Awareness and adaptations to climate change among the rural farmers in different agro-ecological zones of Tanzania

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Abstract

Purpose – This paper generally aimed to evaluate the knowledge of rural farmers towards climate change (CC) and their adaptation practices as a way of reducing the vulnerability in different agro-ecological zones (AEZs) of Tanzania. This establishment is quite important because rural farmers are most vulnerable to impacts of CC. Therefore, there is a need to establish the actual knowledge on this aspect in order to meet the urgency for action on CC by using the endowed environmental resources. This knowledge will assist policy makers and CC practitioners.

Design/methodology/approach – This study employed systematic and simple random sampling procedures in selecting the districts and villages as study sites. It used both quantitative and qualitative data sets derived from climatic records, questionnaires survey, interviews and discussion. The Mann-Kendall test and Sen's slope, and theme content were used for data analyses.

Findings – The results exhibited that most farmers have been greatly adapting to CC through numerous and well-known practices. However, there has been adoption of other new practices mainly influenced by new knowledge from extension services, environmental endowments and temporal environmental change. Although there has been varied perceptions on CC, the results indicate that most farmers (>70%) are aware of the changing climate and their knowledge corresponds to meteorological data.

Originality/value – Most farmers perceived that prolonged drought and erratic rains are the main indicators of CC. These indicators were the base of copping and adaptation mechanisms. Despite this, there is a need for all climate practitioners to join hands in improving the existing adaptation practices that can limit climate impacts in local areas.

Keywords Adaptation strategies, Climate change, Perception analysis, Smallholder farmers, Vulnerability, Tanzanian agro-ecological zones

Paper type Research paper

1. Introduction

The question of what motivates people to take action on climate change (CC) is increasingly important, with the abundant evidence that mitigation and adaptations are needed (IPCC, 2014). The need for adaptation practices is very important, especially in most rural areas of sub-Saharan Africa because CC has been persistent (Paavola, 2008; IPCC, 2012, 2014; Mwongera *et al.*, 2014). This is evident from the global climate projections that show most parts of Africa (especially East Africa) are likely to experience significant climatic changes (Ericksen *et al.*, 2011; Rowhani *et al.*, 2011; Mkonda, 2022).

To secure a reliable and sustainable food source for farmers in rural areas, there is a need to improve their resilience by adopting best and sustainable adaptation measures in their farming (Ahmed *et al.*, 2011; Ayanlade *et al.*, 2017a; Mkonda and He, 2018). This is more practical in the presence of knowledge required for the adaptation URT (2021). Creation of awareness is more imperative to limit the impacts from ongoing CC.

The fundamental reasons for improving the farmer's resilience in these areas include the following: most farming systems are characterized by subsistence agriculture and poor

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technological implements and neglect local people participation and indigenous knowledge in climate adaptation (Altieri, 2002, 2009). Kilembe *et al.* (2012) further revealed that these reasons are amplified by the growing concerns of political and economic instability in most sub-Saharan countries. Therefore, there is a need to have a better understanding on CC and variability among the farmers in order to have best adaptations based on the local condition (Mkonda *et al.*, 2018). This is particularly important in Tanzania because agriculture sector contributes significantly (over 70%) to the people's livelihoods (Nyong *et al.*, 2007; Speranza *et al.*, 2009).

Many scholars and climate practitioners place their trust on scientific analyses and climate modelling as a sole source of climate information (Rao *et al.*, 2011; Muller and Shackleton, 2014; Ndetto and Matzarakis, 2017). Their opinion is that rural farmers' knowledge of CC and their adaptive capacity are insufficient for consistent adaptation. This general ruling has affected the adoption and sustainability of various adaptation plans due to lack of consistency and coherence between scientific information and indigenous knowledge.

In addition, numerous climatic studies have consistently shown that sub-Saharan Africa is amongst the worst regions impacted by CC and with less adaptive capacity (Nyong *et al.*, 2007; Eludoyin *et al.*, 2017; Ayanlade *et al.*, 2017b). Perhaps this information is more significant in the arid, semi-arid and tropical lands of Africa (Nyong *et al.*, 2007; Speranza *et al.*, 2009; Rao *et al.*, 2011; Altieri and Nicholls, 2012; Muller and Shackleton, 2014; Asrat and Simane, 2018). This means that in areas where the farmers have less knowledge of CC, their vulnerability has been increasing significantly.

According to IPCC (2018), Tanzania is amongst the sub-Saharan countries whose farmers suffer from climate impacts. The impacts vary over agro-ecological zones (AEZs) of the country. These zones include coast, arid lands, semi-arid, plateau, south and western highlands, northern highlands and alluvial. These zones have different climatic characteristics such as rains and temperature (Mkonda *et al.*, 2018).

Essentially, Tanzania is grouped among the 13 most vulnerable countries with less capacity to adapt to CC impacts (IPCC, 2014). Unfortunately, this vulnerability is amplified by poor environmental and financial resources among the farmers (URT, 2007; Ogunleyea *et al.*, 2021). While the country considers agriculture as the engine of the economy, the sector has been significantly affected by various attributes such as poverty, poor technology, attitudes and impacts of CC. However, the latter seems to be more pronounced as significantly affected agricultural production across the globe (Lobell and Burke, 2010). In turn, this situation threatens the welfare of many people as the sector employs over 80% of the labour forces across different zones of the country.

Although various studies have established the adaptation to CC, they have largely focused on sole AEZ and thus conceding numerous shortcomings when a collective address of all the AEZ is needed, especially when policy formulation is needed (Ahmed *et al.*, 2011; Rowhani *et al.*, 2011; Mkonda and He, 2017a). Therefore, there is a need to establish a synthesized study that explores awareness and adaptation to CC in all the AEZ of the country.

The main objectives of this paper are to (1) assess the awareness of farmers to CC, (2) establish scientific analyses of climate data, (3) assess the existing adaptation practices adopted by rural farmers across different AEZ in Tanzania and (4) examine the effectiveness of these adaptation practices on yield optimization and environmental conservation. The results will synthesize the knowledge from diverse AEZs and thus establish the baseline that should be applied as a policy guideline in enhancing climate adaptation in various AEZs.

2. Materials and methods

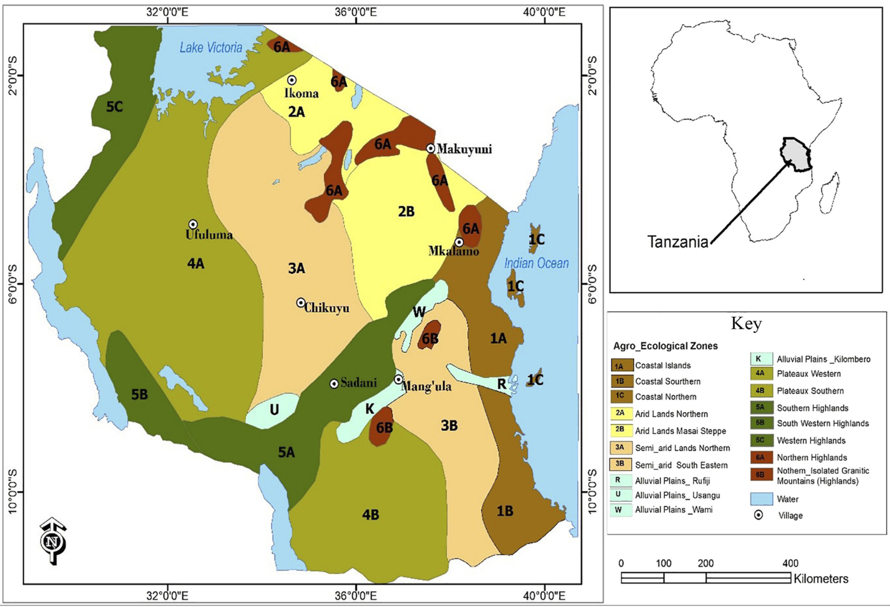
2.1 Study area

Tanzania is located on the eastern coast of Africa, south of the equator between latitudes 1° 00' S and 11° 48' S and longitudes 29° 30' E and 39°45'. Its total land area is 945,087 km^2. Based on altitude, precipitation pattern, dependable growing seasons and average water holding capacity of the soils and physiographic features, Tanzania has 7 main AEZs (URT, 2007 and Figure 1), although there are numerous micro ones. Climate varies over different AEZs, while agricultural systems and crops produced depend on the technology and agricultural knowledge of the farmers.

2.2 Data collection

This study used various sampling techniques such as systematic sampling and simple random sampling to collect the data. Systematic sampling is a type of probability sampling method in which sample members from a larger population are selected according to a random starting point and a fixed periodic interval. This interval, called the sampling interval, is calculated by dividing the population size by the desired sample size. Likewise, a simple random sample is a subset of a statistical population in which each member of the subset has an equal probability of being chosen.

The study employed systematic random sampling to select one district from each AEZ of the country. Here, all districts in each AEZ were arranged systematically to enable this kind of sampling. Then, after every five districts, we selected one district for the study. Further, it employed simple random sampling to select one village from each district (Table 1). This approach enabled all villages to have equal chance during sampling, as all villages had the potential for giving insightful and representative information (Sgro *et al.*, 2011; Grothmann *et al.*, 2017). Here, 10% of the total households in a particular village were randomly sampled as respondents for this study, as seen in Table 1. Despite the randomness of sampling, different ecological zones and gradients such as highlands and lowlands were abundantly represented. These selection criteria were pre-tested during reconnaissance survey.



Source(s): Mkonda *et al.*, 2018

Figure 1. Agro-ecological zones of Tanzania

Questionnaire (i.e. household survey) and participatory rural appraisal (PRA) (i.e. group discussion, physical observation and informative interviews) with the local farmers (Table 2) were useful tools in data collection, and essential climatic aspects were addressed. Besides, meteorological data were collected from Tanzania Meteorological Agency (TMA) and the meteorological stations in the specific study sites. The application of the PRA method has been found in various studies exploring perceptions of rural farmers about the adaptation practices adopted in the area (Cramb *et al.*, 2004; Brown, 2006; Humphrey and Kimberly, 2007).

Climate data from 1980 to 2015 (over 30 years) were collected from the meteorological stations within the selected villages. Then, these data were compared to those collected from TMA, and, where necessary, the average of data from these two sources was calculated to ensure reliability. Therefore, climate data from these two sources were used to compute long-

Table 1. Interviewed respondents in the selected villages across the seven AEZ

Zone	Region	District	Village	Total households	Respondents
Coast	Tanga	Pangani	Mkalamo	430	43
Arid	Mara	Serengeti	Ikoma	390	39
Semi-arid	Singida	Manyoni	Chikuyu	400	40
Plateau	Tabora	Uyui	Ufuluma	750	75
S&W highlands	Iringa	Iringa rural	Sadani	840	84
N. highlands	Kilimanjaro	Moshi rural	Makuyuni	940	94
Alluvial	Morogoro	Kilombero	Mang'ula	650	65
Total				*4,400*	*440*

Table 2. Summary of questionnaires administration and PRAs tools in the selected villages

	Mkalamo	Ikoma	Chikiyu	Ufuluma	Sadani	Makuyuni	Mang'ula
Questionnaires (n = 440)							
Number of households interviewed	43	39	40	75	84	94	65
Crop farmers (%)	66	50	68	72	65	70	73
Livestock farmers (%)	10	30	15	13	14	10	11
Both crop and livestock farmers (%)	24	20	17	15	21	20	16
Focus group discussion (n = 147)							
Number of people participating in groups discussion	23	21	21	18	21	23	20
Crop farmers	15	14	15	12	16	13	14
Livestock farmers	3	3	3	3	2	4	3
Both crop and livestock farmers	5	4	3	3	3	6	3
Interview (n = 35)							
Number of people participating in informative interviews	5	4	6	4	6	5	5
Crop farmers	2	2	6	4	5	5	3
Livestock farmers	2	2	0	0	0	0	1
Both crop and livestock farmers	1	0	0	0	1	0	1

Note(s): *Abbreviations:* PRA: participatory rural appraisal; n, sample time decadal and seasonal rainfall and temperature variability, and to evaluate the intra-annual and decadal trends for 30 years.

Likewise, the present study solicited the long-term climate information from the farmers. Among others, this included climate trends and adaptation practices to respond to the associated impacts. It was possible to grasp the climate information of such time from farmers because about 70% of them were aged above 50 (Table 3). Thus, these farmers had about 30 years of farming experience. The study counted a batch of ten years to determine different climate trends and the associated adaptation measures. To avoid the fact that farmers might embrace strategies as a response to a range of other drivers than CC, it specified the questions into climate scenarios. Thus, this helped us to specify the responses regarding climatic aspects. This was particularly important when soliciting cross-cutting issues, especially on the adaptation strategies of climatic impacts. Some farmers prefer mulching, crop rotation and early planting, just to mention a few.

A total of 440 questionnaires were collected from heads of smallholder households, while 35 interviews with agricultural experts, farmers and village government leaders were convened across the seven AEZs (Tables 1 and 2). For similar purpose, we conducted one group discussion in each village (i.e. each group comprised an average of 21 members), thus making a total of 147 participants who were involved in that discussion (Table 2). The questionnaire involved both closed and open questions, while a checklist of questions

Variables	Percentage
Age	
1. 18–27	7.3
2. 28–37	12.5
3. 38–47	35.2
4. 48–57	20.0
5. 58–67	15.3
6. > 68	9.7
Sex of the household head	
1. Male	65.6
2. Female	34.4
Marital status	
1. Married	89.3
2. Single	8.5
3. Divorced/Separated	2.2
Level of education	
1. Primary	70.5
2. Secondary	19.5
3. Postsecondary certificates	5.2
4. University	4.8
Experience in farming	
1. 10–19	42.5
2. 20–39	54.8
3. ≥ 40	2.7
Agricultural practices	
1. Crop production	63.5
2. Livestock keeping	12.2
3. Mixed farming (i.e. crop and livestock)	24.3
N	440

Table 3. Summary of demographic and farming characteristics of respondents from the 7 AEZs

encompassing a wide range of questions regarding the present study was administered during informative interviews (Manolache *et al.*, 2020).

2.3 Data analyses

Meteorological data from the nearest meteorological stations to each selected village and those from TMA were compared and averaged out to make an authentic and representative set of climate data. These data were then analysed using the Mann–Kendall test and Sen's slope estimate (95% level of confidence), and the Microsoft Excel (window 13) software in which the data were uploaded into in order to run different graphs. *P*-values less than 0.05 were supposed to be statistically significant ($p < 0.05$). The statistical performance involved the coding of data in the Mann–Kendall Excel sheet. Then, the process of running the coded data was eventually carried out. The obtained results clearly elaborated the *p*-values, r^2 and other correlation coefficient aspects.

The data collected through questionnaires, interviews and discussions were parameterized based on different groups of farmers' perceptions of rainfall, such as onset, cessation, occurrence and duration, and intensity. Qualitative data were thematically analysed, that is, they were summarized and inserted in the text during the discussion. Most of the results of the farmers' perceptions were presented in tables.

3. Results and discussion

Table 3 presents the demographic characteristics of the households. In this study, the majority of respondents were male (65.6%), while female (34.4%) were few. The major livelihood activities were crop production (63.5%), livestock keeping (12.2) and mixed farming (24.3). The farmers had different farming experiences, with the majority (56%) ranging between 20 and 39 years. Concurrently, this also gives relevant information on the level of awareness to CC impacts among the rural farmers (Shariatzadeh and Bijani, 2022).

3.1 Farming experience under climate change scenarios

Tables 4 and 5 indicate the knowledge and experiences which the farmers have. The exploration of this information formed important basis in comparing meteorological data and farmer's experiences. Alongside, the result from meteorological data analyses provided some rigorous information on the same (Figures 2–8). The study revealed that there has been considerable correlation between farmers' experience and the knowledge of climate. In addition, this encompasses the understanding on the trends of rainfall and temperature, and the ways of adapting to the associated climate impacts.

Explicitly, Table 4 indicates that older people (>68 years) were sure at 90.6% that climate variables have been varying/changing compared to 89.2% of those aged between 48 and 57 years, 88.4% of those aged between 38 and 47 years, 86.7% of those aged between 28 and 37 and 85.5% of those aged between 18 and 27 years. Further, the result in Table 4 indicates

Table 4.
Response to the question: "*Have you noticed climate change*"

Age range	Yes	No	Not sure	Total
18–27	85.5%	5.2%	9.3%	100%
28–37	86.7%	3.1%	10.2%	100%
38–47	88.4%	5.4%	6.2%	100%
48–57	89.2%	3.3%	7.5%	100%
58–67	90.3%	5.2%	4.5%	100%
≥ 68	90.6%	0%	9.4%	100%

that over 85% of the farmers have noticed that climate is changing. This gives a wide perspective on the magnitude of change.

Moreover, there were variations in response from farmers over AEZs. The farmers from the arid and semi-arid zones asserted that there has been high decrease in rainfall, that is, 83% and 80%, respectively, compared to those from other AEZs who (70%) mainly mentioned that rainfall has been decreasing. The same pattern was observed when 68% and 65% of the farmers from the villages of Ikoma and Chikuyu, respectively, asserted on increasing temperature.

Consequently, the farming experience of the respondents significantly contributed to acquisition of climate knowledge. The results in Table 5 portray the perception of CC based on the farming experience. Those with the longest experience were good climate repository compared to those with least experiences.

Considerably, many farmers expressed some observation of recent changes in the onset of rainfall and cessation. About 40% and 50% of those with experience of 20–39 and ≥ 40 years, respectively, asserted that these particular changes have been more pronounced in the recent years. Additionally, the incidences of increased droughts and floods were almost equally asserted (at 38%) by all farmers across all the groups. This was also applied to the recent alterations of temperature.

3.2 Results from meteorological data

Meteorological data analyses from the seven AEZs were presented (Figures 2–8), which exhibited a temporal variations of climate and temperature in all AEZs. They exhibited that all AEZs have been affected by CC; however, the magnitude of effects may differ from one AEZ to another. These results are specifically based on the total annual rainfall, total number of rainy days and the mean annual temperature.

In the southern, western highlands and northern highlands, the total annual rains and the number of rainy days declined between 1500 and 1200 mm/yr, and between 50 and 35 per year, respectively, while the average trend in all other zones declined between 1000 and 900 mm/yr, and between 40 and 25 per year, respectively. These trends had implications in terms of the pattern, intensity and frequency of the rains. Mostly these oscillations are interpreted in the form of late onset of rainfall and early cessation of rains. In the recent years (within 30 years), there has been great variation in these rain aspects. As a result, the number of dry-soil days increases, which eventually affects crop yields. These results are also in agreement with a number of scholars (Lobell *et al.*, 2008; Lobell and Burke, 2010; Kilembe *et al.*, 2012; Mkonda and He, 2022).

3.3 Overall climate situation in the area

Before embarking to the adaptation practices in the area, it is worthwhile to establish the knowledge base of climate information in the area. Afterwards, this would be a baseline to climate practitioners when underpinning the selection of adaptation measures in the respective

Perceived changes in climate	10–19 yrs	20–39 yrs	≥ 40 yrs	Total %
Changes/shift in the overall rainfall patterns	24	33	43	100
Changes in the onset and cessation	20	29	51	100
Changes in the intensity of rainfall	14	42	44	100
Increased incidences of droughts	25	37	38	100
Increased incidences of flood	30	32	38	100
Recent increase in temperature	29	34	37	100

Table 5. Climate change and vulnerability based on farmers' experience in crop production

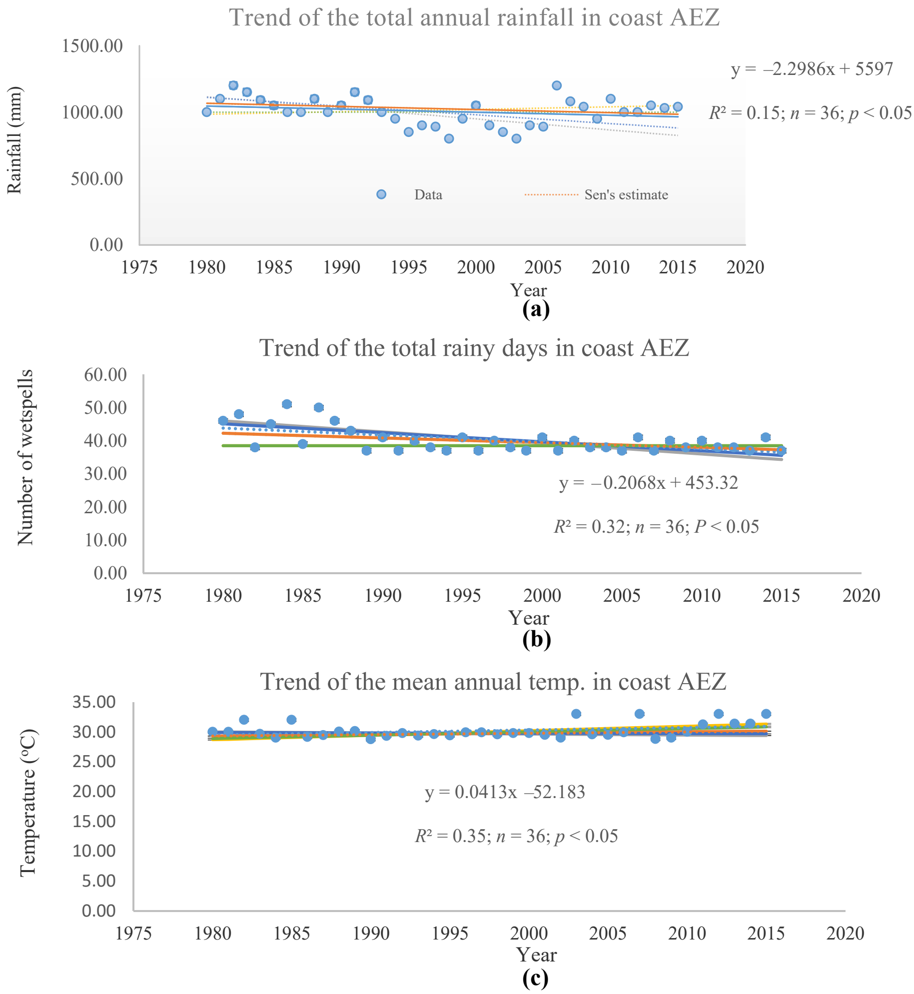


Figure 2.
Total annual rainfall (a), rainy days (b) and mean annual temperature of the coast AEZ

areas. Explicitly, the climate situation in the area is characterized by significant variations from among the AEZs. This is considerably evidenced by the results from Figures 2–5, which exhibit that there has been a persistent high variability in annual rainfall based on 5-year moving average. The 5-year trend lines in the figures are not consistent throughout 30 years under study. About half of the years within the study periods experienced annual rainfall that is below normal in all AEZs (Figures 2–8). This rainfall variability was particularly depicted in the total rainy days. About all AEZs experienced significant decline of rainy days, as depicted in Figures 2b-8b. However, this decline was more pronounced in arid and semi-arid zones (Figures 2b and 3b). This situation has brought climate stress in the respective areas and is thus affecting agro-ecosystem. This has subsequently affected crop yields and livelihoods.

These meteorological findings are in line with farmers' understanding (Birkmann *et al.*, 2013; Sovacool *et al.*, 2016; Cooper and Wheeler, 2017). The farmers asserted that increased dry spells during rainy seasons and pronounced dry season were among the reasons for the

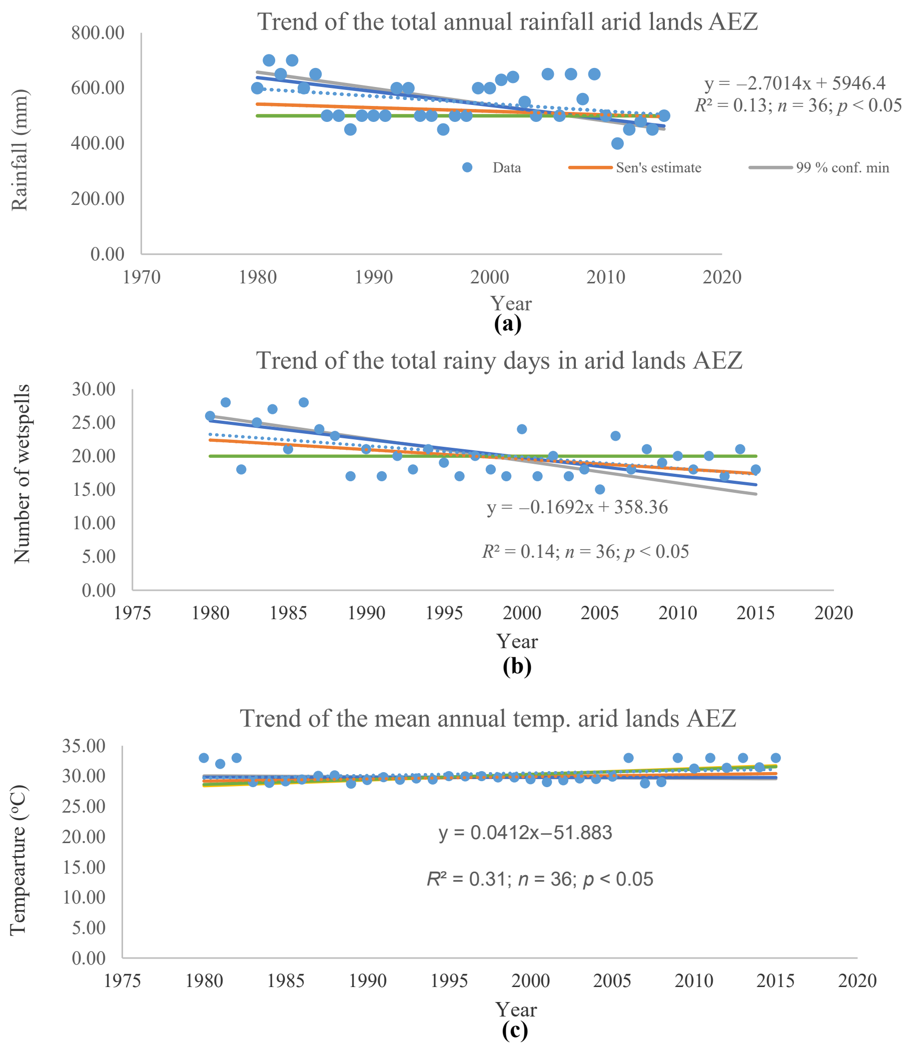


Figure 3. Total annual rainfall (a), rainy days (b) and mean annual temperature of the arid AEZ

notable variability in rainfall in the recent years. Besides, Tables 4 and 5 show that farmers have revealed the recent CC, and their major perception is that temperature has been increasing locally, while rainfall has changed in terms of pattern, frequency and intensity. All these have affected the production systems, and thus affecting yields and food security (Msongaleli *et al.*, 2015; Mkonda and He, 2018).

Likewise, Table 5 indicates that the farmers from the most vulnerable AEZs (Ikoma and Chikuyu villages) were more sensitive, concerned and responsive to CC than those from the resilient AEZs. This was evidenced through crop yields and the resilient livelihoods systems. In addition, most farmers (i.e. 65%) perceived the increasing temperature in their locality. They also noticed that the increase in temperature has adversely impacted crop production in their areas. It affects maize, sorghum, millet, rice, beans, wheat and vegetables, just to mention a few, that are grown across different AEZs. In the present study, however, farmers

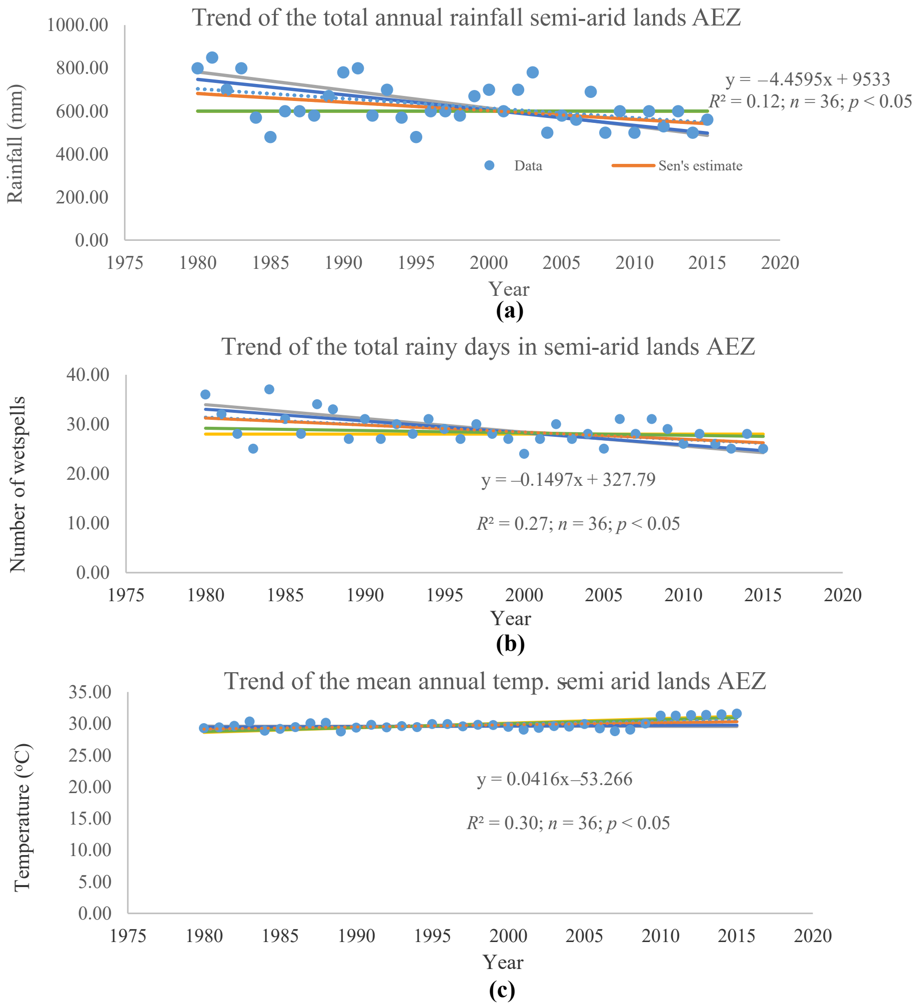


Figure 4.
Total annual rainfall (a), rainy days (b) and mean annual temperature of the semi-arid

who cultivated millet, orange, sorghum and cassava were more resilient compared to those who cultivated the high-water demanding crops such as rice. These findings are in agreement with that of Ahmed *et al.* (2011), Mkonda (2011) and Mkonda and He (2017a).

This change increased the possibility of the occurrence of more dry-soil days than the wet ones, thus affecting crop production and other livelihoods. Despite the variations over different AEZs, the overall temporal trend of total annual rainfall was around R^2 = 0.1–0.4. The arid and semi-arid land had low total annual rainfall compared to the rest AEZs. This was also evident in the total rainy days in the area.

The farmers in the all AEZs asserted correspondingly with the measured/meteorological data. For example, the trend of the total annual rainfall in the arid AEZ declined from 800 to 400 mm/yrs (R^2~0.13), while that of rainy days declined from 35 to 25/yr (R^2~0.27). This trend was supported by majority farmers (83%) from Ikoma village (from arid AEZ), as seen in Table 4. However, the degree of correspondence between the two sets of information varied over AEZs.

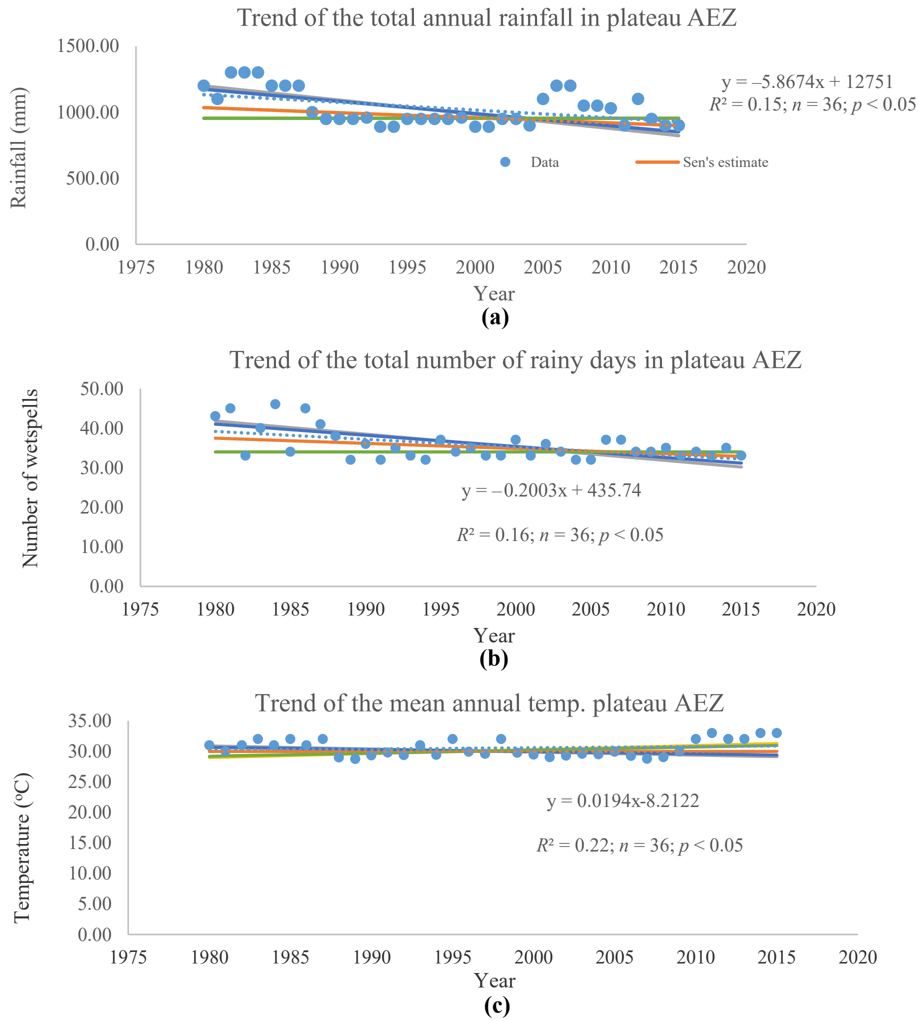


Figure 5.
Total annual rainfall (a), rainy days (b) and mean annual temperature of the plateau AEZ

The alluvia AEZ (Figure 1) receives high total annual rainfall with less oscillation, though with high variation in the number of rainy days (Figure 8). Probably, this was the potential reason of having a moderate number of farmers (60%) who asserted that rainfall has been decreasing. The results from Figures 2, 5 and 7 revealed that there has been a persistent high variability in total annual rainfall, especially from 1990 to 2010. This climatic turbulence is considered to have been influenced by El Niño Southern Oscillation and La Niña that occurred during 1990s. This result was supported by the farmers through discussion who proclaimed that during that time, there were severe floods and droughts, respectively, that later caused crop failure and famine. Tables 4 and 5 underpinned this finding, as farmers who were older and had long farming experience shared their long-standing knowledge of the same.

Further, the number of rainy days was particular important in our discussion, as it was easily perceived by the farmers. They mostly asserted that the change and/or reduction of

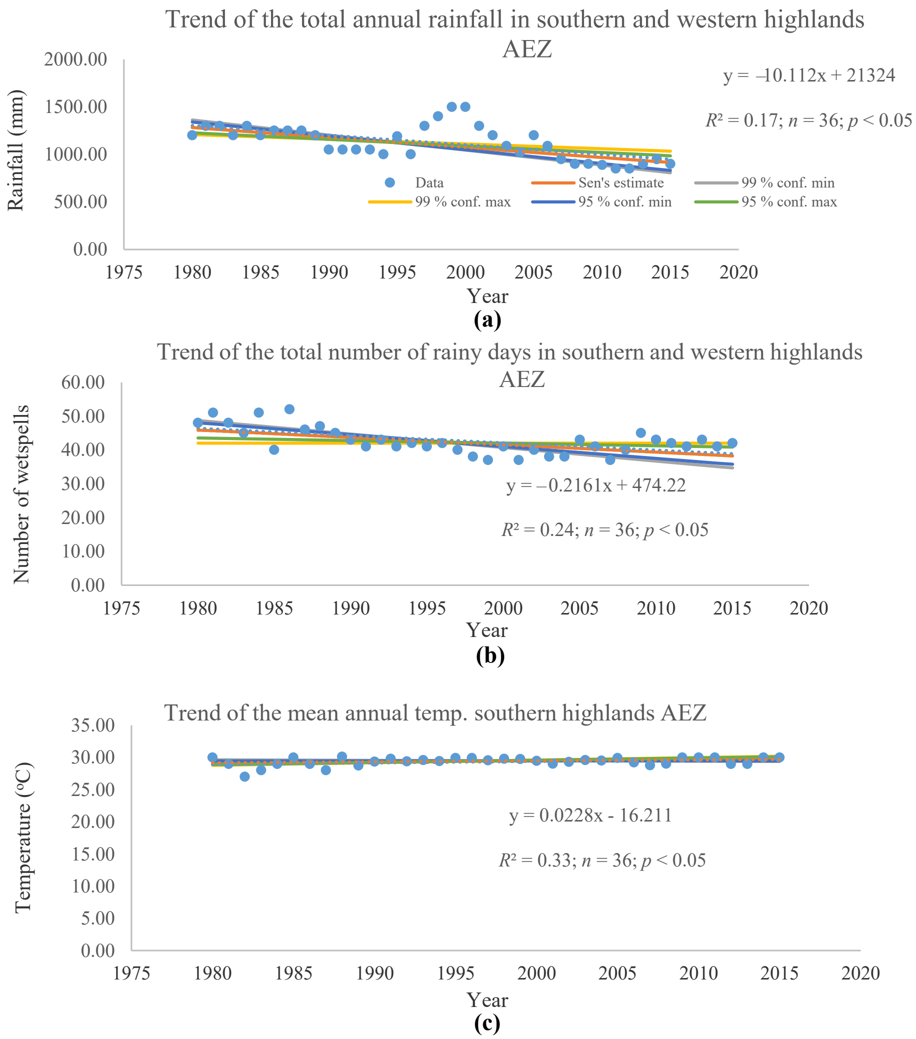


Figure 6.
Total annual rainfall (a), rainy days (b) and mean annual temperature of the S&W

wet spells during the critical growing season increased the number of dry-soil days, which is harmful for crop production. It is this situation that raises high demand for adopting adaptation practices as copping strategies or adaptation measures, and these adaptation differed across AEZs.

The farmers also asserted that, in most cases, these dry spells are more pronounced in February where the number of wet days can drop below seven, as seen in Figures 2c–8c. They argued that January and March have optimal rainy days during the growing season. Obviously, most crop failures emanate in February when numerous dry-soil days are experienced. However, this situation is based on the nature of AEZ. The results from the measured data indicate that arid (Figure 3) and semi-arid (Figure 4) were the most vulnerable AEZs in this aspect, though the southern and western highlands also experienced high

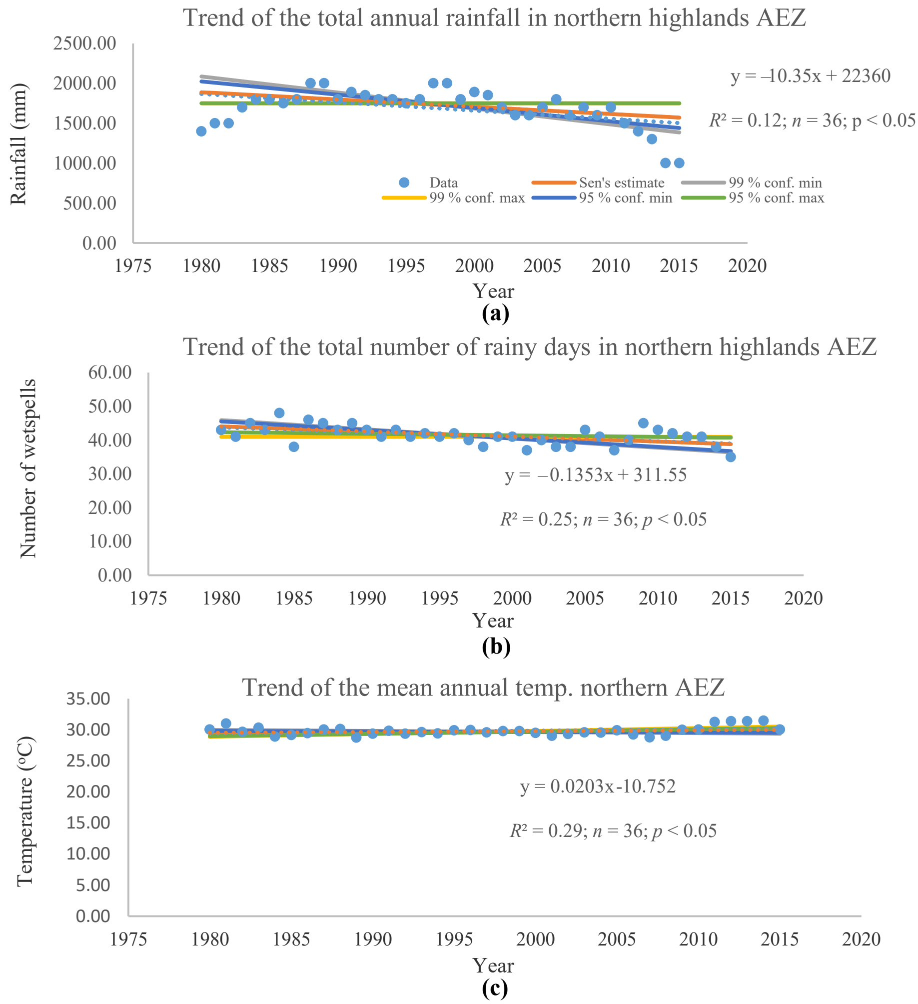


Figure 7.
Total annual rainfall (a), rainy days (b) and mean annual temperature of the northern highlands

oscillation (Figure 6). Therefore, this shows that there were similarities between the farmers' perception and the measured data from meteorological stations.

Additionally, the results indicated that in the last 5 years (2010–2015) there was a high decline in the total rains compared to previous years. During this period, there was high unreliability of the total rainfall, especially in the arid (Figure 4), semi-arid (Figure 5) and alluvial (Figure 8) regions. These results imply that those years actually experienced lower-than-normal rainfall, late onset rainfall and early cessation.

These results are in agreement with the farmers who absolutely asserted that there has been increasing rainfall variability in the recent years and that the amount of the rainy days has significantly declined. The farmers further pointed that the situation was quite realizable due to existence of several dry spells during the rainy/growing seasons (Ahmed *et al.*, 2011; Rowhani *et al.*, 2011; Below *et al.*, 2015; Mkonda and He, 2017b). This farmers' perception in Tables 4 and 5 (i.e. declined rainy days) was also observed in the measured data (Figures 2–8).

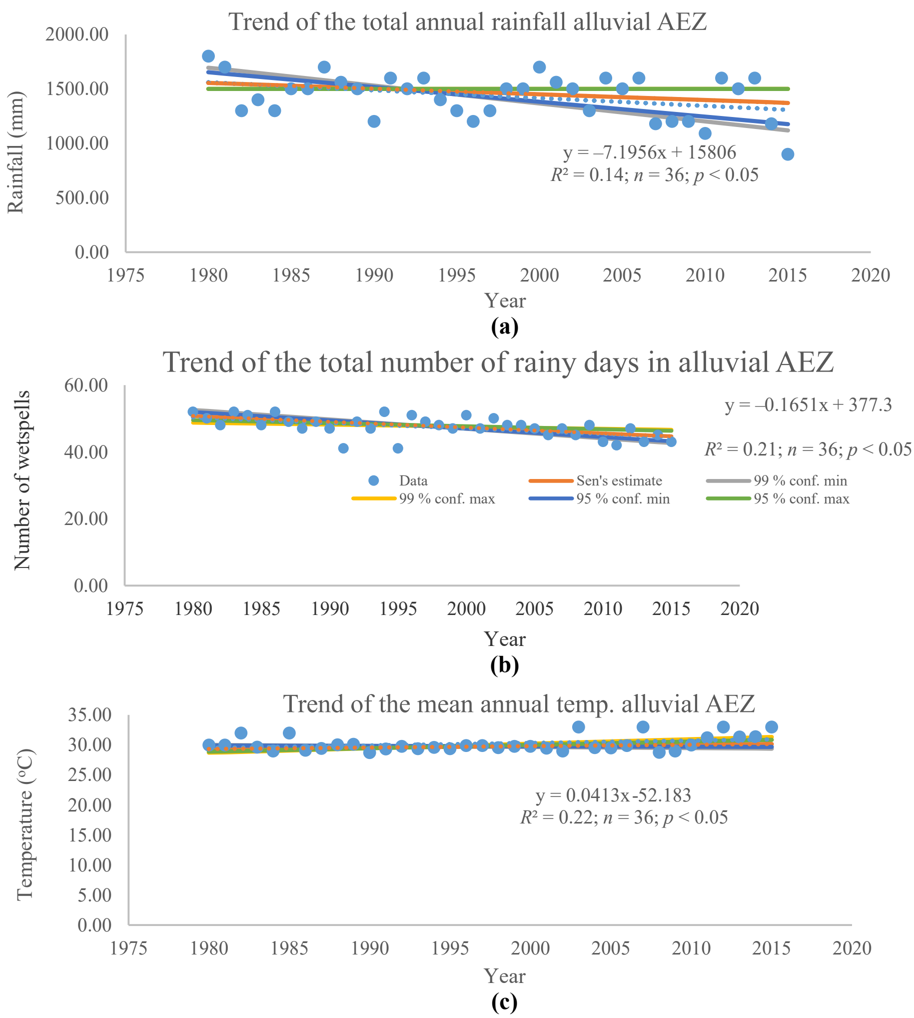


Figure 8.
Total annual rainfall (a), rainy days (b) and mean annual temperature of the alluvial

The significant fluctuations in rainfall during the growing seasons had adverse impacts on crop production, especially maize which is more sensitive to climate stress. Table 7 indicates the magnitude of climate impacts as perceived by the farmers. The farmers emphasized that prolonged droughts, especially in February (Table 5), have adverse effect on maize production.

This evidence was seconded by numerous farmers in that discussion. This verdict is in agreement with the measured data from various climate models that have confirmed that sub-Saharan Africa is the most vulnerable region in terms of CC impact and that its capacity to recover is very limited (Nyong *et al.*, 2007; Speranza *et al.*, 2009; IPCC, 2012; 2014).

Moreover, various climate models confirm that East African region, particularly Tanzania, will experience further unreliable rainfall in the coming few decades. This was also confirmed by IPCC (2014), which placed Tanzania among the 13 countries in the world that would be most affected by CC and that her capacity to cope, adapt or/and mitigate is significantly low. This is also revealed in the present study when the measured data and farmers' perception reported similar findings.

So far, the measured data (Figures 2–8) revealed that temperature was increasing locally. Figure 4c shows that semi-arid AEZ experienced significant increase in temperature, from 30°C in 1980 to 31°C in 2015 (R^2 = 0.3), while plateau AEZ had the least increase, that is, 30°C in 1980 to 30.2°C in 2015 (0.02). The northern highlands, alluvial, coast and arid AEZs had moderate increase, from 30°C in 1980 to 30.5°C in 2015 (R^2 = 0.1). This increase was also observed by Challinor *et al.* (2007, 2014) and Meehl *et al.* (2009).

Therefore, the present study has demonstrated that farmers in all the AEZs of Tanzania have essential knowledge of CC and its impacts on their livelihoods (i.e. crops and livestock), and this situation was a basis for taking adaptation measures. However, the results in Figures 2 and 3 have indicated that arid and semi-arid had high climate variability and that there were significant impacts as a result of this change.

3.4 Adaptation practices

As response to climate impacts, there have been numerous adaptation practices across all AEZs (Kangalawe and Lymo, 2013; Mkonda, 2022; Nitaa *et al.*, 2022). Some of these adaptation practices and coping strategies include mulching, agroforestry and little tillage, as stipulated in Table 7. Before mentioning some new countermeasures that have been adopted in 30 years, here are some old agricultural techniques that have been practised for over three decades. These include terraces, shifting cultivation and fallowing, just to mention a few. These were accompanied by monoculture system that has been in practice for ages.

Table 6 illustrates the percentage of farmers' adaptation strategies that have been adopted over time. Along all studied villages, about 50–80% of the farmers were observant to time of farm operation, while 50–60% adopted shorter crop varieties such as *TMV-1, Staha, Tan 250, Kilima* and *STUKA M1* (maize cultivars). These varieties can grow and give high yields within a very short period, that is, in 60 days.

This is contrary to the former local maize cultivar that took over 120 days to yield. In some AEZs (e.g. coast, alluvial and southern highlands), early maturing and high yielding rice cultivar such as SARO 5 and water-use efficient and drought-tolerant varieties such as New Rice for Africa (NERICA 1, 2, 4 and 7) were adapted to face CC impacts. Apart from adopting these cultivars, some farmers have switched to new crops as adaptation strategy. Among

Adaptation activities	Mklm n = 43	Ik n = 39	Cky n = 40	Uflm n = 75	Sdn n = 84	Mky n = 94	Mnl n = 65
Timing of farm operations	80	75	73	51	60	56	65
Adopted shorter cycle crop varieties	55	35	44	60	50	68	63
Little tillage	47	49	55	65	53	60	41
Mulching	39	48	36	39	54	43	31
Agroforestry	28	45	28	45	35	48	54
Planting high-yielding varieties	27	24	15	42	33	50	45
Practicing crop rotation	20	30	16	43	32	40	18
Small-scale irrigation	5	3	6	9	9	11	12

Note(s): Abbreviation: *Mklm, Mkalamo; Ik, Ikoma; Cky, Chikuyu; Uflm, Ufuluma; Sdn, Sadani;* Mky, Makuyuni; Mnl, Mang'ula; n, sample

Table 6. Comparison of farmers' adaptive strategies to drought conditions (in %)

these crops are cassava, pigeon peas, common beans and chick peas which are adapted as food crops, while sunflower, groundnuts, sesame, castor oil seeds and cashew-nuts are adapted as cash crops. To some extent, this has helped to reduce the vulnerability of the people.

Further, mulching, agroforestry and crop rotation have been recently adopted as climate-smart agriculture. In the study area, there were no significant differences in the adoption of mulching and agroforestry. In all the selected villages, adoption ranged between 30 and 50%. This was contrary to crop rotation that lagged behind, as it was only adopted by 20% in the studied villages.

In addition, Sieber *et al.* (2015b) revealed that along all the adaptation strategies, irrigation practice was poorly implemented (< 10%). Most of the irrigation used traditional irrigation techniques (i.e. small scale) that brought relatively less positive impacts. Probably the major reason for this poor adoption is that there has been no substantial technology to harness the major potential sources for irrigation, that is, ground water and rainfall water harvest.

Various geophysical survey reports indicate that most ground water is found less than 100 metres deep, and on the other hand, most of the rain water has been wasted through run off and infiltration. This is a waste, because this water could be harnessed for domestic and agricultural use (i.e. irrigation).

The result in Table 6 indicates that most of the farmers (80%) in Mkalamo village (Coast AEZ) gave high priority to early planting as their best adaptation strategy. They were followed by Ikoma (arid), Chikuyu (semi-arid) and Mang'ula (alluvial), respectively. On the other hand, Makuyuni (north highlands) and Ufuluma (plateau) were the best at adopting shorter cycle crop varieties. Little tillage, mulching, agroforestry and crop rotation were significantly adopted as the best conservation agriculture practices in Ufuluma (65%), Sadani (54%), Mang'ula (54%) and Makuyuni (50%) respectively. This implies that conservation agriculture is adopted in the area (Mkonda and He, 2017c).

3.5 Effectiveness of the adaptation practices

The adaptations practices adopted across the AEZs had substantial impacts on crop yields. Table 7 exhibits the extent (in percentages) which every adaptation practice contributes. However, the contributions of these adaptation practices differ from one AEZ to another (Dessai *et al.*, 2004; Sieber *et al.*, 2015a). For example, in the most climate-prone AEZs like arid and semi-arid, the contributions of the adaptation practices were significant. This is due to the fact that these areas have high demands of adaptation measures compared to the fewer climate-prone AEZs like alluvial.

Table 7. Effectiveness of adaption practices in yield optimization by percentage

Adaptation practices	Mklm $n = 43$	Ik $n = 39$	Cky $n = 40$	Uflm $n = 75$	Sdn $n = 84$	Mky $n = 94$	Mnl $n = 65$
Timing of farm operations	50	55	60	30	40	50	40
Adopted shorter cycle crop varieties	45	25	30	40	30	40	45
Little tillage	40	30	45	30	30	40	30
Mulching	30	40	30	30	40	40	30
Agroforestry	30	40	20	40	30	40	40
Plating high-yielding varieties	30	20	10	40	30	30	40
Practising crop rotation	40	30	10	40	30	40	20
Small-scale irrigation	50	30	20	15	20	20	10

Note(s): *Abbreviation:* Mklm-Mkalamo; Ik-Ikoma; Cky-Chikuyu; Uflm-Ufuluma; Sdn-Sadani; Mky-Makuyuni; Mnl-Mang'ula

In this aspect, it is recommended that the practices with high yields should be given high priority in areas where it yields much. This is very important, though the effectiveness of these practices may differ from one AEZ to another. In all aspects, the arid and semi-arid zones are more stressed by climate impacts than other AEZs. Thus, there is a need to pay more attention in these areas which occupy about 30% of the total Tanzanian land.

However, in some areas there were conflicts over resource utilizations (e.g. land appropriations). In some instances, these conflicts were caused by poor land-use plans that do not consider all land users. Here, the farmers and grazers are among the land users with conflicting interests, and thus causing chaos between these groups. This is recommended to be resolved through better land ownership as well as creation of awareness among the users.

Above all, there should be continued provision of extension services in the rural farms in order to raise awareness among the rural farmers (URT, 2021). This would, in turn, enable long-term acquisition of knowledge pertaining to CC impacts. The creation of this awareness should be more pronounced in the vulnerable AEZs, more especially, the arid and semi-arid ones.

4. Conclusions

The results of this study demonstrated that CC has substantially affected crop production and livelihoods. This has been a basis for farmers to undertake adaptation practices as response to the associated impacts. Indeed, farmers have adopted numerous adaptation practices; however, these adaptations varies over AEZ. Although the farmers are taking these adaptation practices, some of them need improvements to ensure effectiveness and sustainability. It was also confirmed that farmers residing in the most vulnerable AEZs and those with greater experience were more proactive to reduce the impacts. Under this scenario, there is a need to formulate a robust policy that develops the farmers' capacity to cope with the changing climate. Among other things, this may include upscaling the adaptation measures such as mulching, crop rotation, agroforestry and resistant crop cultivars. This should also include the researched climate-smart agricultural practices that seem to work in the specific locality, that is, different AEZs. The results of this study have widely revealed various aspects to deal with when adapting to CC impacts. Most studies established in this topic fall short as they have largely concentrated in small areas, which, in turn, may not be used to generalize the study in a wider perspective. Lastly, there is a need to expand the involvement of climate practitioners and extension experts in order to serve a wide range of farming communities.

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Appendix 1
Research instruments for the household survey

Appendix I. Farmers Questionnaire

1. Demographic and Socio-economic Characteristics of Respondents

General Information

Zone	Region	District	Village	Age	Sex	Marital status	Education level

2. How do you perceive climate change and variability through? (Tick as appropriate)

Code	Understanding	Tick
A	Change in total amount of rainfall during main rain season	
B	Increasing rainfall in amount during main rain season	
C	Decreasing rainfall in amount during main rain seasons	
D	Shift in the timing of the onset of rain in the main season	
E	Rain starting later than normal	
F	Rain starting earlier than normal	
G	Short rains than normal	
H	Long rains than normal	
I	Planting date change applying to most crops	
J	Temperature of the area decreasing	
K	Temperature of the area increasing	
L	Rainfall increasing	
M	Rainfall decreasing	
N	Rainfall fluctuating	
O	Increase in recurrences of floods	
P	Decrease in recurrence of floods	
Q	Increase in intensity of floods	
R	Increase in recurrence of droughts	
S	Increase in intensity of droughts	

3. What has been the trend of rainfall for the past 30 years to date according to your memory? (Please tick as appropriate)

A. Increasing
B. Decreasing
C. Fluctuating
D. No change
E. Don't know

4. What has been the trend of temperature for the past 30 years to date according to your memory? (Please tick the appropriate answer)

A. Increasing
B. Decreasing
C. Fluctuating
D. No change
E. Don't know

5. In your view, how do you perceive the following:

A. Rainfall and its variability
B. Temperature and its variability

6. Information on existing adaptation strategies and the reasons of doing so.

6.1. Please tick in the appropriate box matching and give the resons for that farming practices as indicated

Adaptation Strategies	Tick where appropriate	Reasons
Adopted higher yielding crop varieties		
Introduce new crop varieties		
Adopted shorter cycle crop varieties		
Stop cultivating some crop varieties		
Agroforestry		
Timing of farm operations		
Practicing crop rotation		
Crop rotations		

6.2. Please distinguish by listing between the old and new adapatation strategies as indicated hereunder

Code	**Old adaptation stratgies**	**New adapataion strategies (within 30 years)**
i		
ii		
iii		
iv		
v		
vi		

6.3. What do you think you can do in the future to be able to adapt to the changes if they persist?

Code	Future adaptation options	Tick
A	Abandon agriculture at the expense of other economic activities	
B	Abandon the current farms and move to wetter areas like river banks	
C	Emigrate from your village to other areas with better conditions	
D	Continue changing agricultural practices in line with the changes in the local climate	
E	Ask for food aid	
F	Ask for government support like introduction of new and modern adaptation options	
G	Seek to obtain more information, knowledge and education on adaptation to climate change	
H	Promote irrigation using underground water	
I	Promote conservation practices further	

MEQ

7. Policy and strategic interventions for long term resilience

What do you propose to be done by policy makers and other relevant stakeholders to help you to adapt to the changes in the long term? (Please tick as appropriate)

Code	Intervention	Yes
A	Undertake research to quantify the magnitude of climate change for each agro-ecological zone and advise accordingly.	
B	Improve institutional capacity and efficiency to work for the vulnerable farmers	
C	Enhance the farmers' capacity through education and training	
D	Enhance awareness and information provision i.e. especially the meteorological information	
E	Respect and disseminate local experience and knowledge	
F	Increased dissemination of research findings to farmers and other immediate agricultural stakeholders	
G	Develop and introduce new crop varieties to increase the tolerance and suitability of plants to temperature, moisture and other relevant climatic conditions	
H	Introduce affordable crop insurance	
I	Increased adoption of of improved crop varieties, modern irrigation and agricultural technologies especially in arid and semi arid lands	
J	Provide the needed infrastructure in the rural areas, post-harvest support and support for agro industries	
K	Develop and/or strengthen early warning systems that provide daily weather predictions and seasonal forecasts	
L	Strengthen timely dissemination of weather forecasting information to farmers	
M	Encourage participation of private sector in agriculture investment;	
N	Improve access to credits i.e. for agricultural investment	
O	Develop and strengthen water management innovations to address the risk of moisture deficiencies and increasing frequency of droughts	
P	Introduce and/or improve subsidy and incentives provisions to support farmers to adapt	
Q	Develop and implement policies and programs to influence farm-level land and water resource use and management practices	
R	Support diversification of agriculture as an economic activity	

Appendix II. Research Instrument for group discussions with farmers and informative interviews

(1) What is your commends on the local climate
(a) Give your view on the local climate situation for the past 30 years
(b) Is there any changes, is so far what are the extremes in terms of high/low ones
(c) What do you think are the major reasons for those changes (if any)?
(d) What is you anticipation on the future state of the climate? Increase or decrease?

(2) Key changes in the farming practices and their sustainability

(a) Is there any changes in crops cultivars, soil management techniques, water harvesting and storage etc.
(b) How abouit the timing of the farm practices e.g. early planting
(c) Is there any sustainable livelihood option e.g. income sources

(3) Motivating factors for changes in the farming practices and adoption of alternative livelihoods options
(a) Climatic conditions
(b) Economic factors
(c) Policy changes
(d) Social
(e) Any other

(4) Socio-economic implications of the changes in the local climate

Identification of the effects of the changes, e.g.,
Food production and security Social
Financial situation
Water availability
Conflicts over resources base
Health status of the vulnerable people
Household conflicts if associated with the impacts of climate change…etc.

(5) **Policy and strategic interventions for enhanced capacity to adapt to climate change impacts and strengthening long term resilience**

About the author

Msafiri Yusuph Mkonda is a senior lecturer with 12 years of experience in research, consultancy and teaching at Sokoine University of Agriculture (SUA); College of Natural and Applied Sciences, Department of Geography and Environmental Studies, in Morogoro, Tanzania. His specialities in publications include *Agroforestry, Agricultural Resources, Tropical Agricultural Systems, Conservation Agriculture, Agro-ecosystems, Organic Farming, Wetland Ecosystems Management, Environmental Conservation* and *Climate Change and Adaptations*. He holds a PhD in agricultural resources and environment from Southwest University in China (2018), with specialty in accumulation of soil carbon and climate change impacts and adaptations. He also holds a second degree (MSc) in natural resources assessment and management from the University of Dar Es Salaam (2012) and a first degree (bachelor of education) in geography from the University of Dar Es Salaam (2007). At SUA, he teaches introduction to physical geography, quantitative methods in geography and environmental education and conservation for undergraduate students, and climate change science and impact management for postgraduate students. His recent consultancy assignment is on “Economics of Natural Capital in East Africa Project. The consultancy project is funded by USAID, and the assignment commenced on 1–30 September 2020”, and (January–December 2021). Previously, Dr. Mkonda was involved in a consultancy: “Ascertaining sources of revenue for the National Environmental Trust Fund”. This consultancy project was funded by the Vice President’s Office, June 2015–March 2016. Dr. Mkonda is an expert in community involvement, using different methodologies, including facilitation of capacity building. Alongside, he is an expert in natural resources governance in local governments, and in the creation of awareness among the local communities towards climate change adaptations and vulnerability. In terms of research, Dr. Mkonda was involved as a research assistant in the research project, "Climate Change Resilience on the Maize and Rice crops in the Rufiji Basin from 2012 to 2015", a case of Kilombero and Kilosa districts, Tanzania. The project was funded by USAIDS. In this project, among others, the team was involved in assessing the impacts of climate change on farmers at the ward, district and regional levels, and proposed adaptation strategies. Dr. Mkonda is the author of 25 journal papers and 6 book chapters published in international peer-reviewed journals. Alongside, he has attended several international conferences on agriculture and the environment to present his works. Among these conferences are International Conference on "Towards a Climate Resilient Society for the Desired Sustainable Futures in Africa", held on 8th – 10th October 2019 at Julius Nyerere International Convention Centre, Dar Es Salaam, Tanzania; CCAI Network Climate Change and Food Security Conference held at Ledger Bahari Beach Hotel Dar Es Salaam, Tanzania, from 21st to 22nd August 2019; International Congress of Ecology held in Beijing, China, from 20th to 26th, August 2017; and The XIX International Botanical Conference held in Shenzhen, China, from 23rd to 29th July 2017. Alongside, Dr. Mkonda has attended several trainings on multidisciplinary research writing. Some of these include The Training on Multidisciplinary Research Writing Proposal phases one and two, both held at Dodoma University, Tanzania, from 27th to 29th November 2019, and from 21st to 23rd October 2020, respectively. He is a regular reviewer of various journals such as *Agricultural Systems, Agronomy for Sustainable Development, Regional Environmental Change, Journal of Soil and Water Conservation, Soil and Water Conservation Society, Environment, Development and Sustainability Journal, Journal of Human Ecology, Advances in Meteorology Journal, Communications in Soil Science and Plant Analysis, Archives of Agronomy and Soil Science* and *International Journal of Climate Change Strategies and Management*. In addition, Dr. Mkonda is an external examiner of some universities and academic institutes (e.g. Institute of Adult Education, Morogoro campus). In this aspect, reviewing dissertations/thesis and moderating examinations are some of his important activities. Msafiri Yusuph Mkonda can be contacted at: msamkonda81@yahoo.co.uk