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RESEARCH ARTICLE

IMPACTS OF CHANGES IN CLIMATE AND LANDUSE ON STREAMFLOW: ASSESSING WATER AVAILABILITY IN THE DRYLANDS OF NORTHERN KENYA

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ABSTRACT

Water in this climate change era is perceived as a treasured commodity that can be traded but to be managed for human survival. The ballooning population further exacerbates climatic shocks evidenced in drylands with land fragmentation and degradation increasing in an effort to settle the growing populations. Increasing demands for food and shelter continue to contribute to land use changes which hamper the biophysical tenets required to sustain water availability in these regions. Turkana County was chosen for this study because of its unique location and its contribution to water availability for the communities. Further, challenges of water availability from rainfall in the drylands were addressed in relation to livelihood sustenance. Drylands often experience disruptions of livelihoods brought about by extremes of water availability. It was established that rainfall in the county is highly variable in both space ($36\% \leq CV \leq 135\%$) and time ($1.0 \leq SAI \leq 4$). Increasing rainfall trends and intensities provide a potential for runoff rainwater harvesting while high variability makes rainfall unpredictable thus calling for the development of an early warning system to support community resilience to floods and droughts. Land use is also changing with time and this has tended to complicate the biophysical aspect of water availability which is always the starting point in defining water availability for livelihood activities.

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INTRODUCTION

With global temperatures increasing, the frequency and intensity of adverse climate change effects will be a continued reality whose impacts on water availability remain untold (1,2). As such dry lands will suffer from physical water scarcity which forms one of the most persistent constraints to dryland livelihoods. This physical water scarcity is inherently tied to climate change and variability with recurrent droughts leading to variations in the households' primary production (3,4). Despite their constraint of water scarcity, drylands still play a key role globally as they occupy over 41% of the terrestrial area and support over 40% of the world's population (5,6). All over the world, dry lands are known for their production of forage for livestock rearing and support to pastoralism which is a major livelihood activity in these areas (7,8). Drylands productivity is inherently tied to water availability as it forms the basis for any meaningful productivity at household level These systems are inter-linked where biophysical water availability links the social and economic aspects of water availability to a society. Biophysical system of water availability, which is the subject of this study, plays a pivotal role in the movement of water within the earth-atmosphere system until it eventually becomes available as streamflow and groundwater (9–12). Biophysical water availability is controlled by a number of factors that include climate and land surface characteristics (12–14). A change in climate or the land surface characteristics impacts on the rainwater water availability in terms of occurrence and distribution (15). Climate variability impacts the distribution of rainwater temporary and spatially while climate change impacts the frequencies and intensities of precipitation. Further, changes in Land use and Land cover (LULC), affect the rainwater storage system through reduced infiltration and hence enhanced surface runoff. Reduced infiltration and enhanced runoff impact negatively on biophysical water availability as well as on food security (12,14,16,17). Therefore, climate and LULC play a major role in influencing how rainfall, the ultimate source of water, eventually becomes water in the rivers and wells where it could be accessed for livelihood support (9,18,19). Water availability in dry lands may be assessed in terms of watershed characteristics such as LULC and historical as well as projected rainfall and streamflow patterns (20). Water availability from rainfall and ultimately as streamflow and groundwater has a significant contribution in determining the necessary component of growth for both crop and fodder (21). To understand the processes leading up to water availability in the dry lands, information on rainfall variability and trends, as well as land cover characteristics, is necessary. Globally, rainfall extremes are becoming more frequent and intense as climate changes thereby impacting on water availability (21). These changes, coupled with changes in LULC, tend to compromise biophysical water availability which further affects the means of community livelihood systems significantly. Turkana County is the driest county in Kenya and is characterized by physical water scarcity resulting from rainfall variability that often swings between the two extremes of droughts and floods (22). The county is mainly arid with warm to hot climate. The southern parts of the county are characterized as semi-humid to semi-arid (23). The county experiences two main rainfall seasons: long rains between April and July and short rains between October and November with a mean annual rainfall of about 200 mm. Rainfall in the county is erratic and unreliable, often coming in heavy storms that lead to catastrophic flash floods (24). The county is drought-prone and has low access to essential services including water supply (25). The low access to water tends to compromise pastoralism, agropastoralism, and fishing which account for 67%, 4%, and 3% respectively of the county's income (22,23).

Livelihoods in the county predominantly rely on rainfall and due to hazards like droughts, floods, and resource-based conflicts, households in the county have become more vulnerable to challenges brought about by climate change and variability (24). Local communities have, over time, resulted to practicing agropastoralism using irrigation schemes to water their animals and crops as a form of adaptation to climate change and variability. The current level of access to clean drinking water in the county is about 53% with the main water sources being boreholes, earth dams, water pans, rock catchments, springs, and Lake Turkana. Turkwel River is an important source of water for Turkana County as it directly and indirectly supplies water to populations for multiple uses such as domestic consumption, watering of livestock, crop watering through flood-based farming and irrigation among other livelihood activities (26,27). The multiple uses of water in the community, and their perceptions of what is essential and non-essential impacts their water management and prioritization of water needs in this regard-(28). The fragile relationship between water needs and their categorization of essentiality affects the community's way of life thus requiring a change of mindset so as to enhance sustainability (29).

The paper attempts to address the perennial challenges of disruptions on livelihoods in the drylands resulting from water scarcity using Turkana County in northern Kenya. Turkana county, the hottest and the second largest in Kenya, often experiences severe disruptions of livelihoods brought about by the two extremes of climate variability; droughts and floods (12). The paper sought to understand the effects of rainfall variability arising from climate change and LULC changes on biophysical water availability in an endeavour to support the attainment of Sustainable Development Goals 2, 13, 6 which influence each other at different levels. The study provides up-to date data on the status and trends in the flow rates of Turkwel River as part of the assessment of the water available for use in different livelihood activities in the drylands.

MATERIALS AND METHODS

Area of Study: This study focused on the north-western part of Kenya between latitudes 1.00°N and 5.50°N and longitudes 34.00°E and 37.00°E **(Figure 1)**. The area straddles two counties, Turkana and West Pokot within which lies Turkwel river basin, the main focus of the study, and covers a total area of about 83,000 km^2. The altitude, which has a notable influence on climate ranges from 330 m near Lake Turkana to about 4300 m above sea level at the source of Turkwel River, the main source of water to the central parts of Turkana County.

Data Types and Sources: Two types of data were used in this paper; primary and secondary datasets. Primary datasets, comprising both quantitative and qualitative datasets, were gathered through household survey, Focus Group Discussions (FGD) and key informant interviews (KIIs) in Turkana Central, Turkana South and Loima sub-counties. These data mainly focused on establishing the communities' level of awareness in matters of climate variability, climate change, LULC changes, water availability, livelihoods, and coping strategies of climate related shocks to their livelihoods as well as their views on future sustainability of their livelihoods. Quantitative data were collected through household survey where respondents responded to close-ended questions on their perceptions of rainfall, livelihoods, water availability, coping mechanisms and livelihood sustainability in their locality. On the other hand, qualitative data were gathered through Focus Group Discussions (FGDs) and Key Informant Interviews (KIIs) where opinions of respondents were sought to corroborate data collected from the households. Secondary data comprised of historical monthly rainfall sourced from the Kenya Meteorological Department (KMD) and supplemented by satellite rainfall data from the Climate Hazards Group Infra-Red Precipitation with Station (CHIRPS) for the period 1981 to 2020 (https://data.chc.ucsb.edu/products/CHIRPS-2.0/); future scenario rainfall data obtained from the World Climate Research Programme's (WCRP) Coordinated Regional Climate Downscaling Experiment (CORDEX) at the Deutsches Klima Rechen Zentrum-DKRZ data portal [https://esgf-data.dkrz.de/search/cordex-dkrz/] for two future scenarios: Representative Concentration Pathways (RCP) 4.5 and 8.5; LULC data obtained from four Landsat images at an average time step of ten years sourced from USGS website (https://earthexplorer.usgs.gov/); streamflow data from the Water Resources Authority (WRA) which were supplemented with hydrological model-simulated streamflow running on the Soil and Water Assessment Tool (SWAT) using LULC, rainfall, maximum and minimum temperatures as the forcing variables (12,30).

Primary Data Analysis: Quantitative primary data were analyzed using descriptive statistics while qualitative data were analyzed using content analysis. Quantitative raw primary data were systematically organised and analysed using descriptive statistics that summarised the data in form of simple quantitative measures like the mean, frequencies, and percentages which were then visually presented in form of bar graphs and pie charts. Content analysis was used to analyse qualitative data collected from responses of open-ended questions. Recorded interviews from focused group discussions were first transcribed from the local language (Ng'arturkana) to English. Key informant interviews were transcribed also to English from Kiswahili and *Ng'arturkana* languages. For easier analysis, responses were then coded to common themes of climate change, rainfall, livelihoods together with coping mechanisms (31).

Secondary Data Analysis: Rainfall data were statistically analysed to detect signals indicative of climate change and variability [coefficient of variation (CV) and standardised anomaly index (SAI)] and climate change (long-term trend in the mean values) in the county for the past, present and in the future (32). Satellite images were processed in the Google Earth Engine and analysed to generate decadal LULC maps for the area of study for the 1980s, 1990s, 2000s, and 2010s decades. Accuracy assessment and change detection were carried out to establish changes in LULC in the area of study (33).

Hydrological Model Simulations: A hydrological model, Soil and Water Assessment Tool (SWAT), was used to simulate streamflow (30) using climate, LULC and Soil type data. Simulated streamflow was analysed to detect their level of variability, long term changes (32), as well as their relationship with climate and LULC changes and hence water available for livelihood support systems (9).

RESULTS AND DISCUSSION

Figures 2 shows spatial rainfall variability in the two rainfall seasons, March-April-May (MAM) and September-October-November (SON), in Turkana County. It was noted from the figure that rainfall in the county is highly variable ranging from moderate to extreme variability as depicted by the coefficient of variation that ranges from 36% in MAM to 135% in the SON season. The central parts of the county tend to experience higher variability than the northern and southern parts. Comparing the two rainy seasons in the county, the short rains season (SON) was found to experience higher variability than the long rains season (MAM) where variability ranged between 54%, in the north and southern parts, and 134% in the central parts during SON. During the MAM season, variability ranged between 36% in the north and 90% in the southern parts. This high spatial variability in rainfall, which also affects the available water from rainfall, tends to strain the main livelihood activity (pastoralism) in the county, and more so in the central parts. In an effort to cushion themselves from the harsh realities of this variability, pastoralists are forced to migrate to the peripheries of the county, where rainfall is more reliable (Figure 2), in search of pasture. This tends to lead to conflicts with the neighbouring communities that often results in loss of lives and livestock. Figure 3 shows results of secondary data analysis (Figure 3a) for the temporal variability of rainfall and its trends during the MAM and SON seasons for the period between 1981 and 2020 and those of a survey on the community perception of rainfall variability (Figure 3b). Figure 3a shows that over the last four decades, Turkana County has experienced rainfall variability ranging from moderate droughts ($1.0 < SAI < 1.5$) to extreme floods ($SAI > 2.0$) during MAM and SON seasons respectively. These results were corroborated by the majority of the community, 53% of who opined that rainfall is no longer predictable in the county (Figure 3b). This was a kind of confirmation of the high variability of rainfall as depicted in Figure 3a. This unpredictability of rainfall has affected the communities' livelihoods as they are unable to plan ahead. It is clear from the results that since the year 2005, the county has been experiencing a higher frequency of extreme floods in both seasons than was the case before with the worst flood in MAM coming in 2020 and that of SON coming in 2011. Figure 4 shows temporal rainfall and streamflow variability during the long rains (Figure 4a) and short rains (Figure 4b) seasons for the period 1986 to 2016. These results show that in both seasons, rainfall and streamflow are highly variable ranging from moderate drought conditions ($1.0 < SAI < 1.5$) to extreme flood conditions ($SAI > 2.0$). This makes it difficult to predict them as opined by the communities (Figure 3b). This high variability in rainfall and streamflow tends to disrupt the communities' main livelihood sources, pastoralism and agropastoralism. Results of the 3-year moving average revealed that both rainfall and streamflow are on an increasing trend, implying that more surface water is becoming available in the county. With proper systems in place, this water could be harvested and conserved for use during the dry periods as a means of enhancing the communities' resilience to impacts of climate change and variability. Figure 5 shows results of a survey to determine the main livelihood sources in Turkana County and how they are impacted by rainfall variability. Figure 5a shows that the main livelihood sources in the county are pastoralism (48%) and agropastoralism (13%), both of which are highly dependent on rainfall and therefore vulnerable to its variability while Figure 5b shows results of household survey to identify the communities' perception of how climate change and variability impacts their livelihood sources. The impacts of climate variability, seen through rainfall variability on livelihood activities that were identified by the community included: decrease in fodder (55%), Low farm yields (21%), and decline in business and casual work (10%). This agreed with the observed LULC changes in the period 1981 to 2020 (Figure 6) as identified from Landsat image analysis. Figure 6 shows decadal changes in various categories of LULC in Turkana County over the last four decades derived from Landsat imagery analysis. These results show that between 1981 and 2020, all the categories of LULC in the county changed from their initial coverage in the 1980s decade with forest coverage having the highest change (+16%) followed by shrub land (-15%) while cropland had the least change at +3%. The changes in shrub land, which generally serve as the main source of pasture and other land covers, which are further amplified in Figure 7, reflect changes in livelihoods in the county resulting from rainfall variability where the communities are shifting from the traditional source of livelihood; pastoralism. The notable growth in the forested area from 1980s onward is due to the emergence and propagation of *Prosopis juliflora*, which tends to reduce invade and colonise the forage species, in the southern part of the catchment and along the riverine area. From the analysis of satellite images, it was established that LULC is indeed changing in line with the communities' perceptions

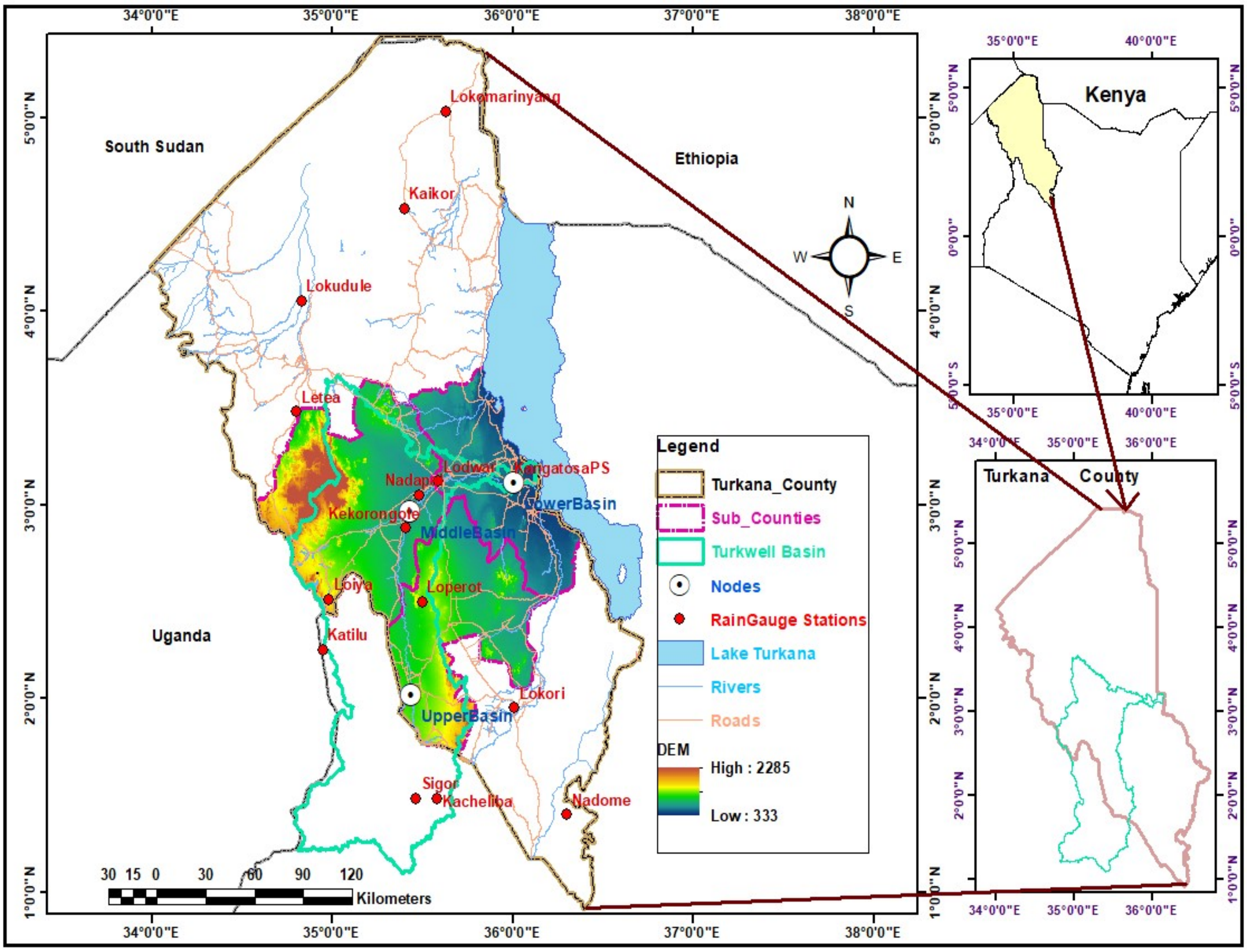

Figure 1. Map of Turkana County and Turkwel River Basin, the area of study. The shaded area is the lower Turkwel basin encompassing three sub counties; Loima, Turkana Central and Turkana South that were the focus of this study (Source, Author, 2023)

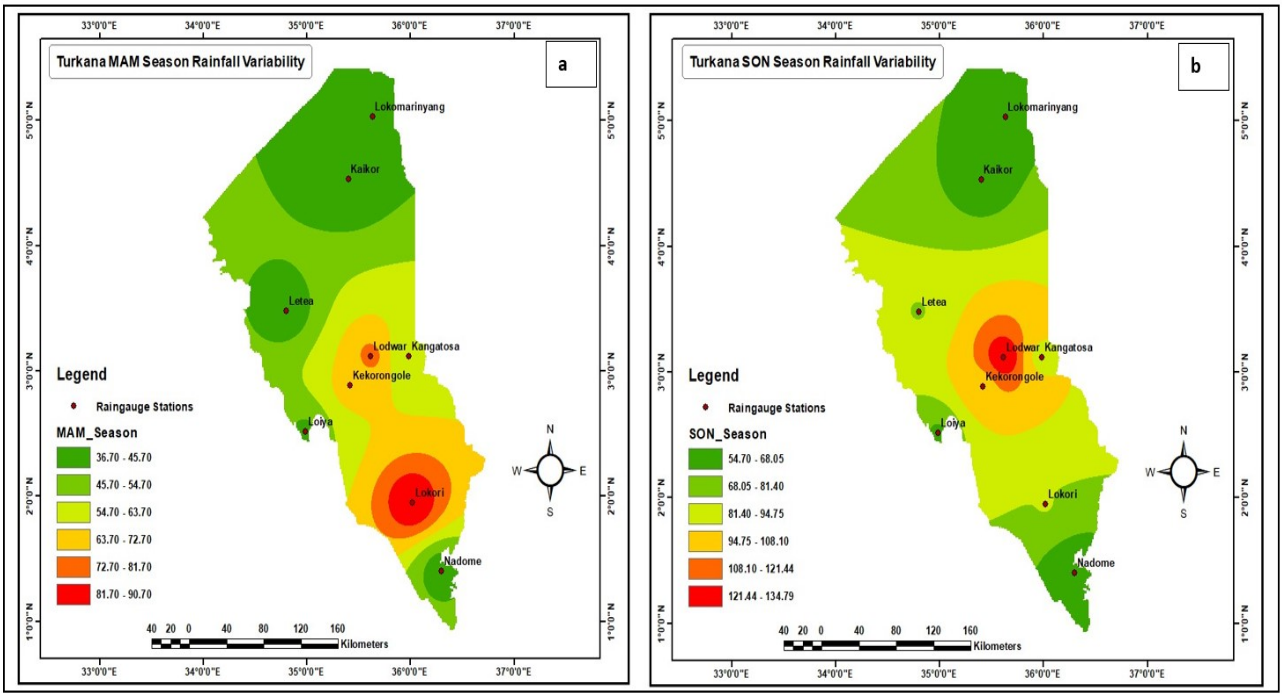

Figure 2. Turkana County (a) MAM and (b) SON seasonal spatial variation of rainfall as determined by the Coefficient of Variation. The central parts of the county experience higher rainfall variability that the northern and southern parts in both seasons

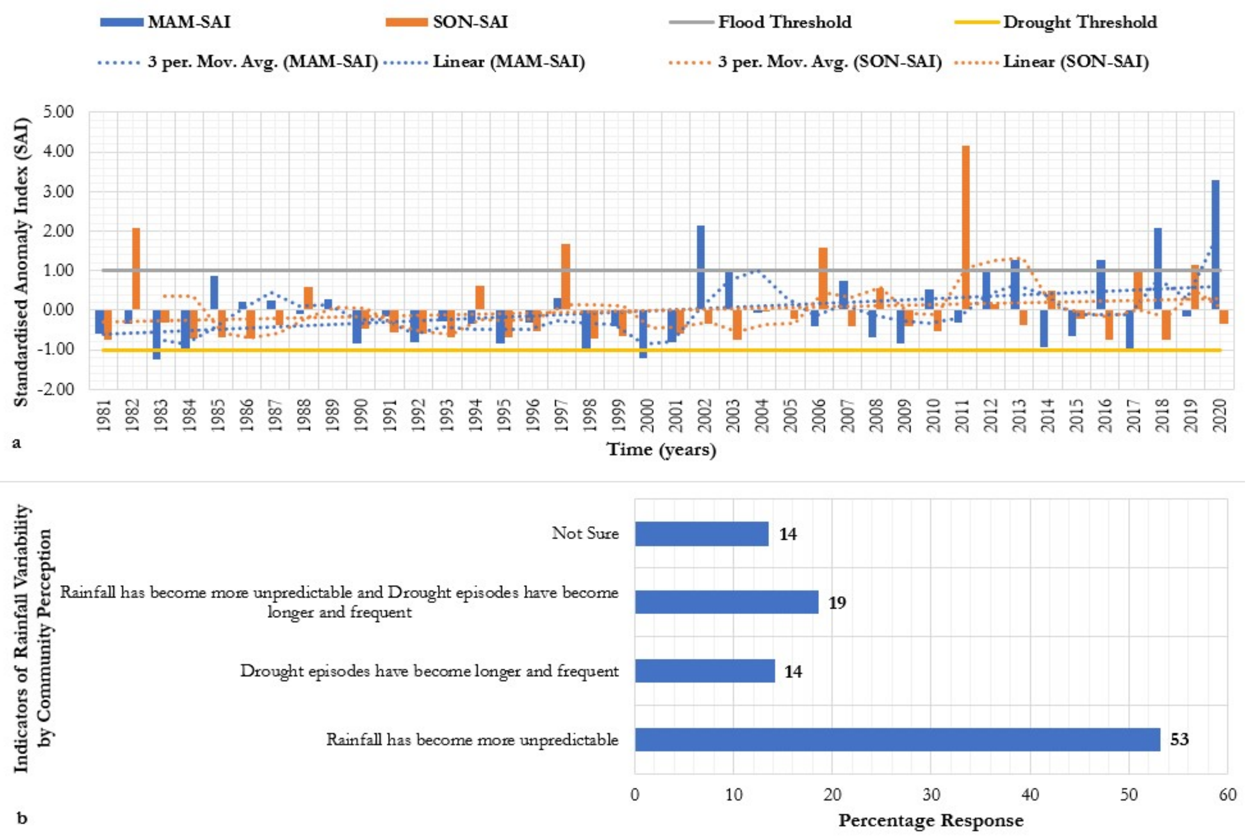

Figure 3. Community perception of rainfall variability (a) and temporal MAM and SON Rainfall Variability (b) in Turkana County between 1981 and 2020. The figure shows that community perception on rainfall variability is corroborated by the secondary data analysis that show higher variability of rainfall in the two rainfall seasons in the area

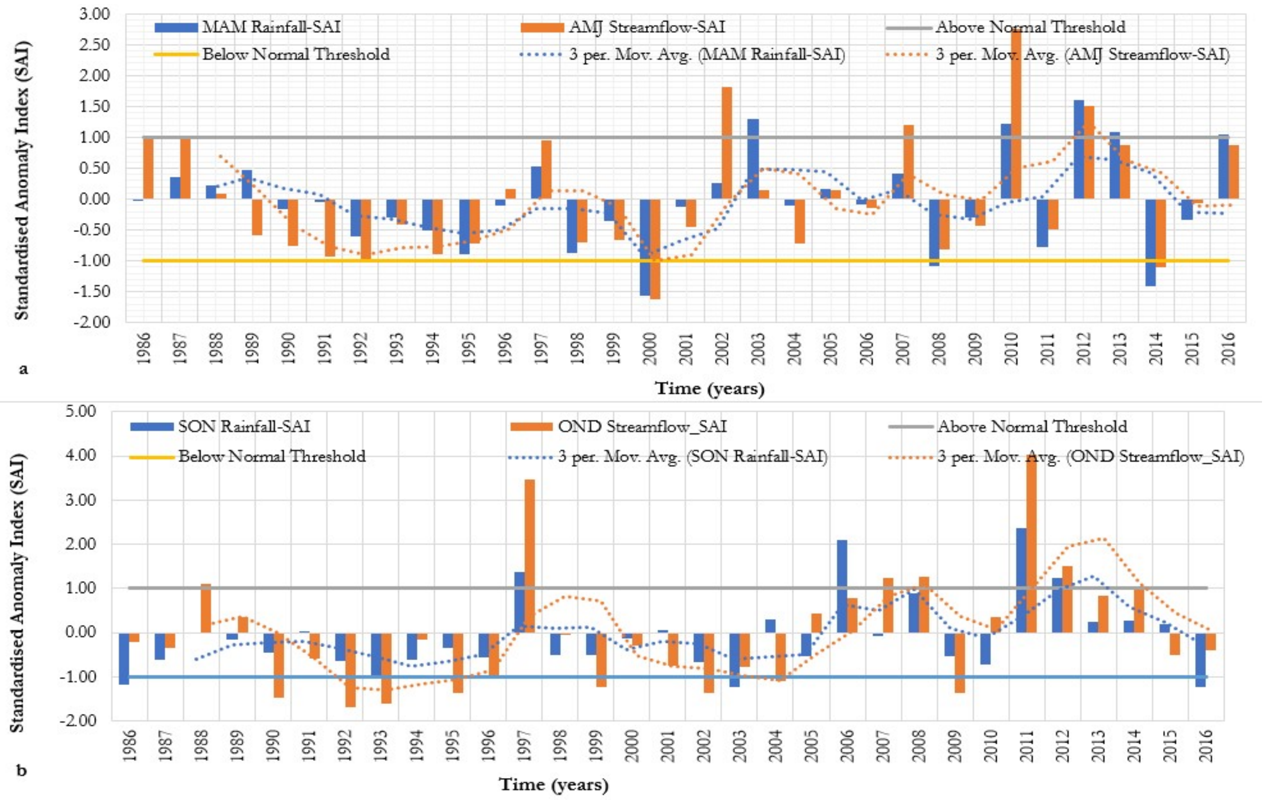

Figure 4. Rainfall and streamflow temporal variability in central parts of Turkana County during the two rainfall seasons. Streamflow is generally more variable than the rainfall in both seasons

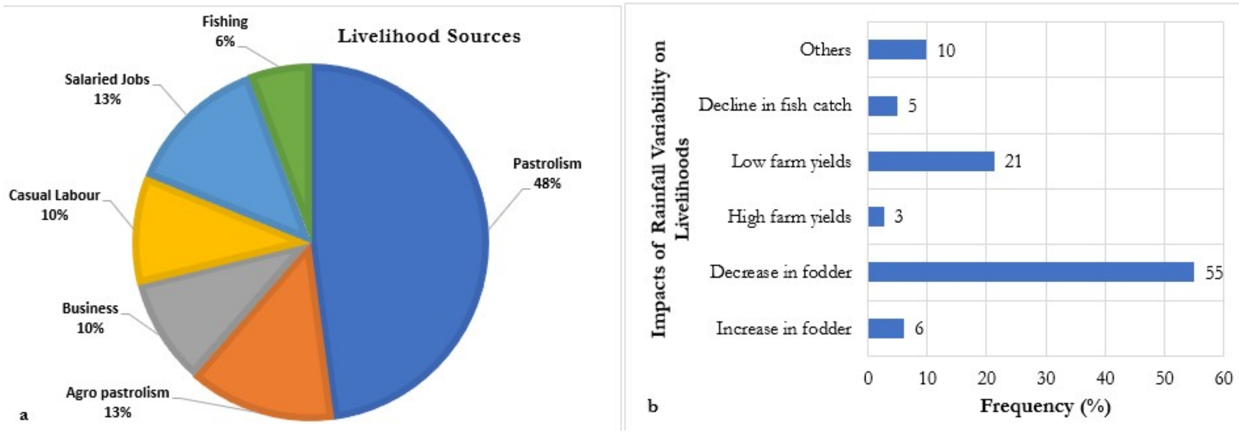

Figure 5. Livelihood sources in Turkana County and how they are impacted by rainfall variability. Pastoralism is the main livelihood Source and also the most impacted by the rainfall variability through decrease in fodder (55%)

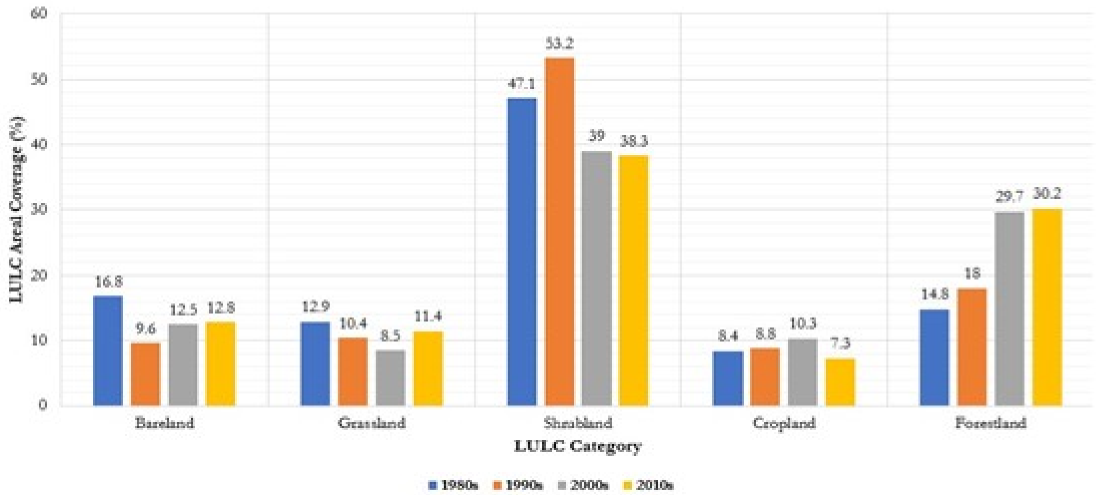

Figure 6. Decadal LULC Coverage over Turkana County between 1981 and 2020. The general decline in grassland and shrubland is in line with the community's perception (Figure 7b) on the declining fodder

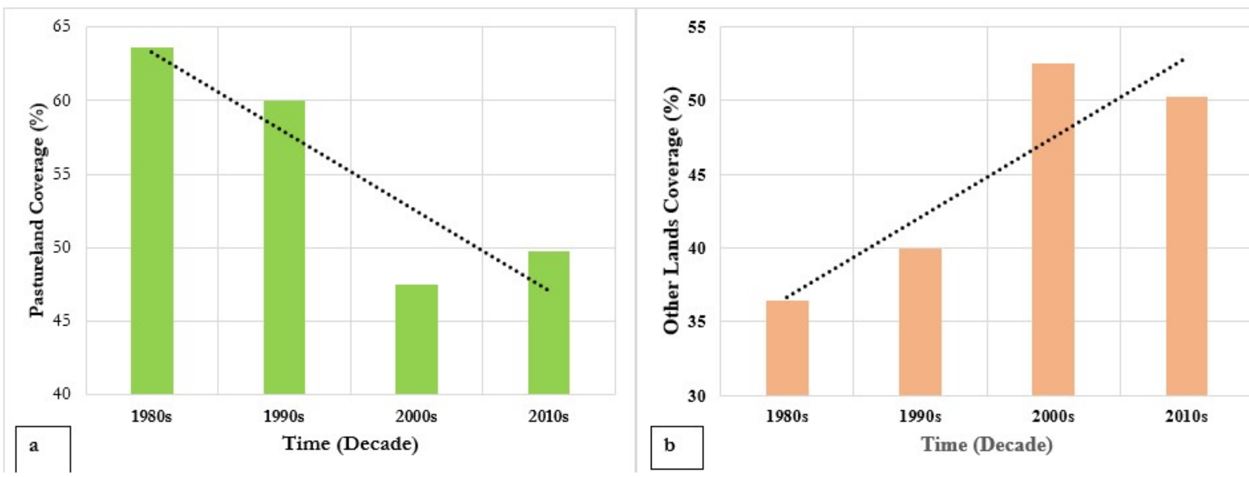

Figure 7. Changes in the coverage of land under pasture (a) and other lands (b) in Turkana County between 1981 and 2020. is on a decreasing trend. Land under pasture is generally declining while the other forms of land coverage are generally growing

(Figure 5b). Grassland and shrubland, which are the main sources of browse and forage for pastoralism, are diminishing while the bare and forest lands are increasing thereby putting pressure on pastoralism, the main livelihood activity in the county. Since these changes in land use affect water availability from rainfall through reduced infiltration, it is important to plan for sustainable land use in the county for sustainable water availability from rainfall. Figure 7 shows changes in two categories of LULC, pasture land (grassland and shrubland) and other land covers (bare land and forestland), between 1981 and 2020 at a decadal time step; 1980s, 1990s, 2000s, and 2010s decades. It was noted from these results that land under pasture has declined from 62% coverage in the 1980s to 48%in the 20210s decade (Figure 7a) while other land covers have grown from 38% coverage in 1980s to 52% in the 2010s decade (Figure 7b). The growth in other land use categories (Figure 7b) is in response to the pressure put on pastoralism, the main source of livelihood in the county, by rainfall variability leading to the decline in land under pasture (Figure 7a). Communities are resulting to other forms of livelihoods such as casual labour, agropastoralism and business among others (Figure 5a) to cushion themselves from the impacts of rainfall variability and hence water availability. The growth in other LULC categories at the expense of the natural vegetation coverage (pasture land) affects water availability from rainfall in the area. This is because of the reduced infiltration and hence storage of rainwater resulting from decreased natural vegetation coverage. It was evident from Figure 7b that other categories of LULC have been on an increasing trend. This trend could possibly be attributed to the communities' desire to diversify their means of livelihoods in response to climate variability which has negatively impacted pastoralism; their traditional source of livelihood.

As a result of rainfall and streamflow variabilities in the county, which have stressed the traditional livelihood activities, households have adopted some strategies to cushion themselves from impacts of climate extremes. Among the main coping mechanisms are food aid at 32%, cutting down on expenses of non-essentials at 25%, and selling of livestock (17%) among others (Figure 8); all of which are not sustainable. Since the future rainfall is also projected to be highly variable, fluctuating between severe floods and droughts and showing a moderately increasing trend (Figure 9b), there is need to adopt some coping strategies that are more sustainable in the face of a changing climate. Figure 9 shows results of the projected rainfall variability and trends for the long and short rains seasons for the period between 2022 and 2094 and the communities' perceptions on how to sustainably cope with the impacts of climate change. These results revealed some evidence that rainfall is projected to be highly variable. Further, rainfall in the short rains season (SON) is projected to increase while rainfall in the long rains season (MAM) is projected to decrease in future (Figure 9a). MAM season, whose rainfall is on a decreasing trend, will continue to experience above normal rainfall interspersed with floods (SAI > 1) up to 2045 and thereafter experience below normal rainfall interspersed with moderate to severe droughts (SAI > 1.5) up to the 2080s decade. Within the same period, SON season, whose rainfall is on an increasing trend, will be experiencing below normal rainfall interspersed with moderate droughts (SAI < -1) and thereafter will experience above normal rainfall interspersed with moderate to severe floods. Future rainfall (Figure 9a) also shows a decreasing trend in the MAM season accompanied by high variability ranging between extreme floods and droughts (-1.5 < SAI >1.5); an indication that contributions to annual water volumes from this season are dwindling with time. At the same time, SON season shows an increasing rainfall trend interspersed with moderate drought to extreme floods ((-1.0 < SAI >1.5); an indication that contributions to the annual water volumes from this season are growing with time at the expense of the long rains season. It is also worth noting that while rainfall in the area will continue to be highly variable in both the long and short rains seasons, year 2045 is projected to mark a transition in the patterns of rainfall in the area where the short rains season (SON) will assume the role of the main rainfall season (Figure 9a). Up to this time, the 3-year moving average rainfall during MAM is above normal while it is below normal during the SON season. After 2045, the SON season is projected to contribute most of the rainfall in the area. This is an indication of a possible change in the seasonal distribution of rainfall in the area. This change in the seasonal rainfall distribution is likely to upset the communities' means of livelihoods.

Further, results show that in the next twenty years MAM season will experience alternate above and normal rainfall with two extreme floods (2022 and 2029) and one extreme drought (2041) while rainfall in the SON season will generally be below normal with three moderate droughts (2023, 2026 and 2030).The moderate to extreme variability in rainfall is likely to lead to continued scarcity and variability of the water available for households' food production in the area there by tending to make it difficult for any meaningful planning of rainfall dependent livelihood activities such as pastoralism and agropastoralism. To be able to sustainably cope with this challenge, the communities will need climate change information and sensitisation. Results of Figure 9a also show that the period between 2042 and 2045 will experience below normal rainfall in both MAM and SON seasons indicating a period of water scarcity in the area. This period of water scarcity will be followed by a four-year period (2046 - 2049) of plenty of water where rainfall will be above normal in both MAM and SON seasons. The projected alternate periods of plenty and scarcity of water in the area revealed by these results provides an opportunity to the policy makers and other stakeholders to plan ahead for the communities' resilience to the impacts of climate change and variability. This could be by way of planning for rainwater harvesting during the period of plenty for use during the period of scarcity. Figure 9b shows results of a survey conducted on household to establish communities' views on how to sustainably cope with the effects of climate variability and change on their livelihoods. Majority of the households (58%) were of the view that community information, awareness and sensitisation on climate change and variability, through their local representatives, supported by capacity building so that households become more resilient to climate related shocks, would enhance their level of coping with the impacts of climate change and variability. 16% of the community felt that funding opportunities through business loans and grants would also help in sustainably coping with the impacts of climate extremes that include floods and droughts. Others included community equity (10%), livelihood diversification (9%) capacity building in technical education (5%), and infrastructure development (2%).

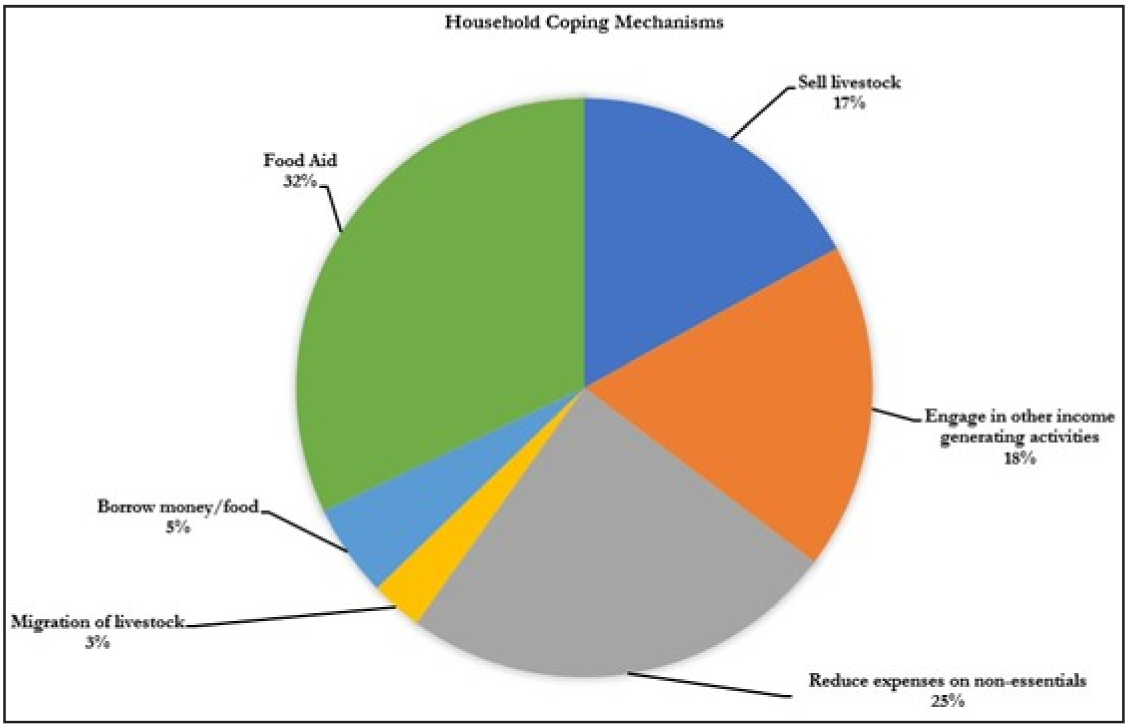

Figure 8. Coping mechanisms identified by communities in Turkana County in response to the impacts of rainfall variability. It is clear from the figure that food aid is the most sought-after coping mechanism followed by reduction in expenses on nonessentials, both of which are not sustainable

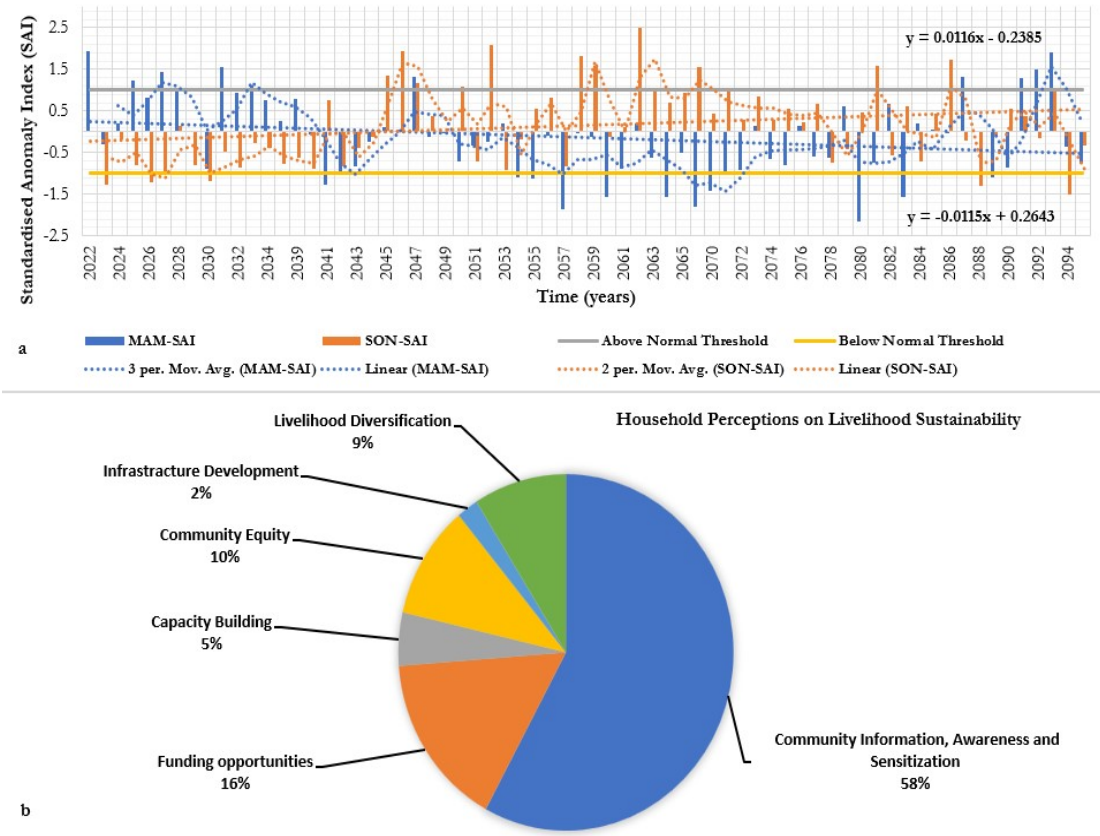

Figure 9. Projected MAM and SON rainfall Variability to the end of the century (a) and the perceptions of communities on how to sustainably combat impacts of climate change and variability (b) in Turkana County. SON season is projected to be the main rainfall season in the area after year 2045 (a) and hence communities in the area need information, awareness and sensitisation (b) to be able to cope with the projected shift in the seasonal distribution of rainfall

CONCLUSION

Results of the study show that indeed climate variability, climate change, LULC changes and streamflow changes in the county, all of which impact on the water availability, are a reality. Rainfall amounts in the short rains season are on an increasing trend and is projected surpass the amount in the long rains season, which is on downward trend, leading to a change in the seasonal distribution of rainfall in the area. This shift in the seasonal distribution of rainfall will also result in the redistribution of the water available from rainfall leading to shocks on the communities' livelihoods; community sensitisation may therefore be necessary to enhance their resilience. Further, increasing rainfall trends during the short rains season coupled with a high frequency of floods, which are partly enhanced by LULC changes and the decreasing trends in rainfall during the long rains season, affects the amount and distribution of the water available from rainfall. There is, therefore, a need for design and implementation of policies supporting rainwater harvesting, sustainable land use conservation and early warning system programmes for a water availability resilient community. To ensure acceptance, and hence sustainability of such programmes, concerted community sensitization, through their elected representatives, is necessary.

Conflict of Interest Statement: The authors declare no conflict of interest in as far as this study is concerned.

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Glossary of Abbreviations

BRECcIA Building REsearch Capacity for sustainable water and food security In drylands of sub-Saharan Africa
WCRPWorld Climate Research Programme
CHIRPSClimate Hazards Group InfraRed Precipitation with Station
CORDEXCoordinated Regional Climate Downscaling Experiment
CV Coefficient of Variation
FGDFocus Group Discussions
KIIsKey Informant Interviews
KMD Kenya Meteorological Department
LULCLand use and Landcover
MAMMarch-April -May
Mo ALFC Ministry of Agriculture, Livestock, Fisheries and Cooperatives
MoEFMinistry of Environment and Forestry
NDMANational Drought Management Authority
RCPRepresentative Concentration Pathways
REACH'Improving Water Security for the Poor' research programme
SAI Standardized Anomaly Index
SONSeptember-October-November
SWATSoil and Water Assessment Tool
TCGTurkana County Government
UKUnited Kingdom
WRAWater Resources Authority

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