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Using traditional agroecological knowledge to adapt to climate change and variability in the Upper East Region of Ghana

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A R T I C L E I N F O

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A B S T R A C T

Ghana's susceptibility to climate change is well documented and the agricultural sector which is the backbone of the country's economy is one of the most vulnerable sectors to the adverse effects of climate change. This study employed both quantitative and qualitative research methods including household surveys and focus group discussions to examine the extent to which traditional agroecological knowledge is used to manage climate change in three selected communities (Gia, Gaani and Nyangua) of the Kassena Nankana Municipality in the Upper East Region of Ghana. The study specifically answers the following research questions: (i) What is the extent of rainfall and temperature changes in the municipality from 1983–2017? (ii) What is the perception of farmers on rainfall and temperature changes in the selected communities for the past three decades? (iii) What are the key adaptation practices used by farmers to reduce the threats of climate change? (iv) What are the traditional agroecological indicators used by farmers to predict rainfall in the study communities? Mann-Kendall trend test was used to assess rainfall and temperature trends over the study period. Results from the trend analysis indicated an inconsistent pattern in rainfall and an increasing trend in temperature in the municipality. Results also showed that farmers perceived decreasing trend in rainfall as well as increasing temperature. Farmers' perception of decreased trend in rainfall was inconsistent with the analysed rainfall data as the trend of rainfall was statistically insignificant ($p > 0.05$) and Sen's slope confirmed a positive slope indicating that amounts of rainfall had increased in the municipality. The farmers employed a variety of on-farm and off-farm practices including the use of traditional agroecological knowledge, use of improved varieties of crops and temporary migration to adapt to the impacts of climate change in the study communities. The farmers predicted rainfall onset using a variety of traditional agroecological indicators including direction of wind, croaking of frogs, appearance of cattle egret and flowering and fruiting of local trees. The study recommends the putting in place of a framework that blends traditional agroecological knowledge and scientific knowledge to develop effective climate change adaptation strategies.

1. Introduction

Globally, climate change is the major cause of stress on food production and availability (Ray et al., 2019). The most susceptible region to climate change is sub-Saharan Africa (SSA), as a result of the combination of its low adaptive capacity with specific socio-economic and eco-climatic conditions (Intergovernmental Panel on Climate Change (IPCC), 2014). The region's population predominantly relies on rain-fed agriculture (Shimeles et al., 2018). Thus, any negative impact of the climate on the water cycle can significantly threaten agricultural production, livelihood and economy (Food and Agriculture Organization, 2020).

West Africa has been identified as a major climate change hotspot, which is expected to reduce crop yields and food production, thereby threatening food security in the region (Sultan and Gaetani, 2016). These effects, anticipated to worsen in the future will significantly affect livelihoods and the economy of countries in the region as well (Sylla et al., 2016). Ghana has also been recognized as a climate change hotspot (Asante and Amuakwa-Mensah, 2015). Several studies have revealed the impact of climate change in Ghana with the most noticeable effects being increasing rainfall variability, rising temperatures, rising sea levels and high incidence of weather extremes and disasters (Food and Agriculture Organization, 2013). The economy of Ghana depends mostly on climate sensitive sectors such as forestry and agriculture. Approximately, 70 percent of the population relies on the agricul-

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ture and forest sector for both non-timber and timber forest products (Food and Agriculture Organization, 2013). Therefore, changes in climate pattern have the tendency to exert influence on Ghana's economy, especially the susceptible sectors (Asante and Amuakwa-Mensah, 2015).

In Ghana, the northern regions have been identified as the most vulnerable regions to the impacts of climate change and variability than the rest of the country (Klutse et al., 2020). This is because the region is poorer, drier, and most of the inhabitants rely on subsistence agriculture (Darko and Atazona, 2013). Contrastingly, the adaptive capacity of the population is the lowest compared to the rest of country due to their dependence on rain-fed agriculture and low socio-economic development (Food and Agriculture Organization, 2013). Communities in northern Ghana are faced with increasing challenges in dealing with extreme weather events such as drought and flooding. Despite these challenges, the region is also faced with a high illiteracy rate (Ghana Statistical Service, 2014) which makes it difficult for most farmers to understand the weather and climate forecast details.

Hence, the use of traditional agroecological knowledge remains an alternative choice for managing climate risks amongst rural farmers in northern Ghana (Gyampoh et al., 2009; Sullo et al., 2020). Traditional agroecological knowledge is defined as the body of beliefs, practices, and knowledge about the relations between a community and its agroecosystems (Berkes et al., 2000). Research has shown that most rural farmers make farm management decisions based on agroecological knowledge resulting in strengthened rural livelihoods (for example: Sullo et al., 2020). The use of agroecological knowledge to manage climate risks has received limited research attention in Ghana (for example: Gyampoh et al., 2009; Sullo et al., 2020). There is therefore the need for sustained research to determine the extent to which traditional agroecological knowledge is used by rural farmers in managing the threats of climate change in agrarian communities in northern Ghana. The study specifically answers the following research questions: (i) What is the extent of rainfall and temperature changes in the Kassena Nankana Municipality of the Upper East Region for the period 1983–2017? (ii) What is the perception of farmers on rainfall and temperature changes in the study area for the past three decades? (iii) What are the key adaptation practices used by farmers to reduce the effects of climate change and extremes in the study area? (iv) What are the traditional agroecological indicators used by farmers to predict rainfall in the study area? The study findings will produce vital information to assist policy makers in formulating relevant policies and interventions to support farmers in managing climate risks thereby improving rural livelihoods.

2. Materials and methods

2.1. Description of study area

The Upper East Region is one of the smallest administrative regions in Ghana covering about 8,842 km^2 (Ghana Statistical Service, 2014). The region has 15 districts including Kassena Nankana Municipality which was purposively selected for this study because of its vulnerability to climate change (Etwire et al., 2013). The municipality is found roughly between latitude 11°10′ and 10°3′ North and longitude 10°1′ West (Fig. 1). The municipality is marked by wet and dry seasons, which are predominantly influenced by harmattan air mass and tropical maritime. The harmattan air mass originating from Sahara desert is generally dusty and dry. Rainfall is practically absent during this period because of low relative humidity. Day temperatures can rise as high as 42°C particularly between February and March while night temperatures can be as low as 18°C (Ghana Statistical Service, 2014). The municipality is found within the Guinea Savannah woodlands and the common trees found in the municipality are Mango (*Mangifera indica*) Sheanut (*Vitellaria paradoxa*), Baobab (*Adansonia digitata*) and Dawadawa (*Parkia biglobosa*) (Ghana Statistical Service, 2014).

Within the municipality, three communities namely Gia, Gaani and Nyangua (Fig. 1) were purposively selected following advice from the Director of the Department of Agriculture in the municipality. These communities were recommended based on their intensive farming activities. Dominant crops grown in these communities include sorghum, millet, maize, groundnut, beans, guinea corn, onions and dry season tomatoes (Ghana Statistical Service, 2014).

2.2. Research design

The study used a cross-sectional research design to determine the perception of farmers on rainfall and temperature changes, the key adaptation practices used by the farmers as well as the traditional agroecological indicators used to predict rainfall in the study communities. Cross-sectional research design was used because it allowed us to look at many characteristics at once in a given population (Busk, 2014). Cross-sectional studies are also employed to describe what is happening at the present moment (Busk, 2014). Furthermore, time series study design was used to determine the extent of rainfall and temperatures changes in the municipality from 1983 to 2017 because it allows the examination of climatic variables over time (Salkind, 2010).

2.3. Data collection

Monthly rainfall and temperature data for Kassena Nankana Municipality were obtained from a Ghana Meteorological Agency station (i.e. Navrongo) covering the period of 1983 to 2017. The elevation above sea level for the weather station is 201 m. Mean annual rainfall and temperature were computed from the monthly data obtained using Microsoft Excel Version 2013.

2.4. Participatory methods

Primary data was collected using both quantitative and qualitative methods including household surveys involving 150 farming households and focus group discussions (FGDs). For the household surveys, a set of closed-ended questions complemented by few open-ended questions (Appendix A) were administered on a one-to-one basis with farmers to determine their perception of rainfall and temperature changes for the past three decades, the key adaptation practices used to minimize the effects of the changing climate as well as the traditional agroecological indicators used to predict rainfall in the study communities. A maximum of fifty households were randomly selected from each community using the fixed household approach (Umulisa, 2012) to attain an intended sample size of 150 respondents. The respondents agreed to take part in the interviews by giving their informed consent. Administration of questionnaires was done in the appropriate local language (Kassem) in July 2018.

FGDs were organized in each community to gather information on the research objectives. An average of ten participants were selected based on their comprehensive understanding of climate change and extensive agroecological knowledge of the communities. The participants included the same number of males and females to create gender-specific information. The participants were farmers, assembly members and traditional authorities. With their permission, the discussions were tape-recorded in their local language, transcribed and later translated into English language by Research Assistants recruited from the communities to assist in the data collection. Each discussion took about forty-five minutes. Every information provided by the respondents or participants in the participatory research methods was treated confidentially.

2.5. Data analysis

Trend analysis was conducted using the Mann-Kendall trend test while the magnitude of the trend was estimated using Sen's slope. The test establishes the null and alternate hypotheses of which the null hypothesis presumes an insignificant trend in the time series whilst the alternate hypothesis presumes the reverse. Serial correlation was taken

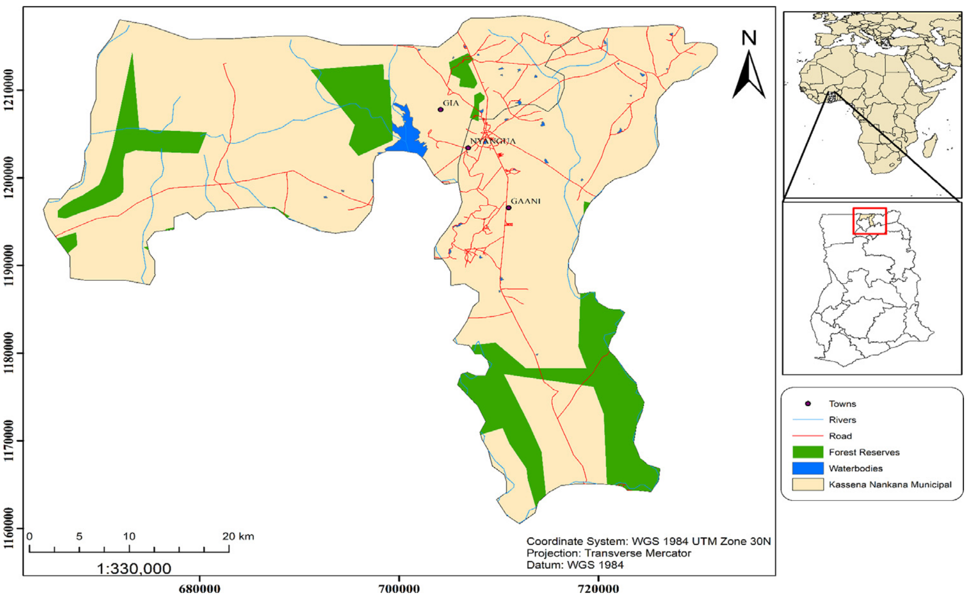

Fig. 1. Map of Kassena Nankana Municipality showing the study communities.

into account with the method proposed by Hamed and Rao (1998). Mann-Kendall trend test has been employed by several researchers (for example: Sa'adi et al., 2019) to assess the extent of climate variables over time due to its non-parametric and robust nature as well as its less sensitivity to outliers. The procedure for calculating Mann-Kendall trend test as described by Gilbert (1987) is as follows:

Let $x_1, x_2, \ldots x_n$ represent n data points where x_j represents the data point at time j. Then the Mann-Kendall statistic (S) is given by

$$S = \sum \sum^{n-1} {}^{n} sign(x_j - x_k)$$

$k = 1$ $j = k + 1$ where:

$$sign(x_j - x_k) = 1 \text{if } x_j - x_k > 0$$

$$= 0 \text{ if } x_j - x_k = 0$$

$$= -1 \text{if } x_j - x_k < 0$$

A very high positive value of S indicates an increasing trend, and a very low negative value indicates a decreasing trend. Nonetheless, it was important to compute the probability related with S and the sample size, n, to statistically evaluate the significance of the trend. The procedure to compute this probability following (Kendall, 1975) is described as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{(p=1)}^{g} tp\left(t_p - 1\right)\left(2t_p + 5\right)\right]$$

Where n is the number of data points, g is the number of tied groups (a tied group is a set of sample data having the same value), and t_p is the number of data points in the p^{th} group. In the sequence {2, 3, non-detect, 3, non-detect, 3}, we have $n = 6$, $g = 2$, t_1 =2 for the non-detects, and t_2 =3 for the tied value 3.

A normalized test statistic Z was computed as follows:

$$Z = \frac{s-1}{[VAR(S)]^{1/2}} \text{ if } S > 0$$

$$Z = 0 \text{ if } S = 0$$

$$Z = \frac{s+1}{[VAR(S)]^{1/2}} \text{ if } S < 0$$

The probability linked with the normalised test statistic was computed. The probability density function for a normal distribution with a mean of 0 and a standard deviation of 1 is given by:

$$f(z) = \frac{1}{\sqrt{2\pi}} e^{\frac{-z^2}{2}}$$

The level of significance (α) was set at 0.05. Coefficient of variation (CV) was used to assess the variation in rainfall and temperature in the municipality. The method for calculating coefficient of variation is as follows:

$$CV = \frac{\sigma}{\mu}$$

Where: σ = standard deviation and μ = mean

With the use of Statistical Package for Social Sciences (SPSS) version 21, descriptive statistics including frequencies and percentages were employed to quantify household survey data. Thematic analysis was employed to analyse the qualitative data obtained from the FGDs (Braun and Clarke, 2019).

3. Results

3.1. Socio-demographic characteristics of respondents

The respondents interviewed comprised of 150 farmers of which majority (n = 112; 75%) of them were males and the remaining were females (n = 38; 25%) (Table 1). In terms of age, most of the respondents (n = 76; 51%) belonged to the age category of 41–60 years. Furthermore, majority of the respondents (n = 76; 51%) had non-formal education. About 90% of the respondents (n = 135) were natives of the communities with only a few (n = 15; 10%) been migrants. About 72 of the respondents representing 48% had between 5 and 10 years of farming experience.

3.2. Extent of rainfall and temperature changes in Kassena Nankana Municipality

Results showed that mean annual rainfall has been variable in the municipality from 1983 – 2017 with the highest annual rainfall (1365 mm) recorded in 1999 while the lowest annual rainfall (617.2 mm) recorded in 2014 (Fig. 2A). Sen's slope had a positive magnitude indicating that there was a rise in annual rainfall from 1983–2017

Table 1
Socio-demographic characteristics of respondents.

Variables	Gender		Total (n = 150)
	Males (n = 112)	Females (n = 38)	
Age (years)			
< 20	5 (4.5)	3 (7.9)	8 (5.3)
21 – 40	17 (15.2)	5 (13.2)	22 (14.7)
41 – 60	56 (50.0)	20 (52.6)	76 (50.7)
> 60	34 (30.3)	10 (26.3)	44 (29.3)
Education			
Non-formal education	52 (46.4)	24 (63.2)	76 (50.7)
Primary education	43 (38.4)	13 (34.2)	56 (37.3)
Secondary school education	15 (13.4)	1 (2.6)	16 (10.7)
Tertiary education	2 (1.8)	0 (0.0)	2 (1.3)
Household size			
1 – 5 individuals	3 (2.7)	3 (7.9)	6 (4.0)
6 – 10 individuals	104 (92.8)	33 (86.8)	137 (91.3)
11 – 15 individuals	5 (4.5)	2 (5.3)	7 (4.7)
Origin			
Native	108 (96.4)	27 (71.1)	135 (90.0)
Migrant	4 (3.6)	11 (28.9)	15 (10.0)
Farming experience (years)			
< 5	8 (7.1)	7 (18.4)	15 (10.0)
5 – 10	56 (50.0)	16 (42.1)	72 (48.0)
> 10	48 (42.9)	15 (39.5)	63 (42.0)
Land tenure system			
Inherited	102 (91.0)	29 (76.3)	131 (87.3)
Purchased	7 (6.3)	1 (2.6)	8 (5.3)
Rented	3 (2.7)	8 (21.1)	11 (7.3)

Numbers in and outside parentheses are percentages and respondent counts respectively.
NB: Males in this study refer to adult male farmers who were household heads while females in this study refer to adult female farmers who were household heads.

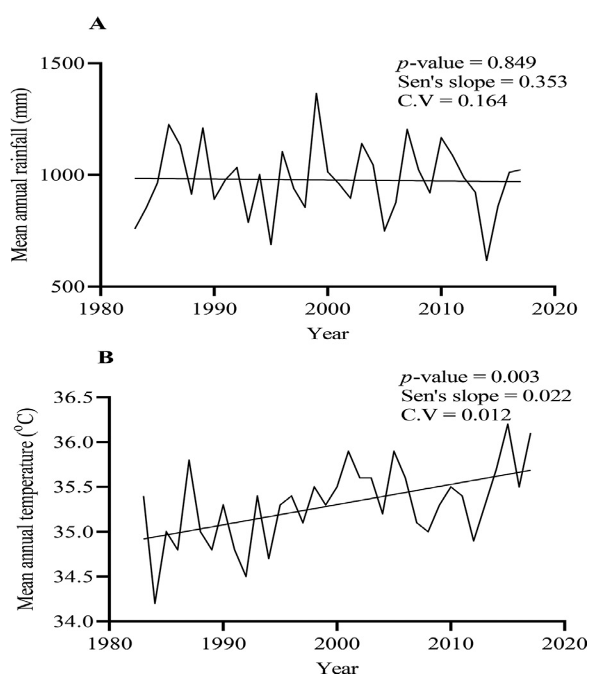

Fig. 2. Mean annual rainfall (A) and temperature (B) for the study area from 1983 – 2017.

though the trend was statistically insignificant ($p =$ 0.849). The municipality experienced a rainfall variation of about 16%. Results also indicated that mean annual temperature has been erratic but significantly increasing ($p = 0.003$) from 1983–2017 (Fig. 2B). This is confirmed by the positive value of Sen's slope. The variability in temperature for the municipality is about 1.2% over the study period.

3.3. Respondents' perception on rainfall and temperature changes

The respondents perceived rainfall and temperature changes in terms of increasing and decreasing patterns, the amounts, duration of the rainy season as well as the onset. With regards to rainfall, majority of the respondents (n = 79; 53%) reported a decrease in the amounts of rainfall compared to past three decades (Table 2). Furthermore, majority of them (n = 143; 95%) reported a decrease in the pattern of rainfall compared to three decades ago. About 79% of the respondents (n = 119) reported shorter rainy season nowadays compared to three decades ago. In terms of temperature, majority of the respondents (n = 110; 73%) reported a rise in temperature for the past 30 years.

3.4. Respondents' adaptation practices

The respondents used a variety of on-farm and off-farm adaptation practices to reduce the effects of climate change on agricultural production. On-farm adaptation practices are mechanisms employed to minimize climate risks on the farm while off-farm adaptation practices are the mechanisms used to reduce climate risks outside the farm (Aniah et al., 2019). With regard to on-farm adaptation, results indicated that majority of the respondents (n = 123; 82%) used traditional agroecological knowledge (Table 3). For instance, some of the farmers reported these:

> "*For so many years, I have used traditional agroecological knowledge to adapt to the changing climate. This is knowledge passed on to us by our ancestors. It is cheaper than using other adaptation strategies and also very efficient*" - (Male farmer, Nyangua, July 2018)

> "*The challenge these days is that, our young men and women are not interested in preserving our culture through the use of traditional agroecological knowledge on the farm. However, the use of traditional agroecological knowledge has proved to be more efficient time after time as*

Table 2
Perception of respondents on rainfall and temperature changes in the study communities.

Variables	Gender		Total (n = 150)
	Males (n = 112)	Females (n = 38)	
Rainfall			
More rain today compared to 30 years ago	52 (46.4)	19 (50.0)	71 (47.3)
Less rain today compared to 30 years ago	60 (53.6)	19 (50.0)	79 (52.7)
Increase in the pattern of rainfall over the past 30 years	6 (5.4)	1 (2.6)	7 (4.7)
Decrease in the pattern of rainfall over the past 30 years	106 (94.6)	37 (97.4)	143 (95.3)
Rainfall season is becoming shorter	85 (75.9)	34 (89.5)	119 (79.3)
Rainfall season is becoming longer	27 (24.1)	4 (10.5)	31 (20.7)
Rainfall comes earlier compared to 30 years ago	80 (71.4)	22 (57.9)	102 (68.0)
Rainfall comes late compared to 30 years ago	32 (28.6)	16 (42.1)	48 (32.0)
Temperature			
Temperature of the growing season has increased over the past 30 years	77 (68.7)	33 (86.8)	110 (73.3)
Temperature of the growing season has decreased over the past 30 years	35 (31.3)	5 (13.2)	40 (26.7)

Numbers in and outside parentheses are percentages and respondent counts respectively.
NB: Males in this study refer to adult male farmers who were household heads while females in this study refer to adult female farmers who were household heads.

Table 3
On-farm and off-farm adaptation practices used by the respondents in the study communities.

Variables	Gender		Total (n = 150)
	Males (n = 112)	Females (n = 38)	
On-farm adaptation			
Crop diversification	73 (65.2)	15 (39.5)	88 (58.7)
Use of improved varieties of crops	79 (70.5)	18 (47.4)	97 (64.7)
Adjusting planting dates	69 (61.6)	17 (44.7)	86 (57.3)
Irrigation	23 (20.5)	10 (26.3)	33 (22.0)
Use of traditional agroecological knowledge	93 (83.0)	30 (79.0)	123 (82.0)
Agroforestry	49 (43.8)	13 (34.2)	62 (41.3)
Soil conservation practices	58 (51.8)	16 (42.1)	74 (49.3)
Mixed farming	46 (41.1)	15 (39.5)	61 (40.7)
Off-farm adaptation			
Reduce food consumption	62 (55.4)	22 (57.9)	84 (56.0)
Temporary migration	75 (67.0)	19 (50.0)	94 (62.7)
Relying on support from government and NGOs	22 (19.6)	10 (26.3)	32 (21.3)
Relying on support from family and friends	59 (52.7)	20 (52.6)	79 (52.7)
Petty trading	43 (38.4)	25 (65.8)	68 (45.3)
Masonry	55 (49.1)	12 (31.6)	67 (44.7)
Sand mining	38 (33.9)	9 (23.7)	47 (31.3)
Change of diets	52 (46.4)	15 (39.5)	67 (44.7)

Numbers in and outside parentheses are percentages and respondent counts respectively.
NB: Males in this study refer to adult male farmers who were household heads while females in this study refer to adult female farmers who were household heads.

compared to other adaptation strategies particularly for aged people like me" – (Female farmer, Gia, July 2018).

Furthermore, about 65% of the respondents (n = 97) used improved crop varieties. The least on-farm adaptation strategy used by the respondents was irrigation (n = 33; 22%). In terms of off-farm adaptation, majority of the respondents (n = 94; 63%) practiced temporary migration. This was followed by reducing food consumption (n = 84; 56%). The least off-farm adaptation strategy used by the respondents was reliance on support from government and non-governmental organizations (NGOs) (n = 32; 21%).

3.5. Traditional agroecological indicators used by respondents to predict rainfall

The respondents used a combination of several traditional agroecological indicators including traditional meteorological knowledge, the appearance of certain insects, birds and other organisms as well as the flowering and fruiting of certain plants or trees to predict the onset of rainfall in the study communities. Majority of the respondents (n = 110; 73%) used wind direction as a meteorological indicator to predict the onset of the rains (Table 4). This was closely followed by cloud type and colour (n = 107; 71%). Regarding indicators by animals, birds and insects, about 59% (n = 89) of the respondents used the croaking of frogs to predict the onset of the rainy season. This was followed by the appearance of the cattle egret (n = 81; 54%). In terms of indicators from phenology of plants, about 60% of the respondents (n = 90) relied on the fruiting of local trees particularly the shea nut (*Vitellaria paradoxa*), baobab (*Adansonia digitata*) and Dawadawa (*Parkia biglobosa*) to predict the rainfall onset. These indicators were also highlighted in the FGDs. For example, some of the focus group participants shared their experiences:

"*I have always relied on the local trees such as baobab, shea nut and Dawadawa to predict the farming season. The moment the shea nut for instance begins to bear fruits, I know that the rainfall season is imminent*" – (Focus group participant, Gaani, July 2018)

"*The appearance of the cattle egret informs me that the rainy season is very near. My grandfather told me to take critical note of this when I was young and this has helped me to monitor the advent of the rainfall season"* – (Focus group participant, Gia, July 2018)

"*There is a time that the clouds appear very close to the ground. The moment those clouds emerge and the colour of the cloud changes to black,*

Table 4
Traditional agroecological indicators used by respondents to predict rainfall in the study communities.

Indicator	Gender		Total (*n* = 150)
	Males (*n* = 112)	Females (*n* = 38)	
Meteorological and astronomical			
Wind direction	85 (75.9)	25 (65.8)	110 (73.3)
Rainbow colours	57 (50.9)	13 (34.2)	70 (46.7)
Cloud type and colour	80 (71.4)	27 (71.0)	107 (71.3)
Stars	63 (56.3)	16 (42.1)	79 (52.7)
Temperature	70 (62.5)	18 (47.4)	88 (58.7)
Moon	61 (54.5)	15 (39.5)	76 (50.7)
Actions of organisms			
Movement of millipedes	52 (46.4)	15 (39.5)	67 (44.7)
Chirping of crickets	58 (51.8)	16 (42.1)	74 (49.3)
Appearance of termites	47 (42.0)	13 (34.2)	60 (40.0)
Singing and chirping of birds	60 (53.6)	19 (50.0)	79 (52.7)
Croaking of frogs	71 (63.4)	18 (47.4)	89 (59.3)
Appearance of butterflies	49 (43.8)	15 (39.5)	64 (42.7)
Appearance of red ants	59 (52.7)	17 (44.7)	76 (50.7)
Appearance of the cattle egret	65 (58.0)	16 (42.1)	81 (54.0)
Flowering or fruiting of trees or plants			
Fruiting of local trees (e.g. Baobab, Shea nut, Dawadawa)	65 (58.0)	25 (65.8)	90 (60.0)
Flowering of certain plants (e.g. Bean pod tree)	56 (50.0)	20 (52.6)	82 (54.7)

Numbers in and outside parentheses are percentages and respondent counts respectively.
NB: Males in this study refer to adult male farmers who were household heads while females in this study refer to adult female farmers who were household heads.

it tells me that there is an impending heavy rainfall" – (Focus group participant, Nyangua, July 2018)

4. Discussion

4.1. Extent of rainfall and temperature changes in Kassena Nankana Municipality

Mann-Kendall trend test indicated variable rainfall pattern and an increasing temperature in the municipality. This finding is in line with results of previous studies conducted in northern Ghana (Issahaku et al., 2016; Klutse et al., 2020) indicating erratic rainfall pattern, and increasing annual temperature. It is also consistent with Environmental Protection Agency's (EPA) projections that rainfall will be increasingly variable and temperature will rise across all agroecological zones of Ghana in 2020, 2050 and 2080 (EPA, 2010). The positive value of Sen's slope indicates that although the trend was statistically insignificant, annual rainfall has increased. The difference between the highest mean annual rainfall and lowest mean annual rainfall is 747.8 mm (Fig. 2) and this noticeable inter annual difference can have significant influence on farmers' consistency for farming activities (Adu-Boahen et al., 2019). It will be difficult for farmers to get an honest idea on how the emerging annual rains would be and which farming activity can be undertaken to enhance crop yield (Adu-Boahen et al., 2019). The erratic rainfall pattern and increasing temperature have substantial implications on food production and show extreme vulnerability amongst the farming communities in the municipality. For instance, the increasing temperature will enhance potential evapotranspiration due to increased atmospheric demand for water. It could also result to increase water stress for the population and decreasing soil moisture leading to a drop in crop yields (Zhao et al., 2017). Furthermore, the inconsistent pattern of rainfall could increase the incidences of extreme events such as floods leading to increase sediment loads from the loss of top soil and damage road infrastructure linking the farmers to major market centres in urban areas. This will substantially affect the livelihoods of farmers and hence the need for better adaptation practices for farmers.

4.2. Respondents' perception on rainfall and temperature changes

Perception is key in climate change studies because farmers will only initiate adaptation practices if they perceive changes in temperature and rainfall. Majority of the farmers reported an increase in temperature, a decrease in annual rainfall, accompanied with shorter rainy season in the study communities (Table 2). The perceived increase in temperature was consistent with the assessed temperature data which is also consistent with results from a previous study (Guodaar et al., 2021) indicating that farmers in northern Ghana perceived an increasing temperature trend. The perceived shorter rainy season is also in line with results from an earlier study conducted in northern Ghana by Guodaar et al. (2021). However, the perception of farmers on decreased rainfall pattern and amounts is in contrast with the analysed rainfall data as there was no significant trend and also the Sen's slope suggested that the amounts has increased. The reason that could be attributed to this disparity is that scientists frequently assess climatic data at various timescales different from timescales that are relevant to farmers and the growth of crops leading to inconsistencies between observed climate data and perception (Limantol et al., 2016). Furthermore, the increase in evapotranspiration in Upper East Region could also account for farmers' perception of decreasing rainfall patterns and amounts in the study communities (Limantol et al., 2016). Agricultural production in Ghana is highly dependant on rainfall hence any changes in the amounts, timing and pattern of rainfall can have significant implications on farming activities as well as crop yields. According to the respondents, the variability in rainfall has made it difficult for them to predict the start and end of the rainy season in the study communities and as a result, planting and harvesting times have been hugely impacted. These findings strengthen the importance of relevant adaptation practices to lessen the negative outcomes of climate change in the study communities.

4.3. Respondents' adaptation practices

Adaptation is crucial if smallholder farmers are to overcome the negative impact of climate change. A greater number of the respondents used traditional agroecological knowledge as a key on-farm adaptation practice in the study communities (Table 3). This finding is in line with result from other studies conducted in Ghana (e.g. Gyampoh et al., 2009; Sullo et al., 2020) suggesting that dryland farmers have frequently depended on the use of traditional agroecological knowledge to manage the consequences of the changing climate on their farming activities. Use of traditional agroecological knowledge is extensive particularly across West Africa where smallholder farmers develop complex traditional mental climate models based on traditional agroecological knowledge and the happenings of their environment to plan farming calendars to facilitate climate change adaptation (Antwi-Agyei et al., 2014). Majority of these smallholder farmers depend on their past farming experiences to make decisions on the start and end of the rainy season to predict the rainfall patterns for the coming season (Antwi-Agyei et al., 2014).

Improved varieties of crops were the second most used on-farm adaptation strategy by the farmers in the study communities (Table 3). The use of improved varieties of crops has been documented as an adaptation strategy to reduce climate risks (Uduji and Okolo-Obasi, 2018). Improved varieties of crops reduce crop yield losses in drought prone areas (Kebede et al., 2019) as well as contribute to the national goal of producing high-yielding crops with better tolerance to physical and biological stresses and improved nutritional quality (Tirado and Cotter, 2010). The least used on-farm adaptation strategy by the farmers was irrigation (Table 3), which can be another viable approach to reduce climate risks. The farmers cited the lack of funds to purchase irrigation equipment as the main reason why irrigation is not used as a climate change adaptation strategy. Given the importance of funding in climate adaptation and agricultural development, the unavailability and inaccessibility of credit are major constraints compounding farmers' vulnerability to climate variability (Jennings and Magrath, 2019). Nonetheless, because access to water all year round farming is crucial to farmers, we suggest that small-scale and large-scale irrigation facilities should be constructed in the area to motivate farmers to cultivate in the dry season.

With regard to off-farm adaptation practices, majority of the respondents practiced temporary migration (Table 3). Consistent with a previous study (Debnath and Nayak, 2020), temporary migration has become one of the adaptation strategies to climate change for many farmers across northern Ghana particularly during the dry season when there are no farming activities. They migrate in search of better jobs to take care of themselves and their families and return when the rains are about to start. Most of the respondents also reduced their food consumption which is consistent as an adaptation strategy and documented in other parts of Ghana (e.g. Antwi-Agyei et al., 2018). The least used off-farm adaptation practice was relying on support from government and NGOs (Table 3). Most of the farmers attributed this to high interest rates on loans taken from the government banks. This situation is very disturbing because if farmers do not have money to buy good fertilizers and pest management products, this will eventually affect crop production and food security of the country. Therefore, we suggest that the government and other NGOs empower farmers through the provision of subsidized fertilizer, weed killers and hybrid seeds. Such assistance can minimize poverty, enhance food security, as well as guarantee the accessibility of specific food crops on the market and producing jobs in the agribusiness value chain.

4.4. Traditional agroecological indicators used by respondents to predict rainfall

Findings indicated that most of the respondents used traditional agroecological indicators such as wind direction, cloud type and colour, croaking of frogs, appearance of the cattle egret and the fruiting of local trees to predict the onset of rainfall in the study communities (Table 4). These results are also consistent with other studies conducted in Ghana and other parts of SSA (e.g. Gyampoh et al., 2009; Nkomwa et al., 2014; Sullo et al., 2020) indicating that indigenous people have used the behaviour and appearance of animals, insects and other organisms, plant phenology and meteorological indicators to predict rainfall onset. These indicators are based on traditional and cultural beliefs related to their perceived changes in the environment, behaviour of animals such as birds and insects and changes in tree phenology (Nkomwa et al., 2014). For instance, Nkomwa et al. (2014) reported that the high occurrence of ants and termites was a good indication of imminent high rainfall in rural communities in Southern Malawi. Furthermore, Sullo et al. (2020) reported that the flowering and fruiting of local trees such as shea nut (*Vitellaria paradoxa*) was a strong indicator for the onset of the rainy season and therefore an appropriate time to begin farming in rural communities of the Wa West District in the Upper West Region of Ghana. Apart from the prediction of the onset of rainfall, most of the farmers also reported that these indicators have helped them to make farm management decisions such as preparation of farmland, weeding, choosing of crops to cultivate, harvesting, storing, and processing of food. Furthermore, the perception of the farmers showed that they trusted the traditional agroecological indicators more than any scientific information they received. These findings suggest that most adaptation practices by smallholder farmers in rural communities in Ghana hinge on the communities' traditional agroecological knowledge, beliefs, traditions and cultural practices. Hence, any conventional design to enhance climate change adaptation in these areas must integrate traditional agroecological knowledge used by farmers.

5. Conclusions

This study investigated the extent to which traditional agroecological knowledge is used by rural farmers in managing the threats of climate change in agrarian communities in Kassena Nankana Municipality in the Upper East Region of Ghana. Trend analysis results indicated that annual rainfall has been variable with an increasing trend in annual temperature in the studied communities. Farmers perceived decreasing annual rainfall, shorter rainy seasons as well as increased temperature. Findings also showed that farmers have employed a variety of off-farm and on-farm practices such as the use of traditional agroecological knowledge, using improved varieties of crops, temporary migration, and reduction in food consumption to mitigate the adverse impacts of climate change in the studied communities. Findings also indicated that farmers use traditional agroecological indicators including the direction of the wind, the colour and type of cloud, the croaking of frogs, the appearance of cattle egret and the flowering and fruiting of local trees such as shea nut to predict the onset of rainfall and make farm management decisions in the study communities. The study recommends the importance of a framework to integrate traditional agroecological knowledge with scientific knowledge as an effective climate change adaptation strategy.

6. Statement of research ethics

All participatory methods used in this study were in accordance with the ethical standards. Informed consent was obtained from all individual participants involved in this study.

7. Limitations of the study

We had difficulties collecting enough data from the studied communities due to relatively small populations and difficulty accessing all farmers. This made our sample size relatively small and this can have several implications such as undermining the internal and external validity of the study. It can also hinder the findings from being extrapolated. Majority of the questions were close-ended and these hindered most of the farmers from expressing extensive opinions on the survey questions.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

Appendix A

QUESTIONNAIRE

This is a SURVEY QUESTIONNAIRE that seeks to assess how farmers adapt to climate change and variability using traditional agroecological knowledge in the Upper East Region of Ghana. Every information provided will be treated confidentially.

Name of community _________________

A. SOCIO-DEMOGRAPHIC CHARACTERISTICS OF RESPONDENTS

NB: Please, answer the following questions by ticking (√) the appropriate one.

1. Gender? Male [] Female []
2. Age of respondent (years)? Below 20 [] 21–40 [] 41–60 [] Above 60 []
3. Education? Non-formal education [] Primary education [] Secondary school education [] Tertiary []
4. Household size? 1 – 5 [] 6 – 10 [] 11 – 15 []
5. Origin? Native [] Migrant []
6. Farming experience (years)? Less than 5 [] 5 – 10 [] Above 10 []
7. Land tenure system? Inherited [] Purchase [] Rented []

B. RESPONDENTS' PERCEPTION ON RAINFALL AND TEMPERATURE CHANGES

1 Have you noticed changes in rainfall and temperature? Yes [] No [] I don't know []

2 If **yes**, then please respond to the following questions by ticking (√) the appropriate one

Variables	**Yes**	**No**	**I don't know**
Rainfall			
i More rain today compared to 30 years ago			
ii. Less rain today compared to 30 years ago			
Increase in the pattern of rainfall over the past 30 years			
Decrease in the pattern of rainfall over the past 30 years			
Rainfall season is becoming shorter			
Rainfall season is becoming longer			
Rainfall comes earlier compared to 30 years ago			
Rainfall comes late compared to 30 years ago			
Temperature			
Temperature of the growing season has increased over the past 30 years			
Temperature of the growing season has decreased over the past 30 years			

C. RESPONDENTS' ADAPTATION PRACTICES

1 Have you been adapting to climate change and variability? Yes [] No [] I don't know []

2 If **yes**, then please respond to the following questions by telling us what strategy you have been using? Please tick (√) the appropriate one.

Variables	Yes	No	I don't know
On-farm adaptation			
i. Crop diversification			
ii. Use of improved varieties of crops			
iii. Adjusting planting dates			
iv. Irrigation			
v. Use of traditional agroecological knowledge			
vi. Agroforestry			
vii. Soil conservation practices			
viii. Mixed farming			
Off-farm adaptation			
i. Reduce food consumption			
ii. Temporary migration			
iii. Relying on support from government and NGOs			
iv. Relying on support from family and friends			
v. Petty trading			
vi. Masonry			
vii. Sand mining			
viii. Change of diets			

1 If there are other adaptation strategies not captured above, please specify

D. TRADITIONAL AGROECOLOGICAL INDICATORS USED TO PREDICT RAINFALL

1 Do you use any traditional agroecological indicator to predict rainfall? Yes [] No [] I don't' know []

2 If yes, please respond to the following questions by telling us which one. Please, tick (√).

Indicator	**Yes**	**No**	**I don't know**
Meteorological and astronomical			
Wind direction			
Rainbow colours			
Cloud type and colour			
Stars			
Temperature			
Moon			
Actions of organisms			
Movement of millipedes			
Chirping of crickets			
Appearance of termites			
Singing and chirping of birds			
Croaking of frogs			
Appearance of butterflies			
Appearance of red ants			
Appearance of the cattle egret			
Flowering or fruiting of trees or plants			
Fruiting of local trees (e.g. Baobab, Shea nut, Dawadawa)			
Flowering of certain plants (e.g. Bean pod tree)			

1 If there are other indicators not captured above, please specify and tell us the sign or description in relation to rainfall.

....

1 Any other comments that you would like to raise?

Thank you for completing this survey

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