Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

ISSN NO. 2320-5407

Article DOI:10.21474/IJAR01/18956
DOI URL: http://dx.doi.org/10.21474/IJAR01/18956

*RESEARCH ARTICLE*

# PERCEPTIONS OF CLIMATE CHANGE AND THEIR DETERMINANTS AMONG THE SMALLHOLDER FARMERS IN MACHAKOS COUNTY

**David M.K. Nyamai[1], Dorothy A. Amwata[2] and Julius Kilungo[3]**

1. Department of Agricultural Sciences, School of Agriculture, Environment, Water and Natural Resources South Eastern Kenya University.
2. Department of Agriculture, School of Agriculture and Environmental Sciences, Murang'a University of Technology.
3. Department of Agricultural Sciences, School of Agriculture, Environment, Water and Natural Resources South Eastern Kenya University.

## Manuscript Info

***Manuscript History***
Received: 20 April 2024
Final Accepted: 24 May 2024
Published: June 2024

***Keywords:-***
Climate Change, Variability, Impact, Adaptation, Smallholder Farmers

## Abstract

Climate change is expected to affect the livelihoods of smallholder farmers in Machakos County due to their overdependence on rain-fed agriculture. Farmers' perception of climate change and variability influences their understanding and management of climate change-induced risks and uncertainties, especially in rain-fed agriculture. The study was carried out to evaluate smallholder farmers' awareness and perception of climate change and the factors influencing the perception of climate change in Machakos County. Data was collected from 400 farmers from six locations sampled through a multistage and simple random sampling procedure. The Heckman probit model was fitted to the data to avoid sample selection bias since not every farmer who may perceive climate change responds by adapting. The analysis revealed that 96% of smallholder farmers in Machakos County were aware of climate change, 87.3% perceived that temperature was rising, and 96.8% perceived that rainfall was decreasing. In this regard, the age of the household head, Gender, education, household size, group membership, distance to the nearest input sellers, distance to the closest market access to insurance, land size, off-farm income, access to information on climate change, access to extension services, access to credit, changes in temperature and rainfall were found to have a significant influence on the probability of farmers to perceive and/or adapt to climate change.



## Introduction:-

Kenya is already experiencing climate changes in high temperatures, frequent droughts, erratic rainfall, and unpredictable onset and cessation of rain (World Bank, 2021; Amwata, 2020). The climate change impacts threaten livelihoods, food production, and infrastructure (Amwata, 2020).While climate change is a global phenomenon, itseffects are expected primarily on developing countries that are under the threat of erratic climate changes, resulting in natural disasters such as floods, droughts, and heavy rainfalls, with adverse impacts on their livelihoods (UN Environment, 2019; IPCC, 2014).The livelihoods of households in most developing countries, including

**Corresponding Author:- David M.K. Nyamai**
Address:- Department of Agricultural Sciences, School of Agriculture, Environment, Water and Natural Resources South Eastern Kenya University.

Kenya, depend on agriculture, which is highly vulnerable to climate change. Smallholder farmers dominate agricultural production in Kenya and contribute significantly to the national economy (World Bank 2015). Agriculture is the primary source of livelihood for most households in Kenya, employing more than 70% of the rural population and contributing about 21 % of the Country's GDP (KNBS, 2019; GoK, 2019).

Despite its importance, smallholder agriculture in Kenya, including Machakos County, is adversely impacted by climate change, resulting in low productivity and food insecurity (Bryan et al., 2011).Therefore, policies and interventionsare necessary to respond to the adverse impacts of climate change facing smallholder farmers from climate variability and future climate change (Kumar et al., 2020; Panthi et al., 2016; Rosenzweig and Neofotis, 2013). However, the successful implementation of climate change adaptation strategies and measures in agriculture will largely depend on farmers' perception of climate change and the knowledge of how the changes will affect them (Meldrum et al., 2018; Carlton et al., 2016; Abid et al., 2015).

The perceptionsof the local farmers that the climate is changing and that the changes are adversely impacting farming activities are the drivers of adaptations and behavioural change (Aryal et al., 2018). Visible changes in weather and climate, such as an increase in temperature, a decline in rainfall, and changes in the onset and cessation of rains, effectively influence smallholder perceptions of climate change and variability (Rankoana, 2016). Interacting with natural hazards is the most significant aspect of climate change and variability perception, which underpins individual risk perception (Lujala et al., 2015; Frondel et al., 2017), may result in the adoption of adaptation measures (Arbuckle et al., 2015).

Understanding how smallholder farmers perceive climate change and variability and associated risks is essential in tailoring initiatives aimed at improving performance in agriculture (Fadina and Barjolle, 2018; Frondel et al., 2017; Silvestri et al., 2012). A low level of smallholder farmers' awareness of climate change may adversely affect their ability to adopt agricultural adaptation strategies in response to climate change impacts. The level of smallholder farmers' knowledge of their local environment could be a guide to responding effectively to the challenges of climate change and improving productivity. Unfortunately, little is known about the smallholder farmers' awareness and knowledge of climate change and the factors influencing climate change perception among smallholder farmers in Machakos County.

Although some efforts have been made to investigate smallholder farmers' perception of climate change and variability and adaptive strategies (Agesa et al., 2019; Kumar and Sidana, 2018; Asrat and Simane, 2018; Gichangi and Gatheru, 2018; Mutunga et al., 2017; Opiyo et al., 2016; Ndambiri et al., 2014),there are still few researches that focus on determinants of perceptionamong smallholder farmers. Moreover, few of the works done focused on Machakos, an area where rainfall is highly variable and barely adequate to support rain fed farming. This study attempts to fill these gaps by investigating the smallholder farmers' awareness of climate change, their perception of climate change and variability, and the determinants of their perception of climate change in Machakos County.

## Methodology:-

### Study Area

The study was carried out in Machakos County (Figure 1). Geographically, Machakos County covers an area of 6208.2 km² (Figure 2.1). Machakos County is located in the dry arid, and semi-arid plains in lower eastern Kenya. The County receives bimodal rainfall with short rains from October to December and long rains from March to May. The rainfall ranges between 500 mm and 1250mm and is highly influenced by altitude, with higher areas receiving an average of 1000mm while lowlands receive 500mm. Rainfall in the County is unevenly distributed and unreliable. Temperatures range from 18 to 29 °C (Machakos County, 2015; MoALF, 2017). The County is categorized into five agro-ecological zones (AEZs) based on the potential crop production suitability (Jaetzold et al., 2012): Upper midland (UM-2-3), UM 5-6, Midland (LM3), LM 4 and LM 5. The UM zones covering 2,730.2 km² have a higher potential for agriculture compared to lower midland zones covering 3,478 km² and are mainly occupied by agro-pastoralists and pastoralists.

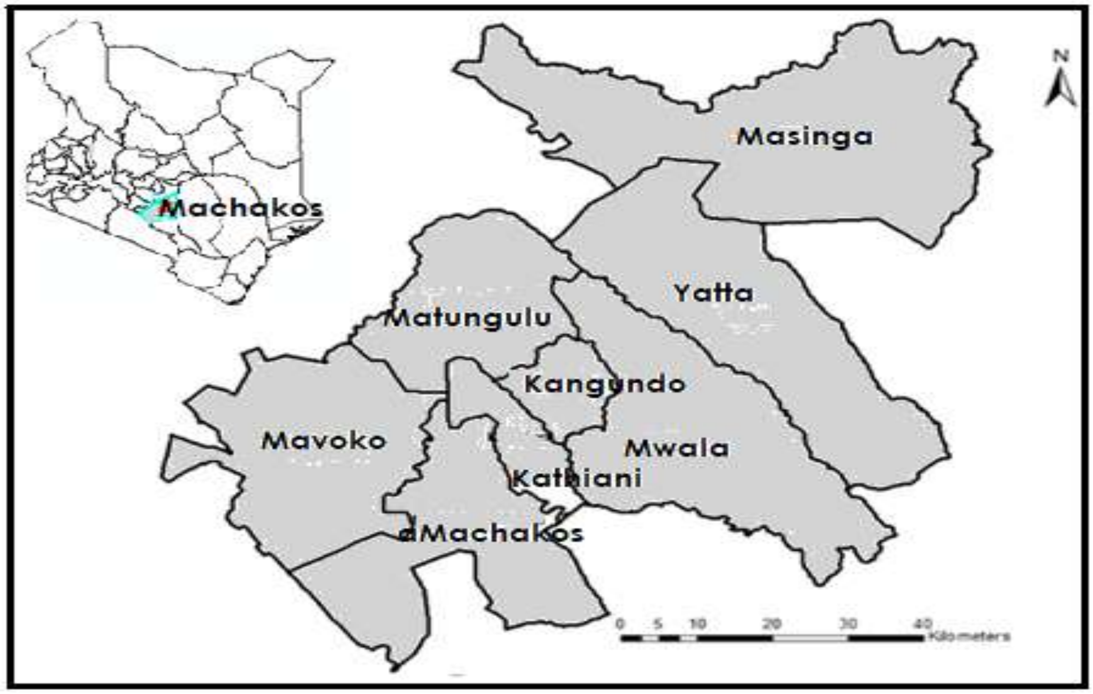


**Figure 1:-** Map of the study area (Source: Research generated from GIS).

Smallholder agriculture is integral to the County's livelihoods (Machakos County, 2018). The County is generally dry, making rain-fed agriculture challenging in most parts. Rain-fed mixed subsistence farming is the main economic activity. Cereals, such as Maize; drought-resistant crops, such as sorghum and millets; grain legumes; root crops and fruits; and industrial crops, such as coffee and cotton, dominate the County's agriculture (Machakos County, 2018). In addition, horticultural crops are produced both for subsistence and for sale. The main livestock species were cattle, beef, hair sheep, meat goats, and indigenous chicken (Machakos County, 2018).

**Data Collection**

In assessing the smallholders' perception of climate change in the study area, this study used a combination of data collection tools, including household surveys, focus group discussions, and key informant interviews. Household interviews using semi-structured questionnaires were conducted to gather qualitative and quantitative information. FGDs were used to collect more information that would supplement the household interviews. Key informant interviews were conducted with extension service staff, opinion leaders, and national and County administrators. Temperature and rainfall data for trend analysis were collected from the Kenya Meteorological Department.A total of 400 households were interviewed in the County. A random start was used to choose the first household to be interviewed.

**Statistical Analysis**

Descriptive and Hackman's probit model was used to analyze interview data. Data from the questionnaire were coded, entered, and analyzed using the statistical package for social scientists (SPSS) and STATA software (version 20). Descriptive statistics of key variables were computed, analyzed, and presented through frequency distribution, percentages, and measures of central tendency. FGDs data entry, cleaning, and coding were done using emergent themes, and analysis was done using qualitative content analysis.

**The Analytical Framework: Heckman's two-step procedure**

Adaptation to climate change is viewed as a two-step decision-making process. Farmers must first notice that the climate has changed and then identify potentially helpful strategies to adopt (Maddison, 2006).In studies where a decision to adopt new technology involves more than one step, models with two-step regressions are widely adopted to correct sample selection biases that may arise during the decision-making process(Maddison, 2006; Yirga, 2007; Deressa, 2008; Gbetibouo, 2009). Farmers' perceptions are assessed in stage one, and then adaptations follow in stage two. Since only those who perceive climate change will adopt, this gives rise to a sample-selectivity problem.

To correct this sample section bias, this study adopted Heckman's sample selectivity probit model (Heckman, 1976; Maddison, 2006; Deressa, 2009). This study used the Heckman probit selection model to analyze smallholders' perceptions of climate change and adoption. Following Maddison (2006), the Heckman sample selectivity model based on the latent variable models is specified as follows:

$Y_1 = b'X + U_1$………………………………………………………….…. (1)

$Y_2 = g'Z + U_2$……………………………………………………….. (2)

where X is a k-vector of regressors, which include factors hypothesized to affect perception, and Z is an m-vector of regressors, which include factors hypothesized to affect adaptation, possibly including 1's for the intercepts. The error terms $U_1$ and $U_2$ are jointly normally distributed, independently of X and Z, with zero expectations. Although we are primarily interested in the first model, the latent variable Y1 is only observed if $Y_2 > 0$. Thus, the actual dependent variable is:

$Y = Y_1$ if $Y_2 > 0$, Y is a missing value if $Y_2 <= 0$………………………….. (3)

The latent variable $Y_2$ itself is not observable, only its sign. We only know $Y_2 > 0$ if Y is observable and $Y_2 <= 0$ if not. Consequently, without loss of generality, we may normalize $U_2$ such that its variance equals 1. If we ignore the sample selection problem and regress Y on X using the observed Y's only, then the OLS estimator of b will be biased because:

$E[Y_1|Y_2 > 0, X,Z] = b'X + rsf(g'Z)/F(g'Z)$…………………………………….(4) Where F is the cumulative distribution function of the standard normal distribution, f is the corresponding density, $s^2$ is the variance of $U_1$, and r is the correlation between $U_1$ and $U_2$. Hence:

$E[Y_1|Y_2 > 0, X] = b'X + rsE[f(g'Z)/F(g'Z)|X]$ ………………………………….(5)

The latter term causes sample selection bias if r is non-zero. To avoid the sample selection problem and get asymptotically efficient estimators, thestudy used the maximum likelihood procedure to estimate the model parameters. The analysis used STATA software.

**Empirical Models of the Study**

The study estimated Heckman's probit selection and Heckman's probit outcome models. In Heckman's probit selection model, the regressand was a binary variable relatedto whether or not a farmer perceived climate change and variability. It was regressed on asset of explanatory variable that included the age of the farmer, Gender, education, access to extension services, access to climate information,off-farm income,household size, distance to market, access to credit, access to insurance, distance to input seller, land size and group membership. The algebraic representation of Heckman's probit selection model was given as;

$Ai = (\beta Xi) + \mu$ ………………………………….……………………………… (6)

Where: Ai = the perception by the $i^{th}$ farmer that the climate is changing

Xi = the vector of explanatory variables of theprobability of perceivingclimate changebythei$^{th}$farmer

β = the vector of the the parameter estimates of the regressors hypothesized to influence the probability of thefarmer i perceptionofclimatechange.

Thus, the linear specification of Heckman's probit selection model was given as:

$Ai=\beta_0+\beta_1X_1+\beta 2\ X_2+\beta_3\ X_3+\beta_4\ X_4+\beta_5\ X_5+\beta_6\ X_6+\beta_7\ X_7+\beta_8\ X_8+\beta_9\ X_9+\beta_{10}\ X_{10}+\beta_{11}\ X_{11}+\mu$

Where; $X_1$=age, $X_2$=education, $X_3$=extension service, $X_4$=off-farm income, $X_5$=household size, $X_6$=distance to market, $X_7$=credit, $X_8$=insurance, $X_9$=distance to input seller, $X_{10}$=land size+$\beta_{11}$ $X_{11}$=group membership

The Heckman's probit outcome model, the regressand was also a binary variable related to whether or not a farmer has adapted to climate change and variability. It was regressed on asset of explanatory variable that included the age of the farmer, Gender, education, access to extension services, access to climate information, off-farm income, household size, distance to market, access to credit, access to insurance, distance to input seller, land size and group membership, temperature, and rainfall. The algebraic representation of Heckman's probit selection model was given as;

The algebraic representation of Hackman's probit selection model was given as;

$Bi = (\beta Xi) + \mu$ ………………………………….……………………………… (7)

Where: Bi = the adaptation by the $i^{th}$ farmer that climate is changing

Xi = the vector of explanatory variables of theprobability of adapting toclimate variability and changebythei$^{th}$farmer

β = the vector of the parameter estimates of the regressors hypothesized to influence the probability of farmers adapting toclimate change and variability.

Thus, the linear specification of the Heckman's probit selection model was given as:

$$Ai=\beta_0+\beta_1X_1+\beta 2\ X_2+\beta_3\ X_3+\beta_4\ X_4+\beta_5\ X_5+\beta_6\ X_6+\beta_7\ X_7+\beta_8\ X_8+\beta_9\ X_9+\beta_{10}\ X_{10}+\beta_{11}\ X_{11}++\beta_{12}\ X_{12}+\beta_{13}\ X_{13}+\mu$$

Where; $X_1$=age, $X_2$=education, $X_3$=extension service, $X_4$=off-farm income, $X_5$=household size, $X_6$=distance to market, $X_7$=credit, $X_8$=insurance, $X_9$=distance to input seller, $X_{10}$=land size+$\beta_{11}$ $X_{11}$=group membership, $X_{12}$=temperature, $X_{13}$=rainfall

## Results and Discussions:-

### Demographic Characteristics of Household Survey Respondents

The results show that females were the most dominant respondents at 54%, while 46% were males. Most (65%)of the respondents in the study area were male-headed, while the remaining 35% were female-headed. The results show that most respondents (44.8%) were in the 36-55 age bracket. This is slightly below the Kenyan farmers' average age, estimated at 60 years (GoK, 2019). Most respondents (46.8%) had primary education, followed by those with secondary education at 37.0%. 9.8% had tertiary education, and the remaining 3.0% had no formal education.

### Knowledge, Understanding, and Perception of Climate Change and Variabilityand Cause

Sample farmers were asked whether they were aware of the changing climate around them and what they understood about climate change and variability. Results indicate that most farmers (96%) reported they were aware of climate change, about 3% said they were unaware, and 1% reported they did not know (Figure 2).

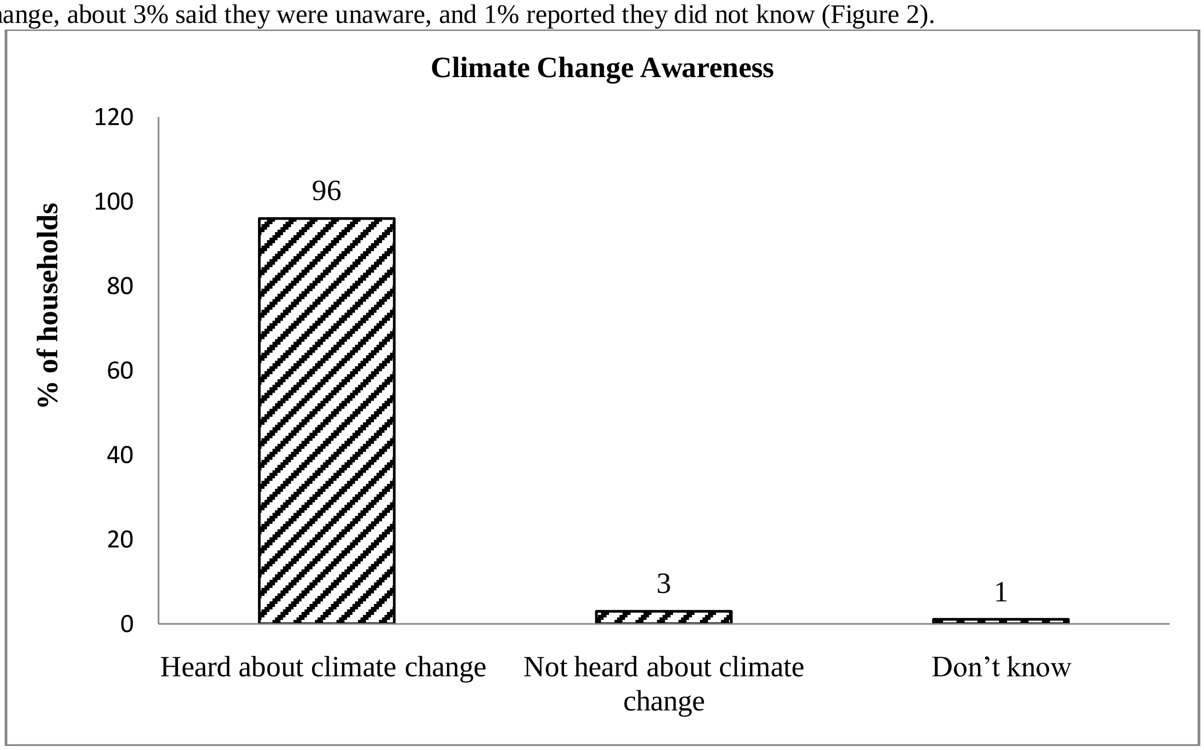


**Figure 2:-** Awareness of Climate Change.

However, when asked to explain what they understood by climate change and variability, the respondents gave varied responses. Results from household interviews and FGDs show that some farmers understood climate change and climate variability as a change in the environment and weather conditions, change in weather, deforestation, increased droughts, reduced availability of water, and increased temperature and hot days. Other farmers described climate change and variability as the disappearance of certain trees, increased pests and diseases, and the disappearance of water sources. Inferences from FGDs show participants' descriptions of climate change and variability as having something to do with rainfall and temperature, excessively high temperatures and deficient rainfall, and erratic rainfall and increased droughts. The in-depth interviews with key informants also indicated a different understanding of climate change and variability. Key Informants described climate change and variability as changes in temperature and rain seasons, the difference between weather now and long ago, and fluctuations in weather conditions of a place over a long period.

Farmers were asked whether they had noticed any significant climate changes over the past 5-30 years. Results from the household survey show that about 99% of the respondents indicated they had observed changes in temperature at least in the last five years, 98.5 % in the last ten years, 98.8% in the last 20 years, while 59.6% had observed changes in temperature for the last 30 years. On rainfall, all respondents (100%) indicated they had observed changes in rainfall in the last five years, 99% in the last ten years, 87.8 % in the last 20 years, and 59.1% in the last 30 years. All (100%) of respondents had observed an increase in droughts in the last 5 and 10 years, 96 % in the last 20 years, while 64.4% had observed changes in droughts in the last 30 years (Figure 3).

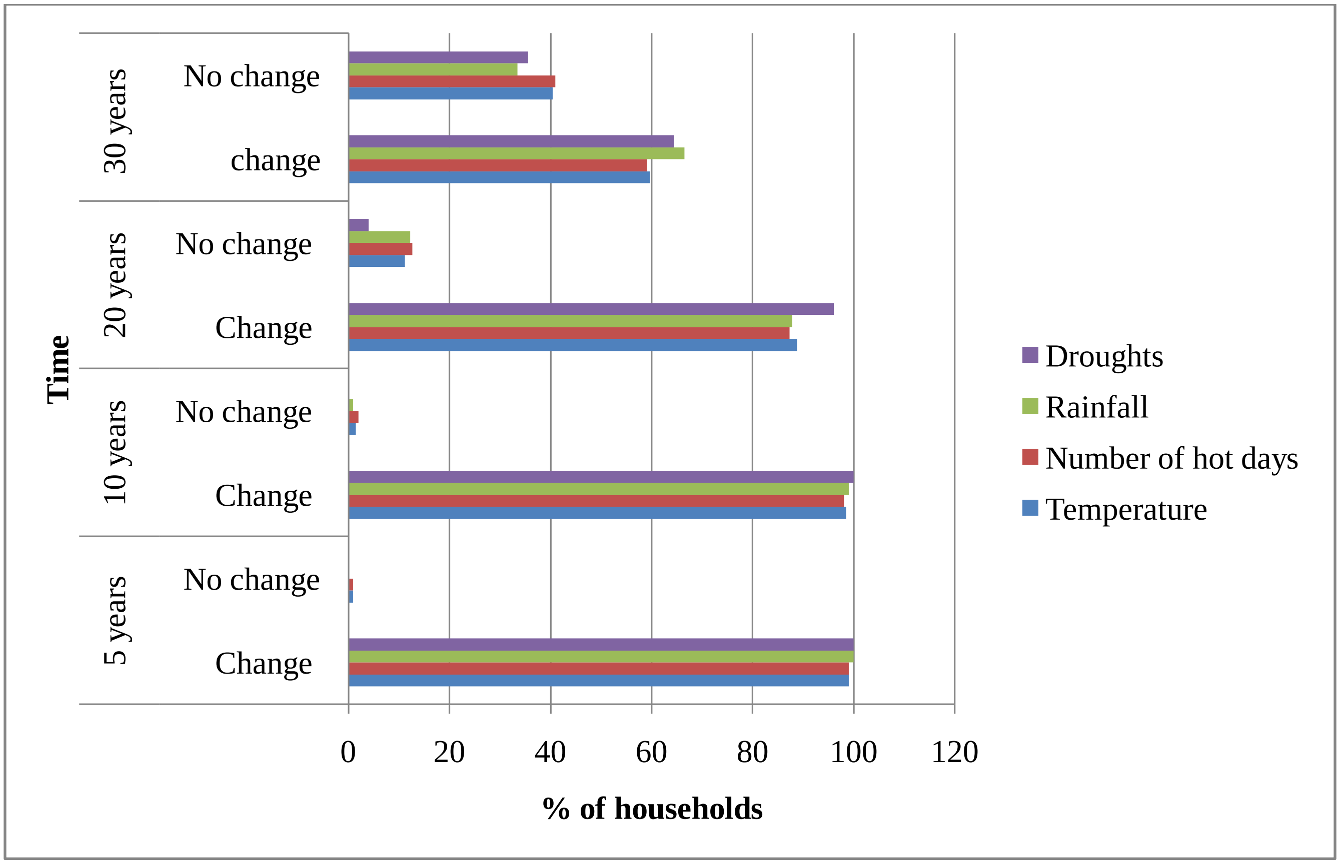


**Figure 3:-** Distribution of Smallholder Farmers Based on Observed Changes in Climate Change and Variability in the Last 30 Years (%).

**Smallholder farmers' perceptions of long-term climate change and variability in the study area**

As shown in Figure 4, the results show that 87.3% of the respondents perceived that there has been an increase in temperatureover the last 30 years. 83.3% of the respondents had perceived an increase in hot days in the study areas over the last 30 years. Results also show that the majority (96.8%) of the respondents had perceived a decrease, while 3.2% perceived an increase in the amount of rainfall.The majority of the respondents (92.3%) perceived a delay in the onset of rain, and many more years than 30 years ago, 6% perceived an increase in early onset, while 1.8 perceived that the onset of rainfall had not changed significantly but only varied from year to year. 60.5% perceived a decrease in late cessation of rainfall, while 39% perceived an increase in late cessation. Results also indicate that 88.5% and 77.3% perceived an increase in late-onset and early-onset cessation, respectively, over the last 30 years. A significant proportion of respondents (90.8%) perceived an erratic rainfall distribution in the study area.A high proportion of the respondents (98% ) perceived an increase in drought incidents, 1.2 % perceived a decrease, and only 0.8 % agreed there had been no change.

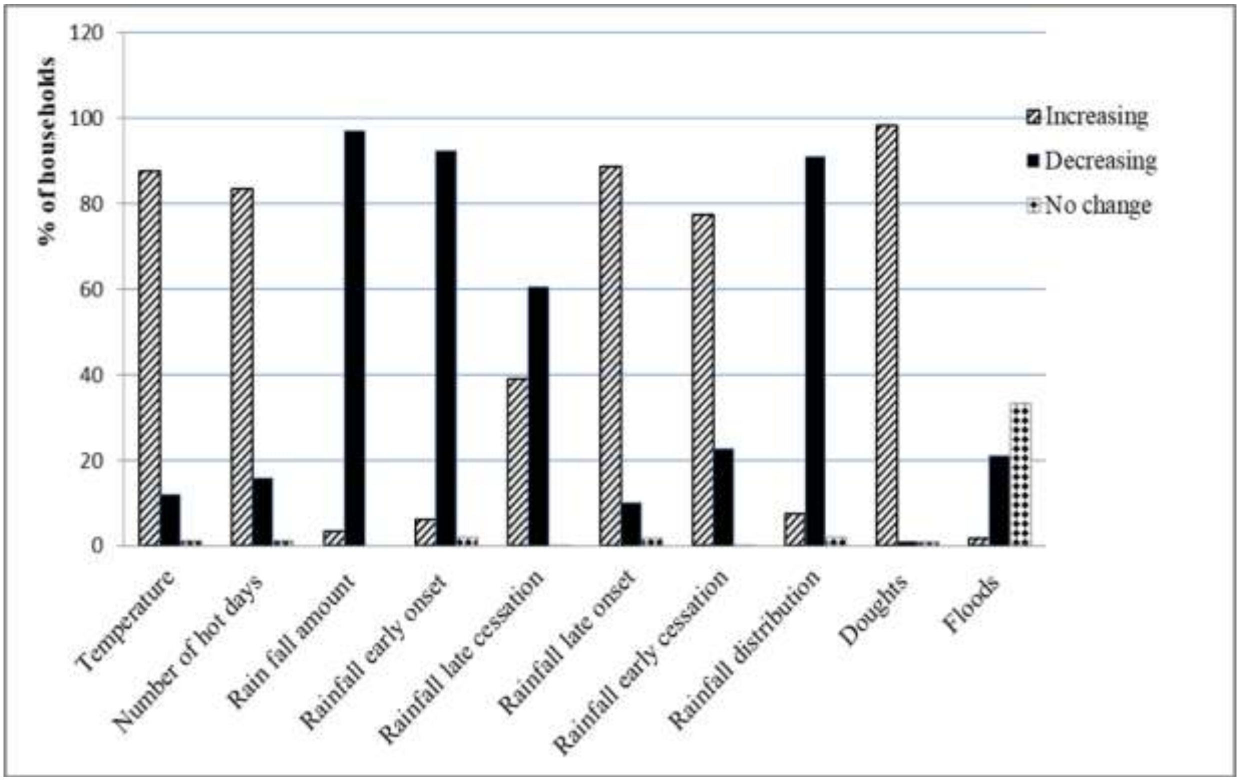


**Figure 4:-** Farmers' Perception of Climate Change and Variability over the Last 30 Years in Machakos County.

A cross-tabulation of data indicated that the majority of farmers who perceived climate changes were in the age group 36-55 years (44.5%), compared to 18-35 years (22%), 56-65 years (19.8%) or above 65 years (13.2%).The study results indicated that 53.2 % of farmers who perceived climate change and variability had attained post-primary education compared to 46.8 % who had up to primary education.Most male farmers (67.3 %) perceived climate changes compared to 32.7% female counterparts (Figure 5).

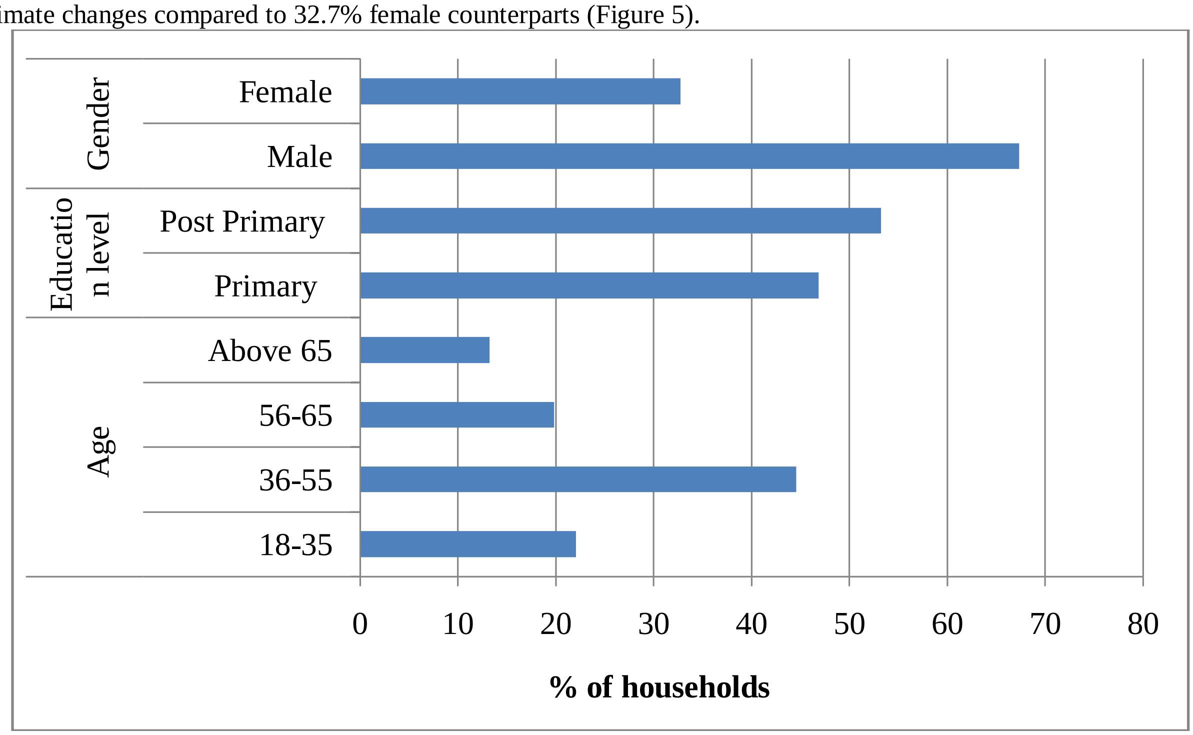


**Figure 5:-** Climate change perception by Gender, level of education, and age of the farmers.

Discussions with participants in FGDs revealed that farmers are aware that the local climate they have previously experienced and adapted to is changing. Participants in all FGDs reported that they had observed temperature changes, rainfall variability, and rainfall amounts. All FGD participants perceived that temperature had increased with higher numbers of extremely hot days in the last three (3) decades. Rainfall had decreased in amounts, increased variability, and was characterized by late onsets and early cessations.

The study's findings revealed that most farmers, regardless of age, Gender, and level of education, were aware of the changing climate and the likely causes of the changes in their local environment. The increasing proportion of respondents perceiving noticeable changes in weather elements and climate events may imply that climate has become more variable and unpredictable over the past three decades. Farmers may also generalize from more recent weather, possibly owing to short memories.The farmers' observations on temperature and rainfall were broadly consistent with trends from data obtained from the Kenya meteorological department that indicate a decline in temperature over the last years (Figure 6) and an increase in annual average temperatures over the last years (Figure 7). The findings indicate that smallholder farmers in Machakos County are generally aware of climatic changes. The results are also consistent with the World Bank (2021) report and similar studies in Kenya and elsewhere (Ochieng et al., 2017; Belay et al., 2017). Similarly, the findings are generally consistent with Bryan et al. (2013) report on climate change events in Sub-Saharan Africa.

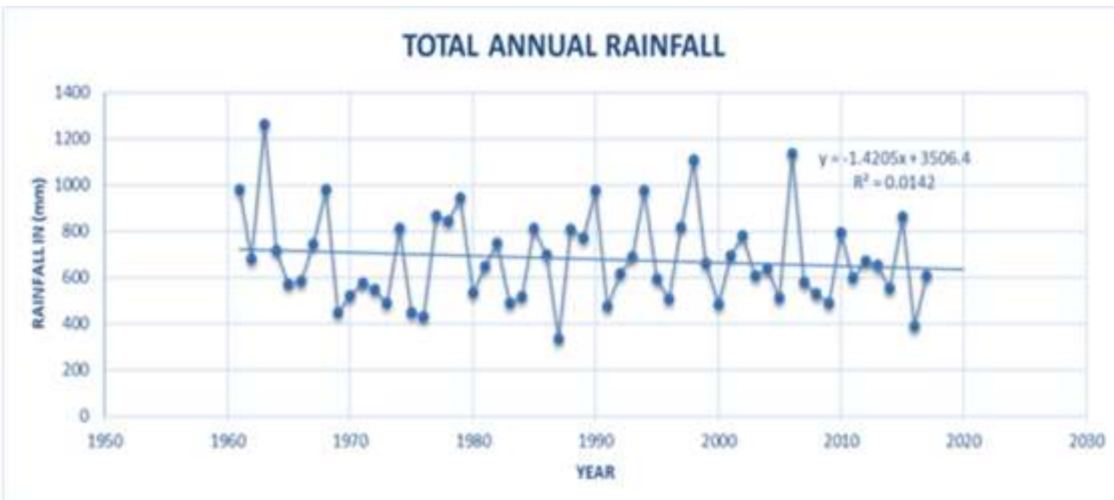


**Figure 6:-** Machakos (Katumani) Annual Rainfall Showing a Decline over the years.

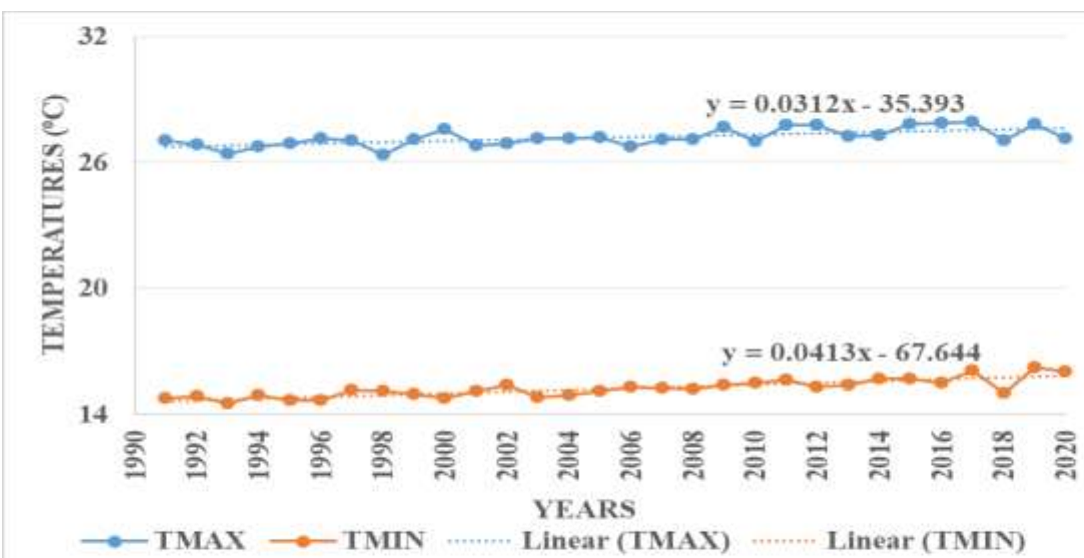


**Figure 7:-** Machakos Annual Mean Maximum and Minimum Temperature Trend over the Years.

**Causes of Climate Change and Variability**

Most farmers attributed climate change and variability to human-related and natural actions (35 %), human activity (32.7 %), an act of God (23%), and natural action (6.5 %). A further 2.8% of the respondents said they did not know the cause (Figure 8). In all FGDs, the most mentioned causes of climate change and variability were deforestation or excessive cutting down of trees, especially indigenous trees, air pollution, and overgrazing. While cutting down trees was mainly for expanding cultivated areas and burning charcoal, the practice was believed to be responsible for drying up water sources, particularly springs, and the deterioration of soil fertility due to soil erosion. This finding concurs with an earlier study by Kuria (2009) that shows deforestation, pollution, and other human activities, including industrial and agricultural activities, contribute significantly to climate change.

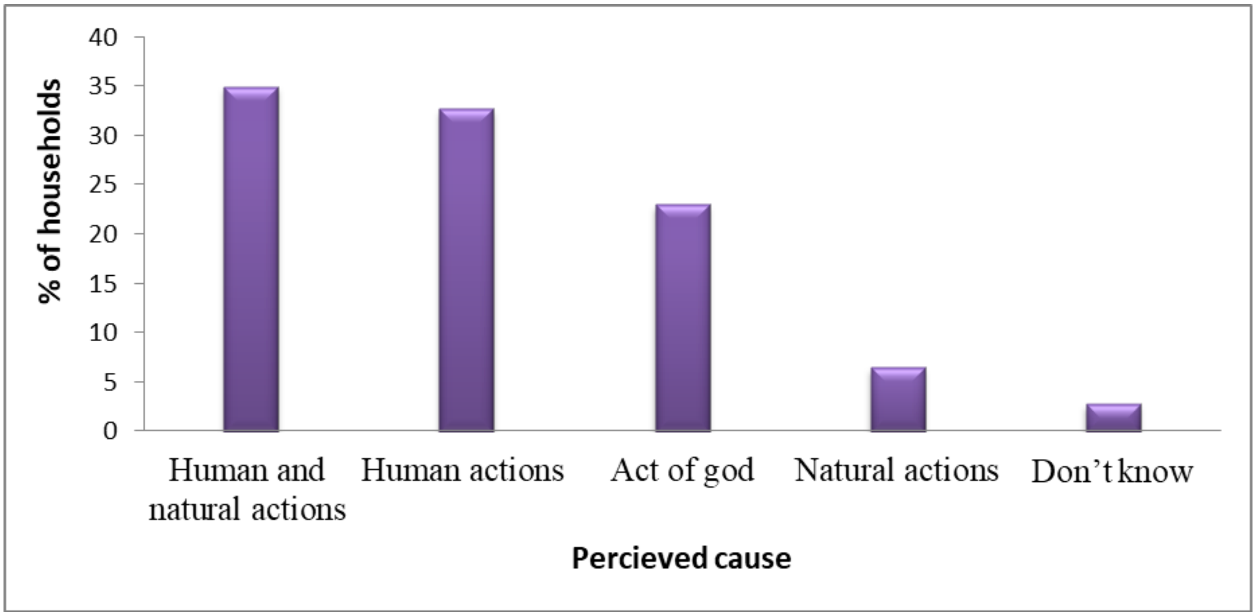


**Figure 8:-** Farmers' Perception of Causes of Climate Change and Variability in Machakos.

Although most farmers could not distinguish between climate change and climate variability, most agreed that there had been changes in the climate in Machakos County. The analysis of smallholder farmers' perception of climate change and variability revealed that most respondents had significant knowledge and understanding of climate change and variability and the likely causes in their local environment. This finding is consistent with studies by Alam et al., 2017 and Tesfahunegn et al. (2016).

**Determinants of Smallholder Farmers' Perception of Climate Change and Variability**

**Econometric Analysis**

**Econometric Estimates of Model Parameters**

Table 1.shows the variables that were hypothesized to influence perception and adaptation decisions by smallholder farmers with regard to climate change and variability.

**Table 1:-** Variables Hypothesized to Influence Perception and Adaptation Decisions by Smallholder Farmers with regard to Climate Change and Variability.

| Variable name | Description/ Measurement | Mean | Std. Dev. | A Priori sign |
|---|---|---|---|---|
| Dependent variable | Perception of climate change and variability. Dummy: 1 if perceived, 0 otherwise<br>Adoption of adaptation strategy<br>Dummy: 1 if adopted, 0 otherwise | | | |
| Explanatory variables | Gender of the HH head<br>Dummy: 1=Male and 0 otherwise | 0.67 | 0.47 | + - |
| | Age of the HH head in years | 38.88 | 7.62 | + - |
| | Years of schooling of the HH head | 1.86 | 1.11 | + |

| | | | | |
|---|---|---|---|---|
| | Access to extension service<br>Dummy: 1=access, 0= No access | 0.24 | 0.43 | + |
| | Access to climate information<br>Dummy: 1=access, 0= No access | 0.90 | 0.30 | + |
| | Off-farm income | 0.73 | 0.44 | + |
| | Household size | 5.38 | 2.51 | + - |
| | Distance to output market in km | 3.80 | 3.39 | + |
| | Access to credit<br>Dummy: 1=access, 0= No access | 0.42 | 0.49 | + |
| | Access to insurance<br>Dummy: 1=access, 0= No access | 0.19 | 0.39 | + |
| | Distance to input market in km | 3.52 | 3.30 | + |
| | Farm size | 2.83 | 4.46 | + |
| | Membership in farmer group<br>Dummy: 1= member of the farmer group,<br>0 =Otherwise. | 0.69 | 0.46 | + |
| | Temperature | 0.98 | 0.13 | + |
| | Rainfall | 0.41 | 0.51 | - |

Before running the Heckman probit model, the explanatory variables were checked for the presence of a multicollinearity problem using the variance inflation factor (VIF). Based on the VIF, the data has no multicollinearity problem with a mean VIF value of 1.261 and a VIF value of less than 5 for each explanatory variable (Table 2). Subsequently, all explanatory variables are included in the model.

**Table 2:-** Variance inflation factor (VIF) for explanatory variables.

| Variable | VIF | 1/VIF |
|---|---|---|
| Gender | 1.186 | 0.84317 |
| Age | 1.147 | 0.87184 |
| HH size | 1.101 | 0.90827 |
| Education | 1.119 | 0.89365 |
| Total Land size acres | 1.100 | 0.90909 |
| Group membership | 1.186 | 0.84317 |
| Access to extension services | 1.119 | 0.89365 |
| Access to climatic information | 1.085 | 0.92166 |
| Distance to input sellers | 1.997 | 0.50075 |
| Distance to extension advice | 1.099 | 0.90992 |
| Distance to market | 2.138 | 0.46773 |
| Access to credit | 1.162 | 0.86059 |
| Access to insurance | 1.206 | 0.82919 |
| Temperature changes | 1.046 | 0.95602 |
| Rainfall changes | 1.228 | 0.8143 |
| Mean VIF | 1.261 | |

To avoid a sample selection bias, this study used the Heckman probit model to estimate the study's parameters. The Heckman probit model was first tested for its suitability and explanatory power. The results showed evidence of a sample selection problem since rho was significantly different from zero (Wald test for independent equations =37.80, with P = 0.0008). The finding, therefore, justified the use of the Heckman probit model. Moreover, the likelihood function of the Heckman probit model was significant (Wald for zero slopes =2137.26, with P = 0.0006), suggesting a strong explanatory power. Table 3 presents the results of Maximum Likelihood estimates and the marginal effects, which is the expected change in the probability of perceiving/or adapting to climate change given a unit change in an independent variable from the mean value, ceteris paribus.

**Table 3:-** Results of the Heckman Probit Modelof Farmers' Perception of Climate Change in Machakos County.

| Explanatory variables | Perception model | | | | Adaptation model | | | |
|---|---|---|---|---|---|---|---|---|
| | Regression model | | Marginal effects | | Regression model | | Marginal effects | |
| | Coefficient | p-value | Coefficient | p-value | Coefficient | p-value | Coefficient | p-value |
| Gender | 0.39* | 0.059 | 0.013* | 0.0553 | 0.103* | 0.0513 | 0.015* | 0.0576 |
| Age | 0.44352*** | 0.042 | 0.015*** | 0.0084 | -0.15** | 0.03828 | -0.012* | 0.0681 |
| Education | 0.569*** | 0.0189 | 0.020*** | 0.00191 | 0.076* | 0.065 | 0.009** | 0.0500 |
| Access to extension services | 0.242* | 0.06 | 0.353*** | 0.0012 | 0.147** | 0.0105 | 0.067* | 0.091 |
| Climate Information | 2.079* | 0.042 | 0.071* | 0.066 | 0.081** | 0.023 | 0.005* | 0.0896 |
| Off-farm income | -1.417*** | 0.01 | 0.075** | 0.0132 | 0.705** | 0.013 | 0.082*** | 0.002 |
| Household size | 0.47* | 0.0648 | 0.016* | 0.066 | -0.093* | 0.07 | -0.011** | 0.030 |
| Distance to market | 0.1111*** | 0.0061 | 0.004*** | 0.00532 | 0.192** | 0.02 | 0.022*** | 0.001 |
| Access to credit | -0.399* | 0.06 | -0.014* | 0.0548 | 0.821* | 0.077 | 0.094*** | 0.007 |
| Access to insurance | 0.0489*** | 0.00 | 0.037** | 0.0145 | 0.60** | 0.025 | 0.070** | 0.0209 |
| Distance to input seller | 0.093* | 0.0543 | 0.086 | 0.0131 | -0.171** | 0.014 | -0.019*** | 0.002 |
| Land size | 0.931** | 0.0146 | 0.031** | 0.0190 | 0.024* | 0.0605 | 0.003* | 0.0546 |
| Group membership | 0.184* | 0.08 | 0.005* | 0.081 | 0.487** | 0.033** | 0.058** | 0.030 |
| Temperature changes | | | | | 0.401* | 0.052 | 0.078** | 0.0255 |
| Rainfall changes | | | | | -0.20** | 0.0175 | -0.200*** | 0.0013 |
| **Diagnostics** | | | | | | | | |
| Wald test for zero slopes | | | 2137.26, Prob> Chi2(1) = 0.0006 | | | | | |
| Wald test for independent equations | | | 37.80, Prob> Chi2(14) = 0.000826 | | | | | |
| Total observations | | | 400 | | | | | |
| Censored | | | 4 | | | | | |
| Non censored | | | 396 | | | | | |

Note* = Significant level at 10%, ** = Significant level at 5%, *** = Significant level at 1%.

The results of the selection model showed that the age of the household head, Gender, education, access to extension services, access to climate information, off-farm income, household size, distance to market, access to credit, access to insurance, distance to input seller, land size and group membership, influenced the farmers' perception of climate change and variability. The results for the outcome model showed that the age of the household head, Gender, education, access to extension services, access to climate information, off-farm income, household size, distance to market, access to credit, access to insurance, distance to input seller, land size and group membership, temperature and rainfall influenced the possibility of a farmer to adapt to climate change and variability.

The likelihood of perceiving climate change and variability is positively related to the Gender of household head, age of the household head, education, access to extension services, access to climate information, household size, distance to market, access to insurance, land size, distance to input market, and group membership. It is, however, negatively related to off-farm income and access to credit. Factors that positively influence smallholder adaptation to climate change and variability in Machakos County include Gender, education, access to extension services, climate information, off-farm income, credit access, insurance, land size, group membership, and temperature. The age of the farmer, household size, distance to market, distance to input seller, and increased rainfall decrease the smallholder farmers' likelihood of adaptation to climate change and variability.

The result of the study established that male-headed households were more likely to perceive climate change and variability than female-headed households ($\beta = 0.013$, $P < 0.1$). The results agree with Asrat and Simane's (2018) and Deressa et al. (2011) findings. This may be explained by the higher probability of male-headed households accessing climate change information than female-headed households. The results show that the age of the household head positively and significantly influences the perception of climate change and variability. The probability of perceiving the impacts of climate change was higher for older farmers compared to younger farmers ($\beta=0.015$, $P < 0.01$). However, the probability of adapting in older farmers was lower than in young farmers. ($\beta=0.012$, $P < 0.1$). Older farmers have more experience in farming and hence have a higher probability of perceiving climate change. However, younger farmer household heads are more innovative and less risk averse and can access and use modern technologies, hence a higher probability of adapting to climate change. The findings agree with Ali and Erenstein(2017) and Gbetibouo (2009) on perception but are contrary to their findings on adaptation.

The study shows that the probability of more educated farmers perceiving climate change and variability was higher than that of less-educated farmers ($\beta=0.020$, $P < 0.01$). Farmers with higher education are more likely to adapt to climate change than those with lower education ($\beta=0.009$, $P < 0.05$). These findings have been reported by Uddin et al., 2017 andNdungu and Bhardwaj (2015). Higher education is likely to enhance access to information on climate change and enhance adaptation as it increases one's ability to receive, decode, and understand information relevant to innovative decision-making.

The study established that farmers who had access to climate information were more likely to perceive climate change than farmers who had no access to climate change information ($\beta = 0.071$, $P < 0.1$). The farmers with access to climate information are also more likely to adapt to climate change than farmers without access to climate change information ($\beta = 0.005$, $P < 0.1$). The findings agree with the findings by Asrat and Simane (2018), Amwata et al.(2018), and Roco et al. (2015).

The study revealed that farmers in contact with extension service providers are more likely to perceive climate change and variability than those not in contact with extension service providers ($\beta =0.353$, $P < 0.01$). Farmers in contact with extension service providers are more likely to adapt to climate change than farmers not in contact with extension service providers ($\beta = 0.067$, $P < 0.1$). Accessibility of information by farmers through extension services has a higher chance of influencing farmers to perceive and adapt to changes in climate. This finding agrees with studies by Gbetibouo (2009) and Nhemachena and Hassan (2007).

Unexpectedly, the study established that farmers without off-farm income were more likely to perceive climate change and variability than farmers who had off-farm income ($\beta= -0.075$, $P < 0 .05$). However, as was expected, farmers with off-farm income were more likely to adapt to climate change and variability than farmers not earning off-farm income ($\beta = 0.82$, $P < 0.01$). The likely explanation for this trend is that farmers with income from off-farm activities could have invested in resilient agricultural production systems, thereby minimizing impacts from climate hazards. Secondly, off-farm activities are not affected by climate change and variability. These observations are similar to earlier observations by Mairura et al. (2021).

Results from the study show that larger households were more likely to perceive climate change and variability than smaller households ($\beta = 0.016$, $P < 0.1$). More interactions among family members in larger families increase the perception of climate change and variability. In contrast, larger households were less likely to adapt to climate change and variability than smaller households ($\beta = -0.011$, $P < 0.05$). This implies that large family consumption needs may hinder investment in adaptation strategies. In an attempt to earn more income to meet the consumption demand by large size, members of large families are likely to divert labour to off-farm activities. This is in line with observations by Ndambiri et al. (2014)

According to the results, farmers farther away from the nearest output market were more likely to perceive climate change and variability than those near the output market ($\beta = 0.0061$, $P < 0.01$). Similarly, the farmers were more likely to adapt to climate change and variability than those near the output market ($\beta = 0.022$, $P < 0.01$). Distance to the nearest market is used to proxy for availability and ease in accessibility of input/output markets. Previous studies by Hassan and Nhemachena indicate that better market access increases farm-level adaptation.

Regarding farmers residing far from input sellers, the study revealed that farmers with longer distances to input sellers were more likely to perceive changes in climate change and variability than those closer to input sellers ($\beta$ = -0.086, P < 0.05). However, farmers further away from input markets were less likely to adapt to climate change and variability than those closest to input markets ($\beta$ = -0.019, P < 0.01). This is, perhaps, because markets serve as a source of information where farmers exchange information with other farmers (Maddison, 2006).

Earlier studies by Kumar and Sidana (2018) and Ndamani and Watanabe (2015 reported access to credit to have positively influenced farmers' perception of and adaptation to climate change and variability. However, in this study, access to credit was found to be inversely related to farmers' perception of climate change and variability contrary to expectation ($\beta$ = -0.14, P < 0.1), meaning farmers who had access to credit were less likely to perceive climate change and variability than those without access. In agreement with the previous studies, access to credit positively influenced adaptation to climate change and variability ($\beta$ = 0.094, P < 0.01). Thus, farmers with access to credit facilities were more likely to adapt to climate change and variability than farmers without access to credit.

The results show a positive relationship between land size and farmers' perception of and adaptation to climate change and variability. Farmers with large farm sizes were more likely to perceive climate change and variability than farmers with small farms ($\beta$ = 0.031, P < 0.05). Similarly, farmers with larger farm sizes are more likely to adapt to climate change and variability than those with small farms ($\beta$ = 0.003, P < 0.1). The finding agrees with studies by Roy et al. (2018).

The results show a positive relationship between membership to a group and farmers' perception of and adaptation to climate change and variability. Farmers with group membership were more likely to perceive climate change and variability than non-group members ($\beta$ = 0.005, P < 0.1). The finding agrees with a study by Mairura et al. (2021). Similarly, farmers who are group members are more likely to adapt to climate change and variability than non-group members ($\beta$ = 0.058, P < 0.05). Membership in groups is a proxy for social capital, andsocial capital is recognized as a resource that can influence production decisions and economic outcomes. According to Maddison (2006), farmers' access to information is through social networks; hence, being a member of a farmer group is expected to positively affect the perception of and adaptation to climate change and variability.

The study established that farmers whohad access to insurance were more likely to perceive climate change than those without insurance ($\beta$ = 0.037, P < 0.05). The farmers with access to insurance are also more likely to adapt to climate change than those who do not access insurance ($\beta$ = 0.070, P < 0.05). This finding agrees with a study byGuo&Bohara (2015) that found a positive relationship between the perception of climate change and weather-based insurance.

The study revealed a positive relationship between temperature changes and farmers' adaptation. Results show that farmers who noted a temperature rise were more likely to adapt than those who did not perceive a temperature rise ($\beta$ = 0.078, P < 0.05). This is probably because temperature rises in Machakos County will likely impact local agriculture negatively and prompt farmers' responses by adapting to the changes. The observations are similar to a study by Deressa et al. (2011) and Gbetibouo (2009).

However, results show a negative relationship between changes in rainfall and farmers' adaptation to climate change and variability. Farmers who perceived an increase in rainfall were less likely to adapt than those who perceived a decrease in rainfall ($\beta$ = - 0.200, P < 0.01). The finding agrees with studies by Deressa et al. (2011) and Gbetibouo (2009). Increased rainfall in Machakos County is likely to be a disincentive to adaptation to climate change by smallholder farmers in the County.

## Conclusion and Recommendations:-

The results of this study indicate that most smallholder farmers were well aware that the climate was changing and that it was the cause of the recurrent droughts ravaging the County. However, the majority of the farmers could not give a clear explanation of what climate change is; their description of climate change was based on their observation of increased temperature extreme, decreased rainfall amount and duration, shift in the timing of rainfall, and adverse effects the particular farmer has observed. Generally, most farmers noted an increase in temperature, a decrease in rainfall, changes in the timing of rains, and an increase in the frequency of droughts. The results further indicate that farmers aged 36-55 were more likely to perceive climate variability and those with post-primarywere more likely to perceive climate variability and change. The results also show that both male and female farmers observed climate changes; however, male-headed households were more likely to perceive climate variability and change.

Farmers' perceptions of climatic variability and change align with climatic data records for the County. The respondents' perception of changes in rainfall temperatures and other weather and climate variables implies that farmers could be valuable informants on initiatives related to climate change in their local environments. This is important in shaping policies on climate change. However, the perception by some respondents that climate change and variability are acts of God implies that due consideration should be given to cultural and religious/ traditional beliefs in designing adaptation measures.

The results of the Heckman probit model indicate that the age of the household head, Gender, education, access to extension services, access to climate information, off-farm income, household size, distance to market, access to credit, access to insurance, distance to input seller, land size and group membership are the factors that influenced the farmers' perception of climate change and variability.

Most of the factors affecting farmers’ perception and adaptation to climate change in the study areas are related to institutions and infrastructure. There is, therefore a need for policy intervention for enhancing institutional services and infrastructural facilities. The results also show that lack of access to information on climate change, low incomes, and low education limit the perception and adaptation decisions of smallholder farmers. Therefore, facilitating effective and reliable access to information, improving farmers’ incomes, and promoting education among smallholder farmers would be important policy intervention measures.

Enhancing perception through climate change policies and actions will help bridge the gaps in knowledge and understanding of climate change and scale up climate change adaptations in the study area.

## Acknowledgement:-
We would like to thank the farmers, agricultural officers, and local administrators of the study area for their assistance during the fieldwork.

**Funding**
The authors thank the World Bank-funded Kenya Climate Smart Agriculture Project (KCSAP) for funding the study. We also thank households we participated in the survey.

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