Impacts of Climate Change on Traditional Irrigation Farming Systems and Adaptation Strategies in West Usambara Highlands, Tanzania

***Maro, F.L.[1] and A.J. Tenge[2]**

[1]Department of Geography and Environmental Studies, The University of Dodoma, P.O. Box 395 Dodoma, Tanzania
[2]Institute of Development Studies, the University of Dodoma, P.O. Box 395 Dodoma, Tanzania

*Corresponding author e-mail: *fredymaro@yahoo.com*

Abstract

Climate change is among the challenges to sustainable development due to its effects on major sectors of economy worldwide. However, its impacts differ from one system to another depending on the magnitude, vulnerability and adaptive capacity of the system. This study assessed the impacts of climate change on crop yields in Ndiwa and Chamazi traditional irrigation farming systems and their adaptation strategies. A cross-sectional research design was adopted employing purposive and systematic random sampling to select 380 respondents for this study. Data was collected through household survey, Focus Group Discussion, interviews, observation and documentary reviews. The results showed that, within 42 years (1981-2022), climate change has caused yield decline (maize, beans and irish-potatoes) by 12% to 51% and Maize being the most affected crop. The decrease in crop yield was linked to the decreased amount of water for irrigation and outbreak of crop diseases. Major adaptation strategies adopted as mitigation measures include cultivation closer to water sources (93.8%), early planting (86.9%), crop diversification (72.6%) and digging of shallow wells (58.7%). However, some adaptation strategies are detrimental to the environment. Adaptive capacity of farmers is low to medium. We recommend to improve adaptive capacity of farmers through access to climate information, financial resources, agricultural extension services and improved irrigation infrastructures.

Keywords: Adaptive capacity, Ndiwa, Chamazi.

Introduction

Climate change refers to the variation or deviation of climatic parameters such as temperature, precipitation, wind pattern and humidity for an extended period of at least 30 years (Guodaar *et al.,* 2021). Climate change is caused by increased concentrations of Greenhouse Gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4) and nitrogen dioxide (NO_2) in the atmosphere (IPCC, 2022). Studies indicated that the increased atmospheric concentrations of GHGs to large extent are caused by human activities such as fossil-fuel combustion and deforestation (Coffinet *et al.,* 2018).

It is estimated that because of climate change, global mean surface air temperature will increase by 2°C by 2100 (Ngcamu, 2023). These changes are expected to alter the rainfall amount and distribution in different parts of the world and cause the rising of sea levels and increase incidences of floods and drought (Pardoe *et al.,* 2018). The effects of climate change when compounded together have devastating impacts on natural ecosystems, human health, forestry, water resources, energy use and transportation, agriculture and food supplies (Opere *et al.,* 2017).

Although climate change has become a global challenge for almost all sectors, agricultural sector is likely to suffer more than other sectors due to its sensitivity to change in climatic parameters such as rainfall and temperature (Opere *et al.,* 2017). Traditional irrigation farming systems (TIFs) is among the smallholder farming system likely to be affected by climate change in Tanzania (Leal Filho *et al.,* 2022). This is because of their low use of irrigation technology such that they directly irrigate crops from water sources such as rivers, natural spring and water from flood plains without storage of water for future use in case of shortage.

Traditional irrigation farming evolved over the course of time from people's own experience and wisdom without any outside institutional interventions. The system rely on traditional methods to harness the available water from rivers, springs and flood plains for irrigation. Various traditional irrigation systems have been practiced in different parts of the World and sustained smallholder farmers for long time. Examples include Moat, chain pump, dhekli and rahat in India; fadama in Nigeria and Spate irrigation in Ethiopia and Yemen (Gebru *et al.,* 2020).

TIFs are important smallholder farming systems in ensuring food security and income generation to farmers in many places within Tanzania (Weerahewa *et al.,* 2023). For instance "*Mifongo* (traditional furrow irrigation through stream diversions in the hills)" and "*Vinyungu* (traditional irrigation farming that utilizes natural moisture or water from either natural springs or diversions in valley bottoms or plains)" have been playing significant roles in livelihood of farmers in Kilimanjaro and Iringa regions respectively (Said *et al.,* 2021; Van der Plas *et al.,* 2021). Traditional irrigation farming systems are likely to face challenges due to changes in temperature, hydrological conditions and incidence of pests and diseases to crops mainly contributed by climate change (Jha, 2023). These changes have impact on crop yields, food security, dependence on forest resources for livelihoods and migrating of people to lowlands and urban centres (Leal Filho *et al.,* 2022).

Relevance of traditional irrigation systems lies on the fact that they are practiced by smallholder farmers who cannot afford modern irrigation systems and in most cases in highland or lowland areas where large scale modern irrigations systems are not feasible. Hence, they will continue to be important sources of food and livelihood to majority of population in rural areas of Tanzania.

Similar to other farming systems, field level experiences show that the impacts of climate change to smallholder farmers relying on traditional irrigation systems and their adaptation strategies vary widely within communities depending on geographical location, specific local settings and along with the capacities and livelihood strategies of individual actors (Chukwuemeka and Agoh, 2022). This is due to the fact that communities in different farming systems are impacted differently and have devised adaptation strategies and technologies which best suit their biophysical and socioeconomic circumstances (Fazliev, 2019). Hence, it is difficult to generalize the available information to all locations, income group and agriculture systems (Mekonen and Berlie 2021). This makes the necessity of this study that aimed to assess the impacts of climate change on crop yields grown under traditional irrigation farming systems and the adaptation strategies by smallholder farmers in West Usambara Highland, Lushoto Tanzania.

Materials and Methods

Study area

This study was conducted in Shashui, Nkukai, Lunguza and Kivingo villages within Lushoto district, Tanga Region, Tanzania (Fig. 1). The district lies between 1000m to over 2500m above the sea level within West Usambara Highland. The West Usambara Mountains are drained by three main rivers namely; Umba, Sine and Lwengera rivers. Apart from these main rivers, there are numerous streams and natural springs that provide water valuable for irrigation farming (Kaganzi *et al.,* 2021).The district is famous for the cultivation of tea, coffee, cardamom, vegetables, fruits, spices, maize, beans, bananas, cassava, yams, sweet and Irish potatoes (Lyamchai *et al.,* 2011; Baddoo and Masao, 2016).

Important traditional irrigation farming systems in West Usambara highlands are Ndiwa and Chamazi. These traditional irrigation farming systems have been in operation on the West Usambara Highlands for several decades

(Kaganzi *et al.,* 2021). Ndiwa irrigation system (NIS) relies more on accumulating water from natural springs or streams until sufficient quantity is attained for irrigating the fields. It is estimated that about 90% of the population in humid climatic zone of West Usambara highlands are involved in NIS because of agro ecological zones and involves above 80% of farmers in this zone. Lushoto District was selected for this study because of existence of two types of traditional irrigation systems and their significance contribution to the livelihood not only to Lushoto population but also to commercial city of Dar es Salaam

Figure 1: A Map of Lushoto District Showing the Location of the Study Villages
Source: University of Dodoma GIS Laboratory (2022)

their potential high yield compared to rain fed farming.

Chamazi relies more on the utilization of residual soil moisture from rainfall or river streams in the valley bottoms to cultivate crops especially during the dry season. Unlike the Ndiwa; Chamazi irrigation system does not constitute storage point/reservoir/dam to irrigate crops rather it only utilizes residual soil moisture in the valley bottom as the result of rainfall and river streams. Chamazi is common in semi-arid

Research Design

This study employed a cross-sectional research design (Busetto *et al.,* 2020). The rationale for using this design includes: its ability to collects data and make inferences about a population of interest at one point in time, and ability to consider many aspects of a problem/issues at hand (Gibson, 2018). The design also offers a possibility to combine qualitative and quantitative approaches in data collection (Busetto *et al.,* 2020).

Sampling Procedures

The sampling frame for this study was a list of household heads involved in traditional irrigation farming in each study village. The criteria used to select a sample was either household head engage in Ndiwa or Chamazi irrigation farming. This study involved a total of 380 sample (Households), estimated using a formula developed by Yamane (1967), at confidence level of 0.05.The estimated sample size was distributed among the study villages based on the proportion of households in each village. Multi-stage sampling was employed in selecting the study villages and households. First stage involved stratification of all wards within the district based on the location in agro-ecological zone (semi-arid or humid area). This stratification was important because the type of TIF depended on the agro ecological zone. From this stratification, two wards were selected from each agro-ecological zone based on the type and intensity of TIFs. The wards were Soni and Sunga in Humid area, Lunguza and Kivingo in Semi-arid area. From each ward one village was selected, with the consideration of type and intensity of TIFs. This made a total of four (4) villages under the study which were; Shashui and Nkukai in humid climatic condition practicing Ndiwa irrigation farming. Lunguza and Kivingo in semi-arid climatic condition practicing Chamazi irrigation farming.

The second stage involved purposefully sampling of key informants from District Commissioner office, Agriculture, Irrigation and Extension Offices at district, ward and village levels, and village leaders and farmers irrigation groups. Criteria for selecting key informants included; their positions, experience and knowledge on traditional irrigation farming system. In the third stage, purposive sampling was used to select a total of 48 members for Focused Group Discussion (FGD). There were 2 FDG per village (adult men and adult women) that make a total of 8 FGDs for the whole study. Each FGD comprised of 6 members. The criteria for selecting members for FGDs included: duration in a particular site, age, sex and familiarity to the traditional irrigation farming practices. Lastly, household heads were also randomly selected from the sampling frame of the list of households in the study villages. This was achieved by assigning number to each household in the sampling frame, the numbers were then thoroughly mixed in a container by shaking. Then without looking and without replacement the researcher select 380 household heads for the study.

Methods of Data Collection

Methods of data collection for this research involved interviews, Focus Group Discussions (FGDs), observations and documentary reviews. FGDs involved discussions with key informants and groups of head of households with the aim of obtaining general views about climate change and its impacts on TIFs. Two FGDs each with 8 members were organized in each village. The first group was for women and the second group for men. This was done mainly due to the fact that men and women perceived differently the impact of climate change (Chukwuemeka and Agoh, 2022). A focus group discussion guide was used as a tool for data collection with this method. Formal household survey using structured questionnaire was conducted to collect data from 380 household heads. Key informants were also interviewed at this stage for technical information.

Secondary data from scientific reports were also used as additional sources of information. This included the meteorological data for 42 years (1981 to 2022) of the study area from Tanzania Meteorological Agency offices (TMA). To avoid missing cases of meteorological data, the study used satellite rainfall data of the study area from Climate Hazard Infrared Rainfall (CHIRPS). CHIRPS is available online at (http://chg.geog.ucsb.edu/data/chirps) (Frunk *et al.,* 2015). Likewise the study used temperature data (maximum and minimum) of the study area from a global Reanalysis ERA5. These data are published by European Centre for Medium-Range Weather Forecast (ECMWF). The reanalysis ERA5 is available online at (http://data.chc.ucsb.edu/experimental/CHIRTS-ERA5/) (Frunk *et al.,* 2015).

Data Analysis

Data was analysed to answer the following research questions; (i) what are the impacts of climate change on TIFs in the study area; (ii) what are the adaptation strategies to the climate change by TIFs farmers in the study area and (iii) how effective and sustainable are the adaptation strategies

Impacts of climate change on TIFs in the study area

The study used non-parametric statistical tests (Mann-Kendal and Sen's slope estimator) to determine the monotonic trend and magnitude of the annual rainfall and temperature trends. Several past studies widely used the Mann Kendal Test to detect monotonic trends of several parameters such as streamflow, temperature and rainfall using time-series datasets (da Silva *et al.,* 2015; Wang *et al.,* 2020). R software version 4.3.2 was used as a tool to compute the temporal Mann-Kendal test and Sen's slope estimator statistics for the rainfall and temperature (Pohlert, 2020). The mathematical formula for The Mann-Kendal test (equations 1 – 3) is as follows (Gou *et al.,* 2020):

$$z = \{\frac{S-1}{Var(s)}\ if\ S < 0\ 0,\quad if\ S = 0\ \frac{S+1}{Var(s)}\ if\ S > 0 \quad (1)$$

Where Z is the transformation of the statistic S:

$$s = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n-1} sign(x_j - x_i) \quad (2)$$

$$sign(x_i - x_i) = \{1,\ x_j - x_i > 1\ 0,\ x_j - x_i = 0\ -1,\ x_j - x_i < 1. \quad (3)$$

Further, the Mann Kendall Test finds a trend in either a positive or negative direction (Marak *et al.,* 2020), and the strength of a trend is estimated using Sen's slope formula (equation 4) (Sen, 1968) as follows:

$$\beta = Median\left[\frac{Y_i - Y_j}{i-j}\right]\ for\ all\ j < 1 \quad (4)$$

Where Y_i and Y_j are data values at time steps i and j, respectively, the test statistic β denotes the median of all slope estimates. The positive value of β indicates an increasing trend, and the negative indicates a decreasing trend.

The coefficient of variation measures (CV) was also used to compute inter-annual variability of the rainfall and temperature in the study area. The higher value of CV indicates a high rainfall variability and vice versa. The study used coefficient of variability because it a single and widely used statistical test for computing temporal variability of rainfall and temperature (Alemu and Bawoke, 2020). The computation of CV was done using the formal 5 below.

$$CV = \frac{\sigma}{\mu} \times 100 \quad (5)$$

Where the σ standard deviation and μ is the mean rainfall for the chosen temporal scale. According to Akemu and Bawoke (2020), CV classifies the degree of rainfall variability into three: low ($CV < 20$), moderate ($20 < CV < 30$), and high ($CV > 30$).

In addition, descriptive statistics such as mean, frequency and percentages of yields for major crops grown in TIFs (Maize, Vegetables, beans and Irish-potatoes) was performed to establish yield trends. Cross tabulation between annual mean rainfall and yield values for major crops was performed to establish the relationship between mean crop yield and rainfall. In addition to the established relations from field data, farmers were asked to explain the historical trends of yields and factors influencing them. Farmers identified the most important factors by pairwise ranking. This was correlated with the relationships established using the mean values

Adaptation strategies to climate change by TIF farmers

The feasibility of adaptation strategies was assessed by considering three actors namely Ndiwa farmers, Chamazi farmers and key informants (representing the government and future generation). Farmers were asked to mention adaptation strategies undertaken for each TIF system and the criteria they use to select the appropriate ones. Selection criteria were weighted to reflect the relative importance to each of the three actors (Tenge *et al.,* 2005; Aguinis, 2004; Varela-Ortega, 2014). The identified adaptation strategies were then evaluated by scoring against each selection criterion. Feasible option was determined by the total weighted score over all criteria as described by Tenge *et al.,* (2005). The option with relatively large score was considered fulfilling most of the criteria and hence more suitable.

Effectiveness and Sustainability of Adaptation Strategies

The effectiveness of adaptation strategies was establish following six stages namely;

i) Adaptation strategies to climate change undertaken by Ndiwa and Chamazi farmers were identified by having questions in the questionnaires related to the measures undertaken by TIFs farmers to reduce the impact of climate change.
ii) Identification of evaluation criteria: The evaluation criteria were chosen based on expert's opinions and reviews of multi-criteria literature on evaluation of adaptation strategies related to water and agriculture (Varela-Ortega, 2014).
iii) Weighting of the evaluation criteria: This was achieved from farmers and key informants in the study villages by providing judgments on the relative importance of each evaluation criterion with regard to what do they want to achieve with the best adaptation option.
iv) The identified adaptation strategies were evaluated in relation to the evaluation criteria. This was achieved by farmers and key informants providing relative importance or weight of each adaptation measure with respect to evaluation criteria. The judgments were based on grading ranging from 1 to 9
v) Farmers responses from the study villages were processed using Analytic Hierarchy Process (AHP) free online software Excel template version 2016.05.04 (http://bpmsg.com), to obtain the rank and priority vectors or weights for criteria and relative importance of each adaptations options.
vi) Then, from the weight results of experts and farmers in study villages, the researcher computed the overall scores for each adaptation option based on the aggregate weight of evaluation criteria. This was achieved by multiplication between weights of adaption options and aggregate priority vector of evaluation criteria.

Results

Evidence of Climate change in the study area

Both secondary data from (TMA), Climate Hazard Infrared Rainfall (CHIRPS), global Reanalysis ERA5 and farmers' experiences on trend of climate parameters (temperature and rainfall) were used to establish evidences of climate change in the study area. Analysis of the trends of major climatic variables of temperature and rainfall for the past 42 years (1981-2022) in the study area were used to establish the scientific evidences of the climate change in the area. Results indicate the following:

The Trends of Rainfall

The results in Table 1 indicate that in the past four decades, mean annual rainfall of the study area show insignificant decreasing trend ($p>0.05$) and moderate inter-annual variability (CV = 22%) (Table 2)

Table 1: Trend analysis of rainfall and temperature

Parameter	Z-value	P-value	Sen's slope
Rainfall	-0.27095	0.786428992	-0.818861412 (mm/year)
Maximum Temperature	1.465159	0.142877578	0.006418207 (0C/year)
Minimum Temperature	5.588535	0.000000023	0.022060833 (0C/year) *

Note: Statistically significant at $\alpha = 0.05$, *significant trends
Source: Analysis of meteorological data from TMA (2022)

In addition, the results in Figure 2 (a) show that in the past four decades, the annual mean rainfall has been decreasing with fluctuating trends. However, extremely high rainfall events was recorded in 1997, 2006, 2019 and 2020 with annual rainfall of 1155.51mm, 1222.95mm, 1235.27mm and 1331.36mm respectively.

Table 2: Coefficient of Variability of rainfall and temperature

Parameter	CV (%)
Rainfall	22
Maximum Temperature	1.3
Minimum Temperature	1.6

Source: Analysis of meteorological data from TMA (2022)

The Trends of Temperature

The results in Table 1 revealed that annual mean maximum temperature of the study area for the past 42 years show insignificant increasing trend ($p>0.05$) and low inter-annual variability (CV=1.3%) (Table 2). Moreover the results in Table 1 revealed that annual mean minimum temperature show significant increasing trend ($p<0.05$) and low inter-annual variability (CV=1.6%) (Table 2)

In addition, the results in figure 2 (b) show that annual mean minimum temperature of the study area has been increasing with fluctuation trends over time, the lowest value being 20.17°C in 1992 and the highest value being 21.42°C in 2019.

Likewise, the results in figure 2 (c) revealed that annual mean maximum temperature has been increasing with fluctuation trends over time, the lowest value being 20.19°C in 2015 and the highest value being 30.5°C in 2003.

Farmer's perception on climate change in the study area

Results on evidences of climate change based on farmer's experiences are presented in Table 3.The results show that majority of farmers mentioned to have experienced a decrease in rainfall amount (89.7%), increase in temperature (81.3%) and increase in wind speed (70%). Few farmers mentioned to have experienced a decrease in temperature (5.3%) and increase in rainfall (4.1%). These are farmers with relatively low level of awareness on the changes of temperature and rainfall respectively.

The Impact of Climate Change on Crop Yields in TIFs

The results in Figure 3 show that the yields of the major crops grown in TIFs have been fluctuating with annual rainfall fluctuations. The highest yields of maize and beans were 30504

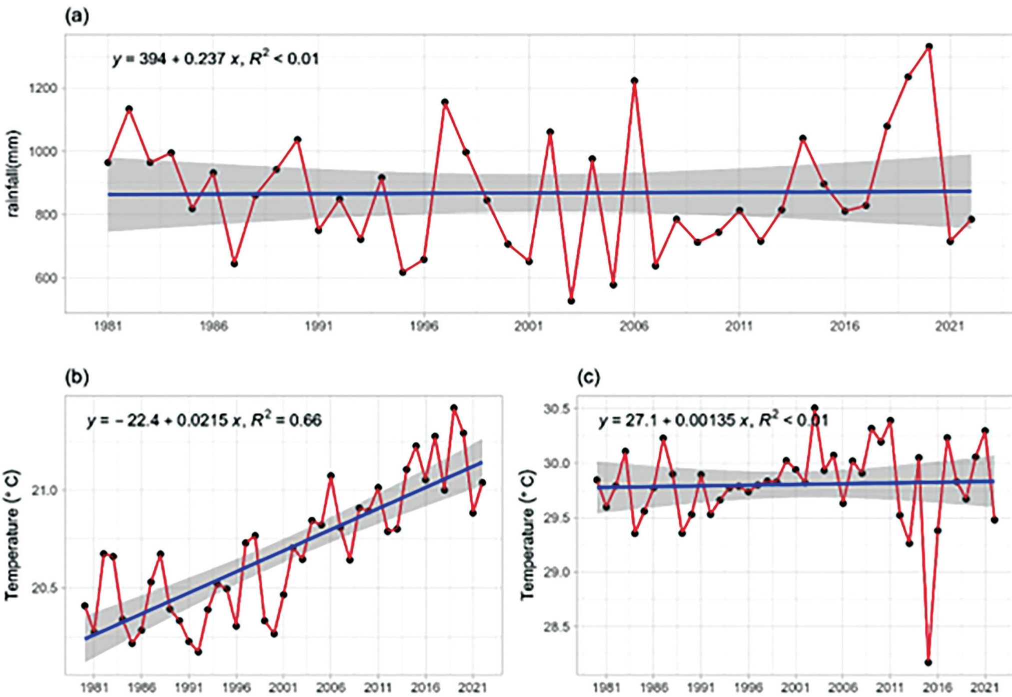

Figure 2: Annual mean rainfall and temperature trends in the study area for 42 years (1981-2022)

Note: *(a) graph showing mean annual rainfal trends; (b) graph showing mean minimum annual temperature trends and (c) graph showing mean maximum annual temperature trends of the study area*

Source: Analysis of Field Data from TMA (2022)

Table 3: Farmers Perception on the Trend of Climate Variables (1985-2014)

Variable	Trend	Respondents (%)				
		Shashui (n=173)	Nkukai (n= 75)	Lunguza (n= 57)	Kivingo (n= 75)	Average
Temperature	Increasing	76.2	78.8	86.2	83.8	81.3
	The same	17.5	17.5	8.8	10.0	13.4
	Decreasing	6.2	3.8	5.0	6.2	5.3
Rainfall	Decreasing	83.8	93.8	91.2	90.0	89.7
	The same	10.0	3.8	6.2	5.0	6.2
	Increasing	6.2	2.5	2.5	5.0	4.1
Wind speed	Increasing	76.2	65.0	75.0	63..8	70
	The same	20.0	28.8	13.8	30.0	23.1
	Decreasing	3.8	6.2	11.2	6.2	6.9

Source: Analysis of Field Data from TMA (2022)

and 48486 tons respectively corresponding with the highest rainfall of 1118mm for 1994/1995 growing season. The lowest yields of maize and beans were 486 and 3562 tons respectively corresponding with the lowest amount of rainfall of 596.8mm in 2012/2013 growing season. Similar trend is observed for vegetables (Cabbage, Carrot, Hot chili peppers *"Capsicum Annum*"), the highest yield was 51346 tons per hectare corresponding to 1146.5mm of rainfall in 2002 while the lowest crop yield was 9656 tons per hectare corresponding to low amount of rainfall of 596.8mm in 2012.

Farmer's experience on crop yields

Farmers identified and ranked a total of 12 factors as the major causes of crop decline in traditional irrigation farming system. The ranking was based on the impacts on crop yield and frequency of occurrence for each factor.

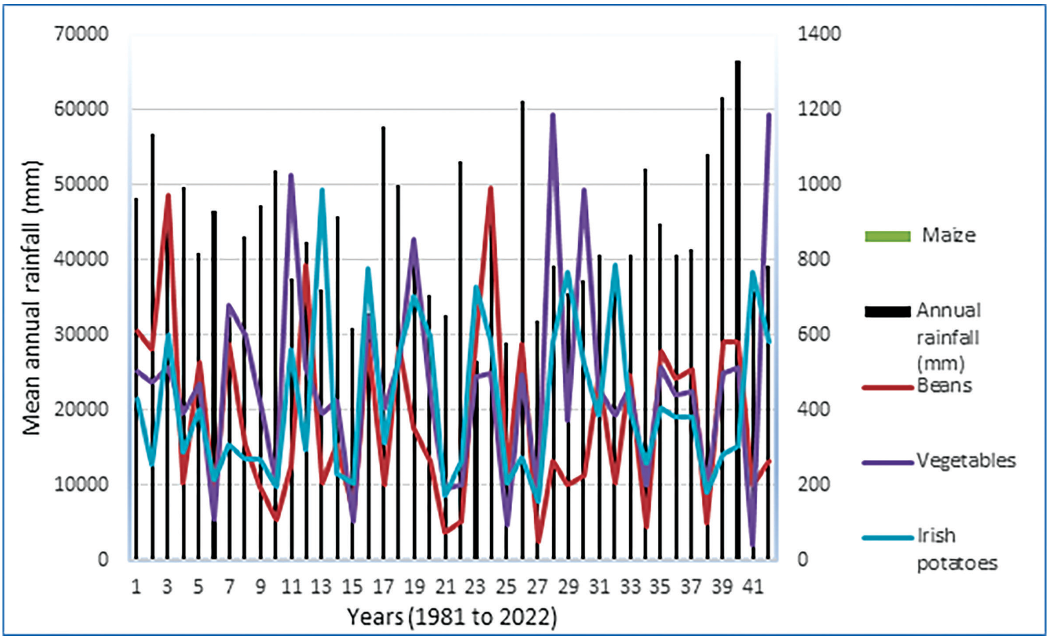

Figure 3: Trends of Crops Yield for major Crops in Ndiwa and Chamazi Irrigation
Source: Analysed Data from District Agriculture, Irrigation and Cooperative Officer (DAICO) and TMA offices, 2022

Results in Table 4 show that major three factors affecting crop yield in both Ndiwa and Chamazi traditional irrigation practices are related to climate change. They include; unreliable and decrease of rainfall, high temperature, outbreak of crop diseases and outbreak of pests and insects.

Adaptation Strategies to Climate Change by Ndiwa and Chamazi Farmers

Results of adaptation strategies to climate change by farmers are presented in Table 5. Results indicate that farmer's strategies are specific to each climate change impact, particularly decrease and unreliable rainfall, pests and diseases. Other adaptation strategies were specific to Ndiwa or Chamazi farming system.

Table 4: Farmer's ranking of the factors effecting crop yields in TIFs

Factors affecting crop yields	Farmer's ranking	
	Ndiwa farmers rank(n)	Chamazi farmers rank(n)
Unreliable & decrease of rain	1(233)	1(126)
Outbreak of crop diseases	2(217)	3(123)
High temperature	4(176)	2(125)
Outbreak of pests and insects	3(181)	4(110)
Poor irrigation infrastructures	6(161)	5(103)
Limited extension services	5(173)	7(97)
Poor access to Agro inputs	7(157)	6(101)
Unreliable crop markets	8(148)	8(88)
Inadequate capital	9(131)	10(53)
Lack of man power	10(72)	9(61)
High wind speed	11(31)	11(27)
Poor storage facilities after harvesting	12(22)	12(21)

*1 = has great impacts and occurs frequently, 12 = Less impact and rarely occurrence *Ndiwa (N) = 248; Chamazi (N) = 132*

Source: Field Data (2022)

Table 5: Adaptation Strategies by Traditional Irrigation Farmers

Impact	Strategies	Farmers (%)	
		Ndiwa n(%)	Chamazi n(%)
Unreliable rainfall	Cultivating closer to water sources	233(93.8)	88(66.4)
	Planting early	0(0)	114(86.9)
	Irrigation schedule	231(93.5)	0(0)
	Improving irrigation canals	173(69.9)	0(0)
	Crop diversification	132(53.4)	95(72.6)
	Construction of storage ponds (Nkunisa)	206(83.1)	0(0)
	Digging of shallow wells	3(1.3)	77(58.7)
	Use of water pump	21(8.6)	0(0)
Pests and diseases	Application of pesticides	195(78.8)	69(52.6)
	Crop rotation	77(30.9)	85(64.7)

*Ndiwa (N) =248; Chamazi (N) =132

Source: Field data 2022

Feasibility of Climate Change Adaptation Measures

Three major actors were considered in evaluation of the feasibility of the adaptation strategies; Ndiwa farmers, Chamazi farmers and the government agency (Key informants). Relative importance attached by each group of actors to each criterion (yield increase, financial efficiency and environmental protection) was established by pairwise ranking by farmers and key informants. The relative importance (weight) of each criterion by each actor (Table 6)

Table 6: Relative importance (Weight) of evaluation criteria

Criteria	Objective	Weight (%)		
		Ndiwa farmers	Chamazi farmers	Experts (Key informants)
i) Financial				
• Low costs	Minimize costs	36	38	8.6
• Improve quality of life	Provide other benefits	16	13	3.2
• Income	Increase income	15	14	5.9
ii) Crop yields	Increase crop yields	29	28	13.8
iii) Environment				
• Degradation	Reduce environmental degradation	02	04	41.8
• Rules and regulations	Comply with rules and regulations	01	03	26.7

Source: Field data 2022

Effectiveness of Adaptation Measures Based on Evaluation Criteria

Results on the effects of each adaption measure on the evaluation criteria are presented in Table 7. Results show crop diversification is a very good adaptation strategies in all evaluation criteria.

Effectiveness of adaption strategies based on key actors and their needs

Results on the suitability of adaptation measures to each group of actors are presented in Table 8. The results show that crop diversification is the most preferred adaptation measure for both experts and traditional irrigation farmers.

Discussion

Evidence of Climate

The results on variations of minimum and maximum temperature in the study area are in agreement with the projection by previous studies that, annual temperature will increase between 2.1°C in the north eastern part to 4°C in the central and western parts of Tanzania by 2100 (Mbilinyi *et al.,* 2013). The results also support observations by Mashingo, (2010) and Mbilinyi *et al.,* 2013) that temperature has been increasing. The observed increase in temperature is likely to affect the amount and pattern of rainfall in the study area because of its effects on evaporation and evapotranspiration. High temperature is also likely to increase incidences of crop pests and diseases because of its influence on chemical reactions. The results in Figure 3 tend to suggest that in the study area rainfall variability is a major challenge in traditional irrigation farming than the long term climate change effects.

The results are in agreement with the augment of Kangazi *et al.,* (2021) that there are some assurance of farmers to adapt and accept various local and national initiatives for reducing the impacts of climate change in their farming activities as long as their perceptions about climate change are consistent with

Table 7: Effectiveness of Adaption strategies against evaluation criteria

Criteria	Effectiveness (Weighted Mean Score)							
	CW	CD	EP	SW	IS	IC	WP	AP
Low cost	6.0	7.6	3.6	3.6	2.9	0.8	1.1	2.0
Crop yield	2.6	7.5	3.2	1.4	1.6	2.4	0.6	3.0
Quality of life	1.6	2.7	0.7	0.9	0.7	1.5	0.4	1.3
Farm income	1.5	3.3	0.9	0.7	0.8	1.5	0.5	1.5
Protection of environment	0.6	5.3	3.4	0.8	3.2	2.5	0.7	1.0
Compliance to regulations	0.4	2.3	2.3	0.5	2.4	1.6	0.4	0.7
Total	**12.7**	**28.7**	**14.1**	**7.9**	**11.6**	**10.4**	**3.6**	**9.5**

CW = Cultivation Closer to Water Sources; CD = Crop Diversification; EP = Early Planting; SW =Shallow Wells; IS = Irrigation Schedule; IC = Irrigation Canal; WP = Water Pumps; AP = Application of Pesticides
Source: Field data 2022

reality. Thus, a pro-adaptation response to their perceptions would be appropriate and helpful to government efforts to avoid potential agriculture losses.

Impact of climate change on crop yields in TIFs

Different crops and farming systems are impacted differently by change in climatic parameter such as rainfall and temperature (Godde *et al.,* 2021). The results provide clear indication that in the study area beans and Maize are highly affected while Irish-potatoes are least affected with changes in climatic parameters.

Studies indicated that there are also other factor apart from climatic parameters that in one way or another affect crop yields in a given farming system such as poor access to extension services, unreliable market, inadequate capital, low manpower and poor storage facilities (Jambo, 2021). These factors although not directly linked to yield they discourage use of improved inputs and timely completion of farming activities. According to Kihila (2023) any efforts to improve crop yield in farming system should be integrative addressing both climatic and non-climatic factors.

Effectiveness and feasible Adaptation Measures Based on Evaluation Criteria

Studies indicated that in most cases in the choice of adaptation strategy, farmers usually attach relatively large importance to costs, crop yields and income and little importance to environmental related benefits (Komba *et al.,* 2018). Unlike farmers, government agencies attach much importance to environment and compliance to regulations. Less importance attached by farmers to environment is reflected by practices observed in this study, such as

Table 8: Suitability of adaptation measures for Ndiwa, Chamazi and Government Experts

Strategy	Ndiwa		Chamazi		Expert	
	Score	Rank	score	Rank	Score	Rank
Cultivating closer to water sources (CW)	19.8	2	15.5	3	2.9	8
Crop diversification (CD)	28.4	1	29.5	1	28.2	1
Early Planting (EP)	5.3	7	17.7	2	19.4	2
Shallow Wells (SW)	9.6	5	10.1	5	3.9	6
Irrigation Schedule (IS)	9	6	6.8	7	19	3
Irrigation Canal (IC)	15.8	3	13.9	4	15.4	4
Water Pumps (WP)	3.7	8	3.5	8	3.6	7
Application of Pesticides (AP)	12.8	4	7.4	6	8.3	5

Source: Field data 2022

cultivation very close to water sources and on steep slopes without any conservation measures. These, threaten the sustainability of these adaptation strategies.

These results concur with Mzyece and Ng'ombe (2020) on adaptation to climate change in the Canadian agricultural sector where crop diversification was ranked highest among farmers and government officials. Other similar studies indicated that among the common adaptation methods in agriculture in East Africa include crop diversification, use of new crop varieties, mixed crop and livestock farming systems (Trisos *et al.,* 2022).

The general observation on the results show that crop diversification, early planting of crops, improvement of irrigation canals and the use of pesticides are the most feasible adaptation strategies for both farmers and agricultural experts. However, adaptive capacity of traditional irrigation farmers in the study area are is low due to limited access to information, credits and low education level.

Conclusion and Recommendation

Based on the results from this study we conclude;

Climate change is real happening and is manifested by the increase in temperature and fluctuation of rainfall with decreasing trend. This climate change has affected traditional irrigation systems by reducing crop yields.

Climate change affects different crops differently, as indicated by 51%, 40.4% and 12.1% decrease of maize, beans and Irish-potatoes respectively.

Temperature increase due to climate change has increased the incidences of crop pests and diseases compounding the low crop yield due to low rainfall.

Traditional irrigation farmers have several adaptation strategies to climate change; they include cultivating near water sources, crop diversification, digging of shallow wells and use of pesticides. However, criteria used to select measures to implement adaptation strategies, attached relatively low importance to environment protection such that some measures are not feasible as they are detrimental to environment. The feasible adaptation strategies that fulfil both farmers and expert requirements are crop diversification, early planting improvement of irrigation infrastructures and application of pesticides.

Based on the findings from this study, the researcher recommends the following:

- Farmers engaged in Ndiwa and Chamazi irrigation systems should be encouraged to form farmers based organizations. Using farmers' irrigation groups, Ndiwa and Chamazi farmers will be able to improve access to water and extension services, provision of irrigation infrastructures and access to reliable crop market. All these will improve farmers' ability to reduce the impact of climate change.
- Financial capital plays a great role in reducing the effects of climate change in Ndiwa and Chamazi irrigation practices. It enables farmers to have access to various technological options for adaptation to climate change. The local and central government authorities should create a good enabling environment for the farmers to have access and control over financial capital.
- Agricultural extension support is required to support traditional irrigation farmers in terms of design to improve irrigation infrastructure, establishment of irrigation water requirements and irrigation schedules, appropriate crop rotation and their agronomic practices.

Acknowledgements

Authors are grateful to the farmers, agricultural irrigation and extension officers as well as local government leaders for their valuable support during this study

References

Aguinis, H. (2004), Regression Analysis for Categorical Moderators, New York: Guilford Press.

Alemu, M.M. & Bawoke, G.T. (2020). Analysis of spatial variability and temporal trends of rainfall in Amhara region, Ethiopia. *Journal of water and climate change.* 11(4)

Baddoo, R.N.N and Masao, C.A (2016), Factors Influencing Spatial and Temperal Trends in

Lushoto's Agro biodiversity, Agriculture and Environmental Management, 5(3), pp 065-074 [http:www.apexjournal.org] site visited on 15/8/2016

Busetto, L., Wick, W., & Gumbinger, C. (2020). How to use and assess qualitative research methods. Neurological Research and practice, 2, 1-10.

Chukwuemeka, O.S., & Agoh, E.C. (2022). Perceptions of Climate Change and Adaptation Strategies among Small-holder Cassava Farmers in Rural Communities of Bende LGA, Abia State, Nigeria. *Nigeria Agricultural Journal,* 53(3), 92-98.

Coffinet, S., Huguet, A., Bergonzini, L., Pedentchouk, N., Williamson, D., Anquetil, C., & Derenne, S. (2018). Impact of climate change on the ecology of the Kyambangunguru crater marsh in southwestern Tanzania during the Late Holocene. Quaternary Science Reviews, 196, 100-117.

da Silva, R.M., Santos, C.A.G., Moreira, M., Corte-Real, J., Silva, V.C.L., & Medeiros, I.C. (2015). Rainfall and river flow trends using Mann–Kendall and Sen's slope estimator statistical tests in the Cobres River basin. Natural Hazards, 77(2), 1205–1221. https://doi.org/10.1007/s11069-015-1644-7

Fazliev, J., Khaitova, I., Atamurodov, B., Rustamova, K., Ravshanov, U., & Sharipova, M. (2019). Efficiency of applying the water-saving irrigation technologies in irrigated farming. Интернаука, 21(103 часть 3), 35.

Funk, C., Verdin, A., Michaelsen, J., Peterson, P., Pedreros, D., & Husak, G. (2015). A global satellite-assisted precipitation climatology. Earth System Science Data, 7(2), 275–287. https://doi.org/10.5194/essd-7-275-2015

Gebru, G.W., Ichoku, H.E., & Phil-Eze, P. O. (2020). Determinants of smallholder farmers' adoption of adaptation strategies to climate change in Eastern Tigray National Regional State of Ethiopia. Heliyon, 6(7).

Gibson, E.W. (2018). Leadership in statistics: increasing our value and visibility. The American Statistician.

Godde, C.M., Mason-D'Croz, D., Mayberry, D. E., Thornton, P.K., & Herrero, M. (2021). Impacts of climate change on the livestock food supply chain; a review of the evidence. Global food security, 28, 100488.

Gou, J., Miao, C., & Han, J. (2020). Spatiotemporal changes in temperature and precipitation over the Songhua River Basin between 1961 and 2014. Global Ecology and Conservation, 24, e01261. https://doi.org/10.1016/j.gecco.2020.e01261

Guodaar, L., Bardsley, D.K., & Suh, J. (2021). Integrating local perceptions with scientific evidence to understand climate change variability in northern Ghana: A mixed-methods approach. Applied Geography, 130, 102440.

Intergovernmental Panel on Climate Change (IPCC), 2022: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi: 10.1017/9781009325844

Jambo, Y., Alemu, A., & Tasew, W. (2021). Impact of small-scale irrigation on household food security: evidence from Ethiopia. Agriculture & Food Security, 10(1), 1-16.

Jha, N. (2023). Determinants of Climate Change Adaptation Strategies among Smallholder Farmers in Nine African Mountains (Master's thesis, Norwegian University of Life Sciences).

Kaganzi, K.R., Cuni-Sanchez, A., Mcharazo, F., Martin, E.H., Marchant, R.A., & Thorn, J.P. (2021). Local perceptions of climate change and adaptation responses from two mountain regions in Tanzania. Land, 10(10), 999.

Kihila, J.M. (2018). Indigenous coping and adaptation strategies to climate change of local communities in Tanzania: a review. Climate and Development, 10(5), 406-416.

Komba, C., & Muchapondwa, E. (2018). Adaptation to climate change by smallholder farmers in Tanzania. Agricultural adaptation to climate change in Africa, 129(168), 129-168.

Leal Filho, W., Totin, E., Franke, J.A., Andrew, S.M., Abubakar, I.R., Azadi, H., & Global Adaptation Mapping Initiative Team. (2022). Understanding responses to climate-related water scarcity in Africa. Science of the Total Environment, 806, 150420.

Lyamchai, C, Yanda, P., Sayula, G., Kristjanson, P. (2011), "Summary of Baseline Household Survey Results: Lushoto, Tanzania", CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Copenhagen, Denmark. Available online at: www.ccafs.cgiar.org.

Marak, J.D.K., Sarma, A.K., & Bhattacharjya, R.K. (2020). Innovative trend analysis of spatial and temporal rainfall variations in Umiam and Umtru watersheds in Meghalaya, India. Theoretical and Applied Climatology, 142(3), 1397–1412. https://doi.org/10.1007/s00704-020-03383-1

Mashingo, M.S.H. (2010), Vulnerability Assessment on Pastoral Livestock and Pasture Development to the Extreme Climatic Events in Tanzania. Paper presented under the study on economics of climate change in Tanzania Phase 3, at the Stakeholder Inception Round Table Meeting held at the Peacock Hotel, Dar es Salaam, Tanzania, 26 March 2010.

Mbilinyi, A., Ole Saibul, G. and Kazi, V. (2013), "Impact of Climate Change to Small Scale Farmers: Voices of Farmers in Village Communities in Tanzania", Discussion Paper No 47, Economic and Social Research Foundation, Dar es Salaam, Tanzania. 44pp.

Mekonen, A.A., & Berlie, A.B. (2021). Rural households' livelihood vulnerability to climate variability and extremes: A livelihood zone-based approach in the Northeastern Highlands of Ethiopia. Ecological Processes, 10, 1-23.

Mzyece, A., & Ng'ombe, J.N. (2020). Does crop diversification involve a trade-off between technical efficiency and income stability for rural farmers? Evidence from Zambia. Agronomy, 10(12), 1875.

Ngcamu, B.S. (2023). Climate change effects on vulnerable populations in the Global South: a systematic review. Natural Hazards, 1-15.

Opere .J.E.A, F. Mutua and J.K. Ng'ang'a, 2017. Assessing the Vulnerability of the Residents of Rachuonyo North Sub-County to Climate Variability and Climate Change. J. clim. chang. Sustain. Vol 1, issue 2, pp. 51-57. https://doi.org/10.20987/jccs.2.08.2017

Pardoe, J., Conway, D., Namaganda, E., Vincent, K., Dougill, A.J., & Kashaigili, J.J. (2018). Climate change and the water–energy–food nexus: insights from policy

Pohlert, T. (2020). Non-Parametric Trend Tests and Change-Point Detection. CC BY ND 4,1-18.

Said, M., Hyandye, C., Mjemah, I.C., Komakech, H.C., & Munishi, L.K. (2021). Evaluation and prediction of the impacts of land cover changes on hydrological processes in data constrained Southern slopes of Kilimanjaro, Tanzania. Earth, 2(2), 225-247.

Sen, P.K. (1968). Estimates of the regression coefficient based on Kendall's tau. *Journal of American Statistical Association.* 63(324), 1379-1389

Tenge, A, Graaff, J and Hella, J, 2005. Financial efficiency of major soil and water conservation measures in West Usambara highlands, Tanzania VoL - 25 DO - 10.1016/j.apgeog.2005.08.003

Trisos, C.H., I.O. Adelekan, E. Totin, A. Ayanlade, J. Efitre, A. Gemeda, K. Kalaba, C. Lennard, C. Masao, Y. Mgaya, G. Ngaruiya, D. Olago, N.P. Simpson, and S. Zakieldeen, 2022: Africa. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1285–1455, doi:10.1017/9781009325844.01

Van der Plas, G.W., Rucina, S.M., Hemp, A., Marchant, R.A., Hooghiemstra, H., Schüler, L., & Verschuren, D. (2021). Climate-human-landscape interaction in the eastern foothills of Mt. Kilimanjaro (equatorial East Africa) during the last two millennia. The Holocene, 31(4), 556-569.

Varela-Ortega, C., Irene, B.G., Paloma, E., Sukaina, B., Stefan, F and Thomas, E.D. (2014), "How can irrigate to Climate Change Insights from the Guadiana Basin in Spain", Department of Agricultural Economics, Statistics and Management, Universidad Politecnica de Madrid, Av. Madrid Spain .

Wang, F., Shao, W., Yu, H., Kan, G., He, X., Zhang, D., Ren, M., & Wang, G. (2020). Re-evaluation of the Power of the Mann-Kendall Test for Detecting Monotonic Trends in Hydrometeorological Time Series. Frontiers in Earth Science, 8, 14. https://doi.org/10.3389/feart.2020.00014

Weerahewa, J., Timsina, J., Wickramasinghe, C., Mimasha, S., Dayananda, D., & Puspakumara, G. (2023). Ancient irrigation systems in Asia and Africa: Typologies, degradation and ecosystem services. Agricultural Systems, 205, 103580.

Yamane, T. (1967), Statistics: An Introductory Analysis (2nd Edition), Harper and Ran, New York.