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Influence of Perceived Climate Change-Related Factors on Sustained Adoption of Climate-Smart Agricultural Technologies in the West Usambara Mountains, Tanzania

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Abstract: *In the West Usambara Mountains Tanzania, crop production is highly challenged by climate change and variability due to farmers' dependence on rainfall and the use of poor technologies. Between 2011 and 2019, the Climate Change Agriculture and Food Security (CCAFS) was implemented to promote the adoption of Climate-Smart Agricultural (CSA) technologies in the West Usambara Mountains. Understanding farmers' perceptions of climate change can enhance participation and adoption of sustainability of CSA technologies when the project is phased out. This study assessed the influence of perceived climate change-related factors on the sustained adoption of CSA technologies at the end of the CCAFs project. A cross-sectional research design was conducted by involving 124 households selected by simple random sampling from 140 farming households which received CSA interventions. Primary data were collected through household questionnaire survey, key informant interviews and focus group discussions while secondary data was obtained from the Tanzania Meteorological Authority. Data analysis employed STATA software version 17 to run the Multivariate Probit Regression model for quantitative data while content analysis was employed for qualitative data. Results show that a perceived increase in pests and diseases had a positive significant influence on the sustained adoption of tree planting and weather information. Increased floods had a positive significant influence on the sustained adoption of terraces and tree planting. Unpredictable rainfall had a positive significant influence on the sustained adoption of organic fertilizers and weather information. Increased droughts had a positive significant influence on the sustained adoption of organic fertilizers and improved seeds. The increased temperature had a positive significant influence on the sustained adoption of weather information. It is concluded that farmers' perceptions of climate change are important to enhance the sustainable adoption of CSA technologies. It is recommended that policymakers and other stakeholders incorporate farmers' perceptions of climate change when reviewing post-project interventions and designing new projects to enhance participation, sustainability of adoption of CSA technologies and improve crop productivity.*

Keywords: *perceptions, farmers, climate change, climate-smart agricultural technology, sustained adoption*

1. Background Information

Sustainable agricultural intensification under climate change is essential for worldwide economic development, particularly in developing countries like Tanzania where smallholder farmers are highly challenged by climate change-related adversities (URT, 2015; Ahmed *et al*., 2022). Increase in temperatures and unpredictable rainfall accelerate more frequent extreme weather events such as floods, droughts and outbreaks of pests and diseases (Nahar *et al*., 2018; Yadav *et al*., 2019; Assefa *et al*., 2021). Adverse impacts of climate change and variability are such as reduced crop productivity, food insecurity, and depletion of natural resources such as forests and rivers. Severe weather conditions such as droughts and floods are associated with agricultural risks and disasters which increase uncertainties among farmers (Ayal and Filho, 2017).

In Africa, farmers' perspectives of climate change are usually different from the scientific community (Nguyen *et al*., 2019). While scientists deal with climate change in distinct ways using meteorological data, most farmers rely on their social values, local community interactions, constructs of climate change knowledge and their understanding of climate change adaptation (Nguyen *et al*., 2019). Hence, understanding farmers' perceptions of agricultural challenges posed by climate change is vital in shaping their decisions and abilities to adapt to climate change using a limited scientific basis (Hundera *et al*., 2019). In agriculture, perceived climate risks are associated with uncertainties led by increased temperature, unpredictable rainfall, frequent flooding, prolonged drought and outbreaks of pests and diseases (Lebel *et al*., 2015; Schattman *et al*., 2016). Apart from decreasing crop production, in some areas, unfavourable climatic conditions have been disrupting food supply networks, increasing food prices and lowering food quality (Edenhofer *et al*., 2011; Raimondo *et al*., 2021). Farmers' perceptions of climate change-related adversities may influence the adoption of Climate-Smart Agricultural technologies depending on whether a new farm technology is risk-increasing or risk-decreasing (Pilarova *et al*., 2018; Talanow *et al.*, 2021).

In the West Usambara Mountains Tanzania, climate change and weather extremes including frequent floods, droughts, increased temperature, unpredictable rainfall and outbreaks of pests and diseases have been contributing to reducing crop yields especially maize, beans, Irish potatoes and vegetables which are mostly grown on hillslopes and in valley bottoms (Lyamchai *et al*., 2011; Rukanda, 2014). Climate change-related challenges constraining crop production can effectively be addressed through farming transformation to Climate-Smart Agriculture (CSA) (FAO, 2013). Climate-smart agriculture is an approach introduced by the Food and Agriculture Organization of the United Nations in 2010 that aims at achieving three pillars; increasing agricultural productivity and income; adaptation and resilience building; and reducing greenhouse gas emissions where possible (FAO, 2013). The CSA can concurrently address challenges constraining three components of sustainable development including economic, social and environmental related challenges posed by climate change. To enable farmers to adapt to climate change in the West Usambara Mountains, the Climate Change Agriculture and Food Security (CCAFS) project was implemented from 2011 to 2019. This project was implemented jointly by the University of Leeds based in the United Kingdom and the Consultative Group for International Agricultural Research (CGIAR) Program based in Copenhagen Denmark in collaboration with Selian Agricultural Research Institute and Lushoto District Council. The project disseminated and promoted the use of CSA technologies including terraces, tree planting, organic fertilizers (compost and animal manure), improved seeds resistant to pests and diseases and tolerant to droughts and promoted the use of weather information.

Adoption and continuous use of CSA technologies especially when used in combination or complementary can combat different challenges related to climate change and land degradation in sloping areas such as pest infestations, low soil fertility and moisture stress (Teklewold *et al*., 2016; Mthethwa *et al*., 2022). For instance, a combination of improved seeds, terraces and organic manure can reduce soil erosion, improve water infiltration by reducing water runoff downslope and increase crop productivity (Kosmowski, 2015; Dhankher and Foyer, 2018). While terraces reduce water runoff down the slope increase water infiltration, compost and animal manure maintain soil structure, retain soil moisture after rain season and improve soil fertility (Saab, 2016; Dhankher and Foyer, 2018). Both Indigenous and scientific weather forecasting inform farmers about weather conditions including the onset and termination of rainfall in order they can prepare their farms on time, select appropriate seeds and harvest crops on time (Muema, 2018; Elia, 2018).

Empirical studies revealed that adoption of promoted CSA technologies is normally higher during the implementation of agricultural projects (Ogada *et al*., 2020; Murwanashyaka *et al*., 2021), but adoption declines after phasing out (Odame *et al*., 2011; McNiven *et al.*, 2016). One of the goals of a diffusion project or program is to achieve a high rate of adoption and continuous use of CSA technologies (Rogers, 2003). Sustained adoption is a continuous use of CSA technology after phasing out the agricultural project (Hulland *et al.* 2015; Wang *et al.*, 2021). Moreover, previous studies (such as Hundera *et al*., 2019; Talanow *et al*., 2021; Ahmad *et al*., 2022; and Dialo *et al*., 2019) conducted in different locations beyond the study area reported that farmers' perceptions of climate change such as increased temperature, increased droughts, increased floods, increased droughts, unpredictable rainfall and increased outbreaks of pests and diseases had significant influence on sustained use of CSA technologies. Shuaibu *et al.* (2014) assert that factors influencing the adoption of climate change adaptation measures are area-specific due to different landscapes, social constructs, attitudes and economic situations of individuals. In the West Usambara Mountains, few adoption studies have already been conducted, especially studies that assessed socio-economic determinants of adoption of CSA technologies in early and mid-implementation phases of the CCAFS project (Nyasimi *et al.*, 2017; Ogada *et al*., 2020). There is a lack of clear understanding about the influence of farmers' perceptions of climate change on sustained adoption of CSA technologies after phasing out of the CCAFS project. Therefore, this study assessed the influence of perceived climate-related factors on the sustained adoption of promoted CSA technologies after the end of the CCAFS project in the West Usambara Mountains. Specifically, the study assessed farmers' perceptions of changes in climatic conditions; it verified the reflection of farmers' perceptions of climatic changes with meteorological data; and it determined the influence of perceived climate-related factors on the sustained adoption of CSA technologies.

Understanding farmers' perceived climate-related factors may inform decision-makers and agricultural extension workers in combating climate risks of agriculture in the study area by incorporating farmers' perceptions to promote sustained adoption of CSA technologies. This study may contribute to achieving implementation of Tanzania's National Agricultural Policy 2013, National Climate Change Response Strategy 2021-2026 and Tanzania's Climate-Smart Agriculture Guideline 2017. The study is in line with Sustainable Development Goals (SDGs), especially SDG number 1 (End poverty in all forms), SDG number 2 (End hunger, achieve food security and improved nutrition, and promote sustainable agriculture) and SDG number 13 (Take action to combat climate change and its impacts).

2.0 Theoretical Framework

Theoretically, the influence of climate-related factors on the sustained adoption of CSA technologies was explained by The Diffusion of Innovation Theory initially introduced by Everett Rogers in 1962. According to Rogers (2003), the two terms innovation and technology are synonymous, which refer to an idea, practice or item which is perceived to be

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new by an individual or unit of adoption. Rogers (2003) defined adoption as the full use of technology as the best course of action available while rejection (non-adoption) is a decision not to adopt technology. Diffusion of Innovation Theory explained five critical stages of the "innovation-decision process" as 1) knowledge, 2) persuasion, 3) decision, 4) implementation and 5) confirmation (Roger, 2003). In the confirmation stage, an individual decides to continue or discontinue the adoption of a choice of technology such as CSA technology after repeated times of trial and evaluation.

The adoption of CSA technology should be self-sustained among members of a social system after confirmation of its relative advantages. The concept of sustained adoption refers to the continued use of CSA technology over time after the end of a diffusion project or program (Rogers, 2003; Wang *et al.*, 2019). In this theory, Napier *et al.* (1984) argue that perceptions of the problem such as climate change risks and disasters and awareness of the potential solution available are a subset of factors influencing adoption. Hence, farmers' perceptions of climate-related factors can influence the adoption and sustained use of particular technologies. To this study, climate-related factors such as increases in temperature, floods, unpredictable rains, drought and outbreaks of pests and diseases can influence sustained adoption of CSA technologies after phasing out the CCAFS project in the West Usambara Mountains since they are contributing to the reduction of crop productivity.

This theory is criticized since it assumes a unidirectional flow of information from experts such as extension officers and researchers to individuals such as farmers. The one-way flow of information discourages the effective participation of farmers in planning and decision-making. Despite some criticism, this theory is useful to this study because it provides a definition of sustained adoption and explains the individual possible influence of perceptions of the problem on adoption and sustained use of technology. Hence, this study adopted the definition of sustained adoption and the concept of individual perceptions of climate change which is related to sustained adoption which was explained by the Diffusion of Innovation Theory.

3.0 Methodology

3.1 Description of the study area

This study was conducted in Lushoto District which is geographically located in the West Usambara Mountains between latitudes $4^{0}05'$ and $5^{0}00'$ and between longitudes $38^{0}05'$ and $38^{0}40'$. The study area was found in altitudes between 600m and 2300m above mean sea level. The CCAFS project promoted the use of CSA technologies in the Lushoto District from 2011 to 2019 to enable farmers to adapt to climate change to improve crop productivity. The main crops grown in the study area include maize, beans, Irish potatoes and varieties of fruits and vegetables which are sources of food and income to the households.

3.2 Research design and sample selection

A cross-sectional research design was employed in this study which allowed data to be collected at a single point in time. The study design incorporated both qualitative and quantitative approaches to enhance the accuracy and trustworthiness of the data collected. It also enables researchers to describe results and empirically establish relationships between variables (Bryman, 2012). The survey population comprised 140 farming households which received CSA interventions during the implementation of the CCAFS project. Sample estimation was based on a hypergeometric formula which is recommended for the determination of a statistically realistic study sample from a small population (Busbee, 2017). The following is a calculation of sample size using a hypergeometric formula:

$$n = \frac{Z^2 Npq}{e^2(N-1) + Z^2 pq}$$

Then,

$$n = \frac{1.96^2 \text{ x } 140 \text{ x } 0.5 \text{ x } 0.5}{0.03^2(140-1) + (1.96^2 \text{x } 0.5 \text{ x } 0.5)} = 124$$

Whereby; n = a sample size; N = survey population; p and q are population proportions (If they are not known, each set at 0.5); Z = is the value specifies the level of confidence at 95% which is set at 1.96; and e sets the accuracy of the sample proportions of plus or minus 3% (or 0.03). Hence, the sample size calculated was 124 farming households. Simple random sampling was used to select 124 households from 140 farming households which received interventions from the CCAFS project. The use of group-received interventions (treatment group) in studying the adoption of innovation helps to control sampling bias which occurs when individuals not engaged in a project or program are included (Diagne and Demont, 2007; Franklin, 2011).

3.3 Methods of data collection

This study used three data collection methods including a household questionnaire survey, key informant interviews and focus group discussion (FGD) to obtain primary data. Quantitative data collected from heads of households were collected by using household questionnaire survey while qualitative data were gathered through key informant interviews and FGD. Key informant interviews involved three staff from Lushoto District Council including the District Agriculture, Irrigation and Cooperative Officer (DAICO) and two Agriculture Extension Officers who participated in the CCAFS project. The FGD was conducted on seven smallholder farmers who were among the targets of the CCAFS project in Yamba Village. Secondary data comprising annual maximum and minimum temperature and annual rainfall spanning 40 years (1981-2020) were gathered from the Tanzania Meteorological Agency. Meteorological data enabled researchers to verify if farmers' perceived climate-related factors reflect scientific climate data. The use of qualitative and quantitative methods of data collection aimed at enhancing the accuracy of results, generating in-depth information and enabling cross-checking the validity of findings where possible.

3.4 Data analysis

Quantitative data were processed and thereafter analysed by using descriptive and inferential statistics. Hence, the study employed STATA software version 17 to analyse climate change-related factors influencing sustained adoption of CSA technologies by using a multivariate probit (MVP) model and descriptive statistics. Qualitative data were

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subjected to content analysis to reveal in-depth information which complemented the quantitative results. The use of the MVP model allows a concurrent analysis of climate change-related factors influencing on sustained adoption of the category of CSA technology while allowing free correlation of unobserved factors (error terms) (Belderbos *et al.*, 2004; Lin *et al.*, 2005). The MVP was used because the CSA technologies promoted are mutually inclusive. Individual farming households can choose more than two technologies to adopt and continue using (Rahut and Ali, 2018). According to Wuensch (2014), the MVP model analyses factors such as climate-related factors influencing choices when three or more categories of dependent variables such as CSA technologies are measured at the nominal level (1, if sustained adoption, 0 otherwise), while independent variables are measured by continuous measurements and dummies (Wuensch, 2014). Hence, the MVP model is represented as follows:

$$Y_{ki}^{*} = \beta_{ki} x_{ki} + \varepsilon_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where; *k* was categorized into *i* technologies (i_1=terraces, i_2=tree planting, i_2=organic fertilizers, i_4=improved seeds, i_5=weather information).

Y_i = 1 if Y_i*>0 and 0 otherwise

Where;

*Yi** is an unobservable latent variable explaining chances of sustained adoption of a choice of *j* (CSA technology), β_k = vector of unknown parameters (k=1,2,3,4,5), X_{ki} = vector of climate-related factors influencing sustained adoption of a chosen type of CSA technology and ε_i=error term (ε_1, ε_2, ε_3, ε_4, ε_5). Thus, the MVP model can be expanded into five equations to show the concurrent influence of climate-related factors on the sustained adoption of five CSA technologies including terraces, tree planting, organic fertilizers, improved seeds and weather information respectively as shown below.

$$Y_{ki1} = \beta_1 X_{ki1} + \varepsilon_{i1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$
$$Y_{ki2} = \beta_2 X_{ki2} + \varepsilon_{i1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$
$$Y_{ki3} = \beta_3 X_{ki3} + \varepsilon_{i1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$
$$Y_{ki4} = \beta_4 X_{ki4} + \varepsilon_{i1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$
$$Y_{ki5} = \beta_5 X_{ki5} + \varepsilon_{i1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

The MVP model assumes that instead of the error terms being independently estimated, they are considered to be multivariate limited dependent variables in which the five error terms are normally distributed. The multivariate normal distribution MVN~(0, Ω) and symmetric covariance matrix Ω are presented in equation seven (7);

$$\Omega = \begin{bmatrix} 1 & \rho_{x_1x_2} & \rho_{x_1x_3} & \rho_{x_1x_4} & \rho_{x_1x_5} \\ \rho_{x_2x_1} & 1 & \rho_{x_2x_3} & \rho_{x_2x_4} & \rho_{x_2x_5} \\ \rho_{x_3x_1} & \rho_{x_3x_2} & 1 & \rho_{x_3x_4} & \rho_{x_3x_5} \\ \rho_{x_4x_1} & \rho_{x_4x_2} & \rho_{x_4x_3} & 1 & P_{x_4x_5} \\ \rho_{x_5x_1} & \rho_{x_5x_2} & \rho_{x_5x_3} & \rho_{x_5x_4} & 1 \end{bmatrix} \ldots\ldots\ldots\ldots (7)$$

Equation seven (7) expressed that the MVP model jointly explains farmers' decision to choose one or multiple CSA technologies if there is a relative advantage with adaptation to climate change. From the above equation, the specification with non-zero off-diagonal elements allows the correlation across error terms of several latent equations, which represent unobserved characteristics that influence the choice of alternative CSA technologies. Table 1 shows explanations of dependent variables and measurements used in the MVP model.

Table 1: Explanations of dependent variable and measurement

Variables	Explanation of variable	Measurement
Dependent variable		
Sustained adoption of CSA technology(Y_k)	Continuous use of a choice of CSA technology after phasing out the CCAFS project.	Y_{ki1}=1 if sustained adoption of weather information, 0 otherwise. Y_{ki2}=1 if sustained adoption of improved seeds, 0 otherwise. Y_{ki3}=1 if sustained adoption of organic fertilizers. 0 otherwise Y_{kj4}=1 if sustained adoption of tree planting, 0 otherwise. Y_{kj5}=1 if sustained adoption of terraces, 0 otherwise.

Independent variables used in this study are perceived climate change-related factors including increased attacks of pests and diseases, increased floods, unpredictable rainfall, increased droughts and increased temperature as shown in Table 2.

Table 2: Explanations of independent variables, measurement and effect sign

Independent variable	Measurement	Effect sign
Pests and diseases (X1)	1 if increased crop pests and diseases; 0 otherwise	+
Floods (X2)	1 if increased floods; 0 otherwise	+
Unpredictable rainfall (X3)	1 if unpredictable rainfall; 0 otherwise	+
Drought (X4)	1 if increased drought; 0 otherwise	+
Temperature(X5)	1 if increased temperature; 0 otherwise	+

Variability of average annual maximum, average annual minimum temperature and annual rainfall over 40 years (1981-2020) was presented by using line graphs plotted in Excel. However, the linear relationship of temperature versus time and annual rainfall versus time was checked by using a simple linear regression model.

$$Y = \beta_0 + \beta_1 X_t + \varepsilon_i$$

Whereby Y stands for average maximum temperature, average minimum temperature or annual rainfall; X_t represents time in year records (from 1981-2020); β_1 represents the coefficient of X_t. One unit increase in X_t increases Y by times β_i. Other parameters including β_0 ε_i represent the constant term and error term respectively. Variations in the dependent variable (maximum temperature, minimum temperature or rainfall) led by the independent variable (time) were explained by the coefficient of determination (R^2) which is represented in percentage.

4.0 Results and Discussion

4.1 Climate-Related Factors Perceived by Farmers in the West Usambara Mountains

This study explained farmers' perceived climate-related factors based on three indicators including whether decreased, no change or increased compared with the past ten-year period. The climate factors assessed include temperature, unpredictable rainfall, floods, drought pests and diseases attacking crops. Results show a majority of respondents said that increased attacks of pests and diseases reduce yields (78.2%) (Table 2). Few respondents expressed that neither perceived an increase nor decrease in pests and diseases in the study area in comparison to the past 10 years. The FGDs confirmed that currently there are more incidences of pests and diseases which are detrimental to crops in comparison to over ten years before this study. During FGDs, one participant said that;

> "*Cases of pests and diseases such as fungus and insects have increased these days, especially to crops such as maize, Irish potatoes, cabbages and tomatoes compared to the period spanning 10 years before.*" (FGDs, Yamba Village, June 2022).

Table 3: Climate change-related factors perceived by farmers

Perceived climate-related factors	Decreased		No change		Increased	
	Number of farmers	%	Number of farmers	%	Number of farmers	%
Temperature	14	11.9	29	23.4	81	65.3
Unpredictable rainfall	09	7.3	29	23.4	86	69.4
Floods	20	16.1	69	55.7	35	28.2
Drought	10	8.1	32	25.8	82	66.1
Crop pests and diseases	11	8.9	16	12.9	97	78.2

The findings also revealed that the majority of respondents perceived an increase in the occurrence of unpredictable rainfall (69.4%) (Table 2). Other farmers said either there was no change or to some extent rainfall is predictable. Results revealed by FGDs confirm that it becomes difficult for farmers to predict the onset, amount and termination of rainfall. One of the farmers who participated in FGD said that;

> *"In these days, rainfall starts either earlier before most farmers have prepared their farms or delays. Even though rains start earlier or later, it usually ends earlier than usual."* (FGDs, Yamba Village, June 2022).

Hence, it becomes difficult to predict the amount and seasonality of rainfall among smallholder farmers due to changes in weather and climatic conditions.

Furthermore, the majority of respondents (66.1%) perceived an increase in the length of drought season compared to the previous 10 years (Table 2). An increase in the length of droughts is a threat to crop production since it dries plants and reduces yields. Related findings were reported by Lebel *et al.* (2015) in Northern Thailand that drought was perceived by farmers as the main climate-related factor constraining agricultural production. It was also found that most respondents perceived a temperature increase in the previous ten years before this study (65.3%) (Table 2). Higher temperatures do not favour the growth and development of many varieties of crops, especially in the West Usambara Mountains where vegetables and fruits grow in cool climatic conditions. One of the farmers who participated in FGDs expressed that;

> *"Temperature is higher especially from October to March than in earlier 2000s. Rising temperature has been contributing to the reduction of crops such as some varieties of vegetables and fruits which grow well in cool conditions"* (FGDs, Yamba Village, June 2022).

The study findings concur with Llones and Suwanmaneepong (2021) in Northern Thailand who reported that farmers perceived an increase in temperature which lowers crop yields. Asare-Nuamah *et al.* (2022) also reported similar findings that farmers perceived the increase in temperature, declining rainfall, and pests and diseases which increase agricultural risks in the Yilo Krobo Municipality in Ghana.

Moreover, most farmers (55.7%) perceived that there was no change in the frequency and severity of floods compared to the previous 10 years; others perceived a decrease in floods (16.3%) and some respondents (28.23%) said that there was an increase of flood in low land areas and valley bottoms (Table 3). Related findings were revealed by FGDs that most farms that are negatively affected by floods are those located in lower areas and valley bottoms where water runs from upper areas of mountains. During the discussion, one participant said that;

> *"Nowadays we experience more floods to our farms located in valley bottoms and low lands. Floods fill our farms with sand and mud from upland areas when it rains."* (FGD, Yamba Village, June 2022).

Hence, the findings justify that although floods are not common in uplands, farmers located in lower areas and valley bottoms are very susceptible to frequent flooding due to running water from uplands especially when there is little conservation.

4.2 Reflection of Perceived Climate-Related Factors with Meteorological Data

Temperature and rainfall data collected from Tanzania Meteorological Authority (TMA) were used to validate the reflection of farmers' perceived climate-related factors with actual climate change in the West Usambara Mountains. Figures 1 and 2 show trends of changes in annual average maximum and minimum temperature, and annual rainfall spanning 40 years (1981 to 2020). TMA recorded an average annual maximum temperature of 29.1^0C and an average annual minimum temperature of 18.3^0C over 40 years. Figures 1 and 2 are used to validate if perceived climate-related factors such as an increase in temperature, unpredictable rainfall, increase in drought period, increase of floods and increase in attacks from pests and diseases reflect scientific climate data. Figure 1 depicts that there was no linear relationship between a change in time and with the trend of maximum temperature in the study area (R^2=0.0008, t=0.177, p=0.860,), but visual observation depict high variability of maximum temperature over years.

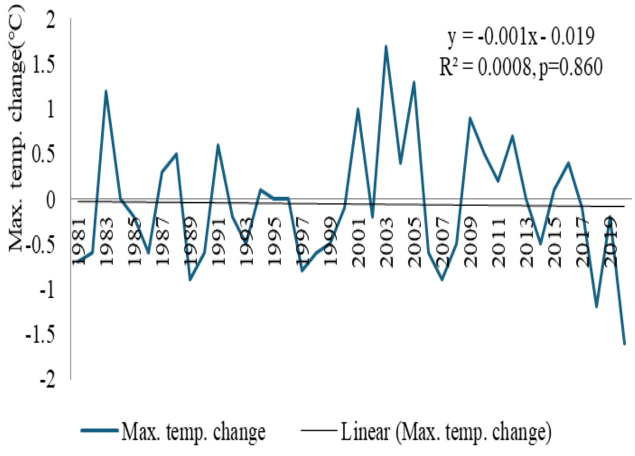

Figure 1: Maximum annual temperature record in degrees centigrade (TMA, 2022).

Furthermore, the findings in Figure 2 revealed that the average annual minimum temperature was increasing with time (t=5.55, p=0.001) and variations of 44.7% are explained by the linear regression. Hence, scientific climate data validate farmers' perception of an increase in temperature in the study area. Although the minimum temperature was increasing with time, it also demonstrated much variation over time. Rising and variability of temperature can reduce yields since crops require optimum climatic conditions to grow well. Similar to the study findings, Darabant *et al.* (2020) reported that farmers' perceived risk of rising temperature was reflected in meteorological temperature records in Lake Tana Ethiopia which demonstrate a rise in annual temperature.

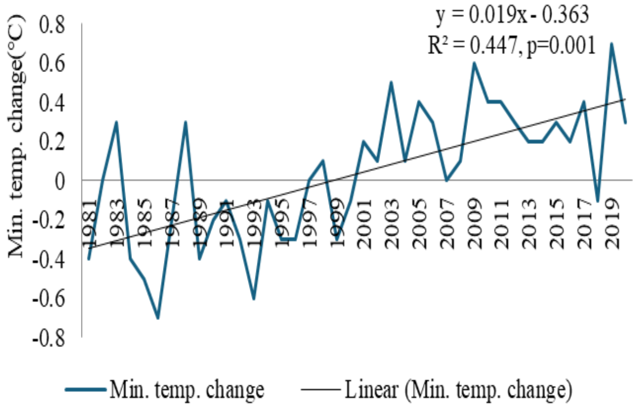

Figure 2: Minimum annual temperature record in degree centigrade (TMA, 2022)

Based on rainfall, meteorological data in Figure 3 shows that there was variability in the amount of annual rainfall in the study area. Between 1981 and 2020, many years experienced lower annual rainfall than an average of 1022.3mm, although some years particularly in 1997 and 2006 experienced the highest rainfall. The lowest rainfall was recorded in 2012 and 2013 in the study area. The study revealed that rainfall was not consecutively increasing with time in the study area (R^2=0.0028, t=0.33, p=0.744). However, visual observation depicted high variability of rainfall which was characterized by high and low precipitations across years (Figure 3). There was the highest and lowest rainfall in some years but most years experienced lower rainfall than average. Variability of rainfall over the years is likely to be associated with weather extremes such as frequent droughts, frequent floods and unpredictable rains which were also reflected by farmers' perceptions of climate-related factors in the study area.

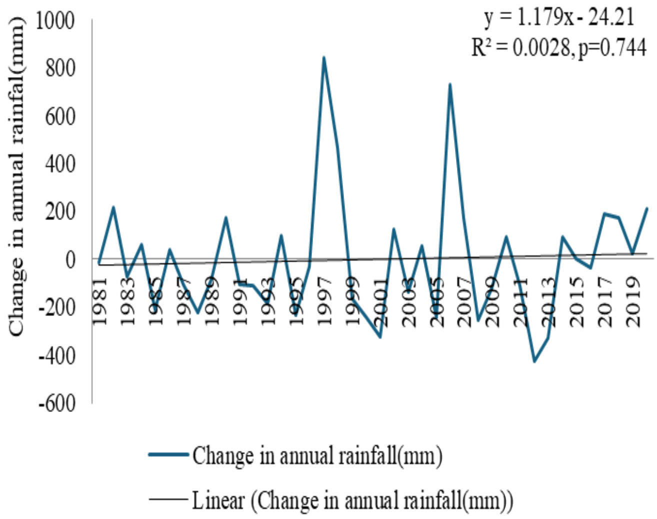

Figure 3: Variability of rainfall over years in the West Usambara Mountains

Related findings were reported by Ayanlade *et al.* (2017) in Southwest Nigeria that farmers' perceptions were validated with meteorological data which depicted rainfall fluctuations leading to unpredictable onset and termination of rain seasons. Similar findings were also reported by Aliabadi *et al.* (2022) that there was consistency in farmers' perceptions of variability in rainfall and increasing temperature with meteorological data of temperature and rainfall in Karmanshah Township Iran. The study findings partly concurred with Ayal *et al.* (2017) who reported farmers' perceptions of increased temperature in Ethiopia which was reflected in meteorological data, but perceptions were contrary to the rainfall trend which was progressively increasing.

4.3 Influence of Perceived Climate-Related Factors on Sustained Adoption of CSA Technologies

This study used a multivariate probit model (MVP) to assess the influence of climate-related factors on the sustained adoption of promoted CSA technologies, particularly after phasing out of the CCAFS project. The findings show that climate-related factors including increased pests and diseases, increased floods, unpredictable rainfall, increased droughts and increased temperature perceived by farmers had a positive influence on a choice of CSA technologies in the study area (Table 3).

The perceived increase in pests and diseases due to climate change had a positive significant influence on the sustained adoption of tree planting (β=0.834, p=0.017) (Table 3). Farmers' perception of the increase in pests and diseases due to climate change increases the likelihood of sustained adoption of tree planting in the study area despite the CCAFS project being phased out. Hence, most farmers continued planting trees on their farms which are mixed with crops to reduce incidences of pests and diseases since some varieties of plants such as *Tephrosia vogelii* and *Tithonia diversifolia* are pesticidal and improve soil fertility. Perceived increase of pests and diseases also had a positive significant influence on sustained adoption of weather information (β=1.101, p=0.066) (Table 3). The perceived increase in pests and diseases increases the likelihood of sustained adoption of weather information among farmers in the study area after phasing out of the CCAFS project. Most farmers who perceived that climate change has increased pests and diseases to their crops had sustained the adoption of weather information since they are aware that certain weather and climatic conditions such as high humidity are associated with risks of pests and diseases to crops including fruits and vegetables. Therefore farmers can minimize risks of pests and diseases through the integration of pesticidal tree varieties with crops.

The perceived increase in floods had a positive significant influence on the sustained adoption of terraces (β=4.032, p=0.001) (Table 3). Farmers' perception of increased floods increased the likelihood of sustained adoption of terraces in the study area. Most farmers perceiving the risk associated with floods on their farms especially in lowlands and valley bottoms decided to continue using terraces during and beyond the CCAFS project period. In contrast, Teklu *et al.* (2023) found that a perceived increase in floods was not a significant predictor of sustainable adoption of soil and water conservation technologies including terraces in the Upper Blue Nile Highlands of Ethiopia after the implementation of agricultural extension programs because farmers prioritized other technologies such as improved seeds and agroforestry. The findings also revealed that perceived floods had a positive significant influence on sustained adoption of tree planting in the study area (β=0.791, p=0.013) (Table 3). Hence, the likelihood of sustained adoption of tree planting increases among farmers perceiving the risk of floods in their areas. Most farmers perceived an increase in floods over time continued adoption of tree planting and taking care planted trees on their farms especially on hills to reduce soil erosion and runoff which are destructive to crops. More results show that the perceived increase in floods had no significant influence on the sustained adoption of improved seeds, organic fertilizers and weather information services. In contrast, Diallo *et al.* (2019) found that the perceived increase in flood had a negative significant influence on the sustainable adoption of improved seeds and integrated soil fertility management which incorporated the use of organic fertilizers since most farmers were more risk averse by escaping the risk of purchasing these agricultural technologies due to possibility of high flooding.

Table 3: Multivariate probit analysis for climate-related factors influencing sustained adoption of CSA technologies (n=124)

Independent variable	Terraces		Tree planting		Organic fertilizers		Improved seeds		Weather information services	
	Coef. (S.E.)	P>z	Coef. (S.E.)	P>z	Coef. (S.E.)	P>z	Coef. (S.E.)	P>z	Coef. (S.E.)	P>z
Constant	-3.296 (0.869)	0.001	-0.560 (0.294)	0.050	-0545 (0.309)	0.077	-1.178 (0.483)	0.015	-2.528 (0.659)	0.001
Increased pests and diseases	0.434 (0.932)	0.642	**0.834*** (0.350)**	0.017	0.501 (0.370)	0.179	7.603 (0.676)	0.999	**1.101* (0.599)**	0.066
Increased floods	**4.032*** (0.586)**	0.001	**0.791*** (0.315)**	0.013	0.559 (0.391)	0.153	1.508 (1.010)	0.136	0.694 (0.562)	0.217
Unpredictable rainfall	0.353 (0.968)	0.715	0.509 (0.409)	0.212	**0.851* (0.472)**	0.071	7.999 (0.675)	0.999	**1.885*** (0.486)**	0.001
Increased drought	0.240 (0.745)	0.747	-0.241 (0.319)	0.451	**0.707** (0.344)**	0.040	**1.503* (0.879)**	0.087	0.086 (0.561)	0.879
Increased temperature	0.204 (0.798)	0.799	0.050 (0.365)	0.890	0.097 (0.430)	0.822	-7.849 (0.676)	0.999	**1.837*** (0.493)**	0.001

Log likelihood = -213.776
Wald Chi² = 125.83, Prob> Chi² = 0.001
***, **, * Significant at 1%, 5% and 10% respectively

Furthermore, perceived unpredictable rainfall had a positive significant influence on the sustained adoption of organic fertilizers (β=0.851, p=0.071) (Table 3). The likelihood of sustained adoption of organic fertilizers increases among farmers who were aware that current rainfall is very unpredictable compared to some past decades. Farmers after recognizing that rain seasons highly shifting which increases unpredictability, opted to continue using improved fertilizers to add organic matter to the soil which can maintain moisture for a longer time after rains. Perceived unpredictable rainfall also had a positive significant influence on the sustained adoption of weather information (β=1.885, p=0.001) (Table 3). Most farmers who perceived that rainfall is unpredictable opted to continue the adoption of weather information so that they can be informed by both Tanzania Meteorological Authority and indigenous weather forecasting about the weather conditions such as the time for onset of rains, possibilities of termination of rainfall and expected amount of precipitations. Access to timely weather prediction services can minimize the risk of crop losses among farmers by selecting appropriate crop varieties, planting and harvesting on time. The study agrees with Teklu *et al.* (2023) who revealed that unpredictable rainfall had a positive influence on the sustainable adoption of improved varieties and organic fertilizers after implementation of agricultural extension programs in the Upper Blue Nile Highlands of Ethiopia.

The perceived increase in droughts had a positive significant influence on the sustained adoption of organic fertilizers (β=0.707, p=0.040) (Table 3). Droughts increase the chances of farmers to continue adoption of organic fertilizers such as compost and animal manure. Most farmers perceived an increase in droughts over time and continued using organic fertilizers on their farms to maintain moisture longer after the rainy season to support the growth and development of crops. In contrast, Diallo *et al.* (2019) found that perceived drought has a negative influence on the sustainable adoption of integrated soil fertility management practices including organic fertilizers in the Ségou Region Mali since farmers were avoiding high costs of investment. The study findings were also different from Ahmed *et al.* (2022) who reported that perceived drought was not a significant predictor of post-project adoption of organic fertilizers after the construction of polders in coastal areas of Bangladesh since the adoption of innovation is area-specific due to differences in social, economic and geographical contexts. Perceived drought also had a significant influence on the sustained adoption of improved seeds (β=1.503, p=0.087) at a 10% significant level (Table 3). The study findings disagree with Teklu *et al.* (2023) who revealed that the perception of drought among farmers had no significant influence on the sustainable adoption of improved varieties in the Upper Blue Nile Highlands of Ethiopia. Hence, in the West Usambara Mountains, farmers' perception of increased drought increases the livelihood of sustained adoption of improved seeds. Most farmers sustained the adoption of improved seeds such as maize seeds and Irish potato varieties which are resistant to drought after phasing out of the CCAFS project to reduce the risks of dryness in crop production.

The perceived increase in temperature had a positive significant influence on the sustained adoption of weather information (β=1.837, p=0.001) (Table 3). Based on the findings, farmers' perception of rising temperatures is likely to increase sustained adoption of weather information. Due to the increase in temperature, most farmers have decided to use weather information in their farming operations which enables them to select a variety of crops to grow that are tolerant to high temperature. Findings revealed by FGDs expressed that temperature in the West Usambara Mountains increased over 10 years before the study. Participants of FGDs added that farmers are nowadays using weather forecasting disseminated by Tanzania Meteorological Agency through radio and television to get information about weather conditions including daily temperature. Other study findings revealed that a perceived increase in temperature had no significant influence on sustained adoption of improved seeds, terraces, organic fertilizers and terraces (Table 3). The study findings concurred with Teklu *et al.* (2023) who found that a perceived increase in temperature was not a significant predictor of sustainable adoption of improved varieties, organic fertilizers, soil and water conservation practices such as terraces and agroforestry.

4.0 Conclusions and Recommendations

This study concluded that not only farmers are victims of climate variability and weather extremes, but also active observers of changes in climatic conditions over time. Their perceptions about changes in climatic conditions over time particularly increased in floods, unpredictable rainfall, increased drought, increased temperature and increased outbreaks in pests and diseases are strong predictors of sustained adoption of CSA technologies in the study area. This study put forward the following recommendations; Policymakers, agricultural extension officers and project management should integrate farmers' climate change perceptions when promoting adoption of CSA technologies to enhance sustainable adoption using a participatory approach. Farmers' perceptions of climate change should also be incorporated by agricultural stakeholders in designing future related CSA projects that can sustain longer while increasing crop productivity despite changes in climatic and weather conditions.

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