ANALYSIS OF CLIMATE DATA AND THE ASSOCIATED RISKS TO MAIZE PRODUCTION IN SEMI-ARID EASTERN KENYA

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Abstract

Climate change is one of the most important constraints to agricultural production and food insecurity in marginal areas that rely on rain-fed production systems. Climate data for two analogue locations in semi-arid eastern Kenya was analyzed using Instat Plus V3.4 statistical package with the aim of determining changes and variability in seasonal and annual rainfall and temperatures, percentages of seasons with adequate rainfall for maize production, probabilities of dry spells in October–December rainfall season, and accumulated rainfall and soil moisture content relations at different maize growth stages. Analysis gave declining trends in both seasonal and annual rainfall amounts at rates between 0.15 and 2.1 mm per annum and increase of 0.04^0C and 0.03^0C in mean maximum and minimum annual temperatures, respectively. This is indicative of changes in climate and hence the need for early exploration of necessary mitigation strategies by all stakeholders and policy makers. There were high chances (> 90% probability) of dry spells in October and high percentages of seasons having less than 250 mm rainfall compared to those with more than 450 mm. Rainfall was low and poorly distributed over the crop growing season and soil moisture remained low even during periods of high crop water demand signifying the high risk involved in maize production and the need for introduction and popularization of alternative crops as well as water conservation measures during months of high rainfall. It also calls for specification of specific crops to be grown in the two seasons with different rainfall expectations.

Introduction

Of all economic sectors, agriculture is one of the most vulnerable to climate variability and increased frequency of extreme events (Anju, 2007). This is because crop productivity in many environments (particularly in the tropical regions with low levels of crop management technology) is highly dependent on weather and climate (Challinor *et al.,* 2004). Most of the world's food is produced under rain-fed systems where climate variability and change play an important role in determining productivity (Slingo *et al.*, 2005). The consequences of climate variability and change affect the poor in developing countries than for those living in more prosperous nations (USAID, 2007). Given that both climate variability and change interact, good risk managers should begin to consider both climatic elements in operational and strategic farm planning (Meinke and Stone, 2005).

Climate change can be advantageous or disastrous. By understanding, planning for and adapting to a changing climate, individuals and societies can take advantage of opportunities and reduce risks (USAID, 2007). Analysis and study of climate trends can provide information on climate change and associated risks and increase the understanding of the current vulnerability of communities, mainly the small-scale farmers, in the affected areas. Such a study can also provide information to farmers, other stakeholders and policy makers on the risks that can be evaded and opportunities to be exploited for sustained agricultural production and current and future economic growth.

Materials and Methods

This study was carried out in Katumani and Kambi ya Mawe in semi arid eastern Kenya. Katumani is situated in Machakos district at 1575 m above sea level on altitude 01º 35'S and longitude 37º 14'E in agro-climatic zone IV. Kambi ya Mawe is in Makueni district at elevation 1125 m above sea level, latitude 1º 50'S and longitude 37º 40'E in the transitional zone between agro-ecological zones IV and V. In this study Kambi ya Mawe was selected as the analogue site for Katumani. Analogues are determined using simulation models and are sought in such a way that their present characteristics resemble or represent simulated characteristics of a given location (Nix, 2006). Both Kambi ya Mawe and Katumani have a bimodal pattern of rainfall with a "long rains" season in the months of March–May (MAM) and "short rains" in October–December (OND). Mean annual rainfall is 655 mm in Katumani and 643 mm per annum in Kambi ya Mawe (Dennett *et al*., Undated). Dominant soils in the two locations are c*hromic Luvisols* (Gicheru and Ita, 1987; Siderius and Muchena, 1977), with low organic carbon contents (0.5 – 1.0%) and a slight acid reaction (pH 5.7–6.9 in water).

Climate data records

Rainfall and temperature records for Katumani (Met station number 9137089) and Kambi ya Mawe (9137075), were analyzed for variability and trends in climate. Katumani rainfall and temperature records ranged from 1957 to 2008 and 1986 to 2008, respectively. Kambi ya Mawe data ranged from 1959 to 2008 and temperature records from 1971 to 2008. However, Kambi ya Mawe rainfall records were inconsistent with many missing values necessitating the use of records from Makindu station (9237000) situated 48 km to the south-east but having similar climatic conditions to Kambi ya Mawe. This meteorological station had rainfall records running from 1961 and temperature records from 1986 to 2008.

Katumani data was obtained from the Meteorological office at the centre and verified using records from Kenya Meteorological Department (KMD) headquarters. Kambi ya Mawe data was obtained from the sub-centre whereas Makindu data was sourced from KMD. All data was organized in Microsoft Excel 2007 software spreadsheets and transferred to Instat+ 3.4 statistical software for analysis. Graphs with trend lines were drawn in Instat+ and used to determine trends and variability's in seasonal and annual means and totals.

Climate data analysis

Grouping of seasons into "low rainfall", "average rainfall" and "high rainfall" seasons and determination of probabilities of dry spells.

This was aimed at determining the percentage of seasons in each category to establish the fraction with adequate rainfall for crop production (assuming fair and uniform distribution). Both short and long rains seasons were categorized into (i) "low rainfall' seasons with 250 mm of rainfall and below; (ii) "average rainfall" seasons having between 251 to 450 mm; and (iii) "high rainfall" seasons with over 450 mm. Low rainfall seasons were considered inadequate for maize production. A total of 52 short rains and 51 long rains seasons were analyzed for Katumani and 46 short and 46 long rains seasons for Makindu.

Dry spells were analysed to determining distribution of rainfall and the probability of availability of rains during the critical water requirement periods of maize growth in the short rains season (OND) which is said to be more reliable for crop production in the region (Okwach and Simiyu, 1999). Dry spells were described as periods with 0.85 mm of rainfall or less. Analysis was carried out for dry spells of at least five, seven or ten consecutive days after the last rains.

Determination of patterns and trends in annual and seasonal rainfall

Seasonal and annual rainfall totals were computed from daily data and trends determined by use of graphs and trend lines. Trend line linear equation of y=ax + b was used to describe changes in rainfall where "y" represented the rainfall amount in millimeters per season or annum, and "a" represented the slope hence the rate of change in rainfall over the years.

Determination of patterns and trends in seasonal and annual temperatures

Daily minimum and maximum temperature data were organized to generate seasonal and annual means, and patterns and trends determined as in the rainfall above. Similar linear trend line equations of y = ax + b were used with "y" representing mean seasonal or annual temperatures and "x" the rate of change in temperatures in ^{o}C.

The problem with available temperature data for the three locations is the high number of missing values which makes it difficult to establish long term trends. Only 22 years data for Katumani and 19 years for Kambi ya Mawe were analyzed. Kambi ya Mawe data require verification to determine the possibility of applying relevant climate models to calculate and fill the missing gaps. This could not, however, be done during the period of study hence only maximum temperature data records were analyzed for this location.

Daily rainfall accumulation and soil moisture determination

Three maize varieties; early maturing DH 04 (V1), medium maturing DK 8031 (V2) and late maturing H 513 (V3) were planted in these locations under two population densities (P1 – 37,000 plants ha^{-1} and P2 – 22,000 plants ha^{-1}) during short rains 2008. Soil sampling was done from auger holes and gravimetric soil moisture content determined at different stages of maize growth at four soil layers, 0-15 cm, 15-30 cm, 30-60 cm and 60-90 cm. The stages were at planting, 15 days after crop emergence (DAE), 30 DAE, at 50% anthesis and at harvest. Daily rainfall data was also collected during the season and soil water contents determined above were then related to the cumulative rainfall to determine the relationship between cumulative rainfall and soil moisture content for plant use.

Results

Grouping of seasons in relation to rainfall totals for suitability for crop production and analysis of dry spells

Table 1 shows rainfall seasons categorized according to total rainfall received in relation to suitability for crop production. There was a high percentage of seasons with “low rainfall” (43% in Katumani and 58% in Makindu) compared to those with “high rainfall” (8% in Katumani and 14% in Makindu). Forty nine percentage of the seasons in Katumani fell under “average seasons, 20 of which were in the short rains and 30 in the long rains seasons. In Makindu 28% were “average rainfall” seasons with 18 in the short rains and 8 in the long rains.

Table 1: Rainfall season grouped depending on total amounts of rainfall received

		Katumani				Makindu			
	Rainfall	Number of seasons				Number of seasons			
Type of season	received (mm)	Long rains	Short rains	Total	Percentages	Long rains	Short rains	Total	Percentages
Low rainfall	≤ 250	20	25	45	43	36	17	53	58
Average rainfall	251-450	30	20	50	49	8	18	26	28
High rainfall	> 450	2	6	8	8	2	11	13	14
Total		52	51	103	100	46	46	92	100

Analysis of dry spells during short rains season shows October as having the highest probability of dry spells in both locations. There is 100% chance of dry spells of more than 5 consecutive days and 93% probability that there will be a dry spell of 10 consecutive days or more in both Katumani and Makindu during October (Table 2). November has a lower chance of dry spells compared to October with probabilities of dry spells of more than 10 days being 39% in Katumani and 46% in Makindu. The probability of dry spells increases in December, a period when most crop varieties are at flowering stages and are highly sensitive to drought conditions.

Table 2: Probabilities of dry spells of more than 5, 7 and 10 consecutive days in the short rains season

	Probabilities of dry spell					
	Katumani			Makindu		
Month/ Consecutive dry days	>5	>7	>10	>5	>7	>10
October	100	98	93	100	94	93
November	78	59	39	87	70	46
December	90	81	48	83	70	46

Annual and seasonal rainfall amounts trends

High variabilities exist in annual rainfall with some years receiving more than 1000 mm of rainfall and others below 400 mm per annum (pa) in both areas (Figure 1). The locations have similar rainfall patterns (Figure 1) and a general decline in total annual rainfall. The results however, gave a higher annual decline in Makindu (2.1 mm) than Katumani (1.2 mm).

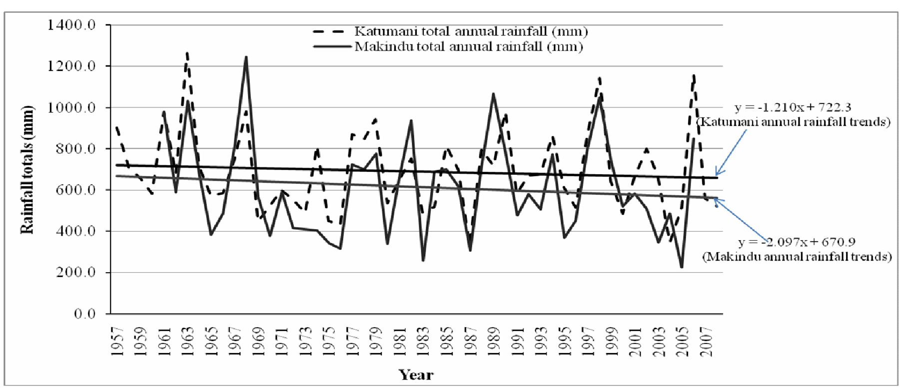


Fig. 1: Total annual rainfall and trends for Katumani (1957-2008) and Makindu (1961-2008)

Results show high variability in total seasonal rainfall and reductions in total amounts of short and long rains (Figure 2a and b). Higher reductions were observed in Makindu (1.02 mm and 1.27 mm for short and long rains, respectively) than Katumani (0.15 and 0.7 mm). There was more variability in the short rains with some seasons having more than 600 mm while others having as low as 100 mm of rain. Long rains were found to be less variable with a range between 400 mm and 100 mm.

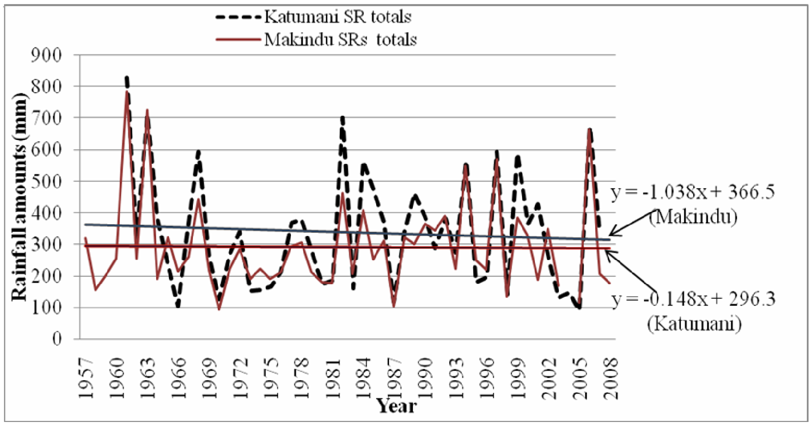


Fig. 2a: Short rains totals and trends at Katumani (1957-2008) and Makindu (1961-2008)

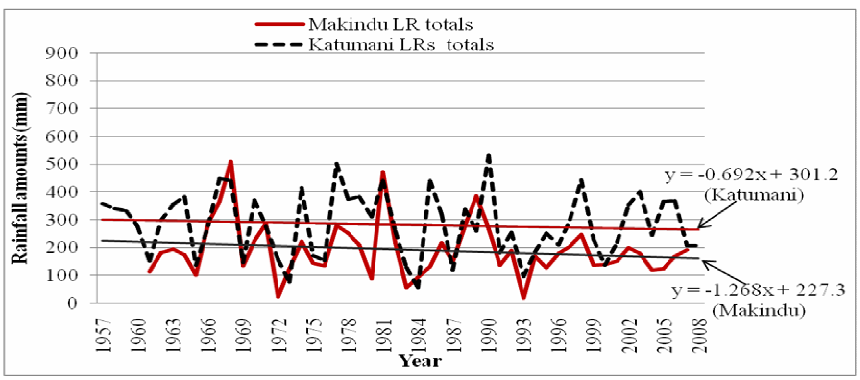


Fig. 2 b: Long rains totals and trends at Katumani (1957-2008) and Makindu (1961-2008)

Mean maximum and minimum temperatures

Increasing trends in maximum and minimum temperatures were realized from analysis of 22 years temperature data at Katumani. Mean maximum temperatures were found to increase at a rate of 0.04 ^{o}C pa (Figure 3a) whereas mean minimum temperatures were increasing at 0.03 ^{o}C pa (Figure 3b). In Kambi ya Mawe 19 years of data recorded between 1971 and 1990 gave increases in maximum temperatures at a rate of 0.03 ^{o}C p.a (Figure 3). Analysis of Kambi ya Mawe minimum temperature data was omitted due to inconsistency in the daily data records for this parameter.

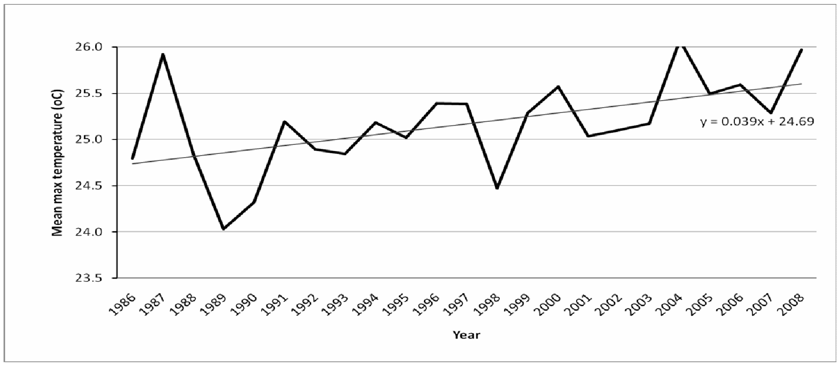


Fig. 3a: Katumani mean maximum temperatures (1986-2008)

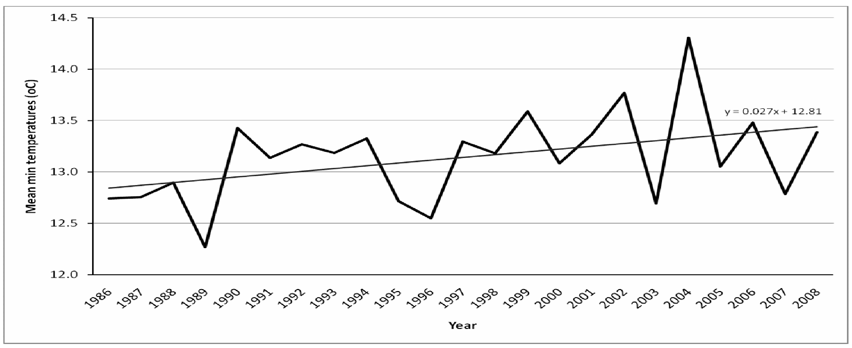


Fig. 3b: Katumani mean minimum temperatures (1986-2008)

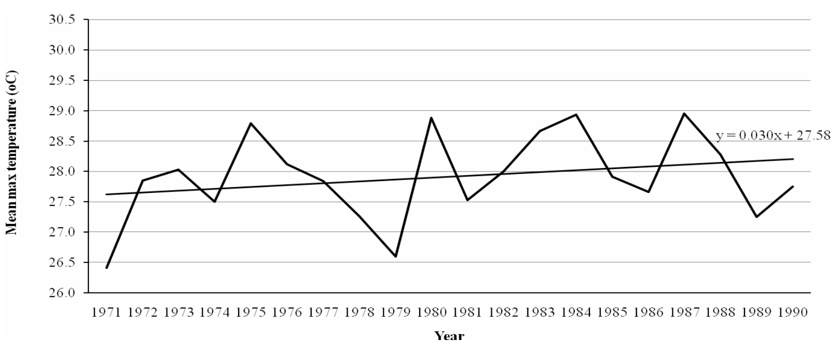


Fig. 1: Kambi ya Mawe mean maximum temperatures and trends (1971-1990)

Daily cumulative rainfall and soil moisture content

The two locations had similar daily cumulative rainfall patterns (Figure 4) indicating fairly similar patterns of rainfall distribution in the season (short rains 2008). The rainfall was poorly distributed and cumulative rainfall for most part of the season when the crop was in the field (about 4 months from planting) was low (less than 250 mm). Total rainfall was low and the season fell among "low rainfall" seasons with below average rainfall for crop production. The increase above 250 mm in Katumani cumulative rainfall only occurred during the last month of the crop growth after the crop had undergone moisture stress conditions at flowering and cob filling.

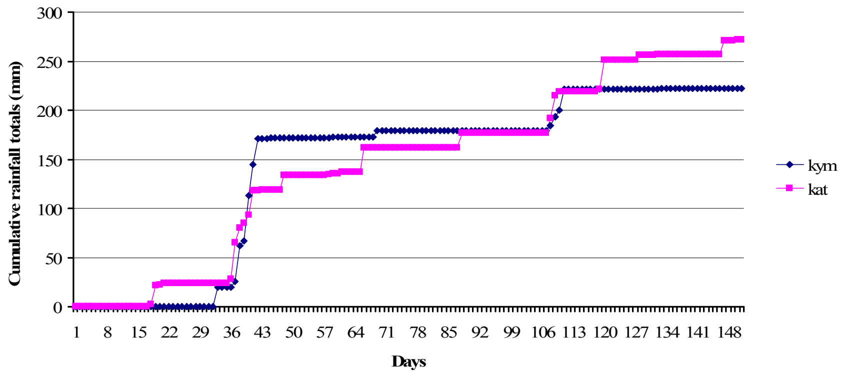
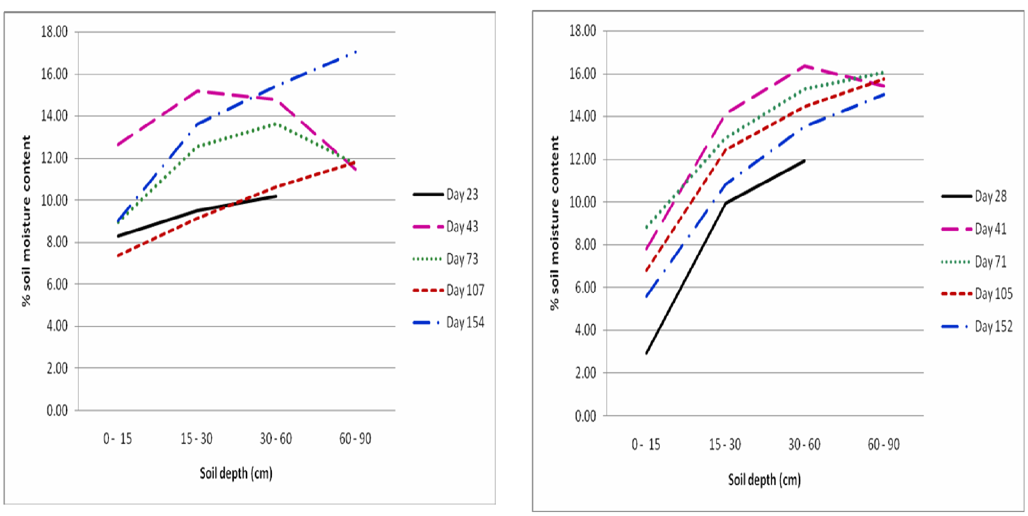


Fig. 4: Daily cumulative rainfall (mm): 1st October 2008 – 28th February 2009

Fig. 5a and b show the temporal and spatial variations in soil moisture content in different soil profiles. The upper soil profile (0–15 cm layer) had lower percent moisture content than lower profiles at both sites at all sampling stages probably due to moisture loss from the soil surface as a result of evaporation, root uptake by maize plant as well as redistribution into lower horizons in the soil profile.



a. Katumani ***b.Kambi ya Mawe***

Fig. 5a and b. Gravimentric soil moisture content (%) on different sampling dates

Constant higher values of moisture content were observed in lower soil profiles in Kambi ya Mawe than Katumani at all sampling stages irrespective of rainfall distribution. This was likely due to a combined effect of cumulative rainfall and soil physical properties resulting in availability of water to maize and a slightly higher yield performance in this location (Table 3).

Table 3: Maize grain yields at Katumani and Kambi ya Mawe during short rains 2008

	Grain yield (kg/ha)	
Maize variety	Katumani	Kambi ya Mawe
P1V1	240	283
P2V1	248	366
P1V2	231	460
P2V2	202	541

P1V3	189	513
P2V3	281	609
Means	231.4	464
l.s.d var (P≤0.05)	67.41	374.9
l.s.d popn	55.04	306.1
l.s.d var x popn	95.33	530.2
C.V%	22.6	62.8

Discussion

High percentages of low rainfall seasons and high chances of dry spells in the growing season confirm the high risks of water shortage in rain-fed crop production in this region. Seasons with below 250 mm of rainfall were considered unsuitable for maize production. The high percentage of seasons with "low rainfall" (43% in Katumani and 58% in Makindu) compared to those with "high rainfall" (8% in Katumani and 14% in Makindu) imply that there are high chances of rain water deficit and maize crop failures in both long and short rain seasons. The low rainfall is accompanied by poor distribution and low soil moisture for plant growth throughout the growing period. This situation is further exacerbated by the slow but evident changes in temperatures and rainfall towards a hotter and drier environment as depicted in the analysis. Such changes are supported by earlier reports that under intermediate warming scenarios, parts of equatorial East Africa will likely experience 5-20% increased rainfall from December-February and 5-10% decreased rainfall from June-August by 2050 (Hulme *et al*., 2001). However, Hulme *et al* (2001) further observes that these changes will not be as uniform as described throughout the year or region, a fact illustrated by decreasing trends in both seasons in this analysis. The worst is, however, to be expected with projections from the Intergovernmental Panel on Climate Change (IPCC) that the mean global temperatures will increase 1.4–5.8°C by the end of the 21st century if greenhouse gas emissions continue to rise (IPCC, 2001).

The upward trends in maximum and minimum temperatures at Katumani and Kambi ya Mawe corroborate increases in temperatures in these locations hence the surrounding regions over time. Although these increases per annum are small (0.03-0.04 mm) they confirm recent reports that the average global surface temperature has warmed in the past three decades largely due to human activities (Hansen *et al*., 2006; IPCC, 2001). This study did not assess the possible anthropologic or other local casual agents of climate changes. However, Cane has suggested that the warming sea surface temperatures especially in the southwest Indian Ocean and the inter-annual climate variability may play a key role in East African rainfall and may be linked to the change in rainfall across some parts of equatorial-subtropical East Africa (Cane *et al*., 1986). Such induced warming and sea surface temperatures can cause extreme weather events leading to decreased precipitation in interior regions, and increased drought and desertification hence food insecurity.

Conclusion

Although the observed changes in temperature and rainfall seem negligible their cumulative effects are likely to cause long term changes in the crop production environment. Globally, climate impacts are reverberating through the economy and in countries with GDP concentrated in a few climate sensitive sectors such as Kenya; climate impacts will affect the ecosystem services that communities are largely dependent upon thereby threatening development and economic stability. Clear, mitigation strategies need to be developed and adopted in view of the varying and changing climate for risks and poverty reduction. Such strategies for semi-arid regions include, but are not limited to; breeding and selection of crop varieties adaptable to the changing climate, timely planting to synchronize the crop stages that require high moisture availability with months having low chances of long dry spells and conservation of as much moisture in the soil as possible to supplement the months with more limited rainfall.

Recommendations

- These results signify the need for development and adoption of mitigation strategies for risk and poverty reduction and elevation of food security in line with climate change. Such strategies include a combination of variety selection and proper and timely crop management techniques for exploitation of opportunities and aversion of risks that may be involved.
- Past and present climate data is vital for agricultural production. Analysis and study of climate trends should be encouraged to provide information on changes and associated risks and opportunities.
- Timely weather forecast information and farmer awareness on impact of climate change are necessary for farm decision making.

Acknowledgment

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