove products like wood, timber, medicine, and honey. Additionally, in the interview with a marine expert from KMFRI, the respondent thought that mangroves in Lamu, just like in other tropical areas, were particularly susceptible to

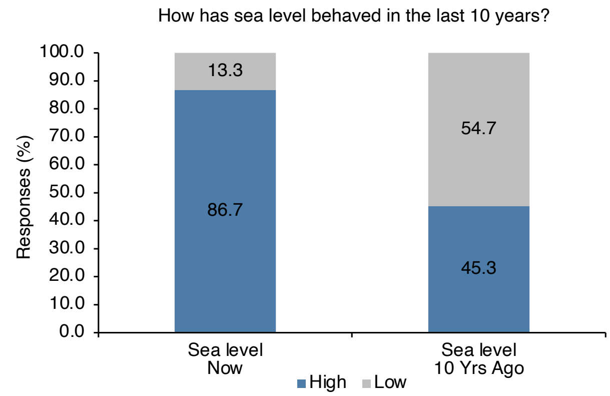

Figure 9. Sea level now and 10 years ago.

sea level rise given that they commonly have limited opportunity to move landward due to terrestrial space constraints, sediment poor environments and existing human structures and land uses in the coastal zone. The expert stated further, "*Changes in SLR can cause sediment erosion, inundation stress, and increased salinity in mangrove habitat leading to the death of mangrove."*

The majority (95.8 %) of the respondents in the HH survey also perceived increased salinity in the underground fresh water. Additionally, one respondent from Mkokoni who participated in the FGD stated,

> "There is a shortage of drinking water as most wells have become salty...climate change has worsened the water situation in some villages such as Faza." Further, another respondent noted, "The Island does not have any piped water. Residents rely primarily on rainwater for their domestic needs as most wells have either dried up or become salty...."

The study also noted that the majority (97.5 %, 97.7 %, and 96.8 %) of the respondents in the hh survey

Table 5. Perceived impact of climate change on mangrove-dependent livelihoods.

	Rainfall		Temperature		Seal Level	
Perceived Impact of Climate Change on Mangrove-dependent Livelihood	Not True	True	Not True	True	Not True	True
	%	%	%	%	%	%
Destruction of property and infrastructure	4.0	96.0	-	-	4.2	95.8
Displaced populations from their ancestral lands	5.9	94.1	-	-	0.0	100.0
Rise in waterborne infectious diseases	5.4	94.6	-	-	2.8	97.2
Reduced mangrove products like wood, timber, and honey.	0.0	100.0	0.0	100.0	5.9	94.1
Increased salinity in underground water	-	-	-	-	4.2	95.8
Destruction and interference with recreational beaches	2.5	97.5	2.3	97.7	3.2	96.8
Destruction of fish habitat hence low fish catch	-	-	4.5	95.5	-	-

revealed that climate change through rainfall, temperature, and sea level rise respectively, was responsible for either destruction of or interference with recreational beaches. In an FGD with a respondent from the Manda area, the respondent stated,

> "The rising sea level is slowly swallowing up most of the beaches that tourists like basking on. I am worried that in the future, all our sandy beaches will be underwater. Our lives revolve around tourism and fishing and if the tourists stop coming because there are no beaches for them to bask and swim, I foresee a difficult life for most of us…"

Finally, most of the respondents in the hh survey were of the perception that temperature (95.5 %) variability was responsible for the destruction of fish habitat, and hence low fish catch. Based on the FGD, respondents observed that high temperatures were affecting fishing and crop production activities. High temperatures have affected the breeding areas of fish, thus reducing quantities in the ocean.

Discussion

The study findings showed that Lamu's mean annual temperatures were on the rise, a finding that is in line with Yvonne *et al.* (2020), and Dzoga *et al.* (2019). The maximum rainfall occurred in 1997-1998, coinciding with El Niño while the driest year was 1992 when the country as a whole was experiencing La Niña effects including Lamu County, which experienced severe drought (Kemarau and Eboy, 2021; Generoso *et al.*, 2020). The current findings also revealed that the longer rainfall season was declining while the short rain season rainfall was increasing, hence the seasonal rains were becoming unpredictable with frequent drought situations in between flooding, a result that is supported by Yvonne *et al.* (2020), Maina, *et al.* (2021), and Yvonne *et al.* (2020). The study also noted that the sea level in Lamu was on the rise, a finding that was in line with Ward *et al.* (2016) and Zachary *et al.* (2023).

The climate change experienced in the Lamu area (i.e., sea level rise, increasing temperature, and erratic seasonal rainfall) was linked to the vulnerability of mangrove-dependent livelihoods in Lamu County. The findings showed that erratic rainfall, increasing temperature, and sea level rise contributed to the reduced availability of mangrove products like wood, timber, medicine, and honey. The findings noted that mangroves in Lamu, as in other tropical areas, are susceptible to sea level rise as they often have limited opportunity to move landward due to terrestrial space constraints and existing human structures and land uses in the coastal zone. The changes in SLR result in sediment erosion, inundation stress, and increased salinity in mangrove habitats leading to the death of mangroves (Cameron *et al.*, 2021; Fongnzossie *et al.*, 2022; Maina *et al.*, 2021; Mung'ong'o *et al.*, 2019).

These findings also revealed that erratic seasonal rainfall and sea level rise have been destroying property and infrastructure (i.e., roads, homes, fishing gear), displacing populations from their ancestral lands, and submerging coastal sandy beaches. The displacement of the local population happens via two major mechanisms. First, the floods from erratic rainfall and sea level rise submerge lands next to the ocean therefore displacing their owners (McMichael *et al.*, 2020; Nicholls *et al.*, 2021). Secondly, the deposition of soils in the mangroves from erosion has resulted in increased landwards growth of mangroves thereby displacing the population from ancestral land (Ghosh *et al.*, 2019; Ward *et al*, 2021). Increasing sea levels have also swallowed most of the land forming recreational beaches hence interference with tourism activities (i.e., basking, swimming) and lives revolving around tourism and fishing (López-Dóriga *et al.*, 2019; Athanasiou *et al.*, 2020).

The study noted erratic rainfall and sea level rise were associated with a rise in waterborne infectious diseases. The use of contaminated stagnant waters left in pools after floods in Faza, Mkokoni, Kiangwe, Mangai, Milimani, and Basuba areas in Lamu was associated with a rise of water-borne diseases such as Bilharzia and diarrhoea due to drinking contaminated water (Cissé *et al.*, 2019; El-Sayed *et al.*, 2020). Further, the increasing temperature was responsible for interference with fish breeding and the destruction of fish habitat, resulting in low fish catch in Lamu. High temperatures have affected the breeding areas of fish, thus reducing quantities in the ocean as fish migrate away from traditional fishing grounds. The reduced fish catch for the population living around the ocean implies that their livelihoods are impaired (Dzoga *et al.*, 2019; Lindmark *et al.*, 2022). Climate change has therefore resulted in increased vulnerability of mangrove-dependent communities in Lamu. These findings call for climate actions and programmes aimed at improving the resilience of vulnerable populations in Lamu via mitigation and adaptation.

In terms of contribution to theory and practice in this field of study, the rising annual mean sea level and erratic seasonal rainfall and associated flooding have implications for decision-makers regarding disaster early warning, relocation, and building of dykes to minimize damage to properties and infrastructure. Further, given the significant impact of climate change on the mangrove ecosystem, the population depending on the mangrove ecosystem is increasingly becoming vulnerable calling for increased revenue allocation to programmes aimed at achieving climate justice. Such increased allocation should enable the full implementation of various climate change-related policies aimed at mitigation and adaptation. The vulnerable mangrove-dependent communities should also seek local solutions to climate change such as joining formal and informal groups to enable them to source funds among themselves to finance adaptation programmes such as purchasing alternative cooking fuels, modern fishing gadgets, and relocation where necessary. The increasing temperature and erratic rainfall have implications for livelihoods related to small-scale farming regarding decisions around planting early maturing and drought-resistant crop verities. The findings on sea level rise are critical for the Lamu County government and disaster management authorities globally.

Conclusions

The study concludes that there is a declining long rainy season (March–June) and an increasing short rainy season (October–December) in the study area and this implies that the rainfall in the longer rainy season has become unreliable with consequences such as drought and flooding. Further, increasing temperatures and rising sea levels in Lamu County have impacted mangrove-dependent livelihoods in Lamu (i.e., fisherfolk, mangrove cutters, mangrove product harvesters, and boat makers) in terms of interference with fish availability, reducing incomes from mangrove products, and impaired tourism activities when beaches become submerged. The study also concludes that the rising sea level for Lamu in the study period has resulted in adjacent lands to the ocean being submerged with the displacement of the local population living around coastal lands. The climate change variables (i.e., sea level rise and associated flooding) have also been linked to the destruction of property and infrastructure such as road networks, fishing gear, and shelter, among others. This now means the livelihoods that depend on mangroves are more vulnerable because of these alterations in climate. Though the current study examined the trend in climate change variables (temperature, rainfall, and sea level rise), the scope of the study did not examine the causal factors of the climate variables. Future studies should go a step further by examining causal factors behind climate change variables in Lamu using the most updated data sets.

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