Natural Resources Forum 41 (2017) 195–208 DOI: 10.1111/1477-8947.12111

Adapting to climate variability and change in rural Kenya: farmer perceptions, strategies and climate trends

Justus Ochieng, Lilian Kirimi and Joyce Makau

Abstract

Climate change has had a significant impact on rain-fed agricultural production in developing countries. Smallholder farmers are the most vulnerable, and currently must make production decisions in a high risk and uncertain environment with regard to rainfall and temperature. This paper uses climate and household survey data to analyse farmer perceptions regarding climate change, adaptation measures taken in response to these changes, and how well these perceptions correlate with meteorological data in Kenya. We find that a significant number of farmers perceive climate change as real, and that they are particularly concerned about changes in rainfall and temperature. Changing crop varieties is predominantly used as an adaptation measure since extension messages often encourage adoption of drought-resistant varieties. Major factors influencing farmer perceptions include age of the farmer, which is often associated with more farming experience and subsequent extension service. Except in low potential zones, farmers' perceptions of climatic variability are in line with climatic data records. Better education, access to extension messages, farm size and credit facilities are necessary for farmers to decide to adapt to climate change. The paper further assesses barriers to the adoption of various adaptation strategies, and lack of finances and knowledge have been found to inhibit adaptation response within the smallholder farming sector. Findings imply that effective adaptation to threats posed by climate variability and change requires a multi-dimensional collaborative approach, with different stakeholders playing key roles in providing support services in terms of education, extension, credit and meteorological information.

Keywords: Climate change; rain-fed agricultural production; smallholder farmers; adaptation methods; rural Kenya.

1. Introduction

Climate variability and change is the most complex and challenging environmental problem facing the world today. Currently, the most pressing questions relate to weather uncertainties, persistent climatic abnormalities, rampant environmental degradation, imminent food insecurity and poverty. The risks resulting from climate variability and change have manifested themselves in rampant soil erosion, landslides, warming and drying, prolonged drought and more intense flooding (CDKN, 2014; Niang *et al.*, 2014). Countries in sub-Saharan Africa (SSA) are particularly vulnerable to the adverse effects of climate change because of their dependence on agricultural production and their limited capacities to effectively adapt. Most farmers are already facing considerable threats, and climate variability and change only worsen these threats through losses in farm profits. Challenges such as persistent poverty and socioeconomic inequality, low levels of development, limited economic capacity, and countless governance and institutional failures (CDKN, 2014) have led to low adaptive capacities and a significant adaptation deficit in SSA (Niang *et al.*, 2014).

Climate variability and change are expected to have a significant impact on Kenyan agriculture in 2020, 2030 and 2040, with some of the greatest effects occurring in the tea sector (Ochieng *et al.*, 2016). The impacts are important for Kenya, a country in which the national poverty rate is 45.9% (49.1% in rural areas), and over 70% of the labour force in rural areas depends on agricultural production for its livelihood (GoK, 2010a). The estimated economic cost of climate change by 2030 will be equivalent to 2.6% of gross domestic product (GDP) per annum in

Justus Ochieng is at the World Vegetable Center, Eastern and Southern Africa, Arusha, United Republic of Tanzania.
E-mail: justus.ochieng@worldveg.org
Joyce Makau and Lilian Kirimi are at the Tegemeo Institute of Agricultural Policy and Development, Nairobi, Kenya.
E-mails: jmakau@tegemeo.org and lkirimi@tegemeo.org

Kenya,[1] with a particularly large economic burden in coastal zones due to sea level rise (SEI, 2009). This is already evident in the periodic droughts and floods that lead to significant economic costs, but Kenya also is not adequately prepared to deal with these challenges. Rainfall variability, coupled with an expected increase in evapotranspiration due to higher temperatures, is expected to lead to production losses of key staples, such as maize (Herrero *et al.*, 2010). For example, maize production declined by 4.2% in 2014, which is attributed to erratic rains, with some regions experiencing depressed rainfall[2] (GoK, 2015). Notably, since the early 1990s, Kenya has been affected by droughts, El Niño rains resulting in the floods of 1997–1998, the drought of 2008–2009 (GoK, 2009) and heavy rains experienced in different parts of the country in 2015–2016.

Given that the majority of the rural population in Kenya depends on agriculture for income, adaptation is vital in enhancing the resilience of the sector, protecting the livelihoods of poor households and ensuring their food security. Several studies have shown that without adaptation, climate variability and change would be detrimental to agricultural productivity and net incomes, but with adaptation, vulnerability would be significantly reduced (e.g., Seo and Mendelsohn, 2008; Di Falco *et al.*, 2012), since the degree to which an agricultural system is affected depends on its adaptive capacity (Ochieng *et al.*, 2016). Kenya's National Climate Change Response Strategy (NCCRS) (GoK, 2010b) and its National Climate Change Action Plan (NCCAP) (GoK, 2013) are the country's main guides in climate change response.[3] As outlined in these documents, it is important to understand farmers' perceptions of climate variability and change, as well as their views on appropriate adaptation measures. This is because farmers' perceptions have a strong influence on how they deal with climate-induced risks and opportunities, and the manner in which they respond to their perceptions in turn determines adaptation measures, the processes involved and adaptation outcomes (Adger *et al.*, 2009). In addition, understanding how farmers judge climate risk is valuable to both Kenyan agricultural extension and meteorological services, in order to upscale farmer support to better manage climate risks and uncertainties.

Several national and farm-level adaptation strategies to reduce negative climate impacts have been proposed. These include investment at the national level in drought-tolerant crop varieties, irrigation systems, early warning and monitoring systems, construction of dykes, disaster relief, insurance and social protection programmes, and integrated strategies to reduce livelihood risks (Howden *et al.*, 2007; Schlenker and Lobell, 2010). The farm-level measures that smallholder farmers can easily adopt by cultivating many crops, intercropping different varieties, using drought-tolerant crop varieties, employing irrigation and water harvesting techniques, adopting crop insurance, changing planting dates, diversifying in and out of agriculture, using safety nets and social networks, selling assets and by livelihood strategies, such as mixed farming and temporary or permanent migration (Bryant *et al.*, 2000; Maddison, 2006; Kabubo-Mariara, 2008; Bryan *et al.*, 2013; Tambo and Abdoulaye, 2013). Previous research on adaptation has demonstrated ways in which policymakers can support adaptation efforts through the provision of credit, training, market information, farm inputs and extension services, among other institutional support services (Kabubo-Mariara, 2008; Gbetibouo, 2009; Tambo and Abdoulaye, 2013). Thus, understanding smallholders' perceptions regarding climate change and the adaptation strategies they undertake in their farming practices will provide insights into the necessary interventions to ensure adequate adaptation at the farm, county and national government levels in Kenya.

This paper contributes to the literature on climate change, farmers' perceptions, and adaptation in several ways, including: (1) the combination of information from household survey data and focus group discussions (FGDs), as well as climate data from the Kenya Meteorological Services (KMS) (we use these data sources to assess how and why farmers undertake particular adaptation strategies to reduce extreme climate impacts); (2) the use of long-term temperature and rainfall data from the last 30 years (1980–2010), while many studies use only rainfall data in a given year, to compare with farmers' perceptions; and (3) the establishment of whether there is consensus between farmers' perceptions and meteorological observations in Kenya, and possible reasons for any mismatch. The remainder of the paper is organized as follows: Section 2, which includes an overview of the literature on perceptions of and adaptation to climate change among rural households; Section 3, which presents research methods, detailing the data sources and empirical modelling strategy employed; and Section 4, which includes the results and discussion, while the conclusion is presented in Section 5.

2. Review of empirical literature on perceptions of and adaptation to climate variability and change

There is limited information from Kenya regarding how well farmer perceptions of climate trends reflect the trends seen in meteorological records. Discrepancies between farmers' perceptions of rainfall and meteorological data

[1] This has been estimated using the FUND model, a global economic integrated assessment model (IAM). The central value includes market and non-market sectors and aggregates positive and negative effects, but excludes future extremes (floods and droughts) and does not capture a large range of potential effects, including those related to all ecosystem services.

[2] Both crop and livestock production suffered from the impacts of poor long rains in some parts of the country, especially in the North Rift, which is a major maize producing zone (GoK, 2015).

[3] The NCCR's vision is a prosperous and climate change-resilient Kenya, while that of the NCCAP is a low carbon, climate-resilient development pathway.

have been reported in the literature (Simelton *et al.*, 2013). This occurs because farmers are likely to base their perceptions on recent years' weather and on extreme events, rather than on the average climate. This may produce inaccurate perceptions of rainfall or temperature change (Marx *et al.*, 2007). For example, farmers in southwest Uganda perceived a change in the seasonality, distribution, amount and intensity of rainfall, as well as a change in temperature, while only temperature had a clear signal in the climate record (Osbahr *et al.*, 2011). However, climate records reflected, albeit to a lesser extent, the perception that rainfall had become more variable. The authors explain that this arises because weather events that impact farmers' livelihoods, especially during consecutive seasons, are remembered more clearly than those without a livelihood impact. Simelton *et al.* (2013) conducted FGDs in Southern Africa, and found that qualitative studies of farmers' perceptions of rainfall add valuable information to conventional meteorological statistics. However, the authors warn that perceptions of rainfall are likely to be confounded unless scientists, practitioners and farmers work together to have a better take on climate change.

Adapting to climate change has been a challenge, especially among smallholder farmers who are most vulnerable to shifting rainfall patterns and droughts. In this regard, for farmers to effectively adapt to climate change, top-down climate exposure and impact scenarios need to be verified with farmers' and extension workers' understandings of how climate is changing (Simelton *et al.*, 2013). Most studies show that farmers use a combination of adaptation options as shown in Oremo (2013) in Kitui District, Kenya, Bryan *et al.* (2013) and Simelton *et al.* (2013) in Botswana and Malawi, Osbahr *et al.* (2011) in Uganda and Tambo and Abdoulaye (2013) in Nigeria Savanna. All of these studies have some weaknesses. For example, Oremo (2013) in Kenya refers only to rainfall for the data collection year, leaving out the long term rainfall and temperature, which often capture climate effects from previous years. Our study uses both rainfall and temperature, as well as covers all agro-ecological zones in Kenya.

Simelton *et al.* (2013) considered only the perception of rainfall, leaving out temperature. Temperature has been found to be the most important component of climate variability and change in Kenya (Kabubo-Mariara and Karanja, 2007; Ochieng *et al.*, 2016). Thus, our study expands upon previous studies in Kenya by combining both qualitative and quantitative methods, as well as considering changes in both rainfall and temperature. On the other hand, Osbahr *et al.* (2010) analysed farmers' livelihood adaptations to climate change in South Africa and Mozambique, and found that livelihood adaptation strategies are strongly influenced by individual circumstances and that households linked to informal social networks adapt better. We extend their study by exploring farmers' perceptions of climate variability and change, how farmers respond and the factors that influence each response strategy.

A recent empirical study in Kenya by Bryan *et al.* (2013) covered most of the agro-ecological zones (AEZ),[4] but does not compare farmer perceptions with meteorological data to explore whether discrepancies exist. In addition, their study uses discrete choice dependent (logit) models to understand what drives the adoption of each adaptation strategy. However, this approach is prone to biases, as it ignores common factors that might be unobserved and affect adaptation strategies differently. Our study, therefore, further contributes to the literature by adopting unbiased multivariate probit (MVP) estimated by simulated maximum likelihood (SML), and combines farmer perceptions with adaptation strategies and climate data to explain farmers' responses to climate variability and change. We also show the similarities and differences between farmers' perceptions of climate trends and variability and the observed climate data. We believe that a good understanding of farmer perceptions regarding long-term climatic changes is fundamental to informing policy for successful adaptation among smallholder farmers in Kenya.

3. Methods

3.1. Data sources and setting

This study employed three primary data sources: (1) a survey of 1,309 households across eight agro-regional zones in rural Kenya, collected by the Tegemeo Institute of Agricultural Policy and Development of Egerton University, Kenya; (2) FGDs conducted by Tegemeo between July and August 2011 in various sub-locations within the eight agro-regional zones; and (3) climate data from KMS. These data sources were supplemented with information on recent floods and droughts from Disaster Preparedness Management (GoK, 2009). Agro-regional zones are a hybrid of broad agro-ecological zones, administrative and political boundaries (Argwings-Kodhek *et al.*, 1999), but in this paper we further reclassified them into high and low potential zones (generally characterized by dry periods and poorer soils).[5] High potential zones are located above 1,200 m altitude, experience mean annual temperatures of below 19°C and have volcanic rocks and fertile loamy soils. These areas are suitable for dairy farming (cattle and sheep), cash crops (coffee, tea and pyrethrum) and key food crops (maize, beans and wheat). In the low potential zones temperatures are higher, reaching up to 35°C, and

[4] The study covered Garissa (arid), Mbeere South, Njoro (semi-arid), Othaya (temperate) and Siaya districts (humid).

[5] High potential zones: western transitional, high potential maize zone, western highlands and central highlands. This includes the following former districts: Trans Nzoia, Uasin Gishu, Kakamega, Vihiga, Bungoma, Narok, Nakuru, Bomet, Nyeri, Muranga, Kisii, and Meru. Low potential zones: coastal lowlands, eastern lowlands, western lowlands and marginal rain shadow. This covers the following former districts: Kilifi, Kwale, Taita Taveta, Kitui, Machakos, Makueni, Mwingi, Kisumu, and Siaya.

the areas are generally characterized by shallow and infertile soils that have mainly developed from sedimentary rocks. While they allow for livestock and crop systems like those found in the high potential areas, productivity is lower. The agro-regions included in the study are coastal lowlands, eastern lowlands, western lowlands, western transitional, high potential maize zone, western highlands, central highlands and marginal rain shadow. The sample covered 107 villages across these eight agro-ecological zones in Kenya.

The household survey included information on household composition, land and other asset holdings, crop and livestock production, perceptions on climate change (changes in rainfall and temperature in their locality over the past 10 years), non-farm sources of income and distance to key services (Table A1 in the Appendix). We conducted a total of 24 FGDs between July and August 2011 in various sub-locations within the eight agro-regional zones. Each focus group had between 15 and 20 participants, with men, women and youth in attendance. We obtained information from farmers on their perceptions regarding trends, patterns and changes in agriculture and rural livelihood activities, general disasters, climate variability and change. We ensured that we obtained reliable and relevant information on farmer perceptions through probing, iteration and observations.

We also incorporated climate data from 29 KMS weather stations across the country. The data were comprised of monthly rainfall and mean temperatures in 2010, as well as their long term means from 1980 to 2010, for various regions in Kenya. In addition, we disaggregated the analysis by high versus low potential zones, since we expected perceptions and adaptation practices to vary among households, depending on their locations. We recognized that most studies on perceptions and adaptation to climate change in Kenya have not included agro-climate zones in their analysis (e.g., Bryan *et al.*, 2013; Oremo, 2013), yet farmers adopt different adaptation strategies depending on the type of climate variability and change they experience.

3.2. Multivariate analysis of climate change adaptation practices

Farmers, as decision-makers, face multiple managerial options, observed outcomes that can be modeled within the framework of theories of discrete choice. The choices they make always depend on a variety of factors, including access to and availability of financial resources, information, physical resource endowment, and personal farmer attributes. Based on this, we use random utility theory to explain farmers' adoption of climate change adaptation practices, where a household's utility is specified as a linear function of household and farm characteristics, attributes of the different available technologies and other institutional factors, as well as a stochastic component (Greene, 2003). The probability of choosing a specific adaptation practice is equal to the probability that the utility of doing so is greater than or equal to the utilities of all other alternatives in the choice set. An approximation of the true underlying utility generated by each alternative can be modeled as a linear function of individual characteristics, choice attributes, or a combination of both (Ben-Akiva and Lerman, 1985). With this, it is possible to estimate a discrete choice process using latent regression modeling techniques.

Many empirical studies have used a multinomial logit (MNL) to model determinants of farmers' choices of adaptation strategies in SSA (e.g., Nhemachena and Hassan, 2008; Deressa *et al.*, 2009; Hisali *et al.*, 2011), while some have used a logit model (Bryan *et al.*, 2013; Oremo, 2013). This modeling approach is not preferred, given that most farmers adopt several adaptation strategies simultaneously, and the number of response categories is often too large to perform an MNL, even after grouping similar responses. Furthermore, with grouping, it is difficult to interpret the influence of explanatory variables on the original separate adaptation measures (farmers may adopt multiple adaptation measures at the same time). We use MVP using SML to model each of the adaptation strategies. This model is preferable to discrete choice dependent models (probit/logit), which ignore the possible correlation in the adoption of adaptation practices, and simply estimate the equations independently. This generates biased and inconsistent estimates of the standard errors of the βj parameters for each practice (Greene, 2003), inducing incorrect inference as to the significant determinants of adaptation choices.

Nevertheless, we also use a MNL model to analyse the factors affecting the perceptions of long-term changes in average temperature and rainfall, as these fall into several mutually exclusive categories, for example, a perception of increase, decrease and no change. This model permits the analysis of multiple responses over a base category. The probability that a household i with characteristics X has climate perception P_j is specified as:

$$P_{ij} = X_i \propto_j + \varepsilon_{ij}, j = 0, 1 \ldots\ldots j. \tag{1}$$

Multinomial logit (MNL) requires that the dependent variables be mutually exclusive so that if farmer i perceives that the temperature has increased, he or she would not also perceive that the temperature has not changed. Moreover, grouping adaptation responses into artificial categories confounds the analysis of the factors influencing farmers' decisions to adopt key strategies, and does not allow for a meaningful analysis of adoption decisions (Bryan *et al.*, 2013).

Following the statistics literature (Ashford and Sowden, 1970) and as applied in Lin *et al.* (2005), the MVP econometric approach used for this study is characterized by a set of n binary dependent variables y_i (with observation subscripts suppressed), such that:

$$y_i = 1 \text{ if } x'\beta_i + \varepsilon_i > 0,$$
$$= 0 \text{ if } x'\beta_i + \varepsilon_i \le 0, i = 1, 2, \ldots\ldots\ldots, n, \quad (2)$$

where x is a vector of explanatory variables, β_1 , β_2 … … … . β_n are conformable parameter vectors, and random error terms ε_1 , ε_2 , . . … . , ε_n are distributed as multivariate normal distribution with zero means, unitary variance and an n x n contemporaneous correlation matrix $R = [\rho_{ij}]$, with density $ø(\varepsilon_1 , \varepsilon_2 , . . … . \varepsilon_n ; R)$. The likelihood contribution for an observation is the n−variate standard normal probability:

$$\Pr(y_{i,\ldots} y_n {}^{\circ} x = \int_{-x}^{(2_{y_i}-1)x'\beta_2} . \int_{-x}^{(2_{y_i}-1)x'\beta_2} \ldots\ldots$$
$$X \int_{-x}^{(2_{y_i}-1)x'\beta_2} ø(\varepsilon_1, \varepsilon_2, \ldots\ldots \varepsilon_n; Z'RZ) d\varepsilon_n \ldots\ldots d\varepsilon_2 d\varepsilon_1, \quad (3)$$

where $Z = diag[2y_1 - 1, \ldots, 2y_n - 1]$. Maximum-likelihood estimation is carried out by maximizing the sample likelihood function, which is the product of probabilities (2) across sample observations. A Geweke–Hajivassiliou–Keane (GHK) probability simulator is used to estimate the standard normal probability of each adaptation option (Hajivassiliou and Ruud, 1994). The GHK simulator exploits the fact that a multivariate normal distribution function can be expressed as the product of sequentially conditioned univariate normal distribution functions, which can be easily and accurately evaluated (Cappellari and Jenkins, 2003). We then calculated asymptotically standard errors of the maximum-likelihood estimates by inverting the outer products of the numerical gradients (Berndt *et al.*, 1974). The marginal effects of explanatory variables on the propensity to adopt each of the different adaptation options are calculated as:

$$\frac{\partial P_i}{\partial x_i} = ø\left(x^i \beta\right) \beta_i, i = 1, 2; \ldots n, \quad (4)$$

where P_i is the probability of event i (an adaptation measure), φ (·) is the standard univariate normal cumulative density distribution function, and x and β are vectors of regressors and model parameters, respectively. The marginal effect is the percentage change in the probability of adoption associated with a unit increase of the variable from the mean value. For dummy variables, the marginal effect shows the impact of the variable changing from 0 to 1.We then tested for multicollinearity among the explanatory variables given that most traditional regression models suffer from this, leading to imprecise parameter estimates (Kleinbaum *et al.*, 1988). We calculated the variance inflation factor (VIF) for each explanatory variable, which ranged from 1.27 to 1.59, and hence did not reach conventional thresholds (10 or higher) that are considered to be problematic in the regression diagnosis literature. Hence, multicollinearity is not a problem in this analysis.

Table 1. Farmers' perceptions of long-term temperature and rainfall changes in the last 10 years in Kenya

	AEZ		
Perception	**High potential**	**Low potential**	**Total**
	Temperature (percent)		
Perceived change	44.4	51.9	46.8
Increase	71.8	80.6	74.9
Decrease	28.2	19.4	25.1
	Rainfall (percent)		
Perceived change	86.0	77.0	83.1
Increase	53.1	54.4	53.5
Decrease	47.9	45.6	46.5
N	887	422	1,309

4. Empirical results and discussion

4.1. Farm households' perceptions of climate change

The importance of understanding farmer perceptions regarding climate variability and change has been emphasized in several studies (Maddison, 2006; Adger *et al.*, 2009; Jones and Boyd, 2011). Farmers' abilities to adapt effectively to climate change require that the past experiences and perceptions of climate change must be understood. We find that about half of the farmers (47%) perceived a change in temperature, and 83% perceived that rainfall had changed in the last 10 years in their area (Table 1). This confirms empirical findings in eleven countries in SSA that indicate that the climate has changed and in Kenya, 58 and 73% of farmers perceived changes in temperature and rainfall, respectively (Maddison, 2006).[6] In terms of the ways in which temperature has changed, results show that 75% of the households perceived that temperature has increased over the same period. These findings are in line with Maddison's, which showed that 62% of farmers believed that temperature had increased, while 70% perceived a decline in rainfall in Kenya. The results differ across the zones, with 81% of households in low potential zones and 72% of households in high potential zones perceiving an increase in temperature. Similarly, most farmers perceived that rainfall has increased (54%), while 46% felt that it has declined (Table 1).

During the FGD meetings, farmers reported that since the 1970s, temperatures both in the hottest and coldest months have been increasing. High temperatures have led to heat stress for plants, thus lowering productivity. As a result, food productivity has been declining, which in turn has led to food insecurity, which has prompted farmers to diversify their crop varieties and look for alternative

[6] This was a GEF funded project on *Climate Change Impacts on and Adaptation of Agro-ecological Systems in Africa*. The project has been implemented in 11 countries: Burkina Faso, Cameroon, Ghana, Niger and Senegal in West Africa; Egypt in North Africa; Ethiopia and Kenya in East Africa; and South Africa, Zambia, and Zimbabwe in Southern Africa.

sources of income (off-farm activities). The number of cold days had also fallen, but with a subsequent increase in the number of extremely hot days, especially in the low potential zone. Compared to the 1970s and 1980s, the months when high temperatures are experienced have increased, and there has also been a shift in the coldest months from June to July and August.

4.2. Factors influencing farmers' perceptions of climate change

The analysis of factors influencing farmers' perceptions of climate change is presented in Table 2, in which columns (1) and (3) show results of the logit model, while columns (2) and (4) show results of the MNL model. The findings confirm those reported by Bryan *et al.* (2013) and Oremo (2013) in Kenya and Gbetibouo (2009) in South Africa that over time, farmers have different perceptions of climate change. Young farmers with less farming experience were more likely to perceive long-term changes in rainfall and temperature and an increase in average temperature. Households with more members were more likely to perceive changes in rainfall and temperature, as well as an increase in temperature. Similarly, education seems to increase the probability that farmers will perceive long-term changes in rainfall and a decrease in temperature.

Female-headed households were more inclined to perceive a decrease in temperature than male-headed households. Households that had most of their land fallow were more likely to perceive a decrease in rainfall and, also as expected, households that have been affected by drought in the last 10 years were more likely to perceive a decrease in rainfall. Farmers who were members of a group were less likely to perceive any change in rainfall, though group participation increased the propensity to perceive a decrease in rainfall. Results from focus group discussions with farmers revealed that, since the 1970s and 1980s, temperatures have increased and rainfall has significantly decreased, and this was also reported by Roncoli *et al.* (2010) in Mbeere, Siaya, Mukurwe-ini, Nakuru and Garissa areas of Kenya. And as indicated by Ogutu *et al.* (2007), perceptions may also be influenced by the prolonged and severe droughts in recent years.

Households in the high potential zone were more likely to perceive changes in rainfall, specifically a decrease. They were also less likely to perceive an increase in temperature, as compared to households in the semi-arid low potential zones. The households in low potential zones were more likely to perceive an increase in temperature and a decrease in rainfall over the years. From the discussions, it is clear that rainfall patterns are becoming more unpredictable, both in their timing and volume. This has led to greater uncertainty and heightened risks for farmers, effectively eroding traditional agricultural knowledge, such as when to plant and harvest crops, as indicated during FGDs. The major concern is that frequent weather variability affects farmers' ability to predict rainfall patterns, and they have to plan their farming activities in response to the change.

4.3. Farmer perceptions and meteorological evidence from KMS

In this subsection, we examine the findings regarding farmer perceptions of climate change presented in

Table 2. Factors influencing farmers' perceptions of climate change

	(1)	(2)		(3)	(4)	
		Perceive change in average rainfall (base: no change perceived)			Perceive change in average temperature (base: no change perceived)	
Explanatory variables	**Perceive change in rainfall**	***Increase***	***Decrease***	**Perceive change in temperature**	***Increase***	***Decrease***
Age	−0.002*	0.000	−0.001	−0.002**	−0.003*	0.001
Gender	−0.038	0.000	−0.028	−0.048	0.023	−0.060***
Household size	0.007*	0.003	0.003	0.013***	0.013***	−0.001
Education in years	0.012***	0.003	0.003	0.009**	0.004	0.005**
Distance to extension	0.002	−0.003	0.004*	0.005*	0.003	0.001
Land size	−0.002	−0.002	−0.001	0.006***	0.003*	0.002**
Flood in last 10 years	0.016	0.003	−0.045	−0.020	−0.035	0.028
Drought in last 10 years	0.037	−0.060	0.126***	−0.059	−0.049	0.022
Fallow	0.033**	−0.009	0.029*	0.008	0.020	−0.016
Credit	0.012	0.098***	−0.025	−0.023	−0.060**	0.040*
Receive relief	0.002	0.010	0.009	−0.006	−0.011	0.007
Group membership	−0.060***	−0.133***	0.054*	0.006	0.026	−0.017
Agro-ecological zone	0.103***	−0.051	0.124***	−0.086**	−0.102***	0.025
Sample (N)	1,243	1,243	1,243	1,243	1,243	1,243

Note: Asterisks denote the level of significance, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. The results presented are marginal effects. Models 1 and 3 are logit estimations, and models 2 and 4 are based on MNL.

subsection 4.1 in conjunction with meteorological data to assess the perceived versus actual rainfall and temperature changes. This helps in discussing why discrepancies may occur between farmers' perceptions and meteorological observations of rainfall and temperature. Climate trends (1980–2010) are presented in Figure 1., with short-term trends (2000–2010) in Figure A1. in the Appendix. A significant proportion of farmers (75%) perceived an increase in temperatures, with the majority of them located in low potential zones. Overall and when only 10 years are considered, we find that farmers' perceptions and climate data both agree upon trends of increasing temperature in high potential zones (Figure 1.) and in low potential zones (Figure A1.). However, there are climate patterns that do not correspond with some of the farmers' perceptions. For instance, farmers in low potential zones perceived increasing rainfall, but the data show a declining trend in rainfall.

From these results, it is evident that sometimes there exists a mismatch between farmers' opinions and evidence of climate data; a similar observation was made by Osbahr *et al.* (2011), Bryan *et al.* (2013) and Simelton *et al.* (2013). The translation of scientific 'truths' about global climate change that morph into myths about environmental change at the local level and the repetitive nature of extension messages about climate change have been given as the reasons for mismatch (Roe, 1999). Thus, farmer perceptions are likely to be based on the causes of climate change (Osbahr *et al.*, 2011) and their experiences of weather events such as floods and droughts. For example, farmers perceive a decline in rainfall, despite there being no evidence in the climate data. This could be due to increasing temperature, since high temperature often leads to higher evapotranspiration and greater demand for water and increased severity of pests and diseases, and affects the nutrients available in the soil. In turn this affects farmers' crop production. Farmers may not be able to distinguish among changes in the actual rainfall (exposure), impacts of rainfall and in the farming system's sensitivity to rainfall (Simelton *et al.*, 2013). Some perceptions also point out that farmers associate causes of climate with climate change because of the historical change of their locality. For instance, it emerged during the FGDs that the need for water has changed over time in the low potential zones due to other factors (e.g., growing population) that increased demand for rain, which is naturally highly variable. Similar observations have been made by Osbahr *et al.* (2010) in Uganda and Thomas *et al.* (2007) in Southern Africa. Focus group meetings (FGDs) with qualitative questions also confirm that some farmer perceptions on climate change do not match meteorological data.

4.4. *Farm households' adaptation to climate change*

The farm-level adaptation strategies being used by farmers in response to changing climatic conditions are presented in Table 3. These strategies are grouped into adaptations by agro-ecological zone and farmer perceptions regarding temperature and rainfall. The findings indicate that more than 60% of the farmers are not using any adaptation strategies. Specifically, the majority of these are farmers in high potential zones (68%) and those who perceive an increase in temperature (87%), but do not adjust their farming practices in response to this change (Table 3). Farmers who perceive changes in rainfall adapt to climate change more readily than those who perceive changes in temperature. It seems like farmers worry about changes in rainfall[7] and have more options to deal with it compared to temperature.

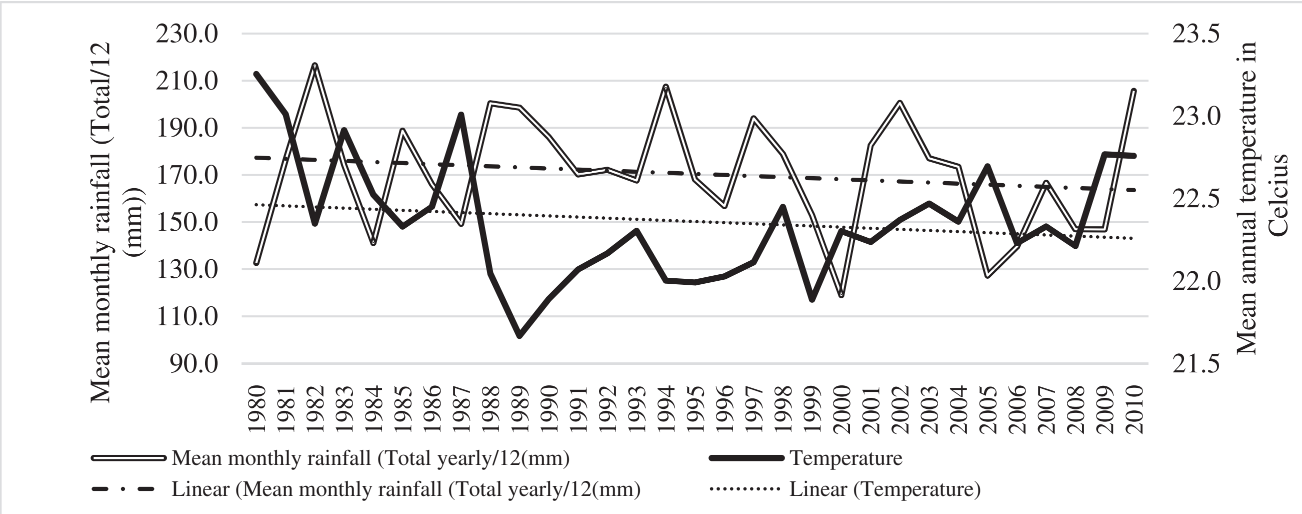
Most farmers use crop management practices such as changing crop varieties, planting trees and using soil and water conservation measures. At the same time, few farmers have adopted irrigation or varying planting dates to ensure that critical stages of plant growth do not coincide with very harsh climatic conditions in a given season. Changing crop varieties is widely used by farmers as an adaptation measure. This confirms reports from the FGDs that since the 1990s, crops grown have changed, with some crops having been abandoned (especially in the lowlands) and others having been introduced. It is only in the western highlands that all crops that were grown in the 1970s and 1980s are still being grown today.[8] Strategies such as irrigation and water conservation measures are useful in lengthening the growing period of crops, even during extreme climate conditions.

Crop diversification, better land preparation, proper timing of harvesting and purchasing more land registered low adoption by farmers. A strategy like crop diversification gives better insurance by reducing the downside risk of crop failure resulting from poor weather conditions, and also helps in diversifying income sources and conserving natural resources. It also reduces susceptibility to climatic variability such as frequent floods or prolonged droughts, which might result in crop failure. It is important to note that these adaptation strategies should not be adopted in isolation, but in a complementary manner.

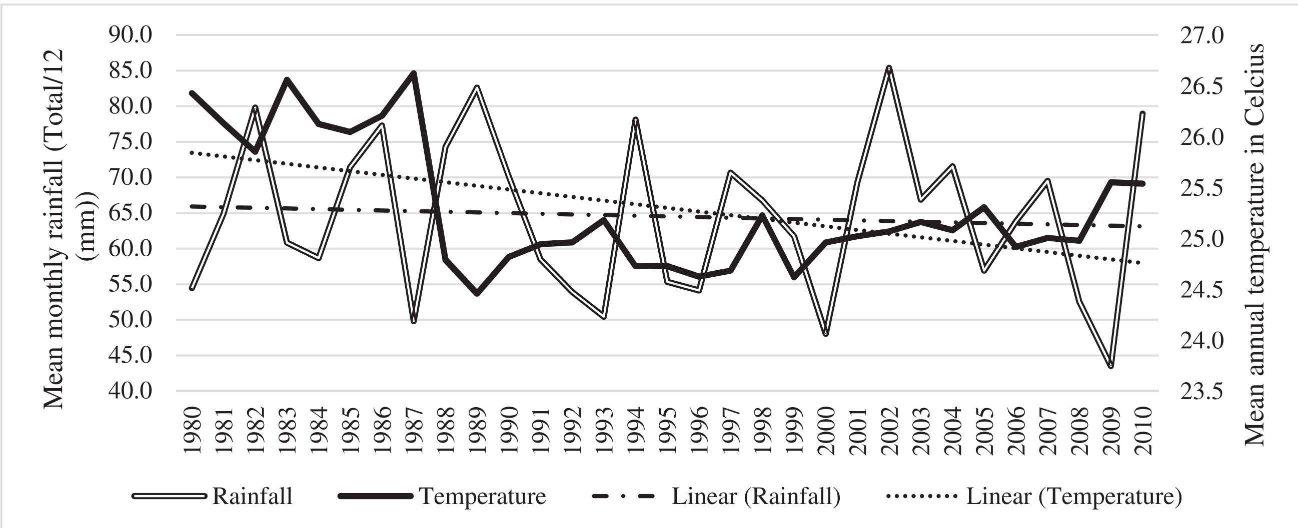
We further assess the factors that influence the adoption of the most frequently implemented adaptation strategies. Older farmers were more likely to adopt new crop varieties and plant trees compared to younger ones (Table 4). As farmers advance in age, they gain more experience and awareness, and accumulate sufficient wealth required to easily enhance their ability to purchase crop varieties. Experienced farmers also have high skills in farming

[7] Changes in rainfall may be more noticeable and have greater and more long-lasting devastating effects.

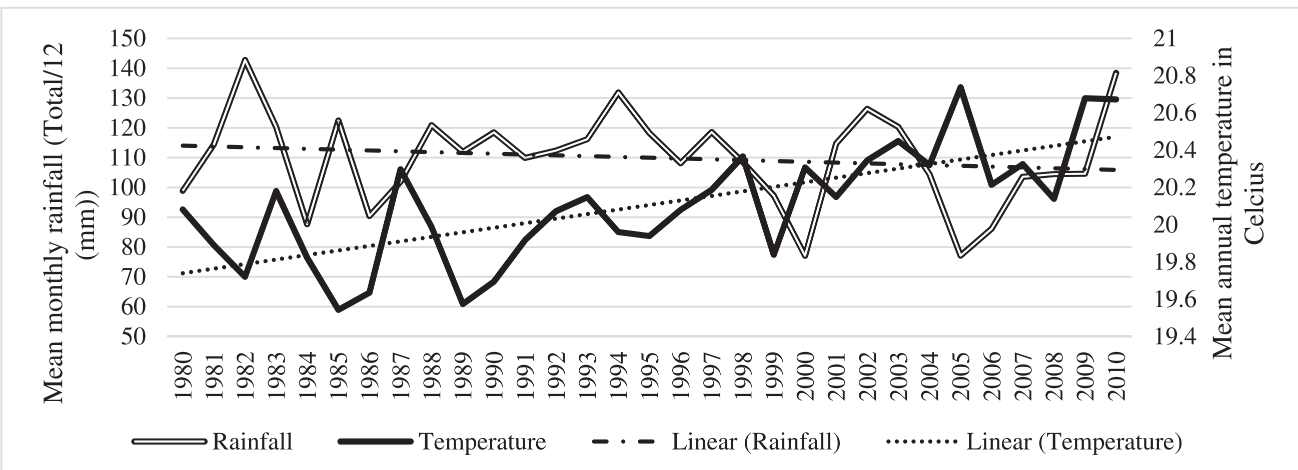
[8] Except in coastal lowlands where cashew nuts and castor oil crops have been abandoned, orphan crops (cassava, sorghum, millet, pumpkins and indigenous vegetables, among others) have been abandoned in eastern lowlands, western lowlands, western transitional, central highlands and marginal rain shadow, and new crops have been introduced.



Climate trends in the last 30 years (1980 to 2010) for all zones



Climate trends in the last 30 years (1980 to 2010) in low potential zone



Climate trends in the last 30 years (1980 to 2010) in high potential zone

Figure 1. Climate trends from 1980–2010. *Source*: Kenya Meteorological Services (KMS).

Table 3. Farm-level adaptation strategies in Kenya (percent of respondents)

	Adaptations by zone		Adaptations by perception on rainfall		Adaptations by perception on temperature		
Adaptation strategies	***High potential***	***Low potential***	***Increase***	***Decrease***	***Increase***	***Decrease***	**Total**
Changing crop varieties	21.8	18.5	20.3	25.1	27.2	17.6	19.6
Planting trees	6.4	13.6	10.3	18.0	18.0	10.5	11.3
Water harvesting	1.7	2.5	2.6	3.2	2.9	4.6	2.2
Soil and water conservation measures	16.4	10.7	17.5	13.2	20.0	12.4	12.5
Irrigation	5.2	5.5	1.2	12.8	8.1	2.0	5.4
Change timing of planting	0.5	1.8	1.0	1.4	2.2	0.0	1.4
Crop diversification	0.7	0.8	1.8	0.0	0.2	0.0	0.8
Better land preparation	0.2	0.0	0.0	0.0	0.2	0.0	0.1
Proper harvesting time	0.0	0.1	0.2	0.0	0.0	0.7	0.1
Bought more land	0.0	0.1	0.2	0.0	0.0	0.0	0.1
Not adapting	68.3	62.2	39.3	45.3	87.4	51.9	64.2
Sample-N	887	422	503	438	456	153	1,309

Table 4. Determinants of adaptation strategies

Factors	**(1) Change crop varieties**	**(2) Planting trees**	**(3) Water harvesting**	**(4) Soil and conservation**	**(5) Irrigation**	**(6) Changing planting time**
Age of head	0.009**	0.009**	0.002	0.007	−0.006	0.006
Gender of head	0.023	−0.130	−0.075	−0.066	0.179	0.964**
Household size	−0.020	0.036**	−0.002	−0.014	−0.025	−0.061
Education of head	0.021*	0.045***	0.020	0.022*	0.025	−0.030
Distance to extension	−0.032*	−0.023*	−0.014	−0.001	−0.009	0.009
Farm size	−0.017**	0.013*	0.008	−0.017*	−0.031*	0.006
Leave land fallow	−0.052	0.080	−0.267	0.120	−0.168	0.089
Receive government subsidy	0.180*	0.194*	0.027	0.164	0.555***	0.029
Access to electricity	−0.086	−0.361*	0.146	−0.374**	−0.038	−0.588
Total income	1.7e-07	−2.5e-07	5.5e-08	−1.8e-08	2.7e-07*	8.7e-08
Receive credit	−0.263***	−0.071	−0.241	−0.206*	−0.195	−0.135
Receive relief	−0.412	0.165	0.278	0.248	−0.272	−2.904
Group membership	−0.048	0.047	0.196	−0.009	−0.171	0.060
Temperature (1980–2010)	0.016	−0.023	0.051*	0.012	−0.017	0.027
Rainfall (1980–2010)	−0.001	−0.002	−0.003	−0.001	−0.004	0.001
Perceived change in temperature	0.415***	0.472***	0.180	0.531***	0.270**	0.347
Perceived change in rainfall	−0.025	−0.010	0.172	0.369***	−0.883***	−0.143
Agro-ecological zone	−0.041	0.509***	0.306	−0.059	−0.087	0.678*
	(0.109)	(0.140)	(0.223)	(0.121)	(0.178)	(0.365)
Constant	−0.899	−1.552**	−3.212***	−1.346**	1.195	−4.138***
Observations	1,243	1,243	1,243	1,243	1,243	1,243
Log likelihood	−1715.222					
Wald $chi^2(108)$	265.93					
Prob > chi^2	0.0000					

Note: Asterisks denote the level of significance, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

techniques and management, and are able to adopt tolerant crop varieties that reduce climate risk.

Male household heads were significantly more likely to adopt irrigation and change planting times than female household heads. Previous research in Africa has indicated that women's lower access to critical resources (land, cash and labour) often undermines their ability to invest in production technologies and mobilize farm labour (Quisumbing *et al.*, 1995). Resource inequities between men and women play a big role in the adoption of these practices. In many African societies, such inequities are often caused by cultural conditions, which traditionally did not grant women secure entitlements to land (Quisumbing *et al.*, 1995). This applies in this case because irrigation is capital intensive, and requires both land and the purchase of irrigation equipment (e.g., sprinklers, water, pipes). This reflects the sentiments of one of the participants in the FGDs, who mentioned that "due to climate variability and change, women and youth are the most affected because they don't have land, unable to access credit and face food shortage during extremely dry season".

Large households are more likely to have adequate labour for the implementation of adaptation practices, and this may explain why household size significantly increased the probability of deciding to plant trees when faced with climate variability and change. Household heads with more years of schooling were more likely to adapt to climate change by changing crop varieties, planting trees and undertaking soil and water conservation measures. Given that adaptation practices are knowledge-intensive and require considerable management skills, formal schooling may enhance latent managerial ability and improve cognitive capacity. This implies that efforts should not only focus on providing technological options to smallholder farmers, but also on promoting education, through an emphasis on farm management training and skills building.

Being far from extension services significantly reduced the likelihood of changing crop varieties and planting trees by 3% and 2%, respectively. This is probably because access to extension messages enhances farmers' knowledge and aids them in making quick decisions. Such messages often emphasize risk spreading and farm-level risk management. At the same time, having larger farm sizes increased the probability of choosing to plant trees as an adaptation measure.

Farmers who received a government fertilizer subsidy were likely to decide to change crop variety or adopt completely new varieties and invest in irrigation technologies. According to Kamara (2004), improved crop varieties often demand fertilizer; therefore, farmers receiving fertilizers would adopt new improved crop varieties to adapt to climate variability and change. In addition, a subsidy helps to relax credit constraints, and subsequently enables farmers to adopt crop varieties and irrigation, all of which require high financial outlay. Households with an electricity connection were less likely to plant trees and use soil and water conservation measures, perhaps because they were well off to begin with, and used different measures, such as purchasing food from the market, in dealing with the effects of climate variability and change. Higher farm and non-farm income proved to be important in fostering the use of the adaptation practices. Having access to credit was an important determinant in increasing the adoption of soil and water conservation and irrigation, but decreased the probability of changing crop varieties. Households that received relief food were less likely to change crop varieties. This may be because such households are often poor, and thus unable to invest in their livelihood activities. Perception of climate variability and change influenced the uptake of adaptation strategies; for example, perceived increase in temperature increased the probability of farmers changing crop varieties, planting trees and investing in soil and water conservation and irrigation measures. Additionally, farmers who perceived an increase in rainfall were more likely to adopt soil and water conservation, but less likely to invest in irrigation facilities, probably due to the large capital required.

Finally, agro-ecological zones have significant effects on the adoption of various practices, indicating the importance of regional characteristics and peculiarities concerning adaptation to climate change. Being located in a high potential zone increased the probability of farmers planting trees, using water harvesting techniques and changing planting time, while farmers in the lowlands were more likely to adopt soil and water conservation techniques. Overall, our study shows that age, gender and education of the household head, distance to extension, farm size, access to credit, subsidy, relief and electricity and AEZ play an important role in enhancing the adaptive capacity of smallholder farmers when faced with climate change. However, most farm households face considerable barriers in adapting to climate variability and change, and the most important barriers are discussed in subsection 4.5.

4.5. Barriers to adaptation to climate change

In this subsection, we assess farmers' perceived barriers to the adoption of the various adaptation strategies discussed in subsection 4.4. Results from household-level data indicate that 64% of farmers do not adjust their farming practices in response to perceived climate change and variability. In all agro-ecological zones, it emerges that lack of finances (52%) and lack of knowledge regarding appropriate adaptation measures (41%) were the most important constraints to farmer adaptation (Table 5). Similarly, from the FGDs, farmers indicated that although they noticed changes in rainfall and temperature in the last ten years, their adaptive capacity was limited by these two constraints. Similar results were reported in Kenya by Bryan *et al.* (2013), in Nigeria by Tambo and Abdoulaye (2013), in South Africa by Nhemachena and Hassan (2008) and in Uganda by Kansiime (2012).

Smallholder farmers require important information related to climate change forecasting, early warnings, adaptation options and other agricultural production activities (rationing of inputs, usage of seed inputs and water conservation techniques), yet results show that they have limited

Table 5. Constraints to the adoption of adaptation strategies in Kenya (percent)

Barriers	High potential zone	Low potential zone	All zones
Inadequate finances	53.8	48.0	51.9
Labour shortage	2.2	2.1	2.1
Lack of knowledge/ information	41.2	41.4	41.3
No need to do anything it's nature	2.4	0.2	1.7
No. observations	208	470	678

ability in accessing the necessary resources and technologies for adapting to the extreme effects of climate change and variability. However, smallholders sometimes fail to adapt, even when provided with adequate information, because they are resource-constrained and lack credit facilities and other inputs, leaving them unable to meet the cost of adaptation measures (Kandlinkar and Risbey, 2000). From the survey, only 27% of farmers accessed credit, mainly from informal sources, further confirming that a lack of sufficient funds to implement adaptation strategies is a major problem. These findings confirm those of Shackleton *et al.* (2015), who extensively documents the barriers to adaptation in Africa, and notes that some barriers are specific to the employment of particular adaptation options (e.g., shortage of land is more of a constraint to soil and water conservation than changing crop variety) whereas others, such as a lack of finances and credit, inhibits almost any adaptation response within the farming sector (Shackleton *et al.*, 2015).

5. Summary and conclusion

This paper analyses farmer perceptions regarding climate variability and change, how well these perceptions correlate with data from the Kenya Meteorological Services, and adaptation options taken in response to these changes. We use data collected through a household survey and FGDs to address these issues. We find that a significant number of farmers perceived that climate is changing, and were particularly concerned about the changes in rainfall and temperature over the past decade. Specifically, more than 70% of farmers in both high potential and low potential zones perceived that temperature had increased, while about 50% perceived that rainfall had also increased. The periods of high temperatures had increased compared to the 1970s and 1980s and in many regions, there was also a shift in the coldest months from June to July and August.

Changing crop varieties or using new varieties was predominantly used as an adaptation measure because farmers are familiar with the practice, and extension messages often encourage the adoption of drought tolerant varieties. The major factors influencing farmer perceptions include the age of the household head, which is often associated with more farming experience, as well as extension service. Except in low potential zones, farmers' perceptions regarding climatic change are in line with climatic data records. The mismatch between farmer opinions and climate data in the low potential zones may arise because farmers are more likely to confuse the causes of climate change with the change itself, ignoring other human and environmental factors that could lead to climate change. As also mentioned by Osbahr *et al.* (2011) in Uganda, farmers sometimes interchange perceptions for their actual rainfall needs and its normal variability to their needs for desired production. For example, farmers may perceive a decline in rainfall, which would be as a result of increasing temperature, higher evapotranspiration and greater water stress. Therefore, to accurately analyze farmers' perceptions regarding climate change, a strong consideration of the socio-economic, cultural and environmental conditions experienced by the affected farmers is required, since they influence decision-making to cope with the downside risk.

Moreover, the results reveal that education, extension, adequate farm size and credit facilities are necessary for farmers to decide to adapt to climate variability and change. This means that effective adaptation to threats posed by climate variability and change requires a multi-dimensional collaborative approach, with many stakeholders playing key roles in providing support services in terms of education, extension, credit and meteorological information. This implies that a collaborative generation of knowledge and innovation to address the challenges of climate variability and change could be useful, since it includes farmers in the process. For the agricultural sector to adapt to climate change, there is a need to encourage the adoption of multiple adaptation measures among farmers and disaster preparedness programmes by county governments. Overall, it is important to increase the investment in agricultural development, as stipulated in Kenya's NCCRS and NCCAP, to enhance the ability of households to make effective decisions and to help reduce the extreme effects on their livelihoods.

References

Adger, W.N., Dessai, S., Goulden, M., Hulme, M., Lorenzoni, I., Nelson, D.R., Naess, L.O., Wolf, J., Wreford, A., 2009. Are there social limits to adaptation to climate change? *Climatic Change*, 93(3-4): 335–354.

Argwings-Kodhek, G., Jayne, T.S., Nyambane, G., Awuor, T., Yamano, T., 1999. *How Can Micro-Level Household Information Make A Difference for Agricultural Policymaking? Selected Examples from the KAMPAP Survey of Smallholder Agriculture and Non-Farm Activities for Selected Districts in Kenya*. Tegemeo Institute, Egerton University, Nairobi.

Ashford, J.R., Sowden, R.R., 1970. Multi-variate probit analysis. *Biometrics*, 26(3): 535–546.

Ben-Akiva, M., Lerman, S., 1985. *Discrete Choice Analysis: Theory and Application to Travel Demand*. MIT Press, Cambridge, MA.

Berndt, E.K., Hall, B.H., Hall, R.E., Hausman, J.A., 1974. Estimation and inference in nonlinear structural models. *Annals of Economic and Social Measurement*, 3(4): 653–665.

Bryan, E., Ringler, C., Okoba, B., Roncoli, C., Silvestri, S., Herrero, M., 2013. Adapting agriculture to climate change in Kenya: Household strategies and determinants. *Journal of Environmental Management*, 114: 26–35.

Bryant, R.C., Smit, B., Brklacich, M., Johnston, R.T., Smithers, J., Chiotti, Q., Singh, B., 2000. Adaptation in Canadian agriculture to climatic variability and change. *Climatic Change*, 45(1): 181–201.

Cappellari, L., Jenkins, S.P., 2003. Multivariate probit regression using simulated maximum likelihood. *The Stata Journal*, 3(3): 278–294.

CDKN, 2014. *The IPCC's Fifth Assessment Report: What's in it for Africa? Executive Summary.* ODI, London.

Deressa, T.T., Hassan, R.M., Ringler, C., Alemu, T., Yesuf, M., 2009. Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. *Global Environmental Change*, 19(2): 248–255.

Di Falco, S., Yesuf, M., Kohlin, G., Ringler, C., 2012. Estimating the impact of climate change on agriculture in low-income countries: Household level evidence from the Nile Basin, Ethiopia. *Environmental Resource Economics*, 52(4): 457–478.

Gbetibouo, G.A., 2009. Understanding farmers perceptions and adaptations to climate change and variability: The case of the Limpopo Basin farmers South Africa. IFPRI Discussion Paper 849. International Food Policy Research Institute (IFPRI), Washington, DC.

GoK, 2009. *Draft National Policy for Disaster Management in Kenya*. Government Printer, Nairobi.

GoK, 2010a. *Kenya 2009 Population and Housing Census Report*. Government Printer, Nairobi.

GoK, 2010b. *National Climate Change Response Strategy*. Government Printer, Nairobi.

GoK, 2013. *National Climate Change Action Plan (NCCAP)*. Government Printer, Nairobi.

GoK, 2015. *Economic Survey 2015*. Government Printer, Nairobi.

Greene, W.H., 2003. *Econometric Analysis*, 5th edn. Prentice-Hall, Upper Saddle River, NJ.

Hajivassiliou, V., Ruud, P., 1994. Classical estimation methods for LDV models using simulation. In: Engle, R., McFadden, D. (Eds), *Handbook of Econometrics* (Vol. IV). North-Holland, Amsterdam. pp. 2383–2441.

Herrero, M., Ringler, C., van de Steeg, J., Thornton, P., Zhu, T., Bryan E., Omolo, A., Koo J., Notenbaert, A., 2010. Kenya: Climate variability and climate change and their impacts on the agricultural sector, ILRI report to the World Bank for the project Adaptation to Climate Change of Smallholder Agriculture in Kenya.

Hisali, E., Birungi, P., Buyinza, F., 2011. Adaptation to climate change in Uganda: Evidence from micro level data. *Global Environmental Change*, 21(4): 1245–1261.

Howden, S.M., Soussana, J.F., Tubiello, F.N., Chhetri, N., Dunlop, M., Meinke, H., 2007. Adapting agriculture to climate change. *Proceedings of the National Academy of Sciences of the United States of America*, 104(50): 19691–19696.

Jones, L., Boyd, E., 2011. Exploring social barriers to adaptation: Insights from Western Nepal. *Global Environmental Change*, 21(4): 1262–1274.

Kabubo-Mariara, J., 2008. Climate change adaptation and livestock activity choices in Kenya: An economic analysis. *Natural Resources Forum*, 32: 131–141.

Kabubo-Mariara, J., Karanja, F.K., 2007. The economic impact of climate change on Kenyan crop agriculture: A Ricardian approach. *Global and Planetary Change*, 57(3): 319–330.

Kamara, A.B., 2004. The impact of market access on input use and agricultural productivity: Evidence from Machakos District, Kenya. *Agrekon*, 43(2): 202–216.

Kandlinkar, M., Risbey, J., 2000. Agricultural impacts of climate change: If adaptation is the answer, what is the question? *Climatic Change*, 45(3): 529–539.

Kansiime, M.K., 2012. Community-based adaptation for improved rural livelihoods: A case in eastern Uganda. *Climate and Development*, 4(4): 275–287.

Kleinbaum, D.G., Kupper, L.L., Muller, K.E., 1988. *Applied Regression Analysis and Other Multivariable Methods*, 2nd edn. PWS-Kent, Boston, MA.

Lin, C.T.J., Jensen, K.L., Yen, S.T., 2005. Awareness of foodborne pathogens among US consumers. *Food Quality and Preference*, 16(5): 401–412.

Maddison, D., 2006. The perception of and adaptation to climate change in Africa. CEEPA Discussion Paper 10. Centre for Environmental Economics and Policy in Africa, University of Pretoria, Pretoria, South Africa.

Marx, S.M., Weber, E.U., Orlove, B.S., Leiserowitz, A., Krantz, D.H., Roncoli, C., Phillips, J., 2007. Communication and mental processes: Experiential and analytic processing of uncertain climate information. *Global Environmental Change*, 17(2): 47–58.

Nhemachena, C., Hassan, R., 2008. Determinants of African farmers' strategies for adapting to climate change: Multinomial choice analysis. *African Journal of Agricultural and Resource Economics*, 2(1): 83–104.

Niang, I., Ruppel, O.C., Abdrabo, M.A., Essel, A., Lennard, C., Padgham, J., Urquhart, P., 2014. Africa. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1199–1265.

Ochieng, J., Kirimi, L., Mathenge, M., 2016. Effects of climate variability and change on agricultural production: The case of small-scale farmers in Kenya. *NJAS –Wageningen Journal of Life Sciences*, 77: 71–78.

Ogutu, J.O., Piepho, H.P., Dublin, H.T., Bhola, N., Reid, R.S., 2007. El Niño-Southern oscillation, rainfall, temperature, and normalized difference vegetation index fluctuations in the Mara Serengeti ecosystem. *African Journal of Ecology*, 46: 132–143.

Oremo, F.O., 2013. Small-scale farmers' perceptions and adaptation measures to climate change in Kitui County, Kenya. Unpublished Msc dissertation, University of Nairobi, Kenya. Available at http://erepository.uonbi.ac.ke:8080/xmlui/handle/123456789/59852 (accessed 1 October 2014).

Osbahr, H., Dorward, P., Stern, R., Cooper, S., 2011. Supporting agricultural innovation in Uganda to respond to climate risk: Linking climate change and variability with farmer perceptions. *Experimental Agriculture*, 47(2): 293–316.

Osbahr, H., Twyman, C., Adger, W.N., Thomas, D.S.G., 2010. Evaluating successful livelihood adaptation to climate variability and change in southern Africa. *Ecology and Society*, 15(2): 27.

Quisumbing, A.R., Brown, L., Hillary, R., Feldsten, S., Haddad, L., Pena, C., 1995. *Women: The Key to Food Security*. Food Policy Statement No. 21. International Food Policy Research Institute, Washington, DC.

Roe, E., 1999. *Except-Africa: Remaking Development, Rethinking Power*. Transaction Publishers, New Brunswick NJ.

Roncoli, C., Okoba, B., Gathaara, V., Ngugi, J., Nganga, T., 2010. Adaptation to climate change for smallholder agriculture in kenya: community-based perspectives from five districts, University of Georgia Report to the World Bank for the Project "Adaptation to Climate Change of Smallholder Agriculture in Kenya".

Schlenker, W., Lobell, D.B., 2010. Robust negative impacts of climate change on African agriculture. *Environmental Research Letters*, 5(1): 1–8.

SEI, 2009. *Economic Impacts of Climate Change in Kenya*. Stockholm Institute of Environment (SEI), Stockholm.

Seo, S.N., Mendelsohn, R., 2008. Measuring impacts and adaptations to climate change: A structural Ricardian model of African livestock management. *Agricultural Economics*, 38(2): 151–165.

Shackleton, S., Thomas, G., Ziervogel, G., Tschakert., P., 2015. Why is socially-just climate change adaptation in sub-Saharan Africa so challenging? A review of barriers identified from empirical cases. *WIREs Climate Change*, 6(3): 321–344.

Simelton, E., Quinn, C.H., Batisani, N., Dougill, A.J., Dyer, J.C., Fraser, E.D., Mkwambisi, D., Sallu, S., Stringer, L.C., 2013. Is rainfall really changing? Farmers' perceptions, meteorological data, and policy implications. *Climate and Development*, 5(2): 123–138.

Tambo, J.A., Abdoulaye, T., 2013. Smallholder farmers' perceptions of and adaptations to climate change in the Nigerian savanna. *Regional Environmental Change*, 13(2): 375–388.

Thomas, D.S.G., Twyman, C., Osbahr, H., Hewitson, B., 2007. Adaptation to climate change and variability: Farmer responses to intraseasonal precipitation trends in South Africa. *Climatic Change*, 83(3): 301–322.

Appendix

Table A1. Summary statistics of independent variables

Variables	Description	Mean	Std. dev.	Min.	Max.
Age (years)	Age of household head in years	60.431	13.239	20	98
Gender	1 if male head	0.728	0.445	0	1
Household size	Number of members	5.504	2.983	1	26
Education (years)	Education level in years	6.519	4.846	0	23
Extension	Distance in kilometres	5.363	5.065	0	52
Land size	Land size in acres	5.283	8.990	0.1	157
Flood in the last 10 years	1 if experience flood	0.419	0.494	0	1
Drought in the last 10 years	1 if experience drought	0.221	0.415	0	1
Leave land fallow	1 if left land fallow	0.121	0.326	0	1
Receive subsidy	1 if received government subsidy	0.124	0.329	0	1
Access to electricity	1 if access to electricity	0.097	0.296	0	1
Household income	Income in Ksh "000"	290.3	490.5	1.5	10400
Receive credit in 2010	1 if received credit	0.274	0.446	0	1
Receive relief food	1 if received relief food	0.044	0.204	0	1
Group membership	1 if a member of group	0.704	0.457	0	1
Long-term temperature (1980–2010)	Mean air temperature (°C) 1980–2010	20.907	3.065	17	30
Long-term rainfall (1980–2010)	Mean rainfall (mm) 1980–2010	103.647	28.883	51	169
Farmer perception of temperature	1 if perceive temperature increase in the past 10 years	0.348	0.377	0	1
Farmer perception of rainfall	1 if perceive rainfall increase in the past 10 years	0.384	0.387	0	1
Agro-ecological zone	1 if located in a high potential zone	0.678	0.468	0	1
Observations		1,309			

Note: Ksh-Kenya shillings.

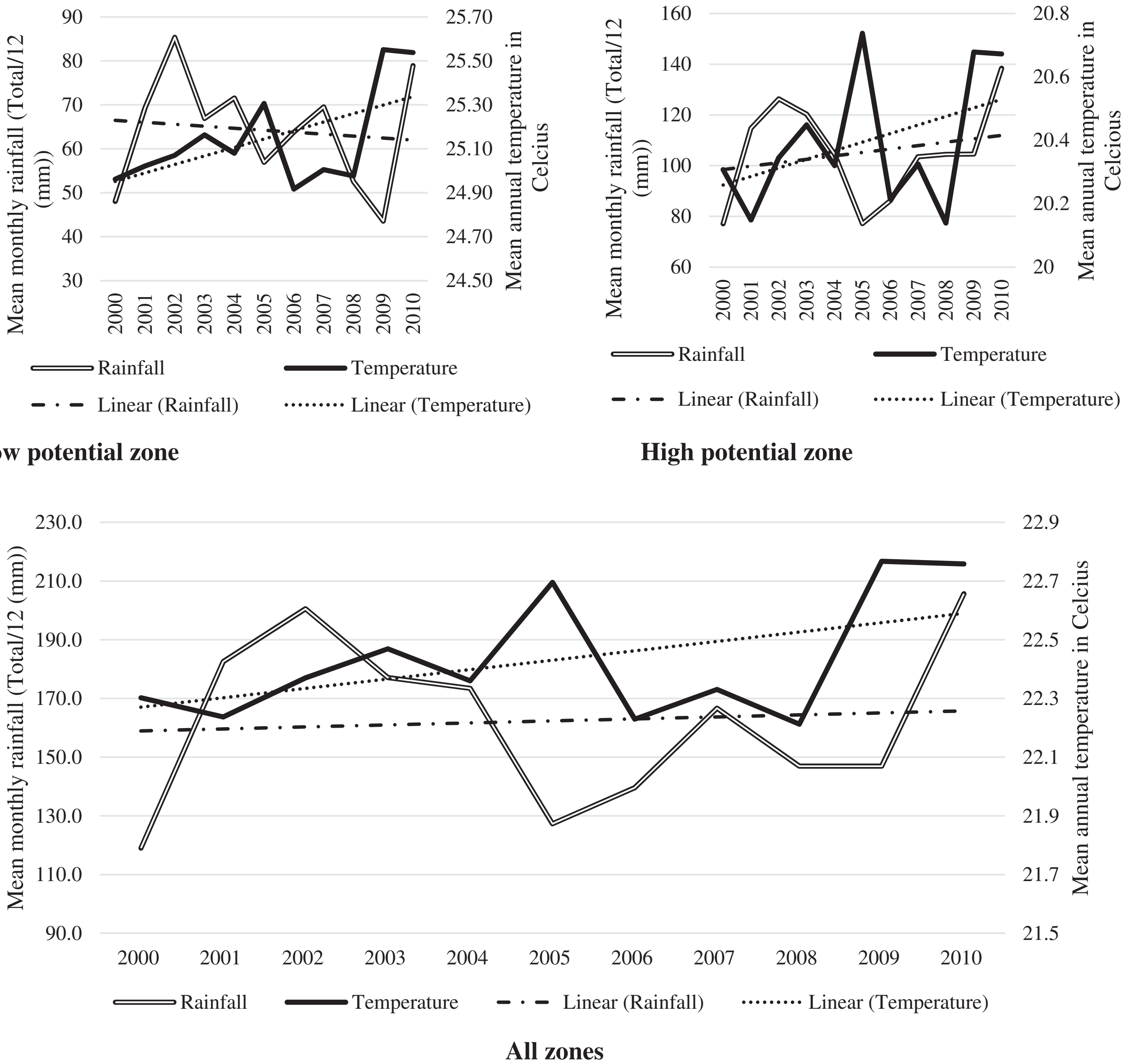


Figure A1. Climate trends for 10 years (2000–2010).
Source: Kenya Meteorological Services (KMS).