Comparing Smallholder Farmers' Perception of Climate Change with Meteorological Data: Experience from Seven Agroecological Zones of Tanzania

MSAFIRI YUSUPH MKONDA

Centre of Excellence for Soil Biology, College of Resources and Environment, Southwest University, Chongqing, China, and Department of Geography and Environmental Studies, Solomon Mahlangu College of Science and Education, Sokoine University of Agriculture, Morogoro, Tanzania

XINHUA HE

Centre of Excellence for Soil Biology, College of Resources and Environment, Southwest University, Chongqing, China, and School of Biological Sciences, University of Western Australia, Crawley, Western Australia, Australia

EMMA SANDELL FESTIN

Southern Swedish Forest Research Centre, Swedish University of Agricultural Science, Alnarp, Sweden

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ABSTRACT

This paper examines and compares smallholder farmers' perceptions of climate change with the collected meteorological data (1980–2015) across the seven agroecological zones (AEZs) of Tanzania. Systematic and simple random sampling procedures were employed in the selection of districts and villages, respectively. This study used both quantitative and qualitative datasets. Quantitative data were derived from climatic records and questionnaires, while the qualitative data were widely derived from interviews and discussions. The Mann–Kendall test (software) and theme content (method) were used for data analyses. The results showed that rain has experienced a significant change in terms of patterns, frequency, and intensity, while temperature was locally increasing in all the AEZs. Moreover, the farmers' responses to both closed and open questions indicated that most of them (>70%) noticed these alterations. Comparatively, the farmers residing in the most vulnerable AEZs, that is, arid and semiarid lands, were more responsive and sensitive to climatic impacts than those in the least vulnerable zones, such as alluvial regions. The increase in temperature and change in the rain patterns led to the decrease in crop yields. As a response to this, farmers have adopted new strategies such as early planting and the use of shorter growing crops cultivars. This study concludes that, although farmers' perceptions were correct and echoed the meteorological/measured data in all the AEZs, adaptation and mitigation strategies are inadequate.

1. Introduction

There is substantial evidence that the mean and extremes of climate variables have been changing in recent decades and that rising atmospheric greenhouse gas concentrations could cause those trends to intensify in the coming decades (IPCC 2014). Climate projections show that most parts of Africa, and particularly East Africa, are likely to experience significant climatic changes as extreme drying and warming will occur in most subtropical regions, with slight increments in precipitation in the tropics (Paavola 2008; Ericksen et al. 2011; Rowhani et al. 2011; IPCC 2012, 2014; Mwongera et al. 2014). To secure a reliable and sustainable food source for farmers in developing countries, more tangible and accessible climate information is required in order to improve their resilience through the impacts of climate change (CC; Ahmed et al. 2011; Ayanlade et al. 2017).

The underlying reason for improving farmers' resilience in the area is that most farming in the sub-Saharan

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Corresponding author: Msafiri Yusuph Mkonda, msamkonda81@yahoo.co.uk; Xinhua He, xinhua.he@uwa.edu.au

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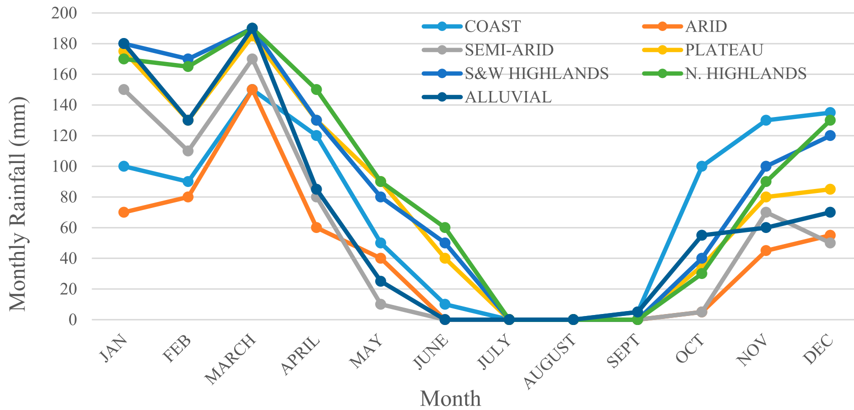

FIG. 1. The total monthly rainfall in different AEZs of Tanzania (1980–2015).

region is characterized by traditional/subsistence agriculture, poor technological approaches, and disregard for the participation of locals and traditional knowledge (Altieri 2002, 2009).This vulnerability is amplified by the growing concerns of political and economic instability in most sub-Saharan countries (Kilembe et al. 2013). A better understanding of climate change and variability is necessary for designing adaptation strategies and policies to deal with the impacts of CC on the agricultural sector that employs over 70% of the labor force in most developing countries in sub-Saharan Africa (Nyong et al. 2007; Ifejika Speranza et al. 2010; Rao et al. 2011; Muller and Shackleton 2014).This understanding largely targets the smallholder farmers who are easily affected by local and global environmental changes and weak policy framework.

Some scholars and climate practitioners place their trust in scientific analyses and climate modeling as their sole source of climate information. Their opinion is that rural farmers' knowledge of CC and their adaptive capacity is insufficient for reliable adaptation. This general ruling has affected the adoption and sustainability of various adaptation plans because of lack of consistency and coherence between the two sources. On the other hand, the perceptions of farmers in various areas are particularly important in improving climate resilience. Adger (2006) revealed that local perceptions are important and have been successfully incorporated in various levels of climate assessment and should continue to be taken into consideration and included in the models.

Various climatic studies show that sub-Saharan Africa is among the worst regions impacted by CC and thus, a better understanding of how farmers view climate issues is a tangible step toward improving resilience (Nyong et al. 2007; Eludoyin et al. 2017; Ayanlade et al. 2018). This understanding is more significant in arid, semiarid, and tropical lands, especially in East Africa (Nyong et al. 2007; Ifejika Speranza et al. 2010; Rao et al. 2011; Muller and Shackleton 2014). In areas where the farmers have less knowledge about CC, their vulnerability has been increasing abundantly. Subsequently, this has been increasing poor yields, food shortages, and poverty. Altieri and Nicholls (2012) argued that despite the fact that the world already produces enough food to feed 9–10 billion people, today there are about one billion hungry people on the planet, and this is mostly caused by poverty and inequality.

In this regard, people need the best agricultural development paradigm that is equipped with better understanding of the environmental change to optimize resilience and sustainable agricultural production. This is especially important in Tanzania, a country with diverse agroecological zones (AEZs) where rainfall and temperatures vary significantly, as seen in Fig. 1. In this figure, the total monthly rainfall varies across the AEZs of the country.

IPCC (2014) grouped Tanzania among the 13 most vulnerable countries with less capacity to adapt to CC impacts. This vulnerability is amplified by limited knowledge concerning CC adaptation among farmers. Although the country considers agriculture as the engine of the economy, the sector is significantly affected by various factors including climatic impacts, and thus the welfare of many people is threatened, as the sector employs over 80% of the labor force across different zones of the country.

Despite the fact that only 30% of the Tanzanian land is considered arid and semiarid AEZs, all other remaining zones have never been free from these impacts. Although various studies have established the perceptions of farmers with regard to CC, they have largely focused on single AEZs and thus conceded numerous shortcomings when a collective addressing of all the AEZs is needed. Therefore, there is a need to establish a synthesized study that explores all the AEZs of the country.

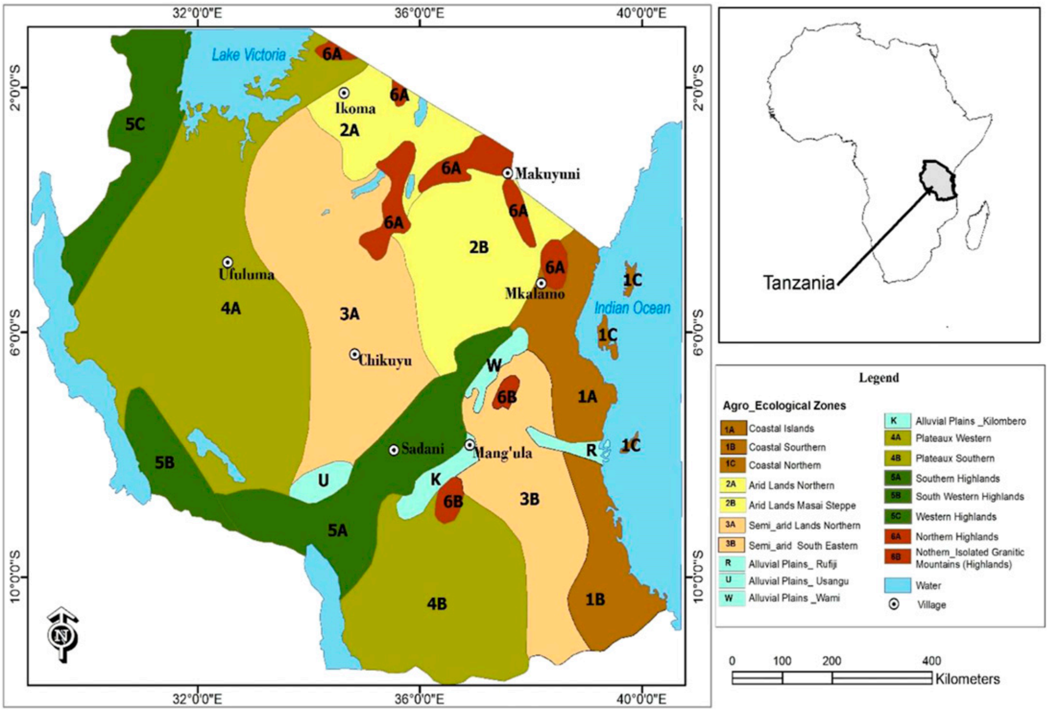

FIG. 2. Study area indicating the study sites in different AEZs of Tanzania.

The main objective of this paper is to analyze the farmers' perceptions of CC across different AEZs in Tanzania and to examine whether these perceptions correlate with the measured data from meteorological analyses. The results synthesize the knowledge from diverse AEZs and thus establish a baseline that should be applied as a guideline in addressing climate challenges along various AEZs.

2. Materials and methods

a. Profile of the study area

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

b. Selection of study sites and 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 the major seven AEZs of the country. Further, it employed simple random sampling to select one village from each district (Table 1). This approach enabled all villages to have an equal chance during sampling, as all villages had the potential to giving insightful and representative information (Sgro et al. 2011; Grothmann et al. 2017). Despite the randomness of sampling, different ecological zones and gradients such as highlands and lowlands were abundantly represented. These selection criteria were pretested during a reconnaissance survey.

Questionnaires (i.e., household survey) and Participatory Rural Appraisals (PRAs; i.e., group discussion, physical observation, and informative interviews) with the local farmers (Table 2) were useful tools in data collection where essential climatic aspects were addressed. In addition, meteorological data were collected from Tanzania Meteorological Agency (TMA) and the meteorological stations in the specific study sites. The

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
Semiarid	Singida	Manyoni	Chikuyu	400	40
Plateau	Tabora	Uyui	Ufuluma	750	75
S. and W. highlands	Iringa	Iringa rural	Sadani	840	84
N. highlands	Kilimanjaro	Moshi rural	Makuyuni	940	94
Alluvial	Morogoro	Kilombero	Mang'ula	650	65
Total				4400	440

application of the PRA method has been used in various studies exploring perceptions of rural communities on environmental issues that affect their lives (Cramb et al. 2004; Brown 2006; Kalibo and Medley 2007).

Climate data from 1980 to 2015 (over 30 years) were collected from the meteorological stations within the selected villages. These data were then compared with those collected from the TMA. This was done to ensure reliability. Climate data from these two sources were then used to compute long-time decadal and seasonal rainfall and temperature variability and to evaluate the intra-annual and decadal trends for 30 years.

Likewise, we solicited 30 years of climate information from the farmers. It was possible to collect climate information about that time from farmers because about 70% of them were aged above 50 (Table 3). Thus, they had about 30 years of farming experience. We counted a batch of 10 years to determine different climate trends, and this duration also featured in the questions that we asked the farmers. To avoid the fact that farmers might embrace strategies as a response to a range of drivers other than CC, we specified the questions into climate scenarios (see the online supplemental material). Thus, this helped us to specify the responses regarding climatic aspects. This was particularly important when soliciting information on various aspects related to adaptation measures.

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 (see Tables 1, 2). For a similar purpose, we conducted one group discussion in each village (each group composed of an average of 21 members), thus making a total of 147 participants who were involved in those discussions (see Table 2). The questionnaire involved both closed and open questions, while a checklist of questions encompassing a wide range of questions regarding the present study was administered during informative interviews (see supplemental material).

c. *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

TABLE 2. Summary of questionnaires administered and PRA 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)							
Group discussions	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)							
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

TABLE 3. Summary of demographic and farming characteristics of respondents from the seven AEZ variables.

Variables	Percentage
Age	
18–33	10.3
34–53	24.5
54–73	55.5
>73	9.7
Sex of the household head	
Male	65.6
Female	34.4
Marital status	
Married	89.3
Single	8.5
Divorced/separated	2.2
Level of education	
Primary	70.5
Secondary	19.5
Postsecondary certificates	5.2
University	4.8
Experience in farming	
10–19 years	42.5
20–39 years	54.8
≥40 years	2.7
Agricultural practices	
Crop production	63.5
Livestock keeping	12.2
Mixed farming (i.e., crop and livestock)	24.3
n = 440	

TABLE 4. Response (based on age) to the question "Have you noticed climate change?"

Age range	Yes	No	Not sure	Total
18–33	85.5	5.2	9.3	100
34–53	88.4	5.4	6.2	100
54–73	89.2	3.1	7.4	100
≥74	90.3	0	10.0	100

then analyzed using the Mann–Kendell test software based on a 95% level of confidence and uploaded into Microsoft Excel 2013 into in order to run different graphs. Statistically significant p values were less than 0.05 ($p < 0.05$).

The data collected through questionnaires, interviews, and discussions were parameterized based on different groups of farmers' perceptions of rainfall, that is, onset, cessation, occurrence and duration, intensity, etc. (see supplemental material). Qualitative data were thematically analyzed, that is, they were summarized and inserted in the text during the discussion. Most of the results of the farmers' perceptions are presented in the tables.

3. Results

a. *Farmers' perception of climate changes*

The results from analyses show that farmers perceived a notable change in climate in the recent years. Table 3 presents the demographic characteristics of the households. In this study, the majority of respondents were male (65.6%). 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.

It was further revealed that there was a correlation between farmers' experience and the knowledge of climate. Table 4 indicates that old people (>74 years) were sure (at 90.3%) that climate variables have been changing compared to 89.2% of those aged between 54 and 73 years, 88.4% of those between 34 and 53 years, and 85.5% of those between 18 and 33 years. Further, the result in Table 4 indicates that over 85% of farmers have noticed that the climate is changing. This gives a wide perspective on the magnitude of change.

Moreover, there were correlations between the vulnerability of the particular AEZ and the farmers' responses. The farmers from the arid and semiarid zones asserted that there has been a high rainfall decrease, that is, 83% and 80%, respectively, compared to those from other AEZs, who (70%) mainly mentioned that rainfall has been decreasing (see Table 5). The same pattern was observed when 68% and 65% of the farmers from the villages of Ikoma and Chikuyu, respectively, mentioned that temperature has been increasing. The two villages represent the arid and semiarid AEZs, respectively.

Similarly, the result from the general perspective (Table 6) indicates that temperature has been increasing while rainfall has greatly changed in pattern, frequency, and intensity. In this aspect, the farmers gave their general understanding of the two climatic variables under evaluation. The results also showed that there were considerable differences in the responses among the farmers from different zones. Those from the most vulnerable zones had stronger assertions than their counterparts. They proclaimed that rainfall has significantly decreased in the area.

Consequently, the farming experience of the respondent had a significant contribution to acquisition of climate knowledge. The results in Table 7 portray the perception of CC based on the farming experience. Those with the longest experience were good sources of climate information compared to those with less experience.

Significantly, many farmers expressed some observation of recent changes in onset of rainfall and cessation. About 42% and 51% of those with experiences of 20–39

TABLE 5. Farmers' response (in %) on climate change (i.e., closed questions).

Village	Rainfall			Temperature		
	Increasing	Decreasing	Fluctuating	Increasing	Decreasing	Fluctuating
Mkalamo	15	55	30	64	4	32
Ikoma	2	83	15	68	2	30
Chikuyu	2	80	18	65	3	32
Ufuluma	5	70	25	60	5	35
Sadani	4	70	26	62	4	34
Makuyuni	8	65	27	60	2	38
Mang'ula	10	60	30	57	3	40

and ≥40 years, respectively, asserted that these particular changes have been more pronounced in recent years. Further, 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.

TABLE 6. Farmers' response on climate change (i.e., open questions). Note that change in rainfall encompasses frequency, amount, intensity/duration, and variability.

Zone	Rainfall	Temperature
Coast	The number of wet days is observed to be unreliable and decreasing. In this case, there have been very few years with no change along the coast. Overall, there has been significant change in the frequency, amount, and intensity of rains as compared to the past three decades. Mostly, this change in rains has affected rice plantation.	Temperature has significantly increased. The increase in temperature along the coast prohibits the production of crops that do not need it. However, rice paddies and other heat-demanding crops have kept optimal production throughout.
Arid	This is the zone most vulnerable to climate change. For the past few decades, rainfall has seriously reduced in frequency, amount, and intensity. In some years, there has been early onset and cessation. This shifts/shrinks the duration of the growing seasons. These changes imply that there have been increased effects to the already affected ecosystems.	The temperature has been extremely high during the night but it is difficult to notice its temporal changes. The increase in temperature/heat has had impacts on crop production, especially maize, which is heat sensitive.
Semiarid	Recently, the total amount of rains, number of rainy days, and their intensity have seriously decreased. This has increasingly affected the already affected areas. Thus, the production of maize, sorghum, millet, groundnuts, and sesame has been in threat.	Although this change may not be easily quantified, there has been significant change in temperature.
Plateau	There has been unpredictability of the onset, cessation, amount, frequency, and intensity of rains, thus adversely impacting the agricultural and livelihood systems. However, the lowlands and conserved areas are less impacted compared to upland and the degraded ecosystems. Overall, rainfall variability has affected the production of maize, rice, cotton, etc.	The change in temperature has been unpredictable. Some years have experienced significant variability while other have been less affected. Overall, the lowland areas seem to experience high temperature compared to highlands.
Southern and western highlands	The cessation and onset, frequency, amount, and intensity of rains have experienced significant decreases. This has affected maize, millet, sorghum, banana, and rice plantations, which are the dominant crops in the area.	There have been insignificant changes (i.e., increases) in temperature. This has been more pronounced during summer (Southern Hemisphere).
Northern highlands	There has been a significant decrease in rainfall in most areas of the region. This decrease has affected the banana plantation, which is the main food crop in the area.	There has been insignificant change in temperature.
Alluvial	Rainfall has been fluctuating over time and place. This means the dominant zonal points, i.e., Kilomberao (Morogoro), Rufuji (Coast), Usangu (Mbeya), and Wami (Morogoro), may have slight climatic differences (i.e., rainfall). Therefore, paddy/rice production has been affected by this climate stress as the crop needs plenty of water for its growth and yields.	Most elders asserted that there has recently been an increase in temperature compared to the past three decades. This increase in temperature has denied the production of some crops, especially fruits that do not do well in high temperatures.
Overall	Rainfall has been slightly decreasing over time. Despite the fact that this change may be subject to location, overall each AEZ has experienced this.	Temperature has been increasing at a nonsignificant rate.

TABLE 7. Perception of climate change and vulnerability based on farmers' experience in agricultural production.

Perceived changes in climate	10–19 yr	20–39 yr	≥40 yr	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	13	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

b. Meteorological data

The results of the meteorological data analyses from the seven AEZs were presented as seen below (see Figs. 3–9). They showed that all agroecological zones have experienced CC, though the magnitude of effects may differ from one AEZ to another. These results are based on the total annual rainfall, total number of rainy days, and the mean annual temperature.

In the southern and western highlands and the northern highlands, the total annual rains and number of rainy days declined between 1500 and 1200 mm yr^{-1} and between 50 and 35 yr^{-1}, respectively, while the average trends in the other five zones declined between 1000 and 900 mm yr^{-1} and between 40 and 25 yr^{-1}, respectively. These trends had implications on the pattern, intensity, and frequency of the rains. Mostly these oscillations are interpreted in the form of late onset rainfall and early cessation of rains. In recent years (within 30 years), there has been great variation in these rain aspects, which resulted in an increase in the number of dry-soil days that eventually affected crop yields. These results are also in agreement with a number of scholars (Lobell et al. 2008; Lobell and Burke 2010; Kilembe et al. 2013).

4. Discussion

a. Comparing farmers' perceptions with the meteorological data

The results from Figs. 3–6 reveal that there has been a persistent high variability in annual rainfall based on a 5-yr moving average. The 5-yr trend lines in the figures are not consistent throughout the 30 years under study. About half of the years within the study period experienced annual rainfall that is below normal in all AEZs (Figs. 3–9). This rainfall variability was particularly depicted in the total rainy days. Approximately all AEZs experienced a significant decline of rainy days, as denoted in Figs. 3b–9b.

However, this decline was more pronounced in arid and semiarid zones (Figs. 4b, 5b). These meteorological findings support the farmers' perception that there is recent variability in the quantity of rainfall and the rainy days. The reasons for the notable variability in rainfall in recent years were due to several dry spells during rainy seasons and pronounced dry seasons. Tables 4–7 indicate how farmers have depicted 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.

They have also been aware of the impacts associated with these changes (see Table 8). It was revealed that the age and farming experience (presented in Tables 4 and 7, respectively) of the farmer were essential in accumulating climate knowledge among the farmers. The old farmers, that is, above 54 years and those who have farmed for at least 30 years, were more accurate and confident than the young ones. 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 more resilient AEZs. This was evidenced through crop yields and the resilient livelihood systems.

The majority (65%) of farmers correctly 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 who cultivated millet, orange, sorghum, and cassava were more resilient compared to those who cultivated crops with a high water demand, such as rice. These findings are in agreement with those of Ahmed et al. (2011), Mkonda (2011), Msongaleli et al. (2015), and Mkonda and He (2017a).

On the other hand, the measured data confirmed the oscillation of both rainfall and temperature. The rains were observed changing in terms of total annual amount, the number of rainy days, and patterns.

This change increased the possibility of the occurrence of more dry-soil days than 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.

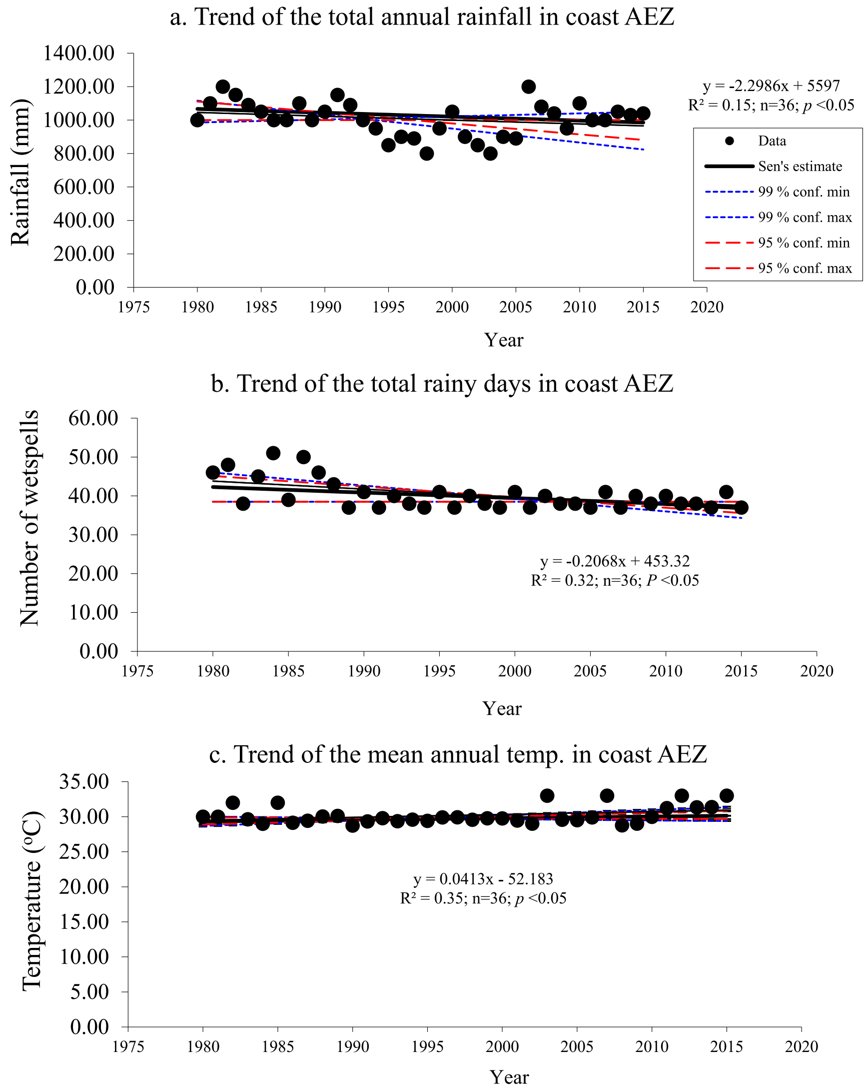

FIG. 3. (a) Total annual rainfall, (b) rainy days, and (c) mean annual temperature of the coast AEZ.

The arid and semiarid land had low total annual rainfall compared to the rest of the AEZs. This was also evident in the total rainy days in the area.

To address the main theme of our work, we compared the farmers' perceptions with the results of temporal trends from meteorological data. Figures 3–9 show the results of 30-yr measured data for coast (Fig. 3), arid (Fig. 4), semiarid (Fig. 5), plateau (Fig. 6), southern and western highlands (Fig. 7), northern highlands (Fig. 8), and alluvial (Fig. 9) that were analyzed from the data collected from the weather stations in the selected sites. The exploration of the measured data, that is, the total rainfall, the number of rainy days, and the mean annual temperature, were compared with the results of the farmers' perceptions that are presented in Tables 4–7.

The farmers in the all AEZs agreed with the measured/meteorological data. For example, the trend of the total annual rainfall in the arid AEZ declined from 800 to 400 mm yr^{-1} ($R^2 \sim 0.13$), while that of rainy days declined from 35 to 25 yr^{-1} ($R^2 \sim 0.27$). This trend was supported by the majority of farmers (83%) from the village of Ikoma (from the arid AEZ), as seen in Table 5. However, the degree of correspondence between the two sets of information varied over AEZs.

The alluvial AEZ (as seen in Fig. 2) receives high total annual rainfall with less oscillation, though with high variation of the number of rainy days (Fig. 9). This was likely the reason that a moderate number of farmers (60%) asserted that rainfall was decreasing. About 10% of farmers asserted that rainfall was increasing (Table 5). This

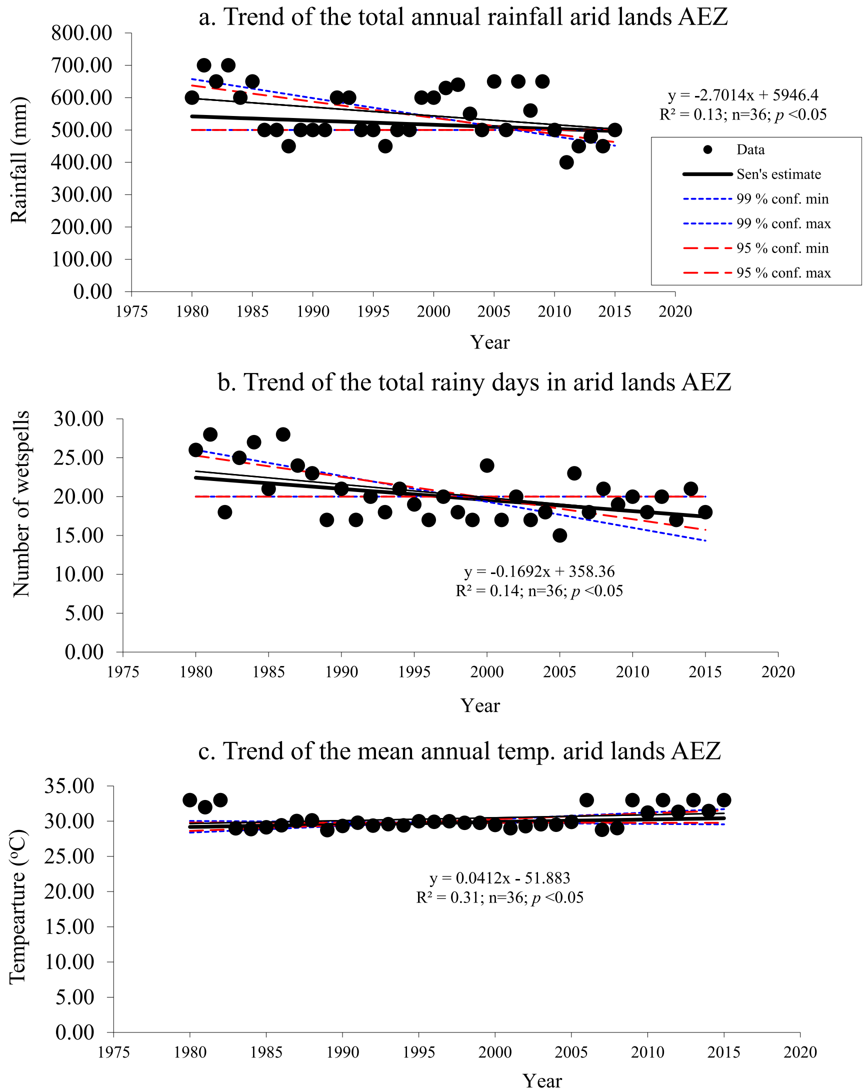

FIG. 4. (a) Total annual rainfall, (b) rainy days, and (c) mean annual temperature of the arid AEZ.

percent was particularly high compared to other AEZs, where few (2%–5%) farmers mentioned that rainfall was increasing.

The results from Figs. 3, 6, and 8 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 the El Niño–Southern Oscillation and La Niña that occurred during the 1990s. This result was supported by discussion with the farmers, who proclaimed that during that time there were severe floods and droughts that later caused crop failure and famine. Tables 4 and 7 underpinned this finding, as farmers with old age and long farming experience shared their long-standing knowledge of the same.

Further, the number of rainy days was particularly important in our discussion as it was easily perceived by the farmers. Table 6 presents the results from the open-ended questions where the farmers were free to interact. They mostly asserted that the change and/or reduction of wet spells during the critical growing season increased the number of dry-soil days that are harmful to crop production.

They further asserted that this situation is always more pronounced in February, where the number of wet days can drop below seven. They argued that January and March have optimal rainy days during the growing season. Obviously, most crops failures occur in February when numerous dry-soil days are experienced. However, this situation is highly based on the nature of the

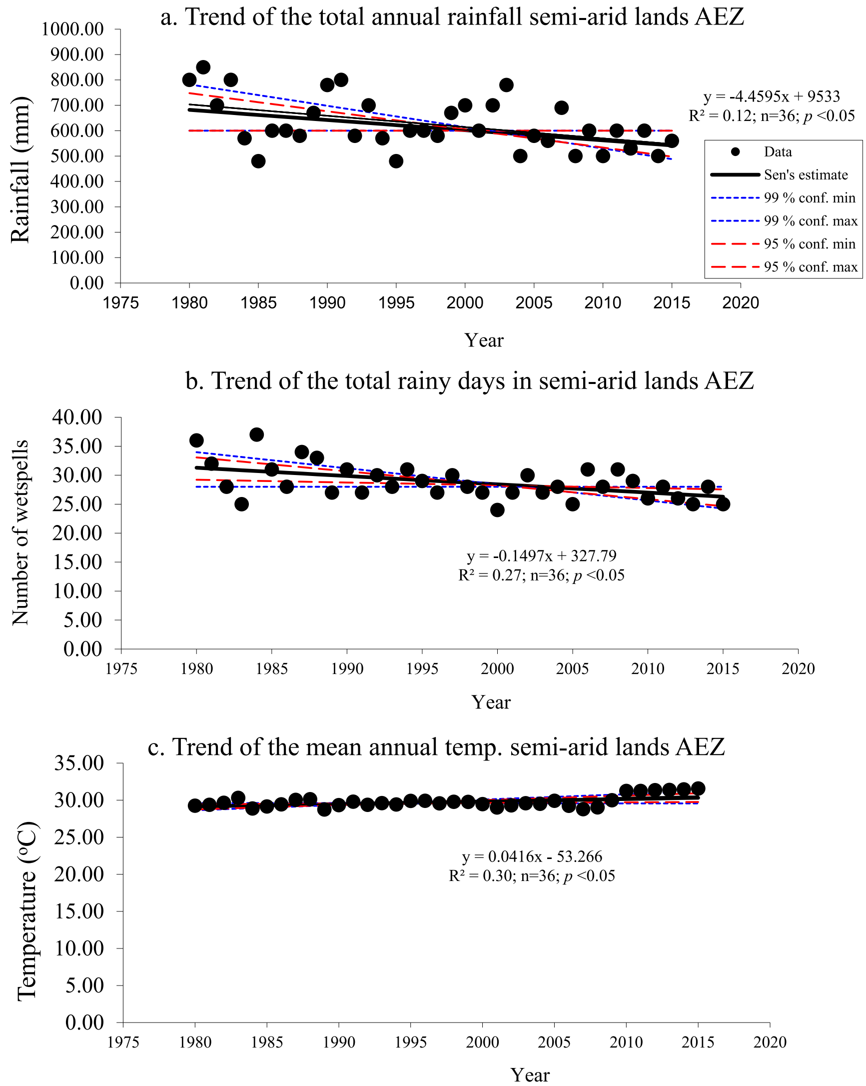

FIG. 5. (a) Total annual rainfall, (b) rainy days, and (c) mean annual temperature of the semiarid AEZ.

AEZ. The results from the measured data indicate that arid (Fig. 4) and semiarid (Fig. 5) zones were the most vulnerable AEZs in this aspect, though the southern and western highlands also experienced high oscillation (Fig. 7). Therefore, we note that 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 (2010–15) there was a large decline in rain totals compared to other years. During this period, there total rainfall amounts were highly unreliable, especially in the arid (Fig. 4), semiarid (Fig. 5), and alluvial (Fig. 9) zones. 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 recent years and that the amount of rainy days has significantly declined. The farmers further pointed out that the situation was quite feasible 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). The farmers' perceptions in Tables 6 and 7 (i.e., declined rainy days) were also observed in the measured data as seen in Figs. 3–9b.

The significant fluctuations in rainfall during the growing seasons had adverse impacts on crop production, especially on maize, which is more sensitive to climate stress. Table 8 indicates the magnitude of

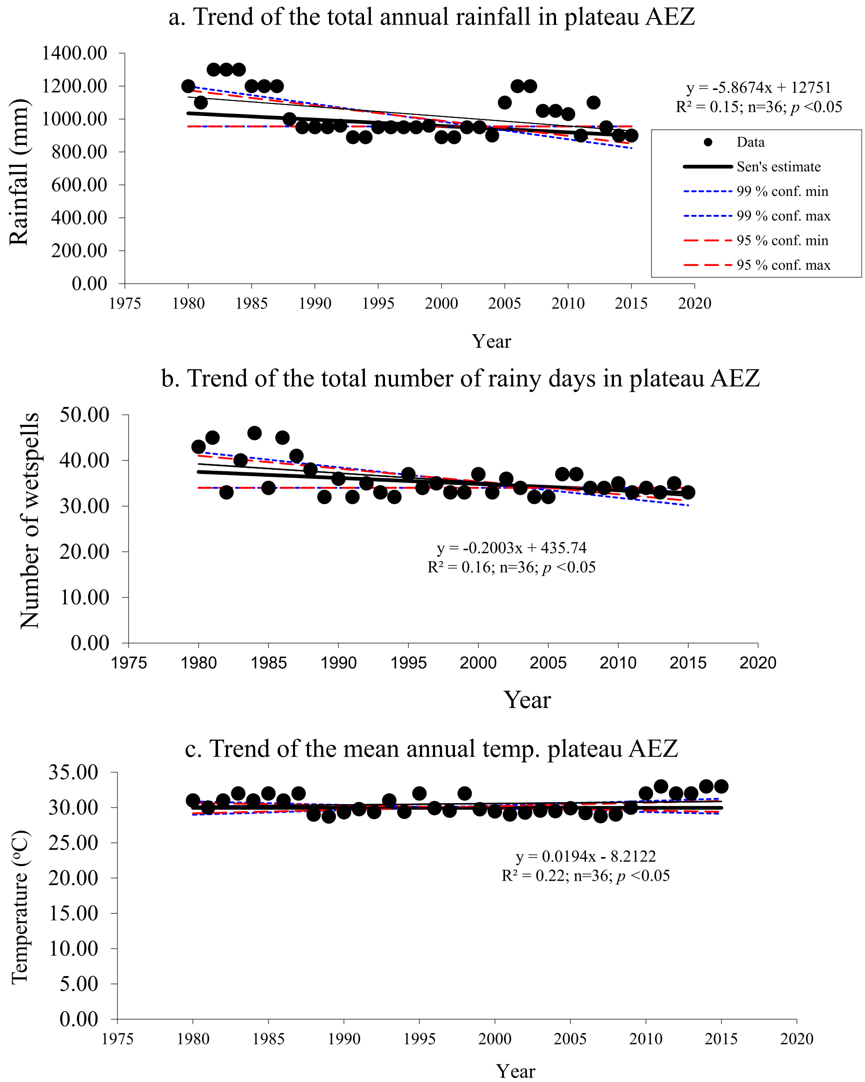

FIG. 6. (a) Total annual rainfall, (b) rainy days, and (c) mean annual temperature of the plateau AEZ.

climate impacts as perceived by the farmers. They emphasized that prolonged droughts, especially in February (Table 6), have adverse effects on maize production. An 80-yr-old man from Chikuyu, the semiarid village, asserted that, in the recent years, farmers have been getting very small yields and sometimes nothing from the farms; for instance, in 2014/15, he only obtained approximately 600 kg ha^{-1} of maize.

This testimony 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 to CC impact and that its capacity to recover is very limited (Nyong et al. 2007; Ifejika Speranza et al. 2010; IPCC 2012, 2014).

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

So far, the measured data (Figs. 3–9c) revealed that temperature was increasing locally. Figure 5c shows that semiarid AEZs experienced significant increases in temperature from 30°C in 1980 to 31°C in 2015 (R^2 = 0.3), while plateau AEZs had the least increase from

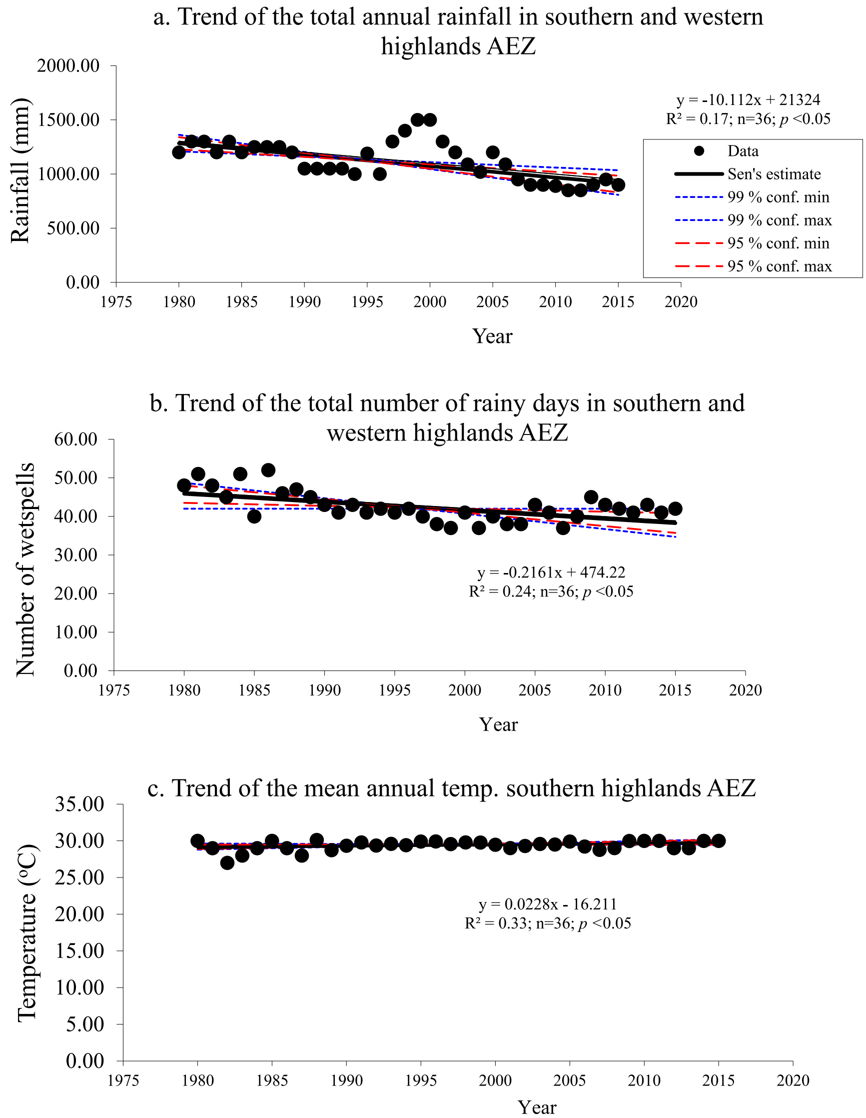

FIG. 7. (a) Total annual rainfall, (b) rainy days, and (c) mean annual temperature of the southern and western highlands AEZ.

30°C in 1980 to 30.2°C in 2015 ($R^2 = 0.02$). The northern highlands, alluvial, coast, and arid AEZs had moderate increases 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).

Table 6 indicates that about 65% of farmers asserted that they have experienced temperature increases for a couple of years. The majority (68%) of farmers in Ikoma, an arid village, asserted that temperature has been increasing and has adversely affected their major livelihoods, that is, crop production and livestock. Through discussion, some farmers affirmed that increases in temperature increased the outbreak of various diseases that affect crops and livestock.

Therefore, the present study has demonstrated that farmers in all the AEZs of Tanzania have essential perception of CC and its impacts on their livelihoods (i.e., crops and livestock). This was affirmed when their perception correlated with the measured data. Likewise, the findings from various models on temporal climate variability and its impacts to crop yields correlated with the farmers' perceptions (Table 7).

The results in Figs. 3 and 4 have indicated that arid and semiarid zones had high climate variability and that there were significant impacts posed as a result of this change. In all of the study sites, the fact that the majority of farmers noticed changes in patterns, frequency of

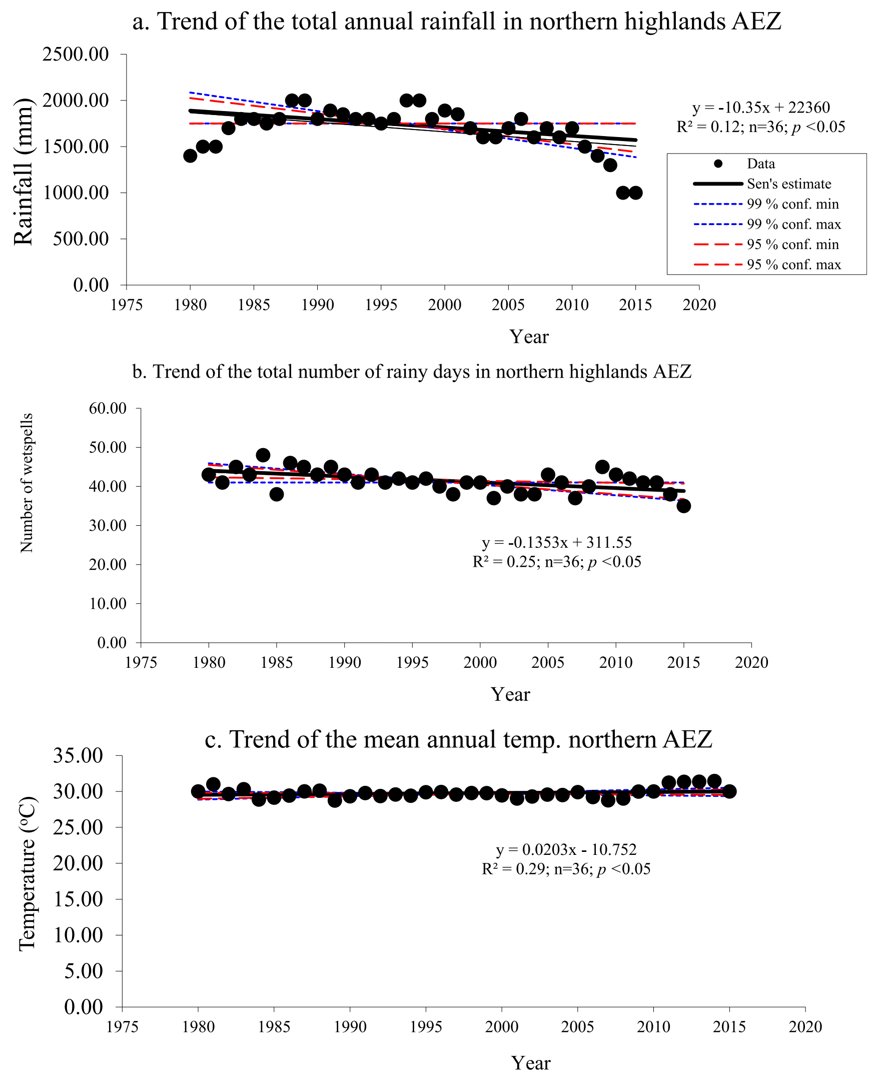

FIG. 8. (a) Total annual rainfall, (b) rainy days, and (c) mean annual temperature of the northern highlands AEZ.

extreme events, and intensity of rains was also determined in the measured data.

While the effects of temperature and rainfall are widely known, many developing countries have not yet applied the suitable adaptation strategies. The science around climate variability that has been established in various models has extensively explored the general perspective of climate but has fallen short in detailing the proper mechanism of adapting at the local level. Among the adverse impacts of rainfall and temperature variability are that they have caused crop yields to decline and affected the environment (Dessai et al. 2004; Sieber et al. 2015a).

This yield decline has resulted in increased hunger and abject poverty. The studies by Ahmed et al. (2011) and Rowhani et al. (2011) are in agreement with the results of the present study. Table 8 indicates the impacts of variability in frequency, intensity, and patterns of rains to livelihoods. The severity of these impacts also varies from one AEZ to another. Some AEZs experience lesser impacts than others, depending on the level of resilience (Kangalawe 2017).

Table 8 further indicates that the arid and semiarid zones were the most affected AEZs compared to the others (Adger 2006). This is also confirmed by various studies that were done in other countries, especially in the Sahel region (Nyong et al. 2007; Birkmann et al. 2015; Muller and Shackleton 2014; Cooper and Wheeler 2017). Sovacool et al. (2017) also realized that most South Asian countries were severely impacted and vulnerable to CC impacts.

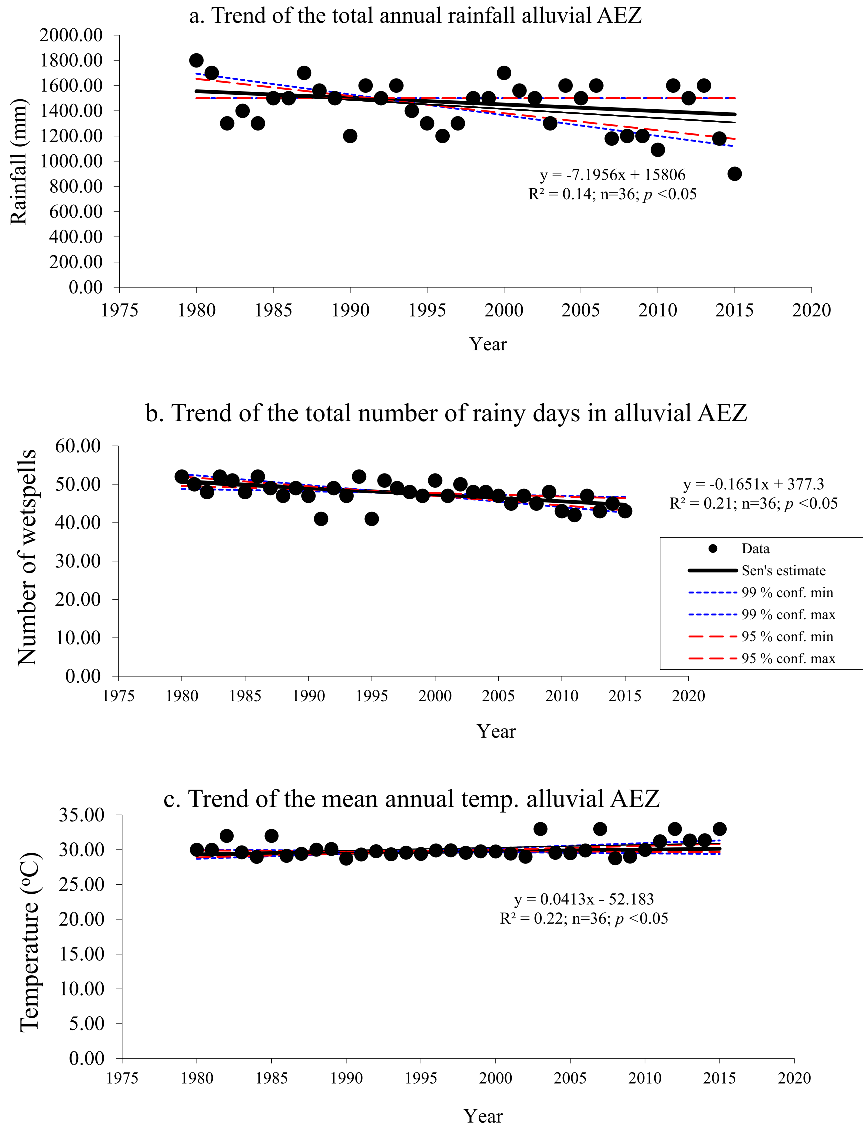

FIG. 9. (a) Total annual rainfall, (b) rainy days, and (c) mean annual temperature of the alluvial AEZ.

These impacts affected the driest areas like southern India, where irrigation agriculture is not well developed. This situation was also observed to be prominent in other countries such as Myanmar, Bangladesh, and Pakistani. It mostly affects wheat and rice, which are the major food crops in the region, and thus limits food security in the region. Hence, it is undoubted that climate impacts have affected the major livelihoods of many people around the world. Table 8 gives more details.

b. Farmers' reactions to climate change

Adaptation and coping strategies to CC varied over crop types and AEZs (Kangalawe and Lyimo 2013). Older agricultural techniques that have been practiced for more than three decades include terracing, shifting cultivation, and fallowing, among others. These were accompanied by a monoculture system that had been in practice for ages. Within the last 30 years, some new countermeasures have been adopted to help cope with climate change.

Table 9 illustrates the percentage of farmers' adaptation strategies that have been adopted within the past 30 years. Along all studied villages, about 50%–80% of the farmers paid close attention to the changes in climate and timed farm operations accordingly, 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, for example, 60 days.

TABLE 8. Perceptions of the effects of climate (effects with high 80% responses are presented).

Variables	Effects on cropping activities and livelihoods
Rainfall	Unpredictable onset and cessation affect the cropping decision. This unpredictability has in most cases shifted and shrunk the threshold of the growing seasons. As a result, crop productivity has been decreasing due to delays in planting. In addition, the prolonged droughts have been affecting the growth of crop yields. The effects have been pronounced, even for drought-resistant crops such as millet and sorghum produced in the most stressed AEZs. In addition, during excess rainfall especially in the coast, plateau, and alluvial plains, there has been suppression of crop development due to floods. This has been somewhat okay for some water demanding crops like paddy. This uncertainty has led to the adoption of transformative adaptation, especially by young farmers with tertiary education who find employment in the town or join politics and quit farming.
Temperature	The increase in temperature has somewhat affected the production of a wide range of crops. Maize is among the most affected crops by this stress. Increased heat wave episodes lead to crop withering and also increase fatigue to farmers, both of which lead to decreases in crop yields.

This is in contrast to the former local maize cultivars that took over 120 days to yield. In some AEZs (e.g., coast, alluvial, and southern highlands), early-maturing and high-yielding rice cultivars 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 an adaptation strategy. Among 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, which lagged behind, as it was only adopted by 20% in all the studied villages.

Along all the adaptation strategies, irrigation was poorly implemented, as less than 10% of all the farmers seemed to adopt it (Sieber et al. 2015b), and most of the irrigation used traditional irrigation techniques (i.e., small scale) that brought relatively little positive impact. Probably the major reason for this poor adoption is that there has been no substantial technology to harness the major potential of sources for irrigation, that is, groundwater and rainfall water harvest.

Various geophysical survey reports indicate that most groundwater is found less than 60 m deep, and most of the rainwater is wasted through runoff and infiltration. This is a waste because this water could be harnessed for domestic and agricultural use (i.e., irrigation).

The results in Table 9 indicated that most of the farmers (80%) in the village of Mkalamo (coast AEZ) gave high priority to early planting as their best adaptation strategy. They were followed by Ikoma (arid), Chikuyu (semiarid), 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 has made good progress in the area (Mkonda and He 2017c).

Comparatively, Table 10 indicates that there has been a significant correlation ($p < 0.05$) between the meteorological data and the farmers' perceptions. The

TABLE 9. Comparison of farmers' adaptive strategies to drought conditions (in %).

Adaptation activities	Mkalamo	Ikoma	Chikuyu	Ufuluma	Sadani	Makuyuni	Mang'ula
	$n = 43$	$n = 39$	$n = 40$	$n = 75$	$n = 84$	$n = 94$	$n = 65$
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
Plating 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

TABLE 10. Comparison between meteorological data and farmers' perceptions.

Zone	Meteorological data	Farmers' perceptions
Coast	Annual total rainfall varied slightly from 1200 to 800 mm ($R^2 = 0.05$; $n = 30$; $p > 0.05$) while rainy days varied from 50 to 40 ($R^2 = 0.32$; $n = 30$; $p < 0.05$). Temperature varied from 30° to 31.5°C ($R^2 = 0.12$; $n = 30$; $p < 0.05$; Fig. 3).	Recently, there has been a change in the frequency, amount, and intensity of rains as compared to the past three decades. Likewise, temperature has significantly increased in the area. The farmers feel that the number of hot days has increased.
Arid	Annual total rainfall varied from 600 to 400 mm ($R^2 = 0.13$; $n = 30$; $p < 0.05$) while rainy days varied from 30 to 18 ($R^2 = 0.27$; $n = 30$; $p < 0.05$). Temperature considerably varied from 30° to 31°C ($R^2 = 0.12$; $n = 30$; $p < 0.05$; Fig. 4).	Rainfall and temperature have been changing. Overall, the total amount of rainfall has been insufficient to suffice crop production and other important livelihoods. Temperature has experienced a drastic increase. Most elders proclaimed that in the past, the hottest days were felt during summer, but recently this pattern has been disrupted as it happens even during winter.
Semiarid	Annual total rainfall varied from 800 to 600 mm ($R^2 = 0.21$; $n = 30$; $p < 0.05$) while rainy days varied from 35 to 25 ($R^2 = 0.27$; $n = 30$; $p < 0.05$). Temperature varied from 31° to 31.5°C ($R^2 = 0.30$; $n = 30$; $p < 0.05$; Fig. 5).	The total amount of rainfall has been moderately low and oscillating, i.e., rainfall onset is becoming later while cessation comes earlier. The received rain is insufficient for important livelihoods. In addition, the temperature variability has been negatively skewed.
Plateau	Annual total rainfall varied from 1400 to 1000 mm ($R^2 = 0.21$; $n = 30$; $p < 0.05$) while rainy days varied from 40 to 30 (0.21; $n = 30$; $p < 0.05$). Temperature varied slightly from 30° to 31°C ($R^2 = 0.02$; $n = 30$; $p > 0.05$; Fig. 6).	Despite high maximum rainfall, its variability has been uncertain. The number of rainy days is inconsistent. Temperature has slightly varied over the period. It has experienced a slight increase.
S. and W. highlands	Annual total rainfall varied from 1500 to 1100 mm ($R^2 = 0.35$; $n = 30$; $p < 0.05$) while rainy days varied from 50 to 40 (0.34; $n = 30$; $p < 0.05$).Temperature varied from 29° to 30.5°C ($R^2 = 0.13$; $n = 30$; $p < 0.05$; Fig. 7).	Rainfall has experienced high variability for a couple of years, and its prediction has been uncertain. This involves the change in rain intensity, onset and cessation, and decline of rainy days. Temperature has slightly varied over a couple of years.
N. highlands	Annual total rainfall varied from 2000 to 1500 mm ($R^2 = 0.20$; $n = 30$; $p < 0.05$) while rainy days varied from 50 to 40 (0.25; $n = 30$; $p < 0.05$). Temperature varied slightly from 29° to 30°C ($R^2 = 0.09$; $n = 30$; $p > 0.05$; Fig. 8).	There has been high rainfall variability in the area. This variation has mostly involved the onset and cessation, intensity, and frequency. Temperature has slightly varied over a couple of years.
Alluvial	Annual total rainfall varied from 1700 to 1300 mm ($R^2 = 0.14$; $n = 30$; $p < 0.05$) while rainy days varied from 50 to 40 (0.31; $n = 30$; $p < 0.05$). Temperature varied from 29° to 31°C ($R^2 = 0.12$; $n = 30$; $p < 0.05$; Fig. 9).	Rainfall and temperature have experienced significant changes. Early in 1980, the areas experienced reliable and plentiful rainfall for agriculture and other livelihoods. Recently, rainfall has been more unreliable and unpredictable. Greater temperature increases have been felt, thus affecting the livelihoods.

table gives a relative summary based on the major climate aspects, that is, rainfall and temperature as perceived by the farmers.

Despite a long-time climate trend, this table further shows that most of the farmers pay close attention to the notable changes of climate. This justifies that the peoples' climate knowledge is authentic.

The overall assessment indicates that despite the possession of essential knowledge of CC, most rural farmers in Tanzania and other developing countries are located in risk-prone, marginal environments with poor entitlement. Therefore, there is a need to advance the use of both modern agricultural technology and traditional knowledge in order to curb the challenges created by both global and local environmental change (UNCCD 2005). This would improve the farmers' resilience as proposed by IPCC (2014). Similarly, the mutual integration of scientific and indigenous knowledge in addressing climate challenges across various AEZs is particularly important in strengthening the farmers' resilience to CC impacts.

5. Conclusions

The results demonstrated that the farmers have noticed changes in climate. In addition, CC has already affected and will continue affecting farmers' livelihoods unless substantial measures are taken. The farmers' knowledge on CC has been a good base for undertaking effective adaptation. It was also confirmed that farmers residing in the most vulnerable AEZs and the farmers with greater experience were more aware of climate change and were the most reactive. However, the actual and potential evidence show that climate impacts will continue affecting the already affected livelihoods.

Therefore, 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, resistant crop cultivars, etc. This should also include the researched climate-smart agricultural practices that seem to work in the specific locality. Last, there is a need to expand the practitioners involved in the climate adaptation and mitigation measures in order to expand the range of the people to be served.

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