

*Full Length Research Paper*

# Vulnerability and adaptation of rain fed agriculture to climate change and variability in semi-arid Tanzania

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**A vulnerability assessment of rain fed agriculture to climate change and variability in semi-arid parts of Tabora Region in Tanzania was conducted in 2009. Four village clusters were selected out of which, three villages represent Millennium Villages Program (MVP) namely Mbola, Mpenge and Isila from Uyui District. One village namely Tumbi from Tabora Urban bordering the MVP was also selected. Both primary and secondary data were collected using different methods including structured questionnaire interviews, focus group discussion, documentary review and field observations. Structured questionnaire interviews were administered to 7% of all farmers selected at random from the four villages and 30 research and extension officers obtained through accidental purposeful sampling. Simple regression and t-test analyses of numeric data for rainfall and temperature collected over the last 35 growing seasons were performed using Microsoft Excel and Statistical Analysis System respectively. Non-numeric data were coded, summarized and analyzed using Statistical Package for Social Sciences spreadsheet. Results indicate that the overall rainfall amount was found to decline while distribution was varying both in time and space. Inter-seasonal dry spells between January and February appeared to increase both in duration and frequency. Temperature has shown an increasing trend. Minimum temperature increased faster ( $R^2 = 0.68$ ,  $p < 0.001$ ) while maximum temperature increased gradually ( $R^2 = 0.24$ ,  $p < 0.01$ ). Farmers, research and extension officers also perceived these changes by the help of a series of indicators. Nevertheless, perception on the climate change indicators varied depending on the type of livelihood activity most affected. Major implications on rain fed agriculture are possible shrinking of the growing season, increasing moisture and heat stress to common food and cash crops, increased insects and pests and eventually low income and food insecurity. This study concludes that there is strong evidence demonstrating the vulnerability of rain fed agriculture to negative impacts of climate change and variability in the study area. It is suggested that there is a need for multi-level interventions on adaptation to climate change and variability taking into account a wide range of stakeholder involvement.**

**Key words:** Climate change, variability, rain fed agriculture, vulnerability, semi-arid, Tanzania.

## INTRODUCTION

Rain fed agriculture is an important economic activity in the developing world. Globally, rain fed agriculture is practiced in 80% of the total physical agricultural area and generated 62 percent of the world's staple food (FAOSTAT, 2005; Bhattacharya, 2008). In sub-Saharan Africa, 93 percent of cultivated land is rain fed (FAO, 2002) thus playing a crucial role in food security and

water availability (Wani et al., 2009). . In Tanzania arable land is 44.2 million ha but only 10.6 million ha was used for crop production in 2003. However there has been an increase in cultivated land due to population increase and investment in agriculture sector (FAO, 2008). Kadigi et al. (2004) argues that land for rain-fed agriculture varies depending on the amount and distribution of rainfall in the area. In semi-arid Tanzania, like other similar regions of sub-Saharan Africa, inadequate soil moisture and low soil fertility have been top challenges facing rain-fed agriculture (Gowing et al., 2003; Barron et al., 2003;

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Quinn et al., 2003; Mupangwa et al., 2006; Makurira et al., 2007). The Department for International Development (DFID) defined semi-arid regions as areas where annual rainfall regime is between 500 and 800 mm (DFID, 2001). Basing on this definition, DFID suggested that total semi-arid area in Tanzania could be between 33 and 67%. The major semi-arid areas in Tanzania are found in the central and mid-western part including Tabora region. Rainfall statistics for Tabora region indicates that the Eastern part receives less than 700 mm annually (URT, 1998b).

Poor rainfall distribution coupled with drought periods, particularly inter-seasonal dry spells have amplified the problem of moisture stress (Paavola, 2003; Tillya and Mhita, 2006) and put at risk between 20 and 30% of human population living in semi-arid areas (DFID, 2001). Climate change and variability has increased the burden on food security and income among many farming families. For example, analysis by Hatibu et al. (2000) revealed that more than 33 percent of disasters in Tanzania over 100 years period were related to drought, which is a major pre-cursor of agro-hydrological problems in the semi-arid regions. Empirical analysis showed that Tanzania had recorded 37 occurrences of drought between 1872 and 1990 (URT, 1998a). Such a situation has serious impact on food security and people's livelihood. Drought occurred mostly in semi-arid areas and represented 33% of all disasters that had occurred in Tanzania during that time (Morris et al., 2003). Climate change and variability is probably the most debated phenomenon of our time. Debates indicate a broad consensus among the public that climate change has happened. However, disagreement exists on the two major causes of climate change: anthropogenic and natural factors. Proponents of the former, on one hand, believe that increasing human activities such as uses of fossil fuels, unsustainable agriculture, deforestation and forest fires have added million of tones of green house gases such as carbon dioxide, methane, and nitrous oxide, that are responsible for the global warming (Antilla, 2005; Watson et al., 2006; Mwandosya, 2006; IPCC, 2007; UNFCCC, 2008). Opponents, on the other hand, believe that the global warning has nothing to do with human activities; rather it is a result of natural changes that have occurred on earth over a long period (Kaser et al., 2004; CSPP, 2005; Schmundt, 2006). On these debates, Mooney (2005) showed that analysis of more than 900 recent scientific articles listed with the keywords "global climate change," has failed to find a single study that explicitly disagreed that humans are contributing to climate change. In this context, Hoggan and Littlemore (2009) warn that despite existing scientific evidence on global warming, some media have been misused to spread propaganda generated by self-interest groups for the purpose of creating confusion about climate change. Evidence of climate change and variability has been presented both from empirical data and perception of

various sectoral stakeholders. Some important evidence of climate change often mentioned for Tanzania include receding ice on Mount Kilimanjaro, sub-mergence of Maziwe Island and intrusion of fresh water by salt water in shallow wells in Bagamoyo district (Mwandosya et al., 1998; WWF, 2006; Mwandosya, 2006). Biophysical and socio-economic aspects of climate change and variability have also been studied and presented. The IPCC report forecasted increasing warming in most parts of Tanzania (IPCC, 2007). According to this report, the major portion of western regions has experienced an increase in temperature of between 1 and 2°C from 1974 to 2005. In the rest of the country temperature has increased from 0.2 to 1°C during the same period. The report projects further increase in temperature of between 3 and 4°C by 2080 under no action scenario. The International Institute for Environment and Development (IIED) in the same scenario forecasts a rise in temperature of between 2 and 4°C and a decline in rainfall of between 5 and 15% over Western Tanzania by the year 2100 (IIED, 2009). In 2005, Tumbi meteorological station reported the highest temperatures of 35.2°C since it started recording over 30 years ago (TMA, 2009b), somehow supporting these findings.

Major impacts of climate change and variability on agriculture in Tanzania has been documented. Often mentioned are recurrent droughts, floods, increasing crop pests and diseases and seasonal shifts (URT, 2007). In 2006 a major drought triggered serious food and power crises in the country. Cost of food shortage to the economy during that year amounted US\$ 200 million in food imports and distribution. In semi-arid areas of Tabora and Dodoma increasing temperature and decreasing rainfall is estimated to reduce maize by between 80% and 90% and therefore threaten the main source of food for millions of Tanzanians (Jones and Kiniry, 1986; Mwandosya et al., 1998). Quantifying this impact, IIED (2009) argued that climate change will trigger a 0.6 to 1% decline in GDP by 2030; and by 2085, the decline in GDP will range from 5 to 68% depending on the severity of climate impacts. There had been frequent food shortages reported in parts or the whole of the region. In 2002/2003 Tabora was the only region without high urban population that reported food shortages (USAID, 2006). Among areas that were projected to suffer food insecurities in the country for 2008/2009, two districts of Tabora Region, Nzega and Tabora Urban were mentioned (URT, 2008). While food shortage may be contributed by other factors such as prices, seasonal outbreak of diseases etc, climate change seemed to be the strongest influence. FEWS (2005) reported that more than three quarters of people in Tabora Region rely on climate sensitive rain-fed agriculture for their livelihood. Therefore, the study of temperature, rainfall and related variables are particularly important. The authors who tried to define the term vulnerability also acknowledged its close relationship with

another term adaptive capacity. Kelly and Adger (2000) defined vulnerability in terms of the capacity of individuals and social groups to respond to, recover from or adapt to, any external stress placed on their livelihoods and well-being. This was mainly a socio-economic perspective basing on resource availability and ownership. McCarthy et al. (2001) described vulnerability to climate change as a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity. Adger (2006) defined vulnerability as the exposure of individuals or collective groups to livelihood stress as a result of the impacts of such environmental change. This was based on cause-effect relationship in the vulnerability assessment. However, there is consensus across climate change researchers that these definitions have led to fragmented conceptual frameworks especially in the vulnerability assessment to climate change (O'Brien, et al., 2004; Füssel, 2007). Two different frameworks have been suggested to reduce the ambiguities. Recently, Lonescu et al. (2009) have suggested a mathematical based framework, arguing that the concept of vulnerability is relative and grammatically broad, thus difficult to define in words alone. Füssel (2007) suggested a framework which combines both socio-economic and biophysical aspects. This framework has been adopted in this study.

Studies on vulnerability and impacts of climate change and variability have been conducted in different parts of the country. Mwandosya et al. (1998) conducted a comprehensive study on vulnerability covering the whole country and including many sectors. Agriculture was one of them. However, due to its scope the study lacked special emphasis on the varying biophysical and socio-economic characteristics at a smaller scale, thus requiring supplementary studies. Paavola (2003) examined vulnerability to climate change and variability and its sources in Tanzania. Despite identifying food security and water supply as the most important areas requiring attention, the study also focused on socio-economic factors supported by projections on climate changes. Tilya and Mhita (2006) studied the contributions of climate change to land degradation in Tanzania. They sampled three regions of western, south western and Lake Victoria Regions. This was a broad study that focused on a few elements of the rain-fed agriculture – the land degradation Yanda et al. (2006) examined the vulnerability, coping strategies as well as excess risks as a result of climate change around Lake Victoria. This study was backed-up by substantial socio-economic data and employed a lot of participatory tools. However, it was based on health aspect particularly malaria disease. A study related to this but focusing on agriculture and crops in particular would supplement the findings from other sectors and shape the multi-sectoral debate on the vulnerability, impacts and adaptations to climate change and variability. This study sought to address the gap of knowledge on the vulnerability and adaptation of rain fed agricultural system to adverse impacts of extreme climate

change and variability in the semi-arid areas of Uyui and Tabora Urban districts and the implications on food security and livelihood. Specific objectives were to:

- Determine the trends of rainfall, temperature and dry spells during the growing season for the last 35 years in Uyui and Tabora Urban districts.
- Assess the understanding on climate change and variability at local scale and ascertain their implications to food security and livelihood in the study area.

## RESEARCH METHODOLOGY

### Description of the study area

The study was conducted in Tabora Urban and Uyui Districts which are located in Tabora region in the mid-western Tanzania. Tabora is the largest region in Tanzania covering an area of 73,500 km<sup>2</sup>. The region is located between latitude 4 - 7° South and longitude 31 - 34° East (URT, 1998b). Four village clusters, three forming the Millennium Villages Project in Uyui district and one outside this project but in neighbourhood was selected from Tabora urban district. Villages selected were Mbola, Mpenge and Isila from Uyui District and Tumbi from Tabora Urban (Figure 1). WUR (1981) defines the topographical features of the study area in form of land units. Generally the land units are characterized as rocky (R) zones. The landscape as flat to gently undulating plains covered with lacustrine and riverine alluviums which are regularly flooded. Vegetation is dominated by Miombo woodlands. Traditionally, the rain season is mono-modal that starts from October to April with a short dry spell between January and February. The two districts have a warm climate with temperatures reaching their peak in September - October just before the onset of the rainy season. The daily mean temperature is around 23°C.

### Data collection and processing

Both secondary and primary data on temperature, rainfall, and dry spells were collected using different approaches including structured interviews, focus group discussion, documentary review and field observations. Structured interviews were administered to 7% of all farmers selected at random from the four villages and to 30 research and extension officers obtained through accidental purposeful sampling. Statistical Analysis System (SAS) was used for analysis of variance (ANOVA) of the average seasonal precipitations of the whole region and the station located in the study area. This process was employed to validate the use regional climatic data at a village or division level. Student's t-test was used to establish any difference in the two data sets.

Simple regression analysis for regional rainfall data was performed by MS Excel using the model below:

$$Y (j) = ak + c \dots\dots\dots (1)$$

Where: Y (j) = Physical factor (rainfall, minimum or maximum temperature,) during the growing season from October to April. It also represented duration or frequency of dry spells during January and February

a = Gradients (slopes) of the regression equation  
 k = Number of growing seasons (years) from 1973/74 to 2007/8;  
 c = Regression constant

The XY scatter plot was produced with both regression line and regression equations established. The R-square (R<sup>2</sup>) values were

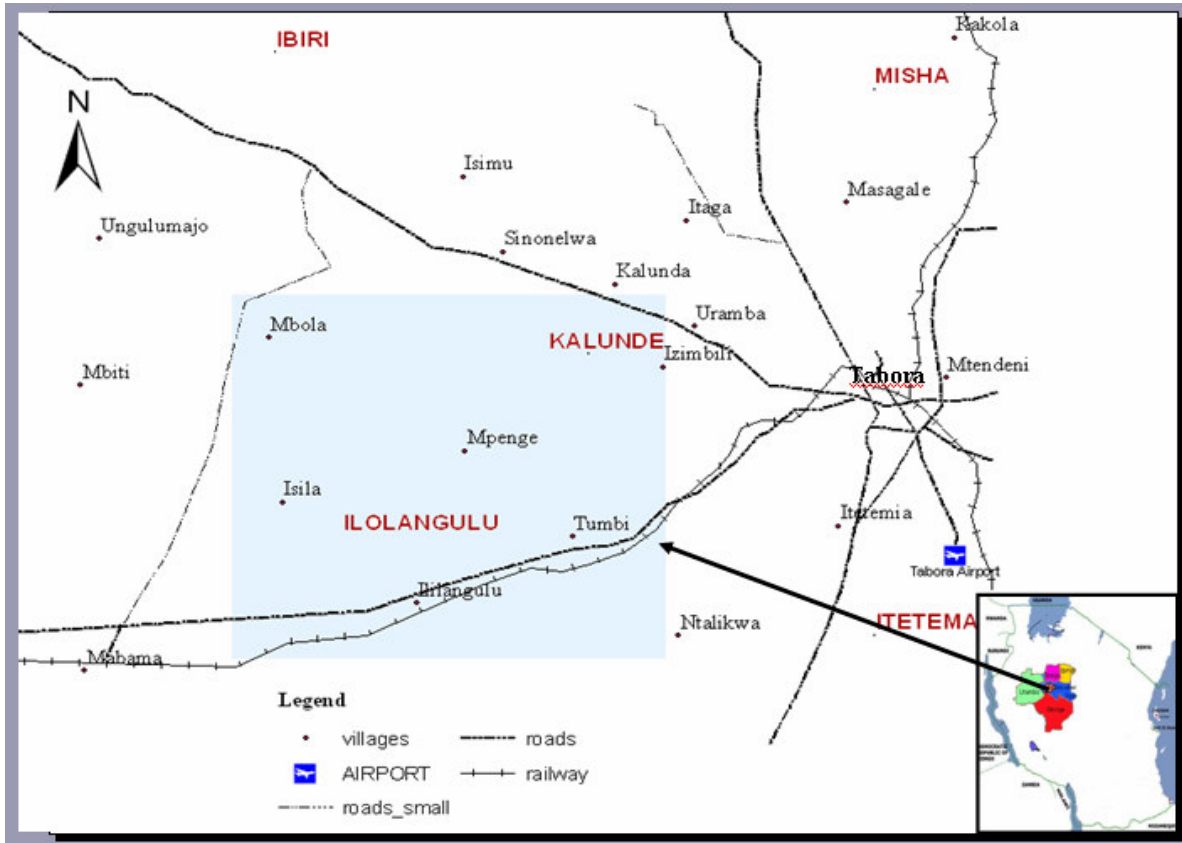


Figure 1. A sketch showing the location of the study area. Source: Modified from WUR (1981).

recorded for each analysis for the purpose of determining the significance of the trends. During pre-analysis of the dry spells data the frequency of dry spells in a given station  $F$  was determined using the following scenario: If a dry spell of  $j^{\text{th}}$  days occurs in a month  $j$  and year  $k$  then the number of occurrences of the dry spell during a month and year for a station will be expressed mathematically as:

$$F_j = \sum_{i=1}^n \sum_{k=1}^m F_{ijk} \dots\dots\dots (2)$$

Where:  $n$  = dry spell runs (January and February)  
 $m$  = total number of growing seasons (years).

Quantitative socio-economic data were analyzed using the Statistical Package for Social Sciences (SPSS). Descriptive analysis such as frequencies and cross tabulations was used to determine simple number of occurrence of a variable or relationship among variables. Spearman correlation analysis was performed to ordinal data as suggested by Keya et al. (1989).

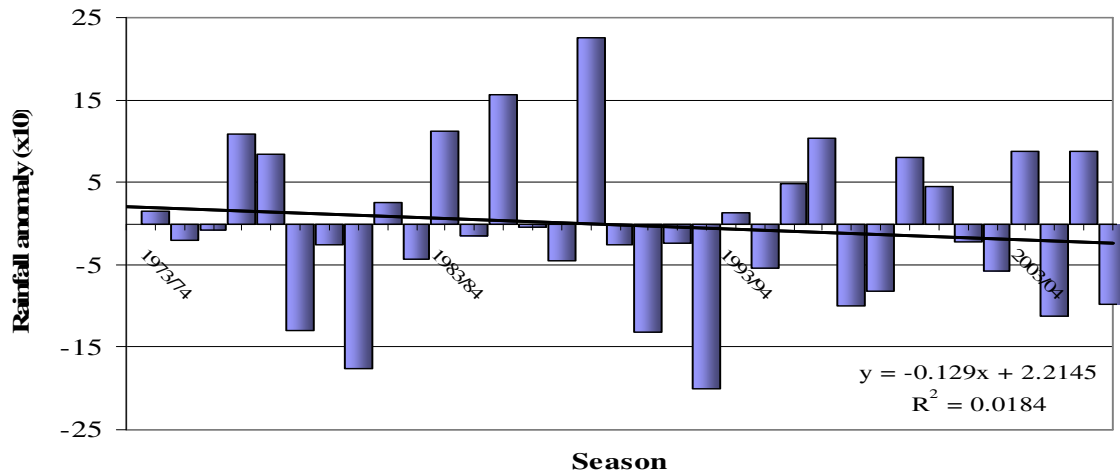
**RESULTS AND DISCUSSION**

**Trends of rainfall, temperature and dry spells**

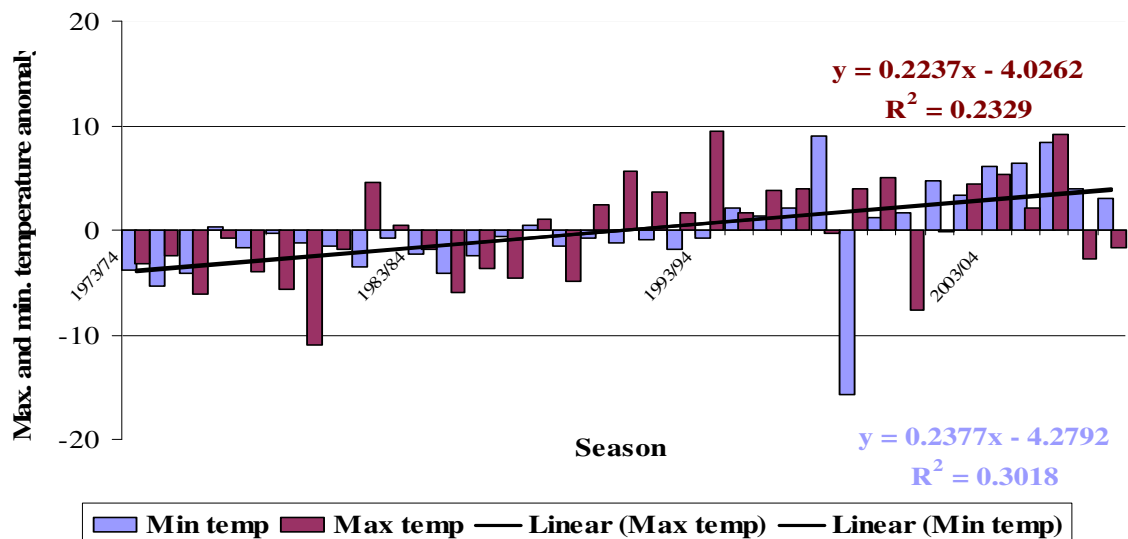
Numerical meteorological data for rainfall and temperature collected at a regional scale were tested against the data collected and maintained in the field at a station

within the study area. Results of Student’s t-test on the regional and station data showed that there was no significant difference between the means for the two data sets ( $t = -0.243, p > 0.806$ ). This justifies the use of regional data which had higher reliability due to being collected from multiple stations could best fit the station data at the study area.

The results of meteorological data for rainfall trends during the growing season from October to April showed that annual rainfall data in the study area had been in declining trends for the last 35 seasons from 1973/74 to 2007/08 (Figure 2). Total rainfall during the seasons from 1973/74 to 2007/08 appeared to decrease at non-significant rate ( $R^2 = 0.018, p > 0.47$ ). However, on monthly basis rainfall tends to decrease in the beginning and at the end of the season. The most affected months were October ( $R^2 = 0.044, p > 0.47$ ), November ( $R^2 = 0.022, p > 0.84$ ), March ( $R^2 = 0.047, p > 0.45$ ), and April ( $R^2 = 0.058, p > 0.41$ ). Also outside the traditional rain season, rainfall seemed to increase in May by a rate that was highly significant. This suggested two possible scenarios: a shrink in the growing season or splitting of the season into short and long rains. Results of meteorological data for temperature trends during the growing season from October to April are shown by Figure 3. Analysis of temperature trends showed a similar trend as the one



**Figure 2.** Trend of rainfall anomaly for seasons from 1973/74 to 2007/08  
Source: TMA (2009a).

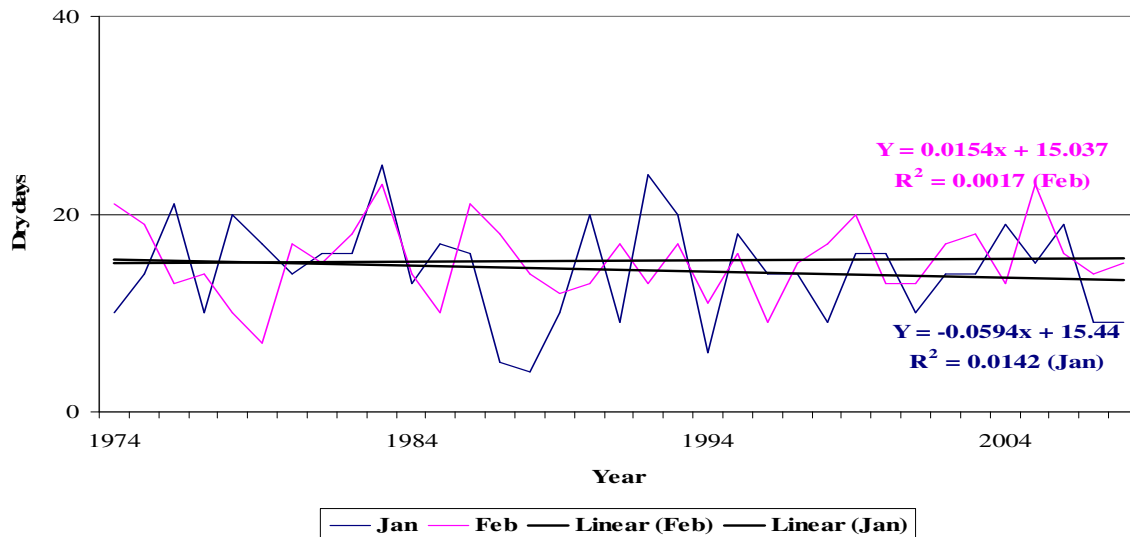


**Figure 3.** Trends of maximum and minimum temperature anomalies for the seasons from 1973/74 to 2007/08.  
Source of data: TMA (2009a).

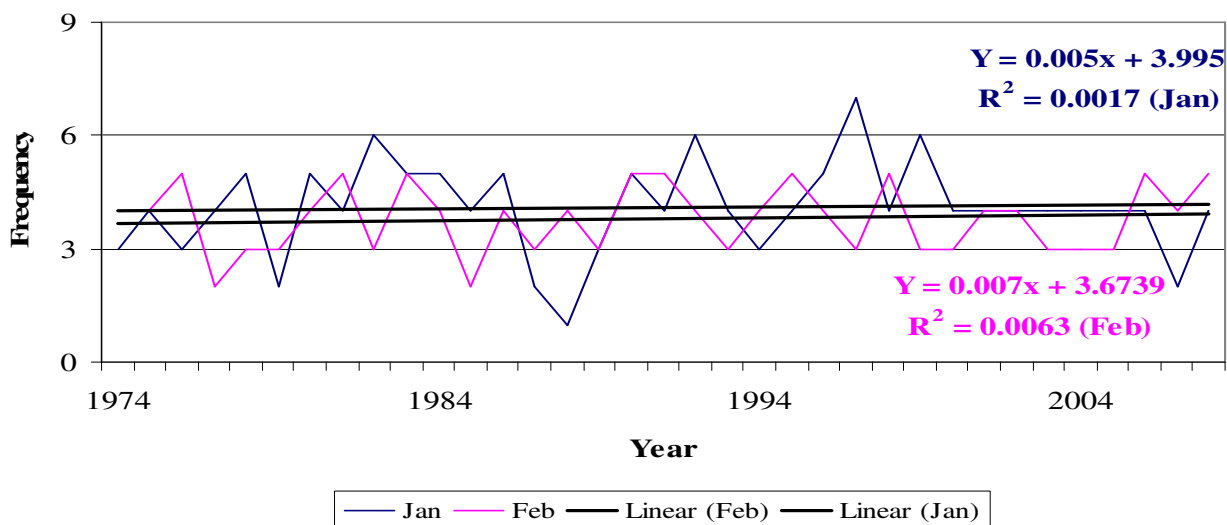
reported by IPCC (2007) for the whole area of western Tanzania. Both minimum and maximum temperatures showed significant increasing trends. Minimum temperature increased faster ( $R^2 = 0.68$ ,  $p < 0.001$ ). Maximum temperature increased gradually ( $R^2 = 0.24$ ,  $p < 0.01$ ) (Figure 3). More than 98% of respondents supported these findings. January and February are very important months in the growing seasons in Tabora Urban and Uyui Districts. The two months accommodate the inter-seasonal dry spells, a common weather phenomenon, but increasingly becoming among major factors negatively affecting crop production in the semi-arid areas. Results of data analysis showed that duration of dry spells tend to decline in January and increase in February (Figure 4).

The results portrayed an indication of possible shift in dry-spell duration from January to February. Although both trends are not statistically significant, they offer substantial information that is linked with other results of data analysis.

For example, general trends of seasonal rainfall at the beginning and the end of the season, as reported earlier may have a link with dramatic but gradual shift in the length of the growing season. The frequency of dry spells tends to increase in February while it remained nearly constant in January. The trends in February, seemed not to have much effect as rainfall tended to increase in the over seasons (Figure 5). However, all trends were not significant ( $p > 0.1$ ). The number of



**Figure 4.** Duration trends of dry spells during January and February from 1974 to 2008 in the Study Villages. (Source of data: TMA, 2009a)



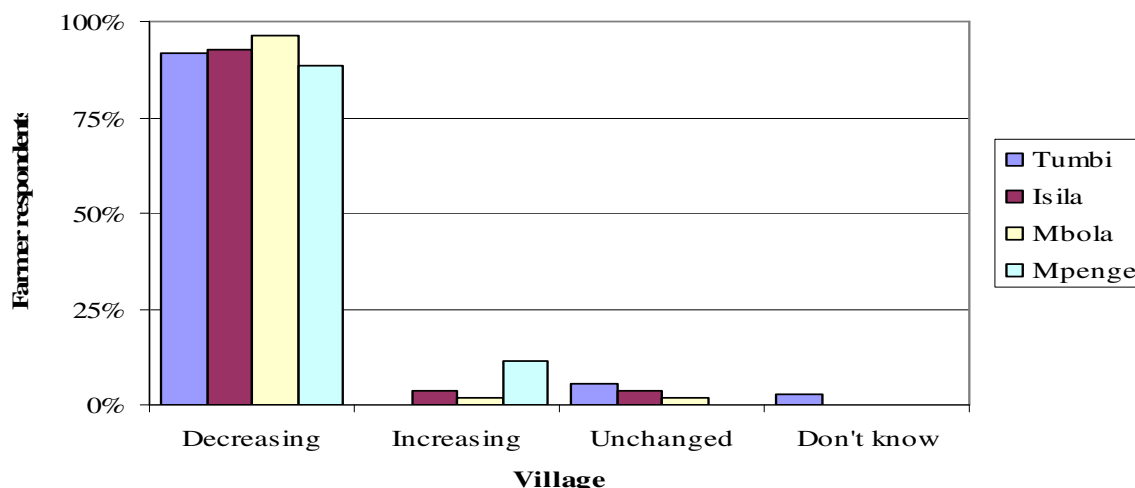
**Figure 5.** Frequency trends of dry spells during January and February from 1974 to 2008, in the Study Villages (Source of data: TMA, 2009a)

respondents who perceived the trends of dry spells varied with village. When the two villages' clusters were compared, 74.6% of respondents from Tumbi village perceived drought to be increasing while 53.8% from MVP perceived the same (Figure 6).

**Stakeholders' understanding on climate change**

Climate change is perceived differently at different levels of conceptualization (c.f Diggs 1991; West et al., 2007). Through focus group discussion and key informant

interviews it was revealed that there is varied understanding on climate change depending on the level of education, livelihood activity, location, and age (Table 1). The local understanding on climate was that climate is continuously changing and it is getting worse over time. Bad years are becoming more frequent than before, resulting in poor performance in agriculture and consequently food shortages in the area. Farmers from different age groups acknowledged an increase in temperature. There was a general agreement across age groups that temperature was becoming much hotter with time (Table 2). The results further show that experienced



**Figure 6.** Farmer perceptions on trends of rainfall by village.  
Source: Field survey (2009).

**Table 1.** Farmers response by level of education on indicators of climate change

Level of education	Yes on Indicators (%)						Average
	Rainfall	Temp.	Humidity	Drought	Floods	Winds	
Informal	86.5	67.3	69.2	62.2	19.2	55.8	58.3
Primary	86.7	68.5	54.5	62	27.3	45.6	57.4
Secondary	100	71	42.8	57.1	28.6	57.1	59.5
Tertiary	100	95	79	94.3	86.7	66.7	88.3

Source: Field survey (2009).

**Table 2.** Farmers response by age group on temperature trends

Status of temperature	Respondents by Age group (%)			
	15 - 20	21 - 40	41 - 60	61+
Very hot	54.5	40.5	56	69.2
Hot	36	58.4	44	30.8
Not very hot	9	0	0	0
Don't know	0	0.1	0	0
Total	100	100	100	100

Source: Field survey (2009).

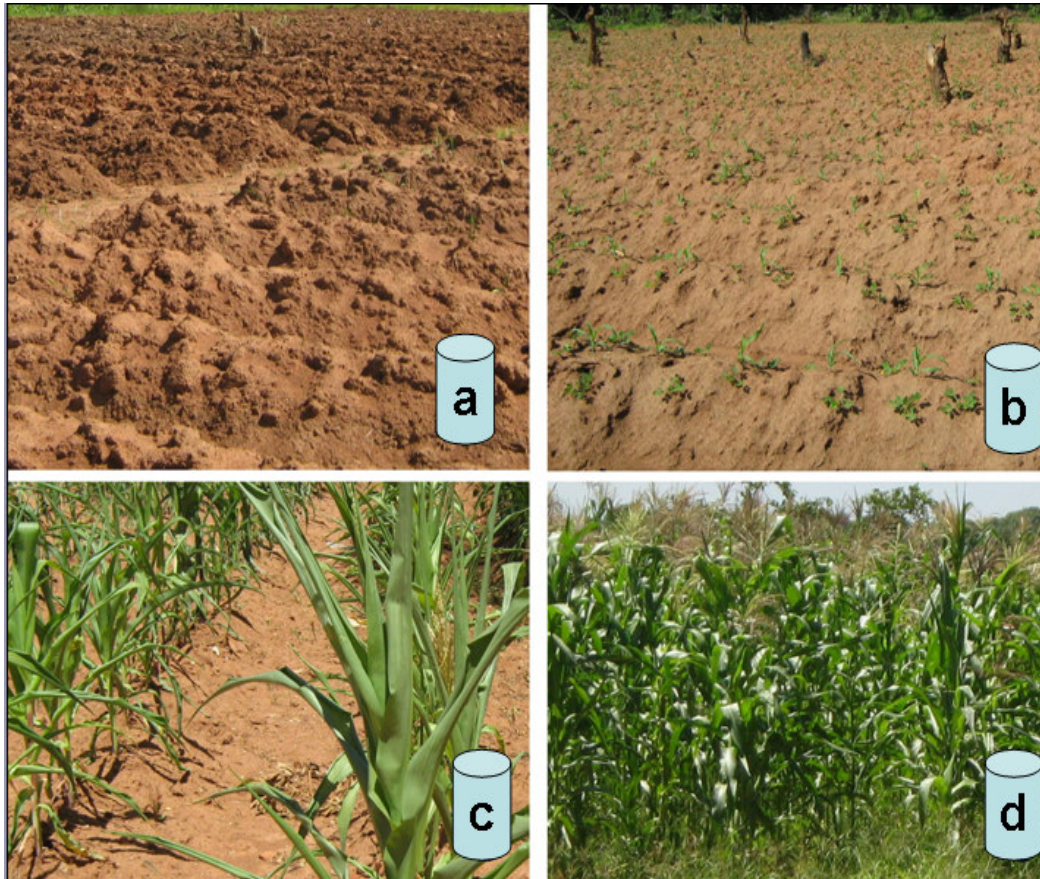
farmers at ages of 41 years and above perceived temperature to be hotter relative to old days. Through Focus group interviews with farmers aged 41 year and above, it was realized that much of the changes in temperature had occurred during the last 10 years.

Stakeholders' perception on rainfall trends was more consistent across location and education levels. More than 97% farmers and 100% research and extension officers perceived rainfall to be declining at least for the last 10 years (Figure 5). The majority of interviewees linked the declining rainfall to climate change and

variability. Yet a small number of them perceived the decline as a result of disobedience of traditional foundations laid by their forefathers. They claimed that during their time, a drought could be simply solved by a rain maker.

#### Implications of the trends observed on food security

Recurrent drought, seasonal shift, dry spells and increasing temperatures are reported by farmers as



**Figure 7.** Varying planting dates. These photos were taken in the same day and the same sub-village (Kipela North, Tumbi village) on 18<sup>th</sup> January 2009. Source: Field survey (2009).

major threats to agricultural production including food crop production. Monthly rainfall for the first and last two months in the season indicated declining trends. This implies delayed propagation for such crops like maize, groundnuts and sunflower, consequently declining yield. Further, it implies delayed transplanting of rice and tobacco, two major cash crops in the study area. The majority of farmers have developed mechanisms of responding to erratic rainfall through splitting their plots and sowing or transplanting at different times in the season (Figure 7). Although this practice could be one of local adaptation measures, it resulted into further fragmentation of the already small fields and sometimes led to counter productivity as distribution of input resources across split plots may not be the same. Again, both increase in temperature and dry spells were connected to increased incidences of crop pests and diseases. Farmers, research and extension officers acknowledged the link between climate change and increased incidences of crop pests and diseases. It was revealed that, new pests and diseases were emerging while old pests were exhibiting new feeding behaviours. They perceived increase in drought, temperature and dry spells as being associated to climate change. According

to their perception, such changes have occurred in the recent ten years as compared to the previous decades. This implies that thousands of farmers in the study area who depend on rain fed agriculture as a sole livelihood activity are at risk becoming food insecure. It was revealed that majority of farmers in all of the study villages have acknowledged decreasing food crop production (Table 2).

Majority of the farmers interviewed associated the declining food crop production with the impact of climate change and variability. However, the declining food crop production trend could also be due to other non climatic related factors such as declining soil fertility, pest and diseases and inadequate extension services. However, the impact of climate change and variability became more pronounced when there is interaction with other non-climatic stressors. A thorough analysis of livelihood activities in the studied villages indicates that agricultural activities are mostly affected through decrease in rainfall which also influences loss in soil moisture. Farmers in the study area have responded to the impact of climate change and variability through various local adaptations including expansion of areas under cultivation to compensate for reduced yields during droughts, partly by



**Table 2.** Farmer's perception on crop production trends .

Village	Farmers' perception on crop production trend (%)		Total % (n=180)
	Decreasing	Increasing	
Tumbi	92.9	7.0	39.4
Isila	82.2	17.8	15.6
Mbola	90.9	9.1	30.6
Mpenge	92.4	7.7	14.4
Average	89.6	10.4	100

Source: Survey (2009).

reducing fallows, switch to more drought-resistant crops such as sorghum and cassava. Some farmers reported growing alternative crops such as sunflower however; increasing pests and diseases incidences has hindered such effort. Another adaptation measures reported is diversification to non farm activities such as brick and charcoal-making, casual labour and carpentry (c.f Paavola, 2006; World Bank, 2009; Majule, 2008; Liwenga et al., 2008; Bushesha 2009; Gbetibouo, 2009).

### Conclusion and Recommendations

The study concluded that stakeholders including farmers at village level have revealed that climate is continuously changing and it is getting worse over time. There is a concerns that rainfall amount has been decreasing over time while temperatures have increased. Bad years are becoming more frequent than before, resulting in food shortages in the area. While this could also be due to other factors, trends of rainfall, temperature and dry spells provide evidence that rain fed agriculture in the study area is vulnerable to the impact of climate change. Rainfall has generally been declining over the last 35 seasons, while both minimum and maximum temperature trends have increased. This was coupled by anomalous behaviour of inter-seasonal dry spells. Analysis of January and February dry spell trends indicated a degree of increase both in frequency and duration of dry spell. The nature of dry spells during this period is very important as it affects most crops at their crucial period of growth when adequate moisture is required. These results may constitute some useful information required by different levels of actors in development particularly in reducing vulnerability of rain fed cultivators in semi-arid areas of Western Tanzania.

The study therefore recommends for development of appropriate strategies for reducing vulnerability of rain fed agriculture by helping farmers use their local knowledge in combination with introduced innovations to enhance local adaptations to climate change and variability. Enabling environment should be created to allow for smooth response to other crops as an adaptation to climate change and variability and sustaining adequate food security. Stakeholders involvement and joint action

among researchers, extension officers, farmers and policy makers would likely help define and implement this roadmap.

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