ANALYSIS OF RAINFALL SPATIOTEMPORAL VARIABILITY AND ITS IMPACT ON LIVELIHOOD IN MARSABIT, KENYA.

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ABSTRACT

Regardless of geographical location, climate variability significantly influences the success or loss of agricultural production as a source of income worldwide. As a result, this research aimed to look into the spatio-temporal variability of rainfall and its impacts on pastoral and agro-pastoral livelihood choices in Marsabit County. The rainfall data was sourced from daily gridded rainfall with a resolution of 0.050 x 0.050 (Approximately 5km x 5km overland) from 1981 to 2021.The Mann-Kendall test was used to determine the significance of the trend by using Sen's non-parametric estimator of the slope. The intra-seasonal climatic characteristics of rainfall were examined using the INSTAT statistical analysis software version 3.36. With a questionnaire as the main data collecting tool for 382 houses, a cross-sectional study method was utilized to gather household data. The study reveals that livestock and crop farming were the most negatively affected livelihood activities, according to 57.1%, 73.7%, and 78.8% of respondents in Maikona, Sololo, and Kargi, respectively. The findings indicate a decreasing trend in the March-May rainy season and mean total seasonal rainfall of 0.3613 mm (Kargi), 0.4617 mm (Maikona), 1.7261 mm (Dakabaricha), and 1.6686 mm (Sololo) every year. This implies a decrease in total rainfall and fewer opportunities for sustained rainfall-dependent livelihood activities in the county. This impacts negatively on crops and livestock, which rely on water for growth and development. The study recommends pastoralists and agro-pastoralists to adopt early maturing crop varieties, pastures, and drought-tolerant animal species to take advantage of the region's declining rainfall amounts.

Keywords: *Climate variability, trends analysis, pastoralist, rainfall, Livelihoods choices*

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INTRODUCTION

Climate variability is a crucial determinant of agricultural production success or failure worldwide. Its effects are felt through changes in the dominant water balance parameters, such as precipitation and temperature, manifesting as extreme weather events, disruptions in seasonal patterns, and negative impacts on agriculture. For example, 2010 to 2019 were observed to be warmer than the 1980s, in line with the 2019 report by the World Meteorological Organization. This is caused by anthropogenic practices that emit greenhouse gases to the surface, raising temperatures. This has resulted in an additional shift in global atmospheric processes, such as changes in rainfall.

Furthermore, observed weather data from meteorology stations on the surface of the earth show dramatic climate variability over the last two million years (WMO, 2019). Therefore, climate fluctuation has significantly impacted the world's agricultural sectors and dependent economies (FAO, 2018; Muoki, 2020). Studies indicate that climate variability has posed a threat to global food security, primarily due to variations in temperature, unpredictable rainfall patterns, and rise in the frequency and severity of weather base pitfalls, with associated adverse impacts varying across the globe, with cereal crop productivity decreasing in low-latitude areas while increasing in many higher-latitude regions in recent decades (IPCC, 2021; IPCC, 2019, Ongoma and Chen, 2017; Tierney *et al*., 2015).

Model results of possible greenhouse gas-induced climate variability imply that temperatures will continue rising and worsening. During the 20th century, Africa warmed by around 0.05°C every decade (Christensen *et al.*, 2007). This will cause the water level to increase significantly more between June and November than between December and May. (Herrero *et al*., 2016). According to reports from the USAID (2018) and the Government of Netherlands (2019), Kenya has continued to face trends in rising temperatures and falling annual precipitation, with heavy seasonal flooding in several regions of the nation. Kenyan temperatures have risen by one degree Celsius over the past 50 years, and by 2050, it is predicted that they will have increased by approximately three degrees Celsius (IPCC 2021). As a result of inadequate rainfall, droughts are occurring more frequently. Droughts used to happen every nine to ten years, but it now seems like they only happen every two to three years (IPCC, 2019). The inter-annual unpredictability of East Africa's climate, particularly its rainfall, has led to severe and recurrent droughts and floods (Tierney *et al*., 2015).

Marsabit County has experienced 28 severe droughts over the last century, four of which occurred within the last decade (ILRI, 2010). Like other pastoral areas in East Africa, Marsabit County has increased food insecurity, under-investment, and marginalization (Obando, 2009), primarily due to increased pastoral settlement caused by increasing population and insufficient natural resource management institutions to manage cattle and pastures sustainably. This has led to many environmental issues, such as overgrazing, soil erosion, and habitat loss. Climate extremes caused by climate variability endanger pastoral livelihoods by destroying property, forcing farmers to sell productive resources, and widening social divides among household members. Many studies have linked this state to the risk of catastrophic poor harvest, decreased farm profitability, poor standard of living, gender imbalances, malnourishment, and increased climate variability (Kangalawe & Liwenga, 2005; Mary & Majule, 2009; Dereje *et al*., 2020).

The effect of Climate variability is more noticeable in the country's marginal and semi-arid regions, including Marsabit County in Kenya. Drought harms crops, livestock, and community livelihoods in Marsabit County, exacerbating pastoral and agro-pastoralists' vulnerability due to the devastating climate variability impacts. Weather variability has harmed the most vulnerable people in dry rural regions, including women, the elderly, children, and smallholder farmers. Over the last twenty years, global warming effects on plants and animals have been primarily blamed for the decline of livelihoods in most pastoral Kenyan regions (Mutimba *et al.,* 2010; Obando *et al.,* 2009). Given the expected increase in weather fluctuations over the next few decades, increasing awareness is critical to improving the adaptive capacity of those who rely on the environment for a living (Batisani *et al.,* 2010; Lioubimtseva & Henebry, 2009). Climate variability significantly impacts household livelihoods and gender roles in resource-poor pastoral communities in Northern Kenya. In some counties, evapotranspiration exceeds twice the annual rainfall. This reduces the county's agricultural potential, leaving the region reliant on pastoralism and agro-pastoralism as the most viable and adaptable livelihood options in this climatic and fragile environment.

The local context, where climatic effects and reaction measures are most felt, has received less attention from scientific studies on climate variability than global and regional scales (Deressa *et al.,* 2008). As a result, Marsabit County must improve its knowledge of climate unpredictability, especially among pastoral residents. In fact, more than 44% of Kenyans who depend on climate-sensitive economic sectors must be aware of climatic variability, according to a 2007–2008 opinion poll in Kenya (Mutimba *et al.,* 2010). In light of the fact that climate variability is predicted to worsen over the next several decades, Batisani *et al.* (2010) believed it was crucial for those whose livelihoods depend on the weather to develop weather-resilience skills. This study aimed to ascertain how differences in intra-seasonal variability of rainfall impact pastoral and agro-pastoral livelihood choices in Marsabit County. Planning and responding to the expected implications of climate variability in Marsabit County will require access to crucial information from the study. The County government, communities, and policy processes will benefit from developing suitable mechanisms to react to climatic variability to pursue sustainable livelihood development pathways.

MATERIALS AND METHODS

Study location

The research was undertaken in Marsabit County, situated in upper eastern Kenya between the latitudes of 02°45'N and 04°27'N and the longitudes of 37°57'E and 39° 21'E. The county of Marsabit encompasses roughly 70,961 km^2 and consists of a flat plain with heights between 300 and 900 meters above sea level (Figure 1). 459,785 people

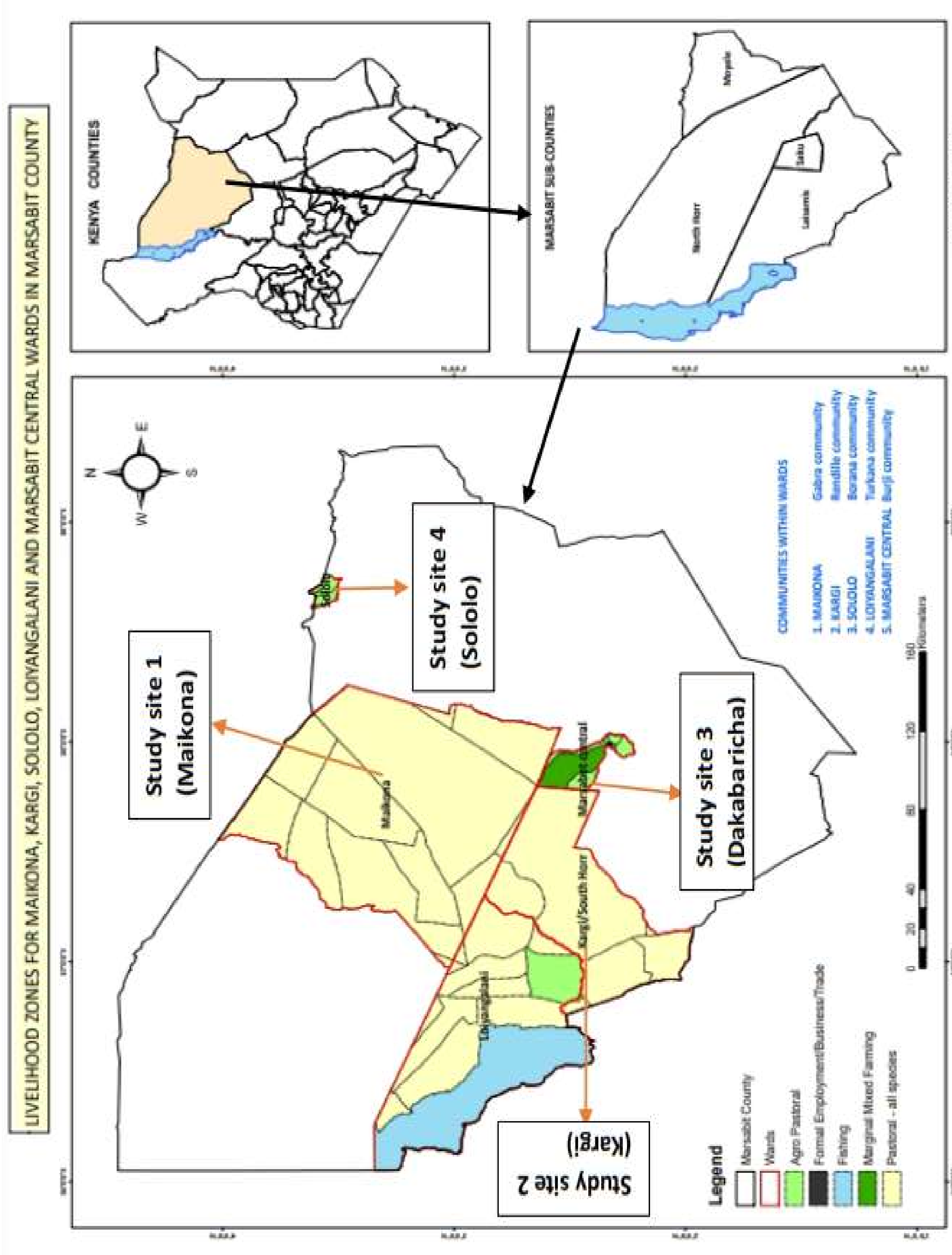

Figure 1: Location of the study area

(243,548 males and 216,219 females) reside in 77,495 households in Marsabit (KPHC, 2019). The county's population density is four people per square kilometer (KPHC, 2019). Marsabit has the highest poverty rate in Kenya (83.2%), ranking 44th out of 47 counties (KNBS, 2013). The county experiences two rainy seasons per year (bimodal) that range between 600 and 1000 mm yr-1. The County receives the long rains from March to May, while the shortest falls in October-December. The average temperature in the county during the hot season is 30–35^{o}C, with February being the month with the highest temperatures. In contrast, the coldest temperatures range from 220C to 250C in March and July (Cuni-Sanchez *et al*., 2018).

Data collection

This was a mixed study design research that applied both quantitative and qualitative data. The qualitative data from the field was collected using a semi-structured household questionnaire, key informant interviews, and Focus Group Discussions (FDGs). Household interviews, a literature review, and professional opinion were carried out during the survey to boost the content's authenticity and validity. This mainly culminated in the purposive choice of the study locations where the sampling of the household interviews was taken. Prior to starting field data collection, research assistants were recruited and trained, and a pre-test was conducted to assess the applicability and relevance of the tools developed. The survey examined climate data from daily rainfall data for four study sites (Maikona, Kargi, Dakabaricha, and Sololo) from 1981 to 2021, gridded at a resolution of 0.050 x 0.050. (Approximately 5km x 5km overland). Meteorological (secondary) data from the study region was compared with household (primary) collected from field surveys to validate the historical and current observed meteorological trends. Selected households participated in the pre-test survey to identify potential issues with questionnaire analysis in the study area. These issues are presented in the form of household socio-economic characteristics, which are likely to influence the propensity of individual households to climate change. These mainly included the gender assessments, livelihoods, age, and level of education of the household head. This allowed for questionnaire restructuring and resolving all questionnaire-related issues before intensive data collection.

Household sample size was identified based on the Kenya National Bureau of Statistics (KNBS) population data. The sample size was calculated based on the method developed by Krejcie and Morgan in 1970. formula for determining sample size.

$$s = X^2NP(1-P) \div d^2(N-1) + X^2P(1-P)$$

s is the required sample size; X^2 is the table value of chi-square for 1 degree of freedom at the desired confidence level (3.841); N is the population size; P is the population proportion (assumed to be 0.50 since this would provide the maximum sample size; d is the degree of accuracy expressed as a proportion (0.05).

By substituting the known household number of Marsabit County

$$s = \frac{3.841 \times 77{,}495 \times 0.5(1-0.5)}{0.05^2(77{,}495-1) + 3.841 \times 0.5(1-0.5)}$$

$$s = \frac{74392.772}{194.69025}$$

Data analysis

Household survey data

Multiple analytical instruments were used to edit, code, and analyze data retrieved from household interviews, including the Statistical Package for the Social Sciences (SPSS) 24-spreadsheet and Excel spreadsheet software. The conclusions of the final assessment were triangulated with qualitative and quantitative data. Focus Group Discussion, Key Informant Interviews, and field observation data were categorized and analyzed to summarize the findings and illustrate the interrelationships between significant regions and aspects. To evaluate qualitative data, however, both the Content Analysis Methodology (CAT) and the Computer Aided Qualitative Data Analysis Software were used (CAQDAS). Using descriptive statistics with 95% confidence intervals, the data was evaluated.

Intraseasonal climatic attributes

Intraseasonal climatic variables were recorded, including rainfall onset (beginning) and termination (ending) dates, wet and dry spell lengths, and growing periods. They were determined by the use of a computer program for statistical analysis, INSTAT, version 3.36, as well as the criteria and methods listed below:

i. The rainy season onset (start) date was defined as the day after 1st March for the long rainy season and 1st October for the short rainy season, when the rainfall total recorded in five consecutive days was at least 20mm, with at least three rainy days and a dry period not exceeding seven days in the thirty days following the start day (Mensah et al., 2016).

ii. The rainy season cessation (end) date was defined as the earliest possible day after 1st May for the March-

April-May season (MAM) and 1st December for the Oxctober-November-December season (OND) when the soil water balance becomes zero after ten days without precipitation and 60mm/meter of maximum soil water retention capacity.

iii. The number of rainy days in a season was defined as the number of days at least 1mm of precipitation was recorded in 24 hours from midnight to midnight local time the following morning.

iv. The seasonal precipitation totals were calculated by totaling all the precipitation reported during the season.

v. Length of wet period was defined as the number of consecutive rainy days with at least 1mm of precipitation during the season.

vi. The duration of a dry period was defined as the number of consecutive dry days with less than 1mm of precipitation during the season.

These Intraseasonal climate parameters were analyzed with version 3.36 of the INSTAT plus statistical analysis software.

Identification of climatic trending characteristics

Historical climate data trends were analyzed using Graphical and Mann-Kendall test statistics. Mann Kendall's non-parametric statistical method was utilized to determine whether or not meteorological parameters of the MAM and OND rainy seasons were rising or decreasing. The Mann-Kendall test was also employed to identify statistically significant patterns at 95% confidence. The obtained p-value was compared to the 0.05 confidence level. Using equation 1, the Mann-Kendall test statistic was obtained.

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sigh(x_j + x_k) \qquad (1)$$

Where:

S is the Mann-Kendall test value

X_j and X_k are progressive data values.

K, j, and n are data lengths.

The +ve value of S indicated increasing trends, while -ve S-values signified decreasing trends.

Standard average statistic, Zs, was calculated using Equation 2.

$$Zs = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & If\ S > 0 \\ 0 & If\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & If\ S < 0 \end{cases}$$

Negative Z values signified decreasing trends, whereas positive values indicated increasing trends. The statistical significance of the trend lines was determined at the significance level of α= 0.05 of the standard normal distribution if $Z_s > Z_{0.05}$.

The magnitude of the trend was determined using Sen's slope estimator (Hamed, 2008) given in equation 3.

$$Q_i = \frac{x_j - x_k}{j-k}, i = 1, 2, \ldots N, j > k \qquad (3)$$

Where:

Qi is Sen's slope, representing the rate of change of the variable.

X denotes the variable

J, K are similar to equation.

N is the data size

$Q_i>0$ indicates an upward trend in a time series, whereas $Q_i<0$ indicates that the data series presents a downward trend during the period.

RESULTS

Climate variability impacts on livelihood activities in Marsabit County

The extent to which climate variability affected livelihood activities across the entire study region was depicted in

Figure 3. Generally, livestock and crop farming were the most negatively affected livelihood activities according to 57.1%, 73.7%, and 78.8% of respondents in Maikona, Sololo, and Kargi, respectively. Non-farming (business) activities and household expenditure were reported to be moderately affected by 37.1%, 34.3%, and 49.2% of the respondents in Kargi, Maikona, and Sololo, respectively. Pastoralism and agro-pastoralism are the county's main livelihoods; therefore, the study concentrated only on these two sources of livelihood. In the agro-pastoral region, crop farming was the most severely affected livelihood activity in the Dakabaricha ward (79.7%), followed by livestock (64.7%). Further, livestock production (84.5%) is climate variability's most severely affected livelihood activity in the Sololo ward, followed by crop farming (75.2%). In the pastoral region, climate variability severely impacts livestock production in the Kargi (85.4%) and Maikona (95.5%) wards. Climate extremes caused by climate variability frequently result in low farm productivity, weak livestock body condition, property loss, and threats to pastoral and agro-pastoral livelihoods.

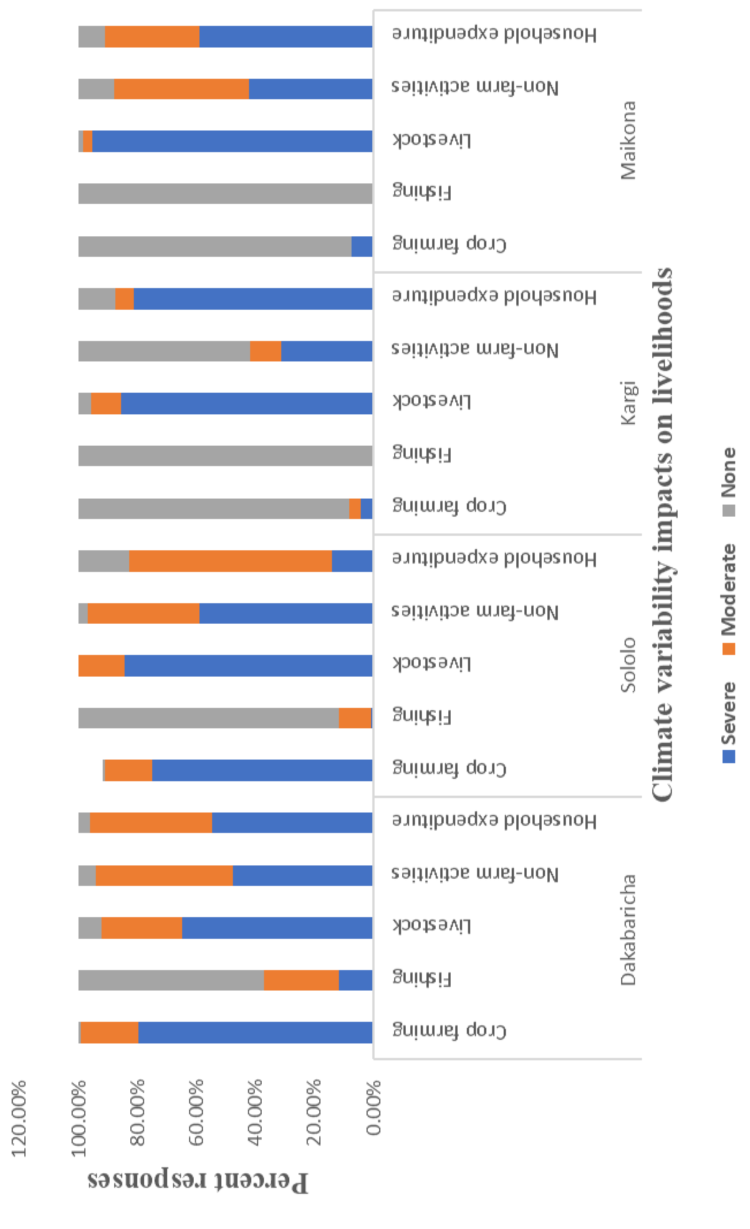

Figure 3: Spatial distribution of the extent of the effect of climate variability on livelihood activities

According to key informant respondents, climate variability impacts manifest through high temperatures, sporadic precipitation, and low yield. Climate variability has devastated pastoral and agro-pastoral communities' livestock, crops, and businesses. Precipitation is the most significant influence on natural pastures' quality, quantity, and spatial distribution. Changes in precipitation patterns are anticipated to cause pastures to become more scarce, dispersed, and irregular (Bai Y.2006). There are also remarkable adverse effects, such as livestock losses due to heat stress, outbreak of animal diseases, a rise in the frequency of drought, and a decline in animal performance, including growth, milk production, and reproduction (Seo and Mendelsohn, 2008; Elasha *et al*., 2007). To protect community livelihoods in Marsabit, investments in water resource management will be needed to increase and sustain crop production, focusing on food crops and providing water and pasture for livestock production.

Trends in spatial intra-seasonal Rainfall characteristics

Rainfall onset dates time series (trends)

Rainfall in Marsabit County is variable and has become more unpredictable in recent years. Climate variability may cause the rainy season to begin late or end earlier or later than usual. Figure 4 depicts the onset dates time series for March to May and October to December seasons for Marsabit County's Dakabaricha, Maikona, Kargi, and Sololo wards from 1981 to 2021. The study region showed varying trends in onset dates in the March – April – May (MAM) and October – November – December (OND) rainy seasons. In MAM, the most extended onset dates were (126th day) in Kargi, 1998 (130th day) in Maikona, 2005 (119th day) in Dakabaricha and 2005 (118th day) in Sololo, with the shortest onset dates recorded in 2012 (43rd day) in Kargi, 2003 (65th day) in Maikona, 2010 (61st day) in Dakabaricha and 2010 (60th day) in Sololo. The study findings reveal that MAM rainy season onset dates are decreasing, as depicted by negative trend lines of -0.1146, -0.0355, -0.1009, and -0.3056 in Kargi, Maikona, Sololo, and Dakabaricha, respectively (Figure 4). All these regression tests were significant at a 95% confidence level. The negative trend line represents the late occurrence of the onset dates.

This implies enhanced onset dates calling for a shift towards timely rainwater harvesting, land preparation, and planting of early maturing crops in these wards. In addition, in the short rainy season (OND), the highest onset dates were received in 1985 (371st day) in Kargi, 1991 (360th day) in Maikona, 1991 (362nd day) in Dakabaricha, and 2000 (323rd day) in Sololo respectively, while the

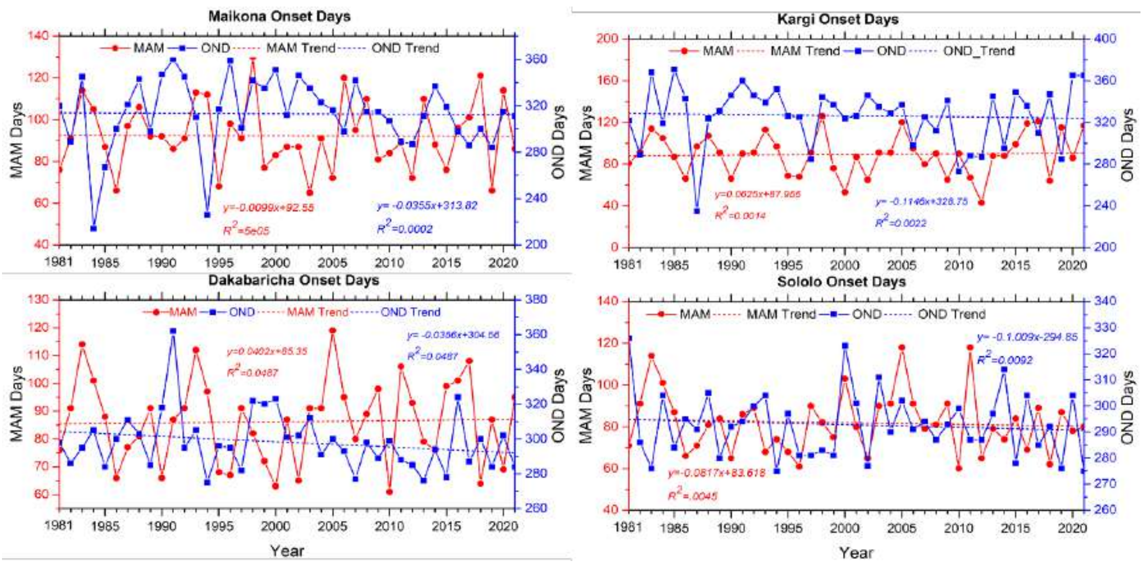

Figure 4: Time series of rainy season onset dates for Kargi, Maikona, Dakabaricha, and Sololo

lowest onset dates were recorded in 1987 (235th day) in Kargi, 1984 (214th day) in Maikona, 1994 (275th day) in Dakabaricha and 1994 (275th day) in Sololo. Maikona and Sololo showed decreasing trends in OND rainy season's onset dates of 0.0099yr^{-1} and 0.0817yr^{-1} (Figure 4) with negative Sen's slope values of -0.067 and -0.01(Table I), respectively. The negative Sen's slope values signify a declining trend as the respective line of fit depicts. This necessitates early land preparation and planting of early maturing crops in order to take advantage of inadequate rains. Kargi and Dakabaricha showed increasing trends in OND season onset dates at 0.0625yr^{-1} and 0.0402yr^{-1}, respectively, with all showing positive Sen's slope values of 0.077 and 0.083, respectively (Table I). Similarly, the positive Sen's slope values correspond to increasing onset date trends. This implies delayed onset dates in Kargi and Dakabaricha, necessitating a shift toward late crop planting in these wards to reduce the risk of loss of seed and other planting material. In the entire study region, the Mann-Kendall test and Sen's slope estimator results trends in MAM and OND rainfall onset dates were statistically significant (P<0.05). At the P <0.05 significance level, the computed Mann-Kendall test statistics were less than the P-value of the standardized normal distribution (Table I). The pastoral and agro-pastoral households in the study region are concerned about the reduction in MAM rainfall because they rely on rainfed agriculture. MAM rainy season is the main rainy season in Marsabit County for crop and livestock production. The agro-pastoral communities (Dakabaricha, Sololo) engage in rain-fed agriculture on a small scale that is not adapted to climate variability. This study confirms Adeniyi *et al*. (2009) that farmers typically use the onset time for March-May rainfall to determine when to prepare and clear the land for sowing. The study results indicate that seasonal rainfall variation is challenging for agro-pastoralists in the study area and that agro-pastoralists must be continuously updated to plant crops appropriately.

TABLE I- MANN-KENDALL TEST RESULTS FOR THE STUDY REGION'S ONSET AND CESSATION DATES FOR MAM AND OND.

Study region	**March to may season**				**Octobe toDecember Season**			
	Onset dates		**Cessation dates**		**Onset dates**		**Cessation dates**	
	P-value (MK-test)	Sen's slope value	P-value (MK-test)	Sen's slope value	P-value (MK-test)	Sen's slope value	P-value (MK-test)	Sen's slope value
Dakabaricha	0.735	-0.067	0.132	-0.2	0.544	-0.069	0.471	0.00
Maikona	0.689	-0.1	0.734	0.00	0.636	-0.048	0.346	0.00
Kargi	0.725	0.077	0.806	0.00	0.389	0.077	0.689	0.00
Sololo	0.553	-0.143	0.78	-0.042	0.409	0.083	0.182	0.00

Table I shows the trends in the MAM and OND seasons' start and end dates. Sen's slope estimator shows a statistically significant decreasing trend in the onset dates of the MAM season across all study locations.

While this is true for the cessation dates during the same season, it is essential to note that the magnitude of the trend change in Maikona and Kargi is negligible, as verified by Sen's slope values of zero. The most noticeable difference between the OND and Kargi seasons was an increase in the trend of onset dates. The cessation dates, however, did not change significantly during OND, as demonstrated by Sen's slope values of zero.

Rainfall cessation date (trends)

Figure 5 depicts the findings of the study region's MAM and OND rainy seasons from 1981 to 2021. Marsabit County's long rainy season (MAM) ends early, while the short rainy season (OND) ends late. The analysis showed that March, April, and May rainy seasons in Kargi, Sololo, Dakabaricha, and Maikona wards, ended earlier than anticipated. During the long rainy season (MAM), the most extended cessation dates were recorded in 1998 (145th day) in Kargi, 1987 (152nd day) in Maikona, 2005 (152nd day) in Dakabaricha, and 2005 (152nd day) in Sololo, with the shortest cessation dates recorded in 2006 (117th day) in Kargi, 2003 (114th day) in Maikona, 2008 (132nd day) in Dakabaricha, and 1988 (141st day) in Sololo. The results showed an increasing trend in MAM season cessation dates in the agro-pastoral region of Dakabaricha and Sololo of $0.0098yr^{-1}$ and $0.00192yr^{-1}$, respectively. In contrast, the pastoral region of Maikona and Kargi ward revealed downward trends in March to May season cessation dates of $0.0533\ yr^{-1}$ and $0.0929\ yr^{-1}$, respectively. This necessitates the growth of early maturing crop types, drought and disease tolerant varieties, and drought-tolerant species identified by communities as potential crops, such as cowpeas, beans, sorghum, green grams, pigeon peas, and millet. In addition, in the short rainy season, the highest cessation dates were captured in 2009 (364th day) in Kargi, 1998 (363rd day) in Maikona, 1983 (363rd day) in Dakabaricha, and 2015 (364th day) in Sololo, respectively, while the lowest cessation dates were recorded in 2001 (326th day) in Kargi, 1993 (329th day) in Maikona, 1984 (335th day) in Dakabaricha, and 1993 (329th day) in Sololo. The trend line equation indicates that OND rainy season cessation dates are increasing at $0.0054yr^{-1}$, $0.052yr^{-1}$, and $0.0498yr^{-1}$ in Kargi, Maikona, and Sololo during the study period (Figure II). During key informant interviews, agro-pastoralists identified crop maturity duration and drought tolerance as factors influencing their crop selection for different planting seasons.

The focus group discussion also reported that agro-pastoralists planting during the MAM rainy season face a very high risk of poor seed germination due to moisture stress, particularly for drought-sensitive crops. As a result of this observation, agro-pastoralists must alter their planting strategy in early October. This was mentioned as one of the strategies already adopted by the farming community in the study region. However, with a limited selection of dryland crops, a gap needs to be bridged, rainfall is a significant climate factor influencing an area's plant and livestock species distribution.

Respondents' perception of changes in rainfall starts and end dates.

Table II depicts the results of changes in rainfall onset

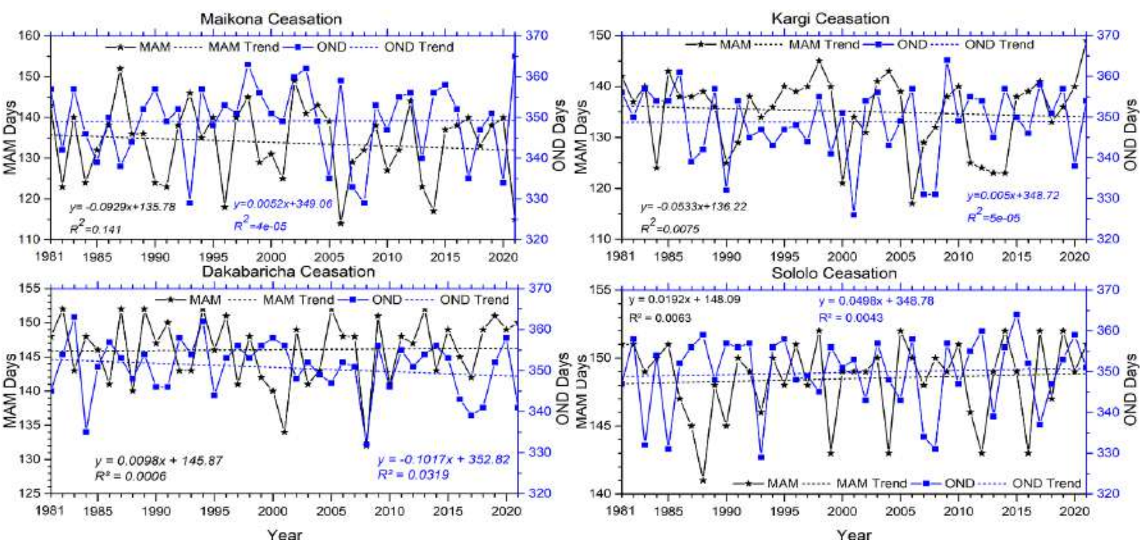

Figure 5: Time series of rainy season cessation dates for Kargi, Maikona, Dakabaricha, and Sololo

and end dates by the survey respondents. According to the study results, 97.7% of respondents in pastoral and agro-pastoral regions (Kargi and Maikona) did not see more rain as a sign of change. In comparison, only 2.3 percent perceived receiving more rain in the study areas. Regarding change, 94.4 percent of respondents perceived less rainfall, while only 5.6 percent did not. According to the study, 54.5% of respondents (Kargi 56.2%, Sololo 76.7%) reported late rainfall onsets in their respective areas.

TABLE II- CHANGES IN RAINFALL ONSET AND CESSATION DATES

What is the nature of change	Responses	Pastoral		Agro-pastoral	
		Kargi	**Maikona**	**Sololo**	**Dakabaricha**
More rains	No	97.40%	100%	32%	100%
	Yes	2.60%	0.00%	68%	0.00%
Fewer showers of rain	No	2.10%	3.70%	4.70%	7.80%
	Yes	97.90%	96.30%	95.30%	92.20%
Late onset of rains	No	43.80%	63.60%	23.30%	56.90%
	Yes	56.20%	36.40%	76.70%	43.10%
Early rainfall cessation	No	87.40%	80.30%	100%	75.80%
	Yes	12.60%	19.70%	0.00%	24.20%

On the other hand, respondents from Maikona (63.6%) and Dakabaricha (56.9%) wards reported early rainfall onset. The two wards' location in the Kenya-Ethiopia border highlands, which receive timely rainfall, could explain this. Regarding rainfall cessation dates, a minority of respondents (12.6%) reported early cessation, indicating that the growing season length was not significantly disrupted. However, the overall rainy seasons were shifting later. This necessitates changes in routine farm operations and management practices by both pastoral and agro-pastoral communities in Marsabit County to use rainwater best. According to focus group discussions (FGDs) conducted in all study centers (n=8), respondents reported that rainy seasons are becoming shorter; and begin later than in the past. In addition, the observations from KIIs and FGDs confirmed the widespread belief from the household survey participants that rainfall has decreased during the long rainy season over the past four decades, as well as other local environmental changes. FGDs discussants further stated that rainfall's amount, frequency, and distribution have changed in the area. This reduction in rainfall amount has resulted in pasture decline, water shortages, and diminishing resources. According to the study findings, long rains (MAM) have also decreased and become more variable than short rains (October-December). Meteorological data analysis agrees with farmers' perceptions of climate variability. These indicate a lack of moisture for plant growth, livestock forage, and crop production. Moisture stress and high temperatures can impact seed germination and crop growth performance as farmers begin sowing with the arrival of long rains.

Determination of rainfall start and cessation dates by the respondents.

Table III shows the respondents' predictions for the onset and cessation of the rainy season in the study region. Despite the importance of predicting the beginning and end of the rainy season for assisting pastoral and agro-pastoral communities in managing rainfall-related risks in their respective livelihood systems and coping with significant rainfall variability, most respondents in all four study areas are unable to predict.

TABLE III- RESPONDENT'S ABILITY TO PREDICT THE START AND THE END OF THE RAINY SEASON.

Name of the ward	Can you predict the start and the end of the rainy season?			When were you last able to predict the start and end of the rainy season?			
	Don't know	No	Yes	50 years ago,	A decade ago,	Don't remember	Last year
Kargi	18.80%	72.90%	8.30%	0.0%	6.30%	93.80%	0.0%
Maikona	3.00%	87.90%	9.10%	15.20%	3.00%	80.30%	1.50%
Dakabaricha	6.50%	52.30%	41.20%	42.50%	12.40%	19.00%	26.10%
Sololo	1.60%	74.40%	24.00%	19.40%	26.40%	49.60%	4.70%
Total	5.80%	67.90%	26.30%	25.30%	14.60%	48.20%	11.90%

Across all study sites, only 26.3% of respondents could predict when the rainy season would begin and end (Kargi, 8.30%, Maikona, 9.10%, Dakabaricha, 41.20%, and Sololo, 24.00%). While 67% of respondents (Kargi, 72.90%, Maikona, 87.90%, and Dakabaricha, 52.30%) could not predict (Table III). Understanding the community's ability to predict weather is essential because it can be used to inform future community decision-making and capacity-building efforts. According to the findings, 25.3% of respondents (Kargi 0%, Maikona 15.20%, Sololo 19.40%, and Dakabaricha 42.50%) could predict the start and end of the rainy season 50 years ago, while 14.6% of the respondents (Maikona 3.0%, Kargi 6.30%, Dakabaricha 12.40%, and Sololo 26.40%) could remember the start and end of rainy season a decade ago.. While 48.2% could not remember when they could last predict the start and end of the rainy season, and only 11.9% could predict the start and end of the rainy season. The researcher examined observed rainfall data from the meteorological department to supplement the respondents' perceptions, as shown in Figures 2 and 3. The study area's short and long rainy seasons had nearly identical downward-trending precipitation patterns.

Number of rainy days

The figure 6 depicts the trends analysis for the number of rainy days experienced in Dakabaricha, Maikona, Kargi, and Sololo wards for MAM and OND seasons from 1981 to 2021. The longest mean number of rainy days were received in 2018 at Kargi (33 days), Maikona (34 days), and in 1981 at Dakabaricha (55 days) and Sololo (51 days) in the long rainfall (MAM). In addition, the OND season had its highest mean number of rainy days recorded in 1997 in Kargi (30 days), Maikona (31 days), Dakabaricha (37 days), and Sololo (41 days). In addition, the lowest mean number of rainy days were recorded in 2021 in Kargi (5 days), 2005 in Maikona (5 days), 2020 in Dakabaricha (11 days), and 1987 (9 days) in Sololo (Figure.6). According to the study findings, Marsabit County encountered a reduction in number of rainy days in the long rainfall season. According to the trend line equation, the mean number of rainy days in Marsabit County has been decreasing at $-0.111mmyr^{-1}$, $-0.055mmyr^{-1}$, $-0.315mmyr^{-1}$, and $-0.295mmyr^{-1}$ in Kargi, Maikona, Dakabaricha, and Sololo, respectively. This means there is a better chance of collecting and storing rainwater for livestock and irrigation purposes. This emphasizes the importance of investing in rainwater harvesting and storage facilities such as earth pans, rock catchments, and sand dams to support crop agriculture and animal watering in Marsabit County. The results also depict that the average number of rainy days in Kargi and Sololo rises by 0.032mm and 0.009mm during the OND rainy season respectively. This shows that early-maturing crop varieties and pasture are both needed to bridge the gap of limited rains. The difference between annual and seasonal rainfall trends from 1981 to 2021 showed that Marsabit County's rain patterns were changing, with less rain, indicating climate variability. The lengthening of intra-seasonal dry spells and the shortening of rainy days observed in Marsabit County will limit the production of traditional crops well adapted to the county, resulting in mediocre or complete crop failure.

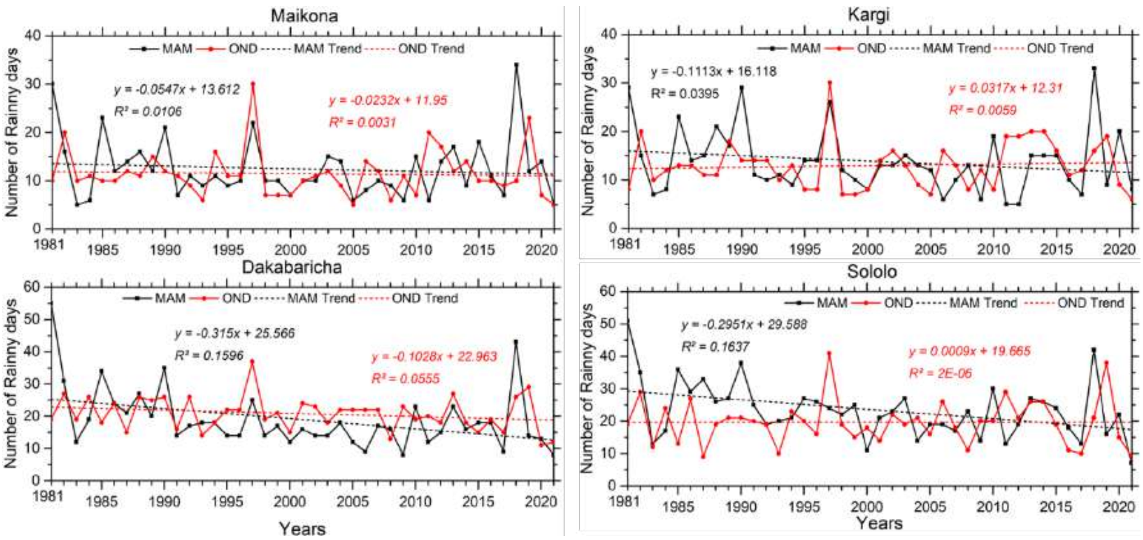

Figure 6: Time series of the mean number of rainy days for Kargi, Maikona, Dakabaricha, and Sololo

The loss of food and income would stymie efforts to reduce poverty, particularly among thousands of rural residents in remote regions of Marsabit County with few options for sustainable livelihoods. The declining seasonal rainfall noted over Marsabit County will adversely impact natural pastures' continued availability, quantity, and spatial distribution (Bai and Bent 2006). This would result in animals wasting, limited water, and pasture resources that would be catalytic to resource-based conflicts and civil strife. Dwindling rangeland resources would result into increased livestock losses due to the compounding influence of rising temperatures leading to heat stress, and increased incidences of animal pests and diseases. The steadily rising rainfall in the OND season, increasing prospects of crop cultivation in that season should not be misconstrued to imply crop extensification but enhance crop intensification within the traditional cropping lands to safeguard rangeland resources that would support livestock production.

Impact of change in precipitation on water resources in the study region

Table IV shows respondents' perceptions of the total precipitation recorded in study wards in the last four decades. Overall, the vast majority of respondents in Marsabit County claimed to have received varying amounts of rainfall each year. In accordance with the research analysis, 82.1% of survey participants have not received the same rainfall annually. In comparison, only 10.6% reported receiving the same amount of rainfall yearly (Table IV). Most respondents from Maikona and Sololo (90.90% and 95.30%) reported differences in annual rainfall amounts. This suggests that rainfall variability is more significant in Maikona and Sololo than in the Dakabaricha and Kargi wards (Table IV). Rainfall fluctuations may have an adverse effect on the production and breeding of hardy and disease-resistant local livestock breeds.

TABLE IV- AMOUNT OF RAINFALL RECEIVED PER YEAR IN THE STUDY REGION.

Name of the ward	Do you receive the same amount of rainfall every year?			How have these changes in rainfall affected water resources in your area?			
	Don't know	No	Yes	Don't know	increased water amount,	no change in water levels,	reduced water amounts,
Kargi	22.90%	64.60%	12.50%	0.00%	0.00%	2.10%	97.90%
Maikona	9.10%	90.90%	0.00%	3.00%	1.50%	21.20%	74.20%
Dakabaricha	7.80%	72.50%	19.60%	5.90%	2.60%	0.00%	91.50%
Sololo	0.00%	95.30%	4.70%	0.00%	0.80%	0.00%	99.20%
Total	7.30%	82.10%	10.60%	2.80%	1.50%	3.80%	91.90%

The observed variation in rainfall patterns across study locations may be due to climate variability, which could have disastrous consequences for Marsabit County's livelihood choices. Climate variability may jeopardize these marginalized people's livelihood security by reducing natural resources and quality essential to sustainable livelihoods. Climate variability will likely impact livelihood choices, water availability, agriculture, extreme events, and diseases. These changes affect livelihoods by exposing people to risks and raising their susceptibility to climate variability. The consequences will be more severe in populations that rely heavily on resources and live in more environmentally and socially marginalized areas. One effect of climate variability is a long-term and steady drop in the number of crops and livestock that can be grown on agricultural land. According to key informant interviews (KII), seasonal precipitation changes may negatively impact the propagation of several plant species that cannot adapt to new rainfall patterns and timing. As a result, it is anticipated that certain plant species in Marsabit County may become extinct in the long run. In general, baseline survey respondents and FGD participants believe that climate variability has occurred and is a reality. Most respondents and FGD participants stated that climate variability was manifesting as a reduction in the amount of rainfall received and a decrease in the intensity of the rains, both of which have worsened over time. Droughts have also become more common, according to respondents and FGD participants. Increased poor rainfall patterns in the study region led to a decrease in pasture production and insufficient water sources, which had a significant negative impact on livestock productivity in the region, as revealed by the focus group facilitator. Due to diminishing resources, most families are compelled to move to urban centres or travel to faraway places in search of relief foods and livestock feeds from the government and non-state actors. As a result, large quantities of animals die due to a lack of pasture and fresh water in extreme circumstances.

Seasonal Total Rainfall

Figure 7 depicts total seasonal rainfall time series plots for the wards of Dakabaricha, Maikona, Kargi, and Sololo for long and short rainy seasons. In MAM (long) rainy season, Sololo and Maikona received the highest and lowest mean seasonal total rainfall of 811 mm (1981) and 19 mm (2011), respectively. The Dakabaricha and Maikona wards received the highest and lowest OND seasonal rainfall totals of 768 mm (1997) and 15 mm (2000), respectively. In the long rainy season (MAM), considerably higher rainfall was captured in Kargi in 1981 (255 mm) and 2018 (265 mm), Maikona in 1981 (258 mm) and 2018 (245 mm), Dakabaricha in 1981 (698 mm) and 2020 (622 mm), and Sololo in 1981 (811 mm) and 2018 (625 mm). At the same time, low precipitations were received in Kargi (15 mm), Maikona (18 mm), Dakabaricha (38 mm), and Sololo (128 mm) in 2000. Nonetheless, high rainfall amounts were captured in the short rainy season (OND) in the years 2011 (244 mm) and 2012 (242 mm) in Kargi, 1997 (240 mm) and 2011 (261 mm) in Maikona, 1997 (768 mm) and 2011 (616 mm) in Dakabaricha, and 1997 (720 mm) and 2011 (631 mm) in Sololo. In contrast, low amounts of rainfall were captured in Kargi (33 mm), Maikona (21 mm), Dakabaricha (96 mm), and Sololo (81 mm) in 2010 (Figure 6). The primary sources of income for pastoral regions of Kargi and Maikona households are livestock production and intensive land use systems for grazing. Dakabaricha and Sololo households are agro-pastoralists who raise livestock and grow crops on a small scale. As demonstrated by the data, changes in seasonal rainfall led to crop yield fluctuations, significantly impacting food security and livelihood. The rainfall distribution has changed in many places, becoming more uneven throughout the year and across the study regions. Predicting rainfall amounts and timing has become more complex. Climate variability is likely to reduce the number of animal and plant species, which could make ecosystems less stable over time. Marsabit County's livelihood sector has been hit the hardest because it relies heavily on climate stability. Inadequate and unpredictable rainfall has far-reaching implications for the entire ecosystem and human activities (businesses, livestock rearing, and farming). The average rainfall for March-May and October - December across the county varied significantly in space and time. Regardless of geographical location, the study regions showed decreasing trends in mean seasonal total rainfall during the MAM season, as shown by negative trend line equations of -0.3613 mm (Kargi), -0.4617 mm (Maikona), -1.7261 mm (Dakabaricha), and -1.6686 mm (Sololo) per year (Figure 7). This implies a decrease in total rainfall and, as a result, fewer opportunities for sustained rainfall-dependent economic activities and livelihoods in the county. Furthermore, the OND rainy season showed increasing trends in mean seasonal totals of 0.727mm, 0.695mm, 2.3276mm, and 2.7036mm per year in Kargi, Maikona, Dakabaricha, and Sololo.

This means that OND is the primary season in Marsabit County, and agro-pastoralists are advised to practice early land preparation, timely rainwater harvesting, and growing of drought-resistant crops in Marsabit County's agro-pastoral regions.

Table V and Figure 6 depict the trend analysis of the observed number of days with more than 1mm of rainfall. These analyses show that during MAM season, which is the main peak rainy season has constantly experienced fewer rainy days in all regions studied. This is confirmed by the negative Sen's slope values in Table V and the negative slope gradients in Figure 6. Nevertheless, only in the Dakabaricha and Sololo regions is this decline statistically significant with tests performed at a 95% confidence level. The total seasonal rainfall during MAM is another indicator of this pattern. Throughout the OND season, there is no substantial variation in the number of rainy days across all study regions (Table V). The seasonal rainfall total only changed in a statistically meaningful way in Dakabaricha. The Mann-Kendall test results were less than the P-value of the standardized normal distribution at a significance value of 0.05.

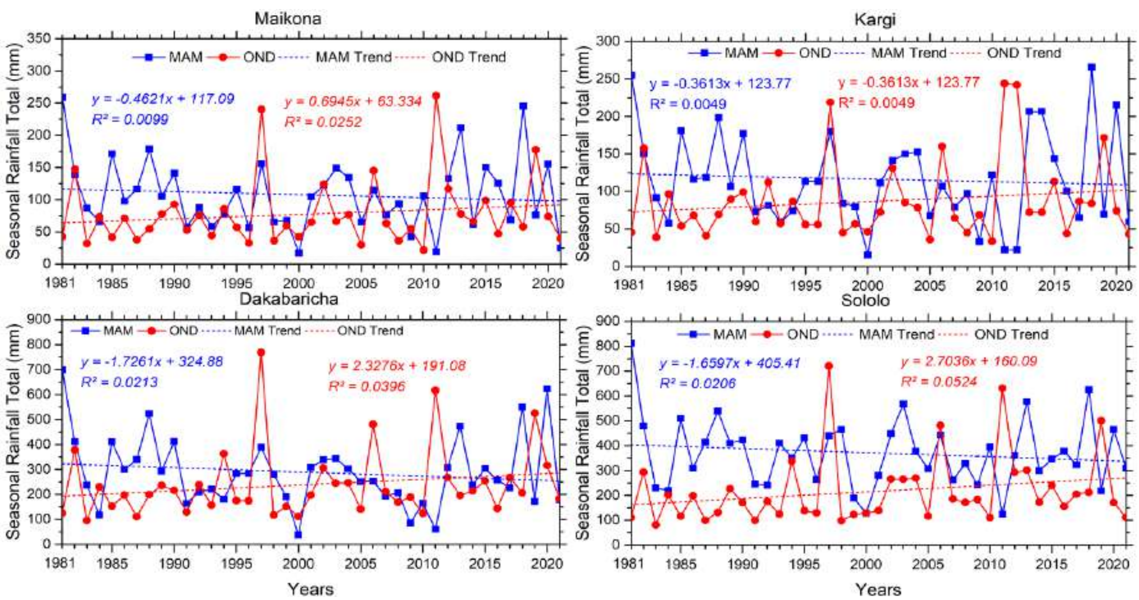

Figure 7: Time series of mean seasonal total rainfall for Kargi, Maikona, Dakabaricha, and Sololo

TABLE V- MANN-KENDALL RESULTS FOR A NUMBER OF RAINY DAYS AND SEASONAL RAINFALL TOTALS FOR THE STUDY REGION.

Study region	March to May season				October to December Season			
	Number of rainy days		Seasonal rainfall total		Number of rainy days		Seasonal rainfall total	
	P-value (MK-test)	Sen's slope value	P-value (MK-test)	Sen's slope value	P-value (MK-test)	Sen's slope value	P-value (MK-test)	Sen's slope value
Dakabaricha	0.014	-0.227	0.004	0.00	0.415	-0.043	0.004	0.00
Maikona	0.535	-0.05	0.663	0.00	0.951	0.00	0.961	0.00
Kargi	0.135	-0.13	0.231	0.00	0.21	0.083	0.961	0.00
Sololo	0.014	-0.323	0.015	0.00	0.636	0.033	0.39	0.00

DISCUSSION

Rainfall in the study region exhibited high variability in both time and space with respect to onset and cessation dates, number of rainy days, and seasonal rainfall totals, among others, during both long (MAM) and short (OND) rainy seasons. Rainfall in Marsabit County is variable and has become more unpredictable in recent years. Climate variability may cause the rainy season to begin late or end earlier or later than usual. According to ATPS (2013) study, Pastoral and agro-pastoral communities are experiencing reduced rainfall patterns, a later start to the rainy season, rising temperatures, and heat stress. Obando *et al*. (2009) conducted a climate effects study in northern Kenya and noted that climate variability contributes to increasing regional poverty. The finding is also consistent with a 2011 study conducted in 13 ASALs counties, in which 65% of 710 interviewees attributed the depletion of livestock fodder to the effects of climate variability (Bryan *et al*., 2011). Climate variability can be ascribed to changes in precipitation's start and end dates in the MAM and OND seasons. Camberlin and Okoola (2003) examined the relationship between large-scale atmospheric and oceanic field onset time series and depth. Inter-annual variations in MAM onset are linked with opposite-sign sea-surface temperature (SST) and sea-level pressure (SLP) patterns over the Atlantic and Indian Oceans (Camberlin and Okoola 2003). A warm South Atlantic and the incredible Indian Ocean are linked with low and high SLP anomalies. These conditions support the intensification of equatorial easterlies and the divergence of surface winds over East Africa (Gudoshava *et al*., 2022). This pushes the north-south branch of the Inter-tropical Convergence Zone (ITCZ) further west, delaying the onset of MAM rain. Gudoshava *et al*., (2022) investigated OND's seasonal onset and cessation times. They concluded that increased rainfall in OND happened in early-onset years, while rainfall deficits occurred in late-onset years for the same months. Warmer sea surface temperatures (SSTs) in the western Indian Ocean, increased moisture flow, and unusual low-level flow into Eastern Africa characterize early-onset years.

This study's findings corroborate with that of Makenzi *et al*. 2013, and Omondi *et al*., 2014, who discovered that agricultural practices in pastoral areas follow precipitation trends. A delayed onset characterizes seasonal precipitation in Marsabit County, decreased rain days, and increased intensity, altering farmers' calendars and reducing yields (Gichangi *et al.,* 2015). This is also consistent with a study conducted in Kenya's Marsabit forest reserve by Muhati *et al.* (2018), which found similar increasing trends in the number of rainy days in the short season with delayed cessation dates. This increases the chances of increasing cropping season lengths and, as a result, growing longer-duration crops and expanding acreage under traditional early maturation crops. In accordance with a 2021 report by the Intergovernmental Panel on Climate Change, shifts in rainfall patterns in East Africa are caused by the El Nino phenomenon, which affirms our findings on seasonal rainfall pattern variability in Marsabit County. These findings are consistent with farmers' reports from Kenya's semi-arid and sub-humid regions. Where some farmers ceased to grow certain crops due to low yields caused by insufficient precipitation and opted instead for early maturing and drought-resistant varieties (Kalungu *et al*., 2013). However, others cultivated crops better suited to the new climate (Antwi-Agyei and Nyantakyi-Frimpong, 2021).

The research findings are consistent with those of Gbangou *et al*., 2019, who found early-onset rainy season dates ranging from 0.3 to 0.5 days/year in Tamale and Wa, located in northern Ghana, and experienced comparable weather conditions between 1986 and 2010. Nonetheless, Laux *et al*. (2008) found a remarkable delay of up to 0.88 days per year in northern Ghana's Volta basin, resulting in a 35-day delay over 40 years. Similarly, Amekudzi *et al*. (2015) found significant variability in the onset and termination of rainfall in Ghana across agro-ecological zones for 2-8 years. Recent research using gauge observations discovered that late-start or early end of rains and a high frequency of dry spells during the growing season cause a substantial decline in crop yields in northern Ghana (Chemura *et al*., 2020). The erratic timing of rain and mid-season breaks makes the farming schedule sporadic, complicating decisions on planting time, crop, and variety selection (Boansi *et al.,* 2019). According to a study by Amekudzi *et al*., 2015, unpredictable and delayed rainfall onset threatens food production and security in most developing countries. Accurate prediction of the start and end dates is required to synchronize crop calendar activities. Accurate data on the start and end of seasonal rain can eliminate the risks and expenses associated with replanting seeds due to a false onset of the season (Sarku *et al*., 2020). The delayed onset of rain is the first indication of a rainy season and a reliable indicator of food insecurity several months before harvest (Shukla *et al*., 2021). Drought detection and warning can help inform intervention planning to save lives and livelihoods.

The marked variability in climate observed in Marsabit in both space and time, based on rainfall onset and cessation dates, number of rainy days, and seasonal rainfall totals range across study locations and seasons would account for the success and/or failure of pastoral and agro-pastoral systems and consequently impact associated livelihoods. The increasing length of intra-seasonal dry spells and shortening wet spells observed in the county will limit the production of traditional crops well adapted to the county, leading to mediocre complete crop failure. The loss of food and income would inhibit poverty and food insecurity reduction efforts, particularly among millions of rural people living in remote areas such as Marsabit County, with few options for sustainable livelihood choices (Brown and Crawford, 2008). Disruptions in climate patterns would thus compound and exacerbate the biophysical and socioeconomic vulnerabilities of pastoral and agro-pastoral livelihoods and erode smallholder households' ability to cope with climatic shocks and related risks (Deressa *et al.* 2008). Over the past thirty years, numerous scholars have interpreted the cause of East Africa's low rainfall diversely. William and Funk (2010) attributed the drying to the human-caused rise in Indian Ocean Sea surface temperatures. In a global study, Liu *et al.* (2013) and Tierney *et al.* (2015) argued that increased greenhouse gas concentrations led to arise in global average surface temperatures, a weakening of the sea surface temperature gradient, and a decrease in tropical rainfall. Changes in water availability and rainfall variability threaten the livelihoods of drought-prone places and the existence of arid and semi-arid remote areas as droughts become more frequent and severe (Ulrichs, Slater, & Costella, 2019). Climate variability endangers farmland productivity by reducing growing periods and crop or livestock yields (UNFCCC, 2007).

The findings of this research are consistent with those of Awange *et al.* (2007), who observed that many parts of Kenya, including the Lake Victoria region, experienced drought between 1983 and 1997, and Onchiri *et al.,* (2016), who found out that drought frequently occurred in Mbita between 1983 and 2012. The study's findings were similar to those of Ongoma and Chen (2017), who found that rain in East Africa decreased from the mid-1960s to the late 2000s, with a significant drop during the long rain. The anomalies in rainfall variability observed in Marsabit County from early 1981 to date affirm previous findings made by CuniSanchez *et al*. (2018), who found out a non-significant reduction in yearly rainfall in Mount Marsabit over the last 30 years. The study findings also corroborate with the findings of Samwel *et al.* (2018) study, who observed that rainfall in Kisii decreased between 1983 and 2013. Marsabit County's total rainfall across the study wards defines a semi-arid climate. According to IPCC 2021 report, changes in East Africa are caused by the El Nino phenomenon, which conforms to our observations on seasonal rainfall pattern fluctuations in Marsabit County (Climate change 2021).

CONCLUSION

Marsabit County, being an Arid and Semi-Arid Land (ASAL) County, is more vulnerable to the negative impacts of climate change. This is affirmed by the recent droughts that have become more catastrophic, leading to a humanitarian situation. This present study applied a mixed study design approach to determine some variation in the climatic conditions and associated household-level perception to these changes. The following are the highlights of the key findings of this study;

1. While the study location has typically been known for pastoralism, the results of the livelihood analysis show that the study locations sampled in this study have diversified their livelihood, this could be a key factor in building resilience to climate-related shocks

2. There is a generally decreasing trend in the total number of rainy days at the seasonal scale of the observations in the four study sites. This may be caused by the delayed onset dates as illustrated in figure 4. The decreasing number of rainy days would necessitate a shift in the growing of early maturing crops and improved water resources management strategies.

3. There is a general decline in the MAM rainfall totals. Being an ASAL county, Marsabit County relies majorly on rainfall for its pasture and agricultural sector production. Sustainable water management practices and other smart agricultural practices ought to be promoted.

One of the main limitations of this study was the sparse distribution of meteorological stations. The gridded data applied in the study could be of some bias to the realistic situation. In addition, the respondent's trustworthiness could not be ascertained.

RECOMMENDATIONS

The findings of this study established that pastoralists and agro-pastoralists cannot continue to do what they used to do with similar outcomes. It is high time they adapt to new foods and build infrastructure supporting the changing climatic conditions. This study can be used by county governments, research institutions, academia, agricultural extension officers, and non-governmental organizations to advise farmers on when and what to plant to avoid crop failure caused by late onset, early cessation, and a short rainy season. Pastoralists are also encouraged to use the findings to reduce livestock losses due to climate variability. However, the shifts in seasonal rainfall's onset and cessation dates may continue due to climate change. Therefore, more sustainable medium to long-term adaptation strategies should be adopted.

In order to increase and sustain community livelihoods, agro-pastoralists should shift from relatively longer maturation crops to early maturation crops, drought-tolerant crops (cowpeas, green grams, beans, sorghum), drought-tolerant animals (camels, goats), and pastures.

In collaboration with the National Government, the Marsabit County Government should incorporate agro-weather advisory services into their extension and outreach programs to support climate risk management in the region through early warning information. Government and government agencies need to increase knowledge sharing and advisory services and support communities on knowledge and skills necessary to adapt to the shifting atmospheric conditions.

Because the rainy season is sometimes different, pastoralists and agro-pastoralists are told to change their cultural practices in the MAM and OND seasons. They should start preparing the land and planting crops earlier, and they should also start preparing water storage facilities earlier.

In addition, the study recommends enhanced synergy between pastoralists, agro-pastoralists, researchers, and development actors for sustainable agricultural production and productivity in Marsabit County.

Suggestions for Future Research

i. Analysis of regular cyclical or periodicity of local climatic parameters, notably temperature and rainfall, and characteristics to indicate their period and dependency on the frequency of fluctuations of the climatic process.

ii. Examining the burden of global warming on the intra-seasonal climate characteristics and climate impact drivers.

iii. Further studies should also determine whether the changing climatic patterns affect the quality of animal pasture.

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