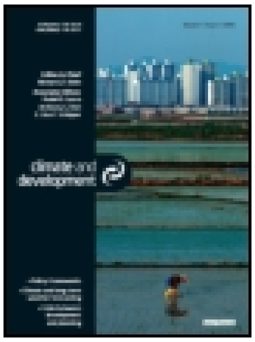

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Effects of climate adaptation on households' livelihood vulnerability in South Tongu and Zabzugu districts of Ghana

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ABSTRACT

This study analysed the effects of climate adaptation strategies on households' livelihood vulnerability, by using primary data from 300 farm households in the north (Zabzugu district) and south (South Tongu district) of Ghana. From a Livelihood Vulnerability Index (LVI) and LVI-IPCC index, the results established that the average farmer was moderately vulnerable, with farmers in the north showing significantly higher vulnerability than those in the south of Ghana. Exposure to climate change was found to contribute more to the vulnerability of the farm households. The beta regression analysis shows that row planting and use of early maturing varieties had positive significant effects on vulnerability, while refilling, strip cropping, mulching, and land rotation had negative significant effects on vulnerability. From a 2SLS, there is a positive feedback between livelihood vulnerability and climate adaptation intensity. Considering the low adoption, and the importance of strip cropping, mulching, and land rotation in reducing the vulnerability farm households, there is the need for actors in the agriculture sector to establish demonstration farms to train farmers on how to adopt as well as the benefits of these technologies. Also, credit opportunities should be made available to farmers especially those in Farmer-Based Organisations.

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Adaptation; climate change; livelihood vulnerability index; 2SLS; Ghana

1. Introduction

Scientific evidence proves the occurrence of climate change and its accompanying negative impacts, especially on the poor who rely on agriculture for their livelihoods (Cobbinah & Anane, 2016). For decades, the concept of climate change has become topical and attracting global discussion (Dian et al., 2015). Overall, Africa's agriculture that contribute about 15% to the continent's Gross Domestic Product (GDP) (Oxford Business Group, 2019) is under threat by the changing climate through declining soil fertility, high temperatures, and irregular rainfall pattern which results in unexpected floods and droughts (Dian et al., 2015). Räsänen et al. (2016) explained that climate change is the main determinant of vulnerability of humans and other animal-based production systems. The developmental plights of Africa, and for that matter Ghana, cannot be resolved if measures are not put to transform the traditional agricultural systems. Significant effort, which include promoting adaptation mechanisms, is therefore required to avert dramatic decline in agricultural productivity (Dian et al., 2015; Mabuku et al., 2019; Wilk et al., 2013).

Ghana's climate vulnerability has increased over time. Average annual temperatures have risen by 1.0 °C since 1960, and is expected to rise further between 1.0–3.0 °C by the year 2060. Also, average annual precipitation has reduced by nearly 2.5% since the 1960s. The extent of human vulnerability to the effects of climate change in Ghana is greatly determined by the exposure to various factors such as droughts, bushfires, floods, as the socio-economic and infrastructural sectors are being affected (USAID, 2012). The net effect of climate change is on all sectors of the economy (USAID, 2012). Farmers have therefore relied on a number of existing and emerging climate adaptation strategies to minimize the effects of climate change on their farm productions and livelihoods. Beyond the positive roles of adaptation strategies on production outcome such as output, the challenge has been the almost absent literature to support the role of these climate adaptation strategies on the livelihood vulnerability of farming households.

According to the Intergovernmental Panel on Climate Change (IPCC) (2007), climate change adaptation is a human or natural system's adjustment process to respond to actual or expected climate stimuli, their effects that reduces harm or exploits beneficial opportunities. Generally, climate adaptation can either be reactive or proactive. Proactive adaptation mechanisms are practiced in anticipation of climate change (Mabuku et al., 2019) while reactive adaptation strategies aimed to respond to climate change impacts after it has been experienced (Shongwe et al., 2014). Some reactive adaptation strategies include control for soil erosion and the construction of irrigation dams for water supply for crop-based agricultural systems. The development of new crop cultivars and the adjustments in the planting and harvesting dates, use of fiscal (taxation) incentives, subsidies and crop insurance programmes are proactive in nature. Because of

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reduced capacities and resources to apply proactive measures, most adaptation strategies adopted by farmers to reduce the effects of climate change on their livelihoods tend to be reactive in nature (Bierbaum et al., 2013). Nonetheless, interventions that affect the context in which climate change occurs are often preconditions for ensuring effective adaptive strategies (O'Brien et al., 2009). Therefore, the level to which farmers can adapt depends on their ability to take actions to reduce the negative impacts of climate change.

Some recent studies have examined the vulnerability and adaptation of farm households to climate change in Ghana. For instance, Lawson et al. (2019) examined the perceptions and adaptation strategies of women farmers in semi-arid Ghana, and found that majority of the households maintain subsistence production systems like mixed farming as well as out-migration. Aniah et al. (2019) found that smallholder farmers engaged in the sale of household assets, migration of entire households and rationing or decreasing food consumption as strategies to respond to the effects of climate change. On on-farm adaptation strategies, Aniah et al. (2019) found that farmers were varying planting dates, using drought tolerant crop varieties and practicing some conservation agriculture practices based on their indigenous knowledge. Azumah et al. (2017) identified spraying of farms with weedicide and insecticides, planting in rows, crop rotation, mixed cropping and farming as the main coping and adaptation strategies adopted by farm households in northern Ghana. From Afriyie et al. (2017), farmlands, human health, housing and financial savings were the most vulnerable household assets, and also the effects of flooding on households' assets was differentiated by gender groups. Antwi-Agyei et al. (2012) applied LVI and found that even within the same agro-ecological area, households and communities experienced different degrees of climate vulnerability, which was largely driven by socio-economic factors such as access to capital and productive assets. In Nepal, Sujakhu et al. (2019) assessed how cultural and gender-related perspectives affect livelihood vulnerability in indigenous mountainous farming communities by applying LVI approach to estimate household vulnerability. They found female-headed households, and membership of disadvantaged social groups as being key drivers of vulnerability. One of the advantages of estimating LVI is that it allows for the estimation of not only the role of climatic factors on vulnerability but also, the role of socioeconomic and other factors within the human system, on vulnerability.

This present study builds on the previous works to provide insights on climate vulnerability in the south and north of Ghana, and estimate the effect of adaptation strategies on the vulnerability levels of the farm households. A number of estimation procedures were assumed to ensure that the findings are cross-validated. In this regard, efforts are made to account for endogeneity in estimating the effects of climate adaptation on livelihood vulnerability. Admittedly, this study is largely exploratory and could provide a new insight into understanding into the impacts of climate adaptation and how future researches should focus. Therefore, this study primarily examined the effect of climate adaptation on the livelihood vulnerability of farm households in the two selected districts of the north and south of Ghana.

2. Material and methods

2.1. Study location

The study was conducted using data from farmers in both northern and southern Ghana. Specifically, farmers who were part of Ministry of Food and Agriculture (MoFA)-led integrated climate resilience and management project in the Zabzugu and South Tongu district of Ghana were targeted. The Zabzugu district is in the eastern part of the Northern region of Ghana, and covers an area of 1,100.1 Km^2. Rainfall is seasonal (unimodal) and unreliable in the Zabzugu district. Mean annual rainfall for the district is around 1,125 mm with temperatures ranging between 21^0C – 36^0C. The vegetation of the district is largely guinea savannah, though some areas in the southern part of the district fall within the transitional zone. Agriculture is the main occupation in the area with about 86% of the active labour population of the district being employed by the sector (Ghana Statistical Service, 2014a).

The South Tongu district is situated between latitudes 6° 10' and 5° 45' North and longitudes 30° 30' and 0° 45' East in the southern part of the lower Volta basin within the coastal savannah vegetation zone. South Tongu has a total land size of 643.57 km^2. The southern part of the district is swampy with mangroves, while the northern part is predominantly characterized by savannah vegetation that supports the production of livestock. The swampy areas also favour the production of rice, sugar cane and vegetables. About 56.3% of households located in the district are engaged by the agricultural sector (GSS, 2014b). Figure 1 shows the map of Ghana indicating the South Tongu and Zabzugu districts.

2.2. Sampling procedure and data collection

The study employed a multi-stage sampling procedure in selecting the respondents. In the first stage, South Tongu and Zabzugu districts were selected purposively because they were beneficiary districts of an integrated climate risk management project implemented by GIZ through MoFA. The project provided education to the farmers on the importance of climate adaptation strategies and monitored the farmers for three years. Therefore, the GIZ project beneficiaries were selected to be sure that the selected farmers have much understanding on climate adaptation to allow them make more rational decisions on the adoption of each adaptation strategy. Although these districts may not be representative of the north and the south of Ghana, they have minimum characteristics of the two geographical locations which can allow for comparison. In the second stage, ten communities (out of a total of 20) that had benefited in each of the two districts were sampled through simple random sampling procedure. This involved listing all the beneficiary communities in excel and using the random number generation function in excel. The first five communities with the highest random numbers in each district were selected. In final sampling stage, 30 beneficiary farmers in each community were selected using simple random sampling procedure. Again, this involved the generation of random numbers for each beneficiary in excel and selecting the first 30 with the highest random numbers. This

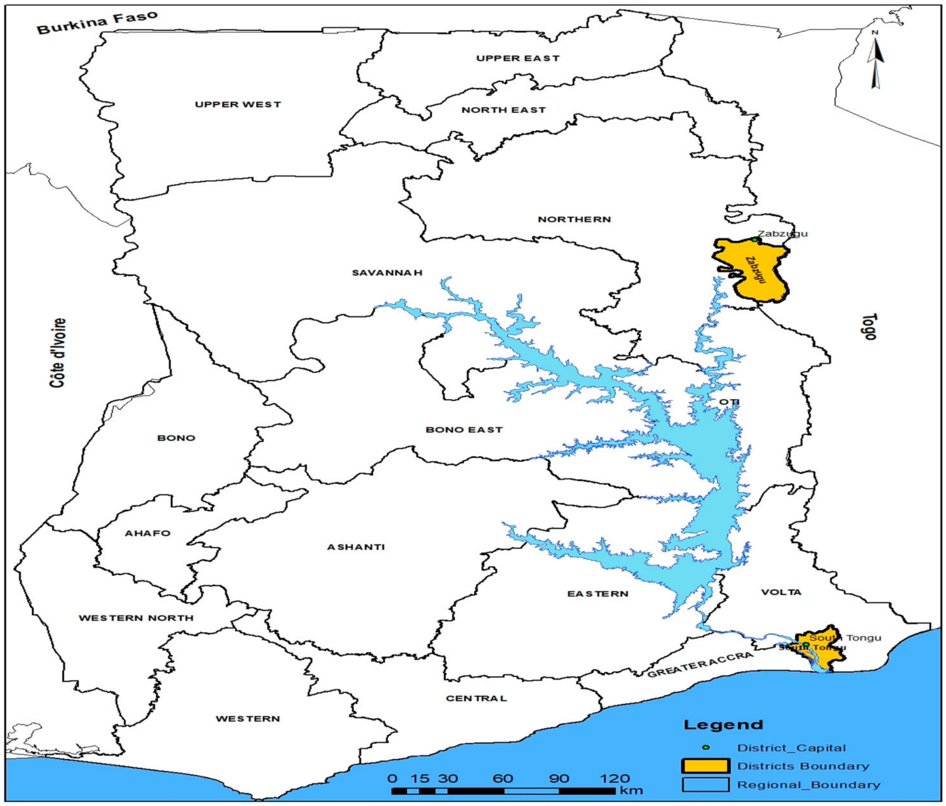

Figure 1. A map of Ghana showing the study areas. Source: Authors' construct.

resulted in a total sample size of 300 (150 from each district). The sample was informed by the financial constraint of the research; hence, this may not provide adequate representation of farmers in the study area. As such, the findings of this research should be interpreted within this caveat.

The data were collected via face-to-face interviews using questionnaires, with the help of trained enumerators who understood the local dialects as well as the agricultural production conditions of the respective communities and districts. Prior to the data collection, a list of climate adaptation strategies was generated through literature review, inputs from district extension officers and GIZ officials and from pre-test results of this present study. The final list was then provided to individual farmers to indicate those they had adopted in 2018 production season. Admittedly, some of the strategies identified have been used by farmers for several years beyond the project period. However, the pre-test survey showed that the farmers are attributing their climate adaptation decisions to the changing climatic conditions. The data collected includes socioeconomic characteristics, climate shocks experienced by the farmers and their perception on changes in climate variables, and other list of indicators for determining the livelihood vulnerability of the farm households.

2.3. Data analysis

Theoretically, there are two basic methods of analysing the climate vulnerability of a system. These are the indicator method which includes socioeconomic, biophysical or integrated approaches, and econometric method which involves defining vulnerability as expected poverty, vulnerability as expected utility or vulnerability as uninsured exposure to risk. Following Hahn et al. (2009), this study was based on the integrated indicator approach where LVI was constructed for each beneficiary in the two selected districts of Ghana. The effect of climate adaptation on climate vulnerability was also determined using beta regression and two stage least square regression (2SLS). The indicator approach is chosen in this study because, not only does it allow for the identification of the indicators that are relevant for determining the vulnerability of farmers, but also allows for the determination of the adaptive capacity, sensitivity and exposure of the farm households to climate change. As explained by Hahn et al. (2009), the LVI procedure is flexible, thus, permits the researcher to test the effect of specific indicators on the overall vulnerability index. The LVI was determined through the following steps:

i Livelihood vulnerability is determined by three major components (MC) as adaptive capacity, sensitivity and exposure of the beneficiary to climate change. Under the indicator approach, the major components can be classified under minor components (MI). Following previous studies such as Adu et al. (2018), Huong et al. (2018), Oo et al. (2018), Gerlitz et al. (2016) and Hahn et al. (2009) and inputs from extension officers at the district levels, a list of indicators were outlined and responses obtained from the farmers.

ii To defray the effect of the differences in the unit or scale of measuring each indicator, the observed responses for non-binary variables from step (i) are normalized by

Table 1. Definition of variables.

Variable	Definition/Measurement	Expected sign
Sex	Dummy: 1 if a farmer is a male and 0 if female	–
Age	Total number of years from birth	–
FBO	Dummy: 1 if a famer belonged to a farmer-based organization (FBO) and 0 if not	–
Education	Number of years of formal education	–
Extension access	Dummy: 1 if farmer had access to extension and 0 if not	–
Nonfarm income	Total annual income from nonfarm activities in Ghana cedis	–
Credit	Dummy: 1 if farmer had access to credit and 0 if not	–
Location (District)	Dummy: 1 if farmer is selected from South Tongu district and 0 if selected from Zabzugu district	–
Welfare	The per capita consumption expenditure of a farmer's household	–
Row planting	Dummy: 1 if farmer practiced row planting in the 2018 production season and 0 if not	–
Refilling	Dummy: 1 if farmer practiced refilling in the 2018 production season and 0 if not	–
Strip cropping	Dummy: 1 if farmer practiced strip cropping in the 2018 production season and 0 if not	–
Zero tillage	Dummy: 1 if farmer practiced zero tillage in the 2018 production season and 0 if not	–
Mulching	Dummy: 1 if farmer practiced mulching in the 2018 production season and 0 if not	–
Bunding	Dummy: 1 if farmer practiced bunding in the 2018 production season and 0 if not	–
Organic farming	Dummy: 1 if farmer practiced organic farming in the 2018 production season and 0 if not	–
Cover cropping	Dummy: 1 if farmer practiced cover cropping in the 2018 production season and 0 if not	–
Early maturing variety	Dummy: 1 if farmer planted early maturing seed variety in the 2018 production season and 0 if not	–
Drought resistant variety	Dummy: 1 if farmer planted drought resistant see variety in the 2018 production season and 0 if not	–
Crop rotation	Dummy: 1 if farmer practiced crop rotation in the 2018 production season and 0 if not	–
Land rotation	Dummy: 1 if farmer practiced land rotation in the 2018 production season and 0 if not	–
Mixed farming	Dummy: 1 if farmer practiced mixed farming in the 2018 production season and 0 if not	–
Adoption intensity	Total number of onfarm climate adaptation strategies adopted by a farmer	–

Source: Authors' construct, 2019.

$z = \frac{S_d - S_{\min}}{S_{\max} - S_{\min}}$, where z is the normalized value, S_d is the observed value of the variable, $S_{\min}$ is the minimum observed value and $S_{\max}$ is the maximum observed value.

iii Each identified indicator from stage (i) was classified under ten MI based on the similarity in the factors. These are socioeconomic, livelihood strategies, social network, resources and energy, water, food, health, climate perception and environmental shocks and information. The index for each MI was determined by dividing the sum of products of the normalized values of each factor (z) in step (ii) and the number of factors known as weights (w) under the component by the weight (w). Thus, $MI = \frac{\sum^{z} w}{w}$.

iv The LVI for each beneficiary was computed as a composite index using $LVI = \frac{\sum^{M} I*w}{\sum^{w}}$. The LVI is expected within a range of 0 (least vulnerable) to 1 (most vulnerable). To incorporate IPCC's definition of climate vulnerability based on three major components (MC), the study followed Hahn's (2009) classification of MI under MC and estimated a second climate vulnerability score using LVI-IPCC = (Exposure-Adaptive capacity) * Sensitivity. Each MC is determined by $MC_i = \frac{\sum^{M} I*w}{\sum^{w}}$. The LVI-IPCC is expected to range between −1 (Least vulnerable) to 1 (most vulnerable).

After estimating the livelihood vulnerability scores, the study proceeded with the estimation of beta and 2SLS regressions. As introduced by Ferrari and Cribari-Neto (2004), beta regression is used to analyse economic relationships where the dependent variable is bound between zero and one. According to Unlu and Aktas (2017), simply transforming a dependent variable that lies within 0 and 1, and estimating a linear regression is limited, and can be resolved through a beta regression. The beta regression is based on the assumption that the variable has a beta distribution based on different values of the mean and precision or scaling (Ferrari & Cribari-Neto, 2004; Unlu & Aktas, 2017). The beta regression is obtained by:

$$g(\mu_t) = \sum_{i=1}^{k} x_i \beta_i \quad (1)$$

where β_i is a vector of parameters to be estimated. x_i is a vector of exogenous variables observed on a set of observations. $g(\mu_t)$ can assume different links and is assumed to follow a logit link in this study. Given the logit functional link, the empirical model estimated is given for specific adaptation strategies and adaptation intensity in equations (2) and (3), respectively as:

$$\begin{aligned}\text{Vulnerbility} = {} & \beta_0 + \beta_1 Sex + \beta_2 Age + \beta_3 FBO + \beta_4 \text{Education} \\ & + \beta_5 \text{Extention access} + \beta_6 \text{Credit} + \beta_7 FBO \\ & + \beta_8 \text{Welfare} + \beta_9 \text{District} + \beta_{10} \text{Nonfarm income} \\ & + \beta_{11} \text{Row planting} + \beta_{12} \text{Refilling} \\ & + \beta_{13} \text{Strip cropping} + \beta_{14} \text{Zero tillage} \\ & + \beta_{15} \text{Mulching} + \beta_{16} \text{Banding} \\ & + \beta_{17} \text{Organic farming} + \beta_{18} \text{Cover cropping} \\ & + \beta_{19} \text{Early maturing variety} \\ & + \beta_{20} \text{Drought resistant variety} \\ & + \beta_{21} \text{Crop rotation} + \beta_{22} \text{Land rotation} \\ & + \beta_{23} \text{Mixed cropping} \quad (2)\end{aligned}$$

And

$$\begin{aligned}\text{Vulnerbility} = {} & \beta_0 + \beta_1 \text{Sex} + \beta_2 \text{Age} + \beta_3 \text{FBO} + \beta_4 \text{Education} \\ & + \beta_5 \text{Extention access} + \beta_6 \text{Credit} + \beta_7 \text{FBO} \\ & + \beta_8 \text{Welfare} + \beta_9 \text{District} + \beta_{10} \text{Nonfarm income} \\ & + \beta_{11} \text{Adoption intensity} \quad (3)\end{aligned}$$

In order to account for endogeneity in equation (3), a two stage least square (2SLS) was estimated. 2SLS is a simultaneous equation model that corrects for the presence of endogeneity in each equation. In this study, it was expected that both livelihood vulnerability and adoption intensity affected each other. Therefore, modelling such feedback effects without addressing simultaneous bias would lead to biased estimates. Practically, the 2SLS involve estimating the function without the endogenous variable, obtain the predicted variables and use as an explanatory variable in another equation. In this study, equation (3) was estimated without adoption intensity using OLS and the predicted values of vulnerability were obtained and put into equation (4):

$$\begin{aligned}\text{Adoption intensity} = {} & \beta_0 + \beta_1 \text{Sex} + \beta_2 Age + \beta_3 FBO \\ & + \beta_4 \text{Education} + \beta_5 \text{Extention access} \\ & + \beta_6 \text{Credit} + \beta_7 \text{Welfare} + \beta_8 \text{District} \\ & + \beta_9 \text{Nonfarm income} \\ & + \beta_{10} \text{Vulnerability predicted} \qquad (4)\end{aligned}$$

Again, equation (4) was estimated using OLS without 'vulnerability predicted'. The predicted values of adoption intensity were obtained and replaced with adoption intensity in equation (3) as:

$$\begin{aligned}\text{Vulnerbility} = {} & \beta_0 + \beta_1 \text{Sex} + \beta_2 \text{Age} + \beta_3 \text{FBO} + \beta_4 \text{Education} \\ & + \beta_5 \text{Extention access} \\ & + \beta_6 \text{Credit} + \beta_7 \text{Welfare} + \beta_8 \text{District} \\ & + \beta_9 \text{Nonfarm income} \\ & + \beta_{10} \text{Adoption intensity predicted} \qquad (5)\end{aligned}$$

Equations (4) and (5) were therefore modelled using OLS to estimate the effect of adoption intensity on vulnerability and vice versa. The definition of the variables is provided in Table 1. The variables were carefully selected by drawing from the existing literature. For instance, while men often have greater access to productive resources to aide them in the adoption of a number of climate adaptation strategies (Awuni et al., 2018), females are more vulnerable to the effects of climate change (Adzawla & Baumüller, 2020) due to their reduced access to productive resources. Education is expected to improve the adoption of many climate adaptation strategies since well-educated farmers would be able to understand the scientific effect of the complementarity of various climate adaptation mechanisms. Extension, FBO and credit are institutional factors that are expected to also improve adoption and reduce climate vulnerability among farm households. For instance, Ndamani and Watanabe (2015) found that limited access to extension service and lack of access to credit are major barriers to climate adaptation in Ghana. Sujakhu et al. (2018) indicated that social networks help to improve climate vulnerability, while Opiyo et al. (2014) explained that access to credit helps to improve adaptive capacity of farmers. Geographically, climate vulnerability differs across Ghana. The north is more exposed to climate risks and thus, more vulnerable to the effects of climate change compared to the south of the country (Adzawla & Baumüller, 2020). Welfare and non-farm income are important in improving the adaptive capacity of the farmers and does reduce their vulnerability. For instance, Adzawla and Baumüller (2020) explained that livelihood diversification into non-farm activities such agro-processing is an important factor for reducing farm households' vulnerability to climate change, while Ncube et al. (2016) showed that the poor are more vulnerable to climate change.

3. Results and discussion

3.1. Descriptive statistics of sub-components of climate vulnerability

The factors contributing to climate vulnerability of the farm households were organized under ten minor-components based on similarity, and are assumed to contribute equally to the overall vulnerability of households. Unlike weighting through expert judgement or principal component analysis, the equal weighting allows for results that are close to the revealed information provided by the respondents. The mean contribution by individual factors is provided in Table 2. The result shows that not using electricity as the primary source of domestic lightning had the highest (0.93 units) contribution to the MI, and for that matter, the livelihood vulnerability of the farmers. Other factors that had high contributions include non-membership in a farmer group, gas as secondary source of domestic (cooking) fuel, lack of access to climate information and wrong perception on the directions of change in climate variables such as temperature and rainfall. The result also showed that being a female contributes significantly to livelihood vulnerability compared to being a male.

3.2. Minor and major components of livelihood vulnerability

Moving from the contribution of individual factors to livelihood vulnerability, the study proceeded with the analysis of step (iii) from the procedure described under data analysis. The result is shown in Figure 2. From the result, the main contributing minor component to livelihood vulnerability in Zabzugu is climate perception (0.855), followed by social networks (0.680), and resources and energy (0.436). For South Tongu, the minor component that contributed the greatest to livelihood vulnerability is social networks (0.628), followed by climate perception (0.599) and water (0.414). The socioeconomic characteristics of the beneficiaries, wellbeing as well as food related factors also contributed remarkably to livelihood vulnerability. On the contrary, livelihood strategy/factors contributed the less to livelihood vulnerability. Empirically, Adu et al. (2018) found that social network is the major contributor to households' climate vulnerability in the Brong-Ahafo region of Ghana. Also, Sujakhu et al. (2019) found that the most important factors that determine the LVI of farmers in Central Nepal were financial assets, and natural disaster and climate variability.

As discussed under data analysis and shown by Table 1, the minor components are composited into the three major components of climate vulnerability – as defined by the IPCC. This is shown in Figure 3. The spider diagram shows that exposure had the highest contribution to livelihood vulnerability in the two districts, but this is higher for farmers in

Table 2. Descriptive statistics of normalized values of vulnerability indicators.

MC	MI	Indicator	Mean	Std. Dev.	Min.	Max.
ADAPTIVE CAPACITY	Socioeconomic	If a farmer is a female	0.593	0.492	0	1
		Number of household members under 18 years	0.352	0.238	0	1
		The inverse of years of formal education	0.274	0.317	0	1
		The inverse of the total years in crop (proxied by maize) farming	0.218	0.193	0	1
	Livelihood strategies	The inverse of the number of livelihood activities engaged by a farmer.	0.301	0.156	0	1
		The inverse of total nonfarm income	0.138	0.208	0	1
		Number of household members unemployed	0.12	0.133	0	1
		Number of household members engaged solely in agriculture	0.188	0.167	0	1
		Number of emigrants remitting to resident household	0.069	0.173	0	1
	Resource and energy	Gas is not the primary source of cooking fuel	0.043	0.204	0	1
		Electricity is not the primary source of lightening	0.973	0.161	0	1
		The farmer is a not landowner	0.203	0.403	0	1
	Social network	A farmer is not a member of a farmer group	0.907	0.291	0	1
		A farmer had not participated in capacity building on improved farming methods in the past 3 years	0.87	0.337	0	1
		A farmer had no access to extension services	0.185	0.169	0	1
SENSITIVITY	Water	Pipe is not the primary source of domestic water	0.433	0.496	0	1
		A farmer has no access to irrigation	0.19	0.393	0	1
		There is no conflict over water resource in a year	0.797	0.403	0	1
		Walking distance to domestic water source	0.193	0.214	0	1
		Months in a year with severe water shortage	0.097	0.142	0	1
	Well being	A farmer accessed agricultural credit	0.147	0.354	0	1
		A farmer placed his/her household into poor-, middle- or rich-income category	0.56	0.165	0.333333	1
		Total food and nonfood expenditure of a household	0.341	0.161	0	1
	Food	Fertilizer must be used on farmland for crop production	0.477	0.5	0	1
		Farm is insured	0.107	0.309	0	1
		Number of months with food deficit in a year	0.254	0.216	0	1
		Proportion of household's food obtained from farmer's own farm	0.643	0.161	0	1
	Health	Number of children under five reported ill of malnutrition in the past six months	0.1	0.191	0	1
		Number of household members reported ill within the last three months	0.08	0.115	0	1
		Number of household members without valid NHIS card	0.177	0.122	0	1
		Kilometers to health centre attended	0.236	0.246	0	1
EXPOSURE	Environmental shocks and information	Number of times of windstorm in past 5 years	0.224	0.231	0	1
		Number of times of bushfires in past 5 years	0.143	0.143	0	1
		Number of times of drought in past 5 years	0.161	0.139	0	1
		Number of times of flood in past 5 years	0.154	0.141	0	1
		A farmer had no access to climate information	0.94	0.238	0	1
		Farmer received no warning information on climate shock prior to its occurrence	0.63	0.484	0	1
		Pest infestation has decreased on farmers field	0.237	0.426	0	1
	Climate perception	Farmer perceived no decline in rainfall duration	0.807	0.396	0	1
		Farmer perceived no decline in rainfall intensity	0.653	0.477	0	1
		Farmer perceived no decline in timeliness of rains	0.77	0.422	0	1
		Farmer perceived no increase in minimum temperature	0.743	0.438	0	1
		Farmer perceived no increase in maximum temperature	0.787	0.41	0	1
		Farmer perceived no increase in windstorm	0.6	0.491	0	1
		Farmer perceived no increase in floods	0.73	0.445	0	1
		Farmer perceived no increase in droughts	0.803	0.398	0	1
		Farmer perceived no increase in bushfires	0.65	0.478	0	1

Source: Computation from STATA using field data, 2019.

Zabzugu district (0.6698) than the South Tongu district (0.4592). This is due to the fact that the northern part of Ghana is more exposed to climate shocks and naturally warmer with unimodal rainfall, compared to the southern part that experience relatively lower temperatures and have a bimodal rainfall pattern. On the contrary, the adaptive capacity of farmers was higher for farmers in the Zabzugu district (0.3747) than those in the South Tongu district (0.3502). Adaptive capacity has a positive relationship with climate vulnerability, therefore, farmers with higher adaptive capacity are likely to have less climate vulnerability. The implication is that measures to improve adaptive capacity are necessary for the selected farmers to offset the negative effect of exposure to climate shocks on the farmers' vulnerabilities. Overall, farmers had low sensitivity to climate change. In their study, Adu et al. (2018) found that adaptive capacity contributed the highest to LVI-IPCC while sensitivity contributed the least. Similarly, Hahn et al. (2009) found that the sensitivity to climate had the lowest contribution to climate vulnerability. Consistent with this study, Oo et al. (2018) found that exposure to climate change contributes the highest proportion to LVI.

3.3. Livelihood vulnerability by district among farm households

Table 3 shows the mean distribution of LVI and LVI-IPCC of farmers in the two districts. Overall, the mean livelihood vulnerability of the farmers is 0.4107 while the LVI-IPCC is 0.0621. While Zabzugu recorded a higher vulnerability (0.4451 for LVI and 0.0849 for LVI-IPCC) above the total

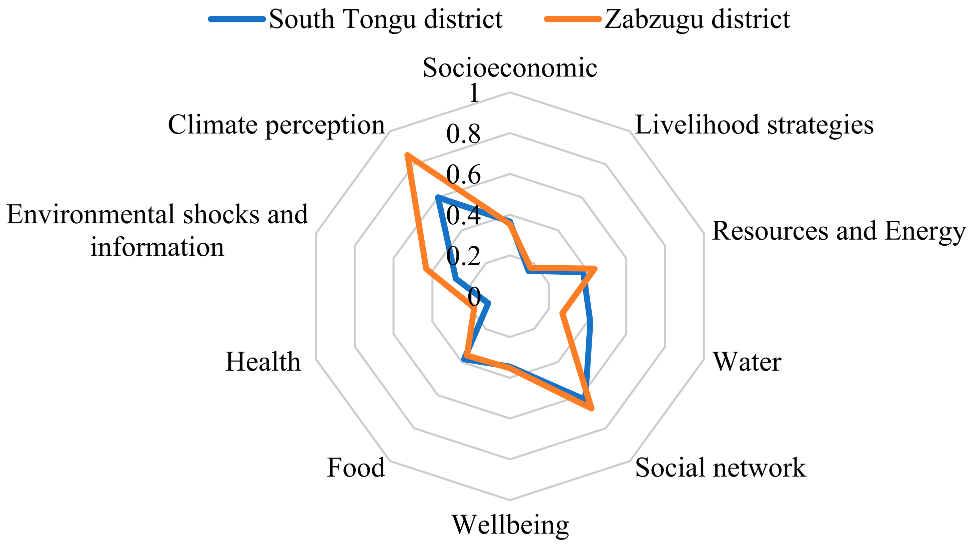

Figure 2. Minor components of climate vulnerability – by district. Source: Field data, 2019.

sample mean, South Tongu recorded a mean LVI of 0.3762 and LVI-IPCC of 0.0392. These results show that the level of vulnerability of an average farm household can be classified as moderate. The relatively higher vulnerability scores of farm households in Zabzugu is as a result of the high impacts of climate change on these households. A student *t*-test result shows a significant difference in the mean LVI and LVI-IPCC of farmers in the South Tongu and Zabzugu districts of Ghana. The estimated average vulnerabilities are higher than those obtained by Adu et al. (2018) and Hahn et al. (2009). This finding is corroborated by Ghana's National Climate Change Adaptation Strategy report, compiled by UNDP in 2012 where it was indicated thatclimate vulnerability in Ghana is differentiated spatially, with each ecological zone having peculiar physical and socio-economic characteristics that determine their level of resilience and sensitivity to climatic impacts (UNDP, 2012). A study by Antwi-Agyei et al. (2012) revealed that climate vulnerability differs evenly among households located in the same agroecological zones. Shah et al. (2013) also observed that LVI differs among communities especially due to differences in socio-demographic characteristics, health and water security. Dendir and Simane (2019) found that climate vulnerability differs based on the agroecological location of the farmer and that climate vulnerability is higher for those living in lowland agroecological zones. Also, Sujakhu et al. (2019) opined that, the observed differences in LVI were also due to differences in the rate of dependence on agriculture and livestock as an income generating source.

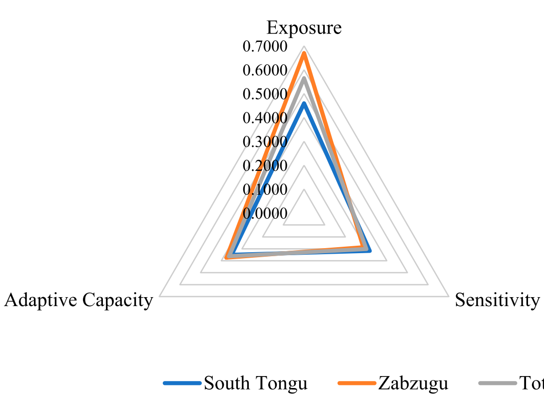

Figure 3. Major components of livelihood vulnerability. Source: Field data, 2019.

3.4. Effects of climate adaptation strategies on households' livelihood vulnerability

The results in Tables 4 and 5 show that both socioeconomic and climate adaptation strategies have significant effect on the climate vulnerability of the farmers. The effect of sex on both LVI (Table 4) and LVI-IPCC (Table 5) are negative and this suggests that male farmers have lesser probability of obtaining higher livelihood vulnerability. Women's high climate vulnerability can be due to their low access to production inputs and low adaptive capacities compared to their male counterparts. This is consistent with the findings of Ncube et al. (2016) who found that women were most vulnerable to climate change due to their low access to productive resources. Membership of farmer-based organisation (FBO) had a negative effect on livelihood vulnerability. This implies that farmers who belonged to FBO had lesser probabilities of becoming more vulnerable to climate change. FBOs are important social capital required to enhance the adaptive capacities of farmers. Similarly, FBOs provide media for sharing ideas and for implementing developmental projects such as climate adaptation

Table 3. Distribution of climate vulnerability – by districts.

Sample group	Statistic	LVI	LVI-IPCC
South Tongu	Mean	0.3762	0.0392
	Min	0.1541	−0.0991
	Max	0.5764	0.2092
Zabzugu	Mean	0.4451	0.0849
	Min	0.2525	−0.0589
	Max	0.5926	0.2125
Total	Mean	0.4107	0.0621
	Min	0.1541	−0.0991
	Max	0.5926	0.2125

Source: Field data, 2019.

Table 4. Effects of climate adaptation on livelihood vulnerability (LVI).

Variable	Coef.	Std. Err.	dy/dx	Coef.	Std. Err.	dy/dx
Sex	−0.087***	0.026	−0.020	−0.068**	0.031	−0.016
Age	−0.0004	0.001	−0.0001	−0.002	0.001	0.0004
Education	0.008***	0.003	0.002	0.010***	0.004	0.002
FBO	−0.235***	0.051	−0.056	−0.403***	0.055	−0.096
Credit	−0.368***	0.038	−0.087	−0.422***	0.043	−0.100
District	−0.550***	0.076	−0.130	−0.553***	0.052	−0.131
Extension	−0.045	0.035	−0.011	−0.045	0.040	−0.011
Nonfarm income	0.00003***	0.00001	0.00001	0.00002**	0.00001	0.00001
Welfare	−0.001***	0.00002	0.00002	−0.001***	0.0003	−0.0003
Adoption intensity				−0.029***	0.005	−0.007
Row planting	0.215***	0.046	0.051			
Refilling	−0.105***	0.039	−0.025			
Strip cropping	−0.110**	0.055	−0.026			
Zero tillage	0.021	0.038	0.005			
Mulching	−0.108***	0.037	−0.026			
Bunding	0.028	0.039	0.007			
Organic farming	−0.050	0.043	−0.012			
Cover cropping	−0.027	0.056	−0.006			
Early maturing	0.140*	0.081	0.033			
Drought resistant	0.004	0.017	0.001			
Crop rotation	−0.001	0.067	0.0002			
Land rotation	−0.219***	0.066	−0.052			
Mixed farming	0.041	0.039	0.010			
Constant	0.814***	0.177		1.447	0.157	
Scale constant	4.628***	0.081		4.252	0.081	
LR Chisq.	367.9***			255.41***		

Note: ***, ** and *indicate significance level at 1%, 5% and 10%, respectively.
Source: Field data, 2019.

projects. Therefore, with this added advantage, farmer group members would be able to reduce the climate vulnerability of its members. Sujakhu et al. (2018) also found that socialized group members are less vulnerable to climate change.

Also, credit was found to have a negative effect on LVI and LVI-IPCC, implying that farm households who accessed agricultural credit were less vulnerable to climate change, compared to those who had no credit access. One of the major constraints to smallholder agriculture is the inadequacy or lack of credit for investment into farm business. Therefore, farmers who have access to credit are able to invest into the use of appropriate inputs that would increase their farm incomes and to improve their adaptive capacities to climate change, corroborating with the finding of Opiyo et al. (2014). Conversely, farmers with higher per capita income that defines their welfare have significantly lesser LVI but

Table 5. Effects of climate adaptation on livelihood vulnerability (LVI-IPCC).

Variable	Coef.	Std. Err.	dy/dx	Coef.	Std. Err.	dy/dx
Sex	−0.137***	0.025	−0.027	−0.150***	0.027	0.030
Age	−0.001	0.001	0.000	−0.0004	0.001	−0.0001
Education	−0.004	0.003	−0.001	−0.004	0.003	−0.001
FBO	−0.026	0.048	0.005	−0.044	0.047	−0.009
Credit	−0.36***	0.037	−0.070	−0.370***	0.037	−0.073
District	−0.48***	0.074	−0.094	−0.406***	0.046	−0.080
Extension	0.035	0.034	0.007	0.034	0.035	0.007
Nonfarm income	0.00001	0.00001	0.000001	−0.00001	0.00001	−0.000002
Welfare	0.0003	0.0002	0.00006	−0.0005**	0.0002	−0.0001
Adoption intensity				−0.021***	0.005	−0.004
Row planting	0.021	0.044	0.004			
Refilling	−0.018	0.037	−0.003			
Strip cropping	−0.019	0.054	−0.004			
Zero tillage	0.049	0.037	0.010			
Mulching	−0.086**	0.035	−0.017			
Bunding	0.070**	0.038	0.014			
Organic farming	−0.101**	0.042	−0.020			
Cover cropping	−0.056	0.055	−0.011			
Early maturing	0.089	0.078	0.018			
Drought resistant	0.007	0.016	0.001			
Crop rotation	−0.051	0.065	−0.010			
Land rotation	−0.117*	0.065	−0.023			
Mixed farming	0.005	0.038	0.001			
Constant	−0.215	0.170		0.010	0.138	
Scale constant	4.882	0.082		4.687***	0.081	
LR Chisq.	256.2***			198.1***		

Note: ***, ** and *indicate significance level at 1%, 5% and 10%, respectively.
Source: Field data, 2019.

insignificant in LVI-IPCC. This is an indication that although agrarian households are generally reported to be highly vulnerable to climate change, the poor among these households are more vulnerable than the rich. Since exposure to climate change is generally covariate, this finding can be justified through low adaptive capacity and high sensitivity of the poorer farmers. Ncube et al. (2016) explained that the poor are more climate vulnerable because they often lack the required capital to liquidate when there is a climate shock. Based on the climatic differences between the north and south of Ghana, it is generally observed that households located in the north are more vulnerable to the impacts of climate change. From the result, location had a negative effect LVI, which implies that farmers who are located in South Tongu district had a lower vulnerability than those located in the Zabzugu district.

Extension access had negative effect on vulnerability implying that farmers who had access to extension services have lower vulnerability than those who had no access to extension services. This is because extension services provide the opportunity for farmers to improve their farm outcomes, hence, leading to reduced vulnerability. Unexpectedly, education and non-farm income had positive significant effects on the livelihood vulnerability of the farmers. Thus, an increase in formal education and non-farm income does not support a decline in the vulnerability of farmers.

Among the on-farm adaptation strategies, row planting and sowing early maturing varieties had positive significant effect on LVI. Refilling, strip cropping, mulching and land rotation were found to have negative significant effect on LVI. Also, mulching, organic farming and land rotation had negative effects on LVI-IPCC while bunding had positive effect on LVI-IPCC. While the positive marginal effects suggest that farmers who adopted such technologies are more climate vulnerable, the negative marginal effects indicate that the adopters of such strategies were less vulnerable to climate change. Refilling involves the re-planting of seeds where there is significant germination failure. This ensures optimal plant population for higher farm output. Strip cropping involves the cultivation of two or more crops on the same piece of plot in separate strips. Although this strategy is less adopted by farmers, strip cropping allows the farmer to cultivate different crops and to manage them simultaneously at ease. Since different crops are sensitive to the weather differently, it is expected that farmers who adopt this strategy would become less vulnerable to the negative impacts of climate change. Strip cropping is also a soil and water conservation technique; therefore, the system would permit the farmers to obtain optimal yields on the same piece of farmland over the years. Głowacka (2013) observed from an experiment that strip cropping increases the number of seed per plot and the weight of the seeds/beans for instance. Mulching is an important soil and water conservation technique for improving sustainable production. It is therefore consistent that farmers who engaged in mulching were more likely to have lower climate vulnerability. Bhardwaj and Kendra (2013) opined that mulching increases plant growth and development, reduces pest control, increases the quality of produce, promotes early harvesting, which eventually translates into higher yields. These merits of mulching obviously contributed to its observed negative effect on climate vulnerability. Maguza-Tembo et al. (2016) also observed that soil and water conservative strategies help to reduce the vulnerability to poverty of resource-poor households.

3.5. Livelihood vulnerability and adoption intensity

Further analysis was conducted to determine the effects of the adoption of multiple climate adaptation strategies on LVI. Prior to the estimation of a reduced form of 2SLS regression, the distribution of livelihood vulnerability by level of adoption intensity was determined in Figure 3. The results in Figure 3 show that households in the north of Ghana (i.e. the Zabzugu district) adopted at least seven to twenty adaptation strategies, while farmers in south of Ghana (South Tongu district) adopted at least three to thirteen climate adaptation strategies. The common adaptation intensity in the two districts is within seven to thirteen strategies. Evidently, farmers in the Zabzugu district had higher LVI irrespective of the adoption intensity. While the highest LVI for Zabzugu district was recorded at an adoption intensity of ten, the highest LVI for farmers in South Tongu was recorded at an adoption intensity of nine. While the LVI by adoption intensity in South Tongu showed a somehow up–down pattern, that of Zabzugu district showed a slight decline in LVI as adoption intensity increased.

The results of the reciprocal effects of livelihood vulnerability and adoption intensity are shown in Tables 6 and 7. The purpose of this estimation is to account for the failure of the beta regression to allow feedback effect between livelihood vulnerability and adoption. As such, the beta regression on adoption intensity was also estimated for comparison. Due to the inability to obtain instruments for each adaptation strategy and adoption intensity, the study proceeded to estimate a reduced form of 2SLS. To obtain same units of measurement, both livelihood vulnerability and adoption indices were converted into percentages before the estimation. District (location) was also dropped in the second step of the estimation because it did not converge with the residual values of the endogenous variables.

The results in Tables 6 and 7 show that both adoption intensity and livelihood vulnerability have positive reciprocal effects. Thus, an increase in adoption intensity leads to an increase in livelihood vulnerability irrespective of the measurement approach (either LVI or LVI-IPCC). This is contrary to the results estimated under beta regression (Tables 4 and 5). However, the result is consistent with the results in Figure 4. The implication is that there is a threshold to which climate adaptation intensity can decrease livelihood vulnerability, beyond which, livelihood vulnerability would increase. All other variables in the livelihood vulnerability model maintained their signs and remained significant, except education that became significant while credit loss its significance. The positive effect of non-farm income on livelihood vulnerability is contrary to the result of Adzawla and Baumüller (2020) where livelihood diversification into activities including non0farm activities reduce households' vulnerability to climate change.

The positive effect of livelihood vulnerability on adoption intensity is an indication that farmers who are more vulnerable to climate change would adopt more on-farm adaptation strategies as a way of increasing yields to offset the impacts from

Table 6. 2SLS of the effect of adoption intensity on LVI.

	LVI			Adoption intensity		
Variable	Coef.	Std. Err.	$P>t$	Coef.	Std. Err.	$P>t$
Sex	−1.688**	0.768	0.029	6.402***	1.868	0.001
FBO	−8.099***	1.298	0.000	30.713***	3.945	0.000
Credit	−8.953***	1.059	0.000	33.949***	2.934	0.000
Age	0.076**	0.032	0.017	−0.288***	0.065	0.000
Education	0.053	0.082	0.519	−0.201	0.178	0.262
Extension	5.048***	0.952	0.000	−19.144***	2.292	0.000
Nonfarm income	0.001**	0.0003	0.012	−0.003***	0.001	0.000
Welfare	−0.028***	0.007	0.000	0.105***	0.017	0.000
Adoption	0.264***	0.030	0.000	NA	NA	NA
LVI	NA	NA	NA	3.792	0.256	0.000
Constant	49.323	4.215	0.000	−187.040	20.105	0.000
F(9, 289)	35.870			45.750		
R-squared	0.528			0.588		
Adj R-squared	0.513			0.575		

Note: ***, ** and *indicate significance level at 1%, 5% and 10%, respectively.
Source: Field data, 2019.

Table 7. 2SLS of the effect of adoption intensity on LVI-IPCC.

	LVI-IPCC				Adoption intensity	
Variable	Coef.	Std. Err.	$P>t$	Coef.	Std. Err.	$P>t$
Sex	2.864***	0.551	0.000	−17.959***	1.834	0.000
FBO	−0.558	0.931	0.549	3.501	2.959	0.238
Credit	−6.789***	0.759	0.000	42.570***	3.325	0.000
Age	0.014	0.023	0.527	−0.090	0.068	0.188
Education	−0.189***	0.059	0.001	1.183***	0.222	0.000
Extension	3.000***	0.683	0.000	−18.813***	2.283	0.000
Nonfarm income	0.000	0.0002	0.830	0.0003	0.001	0.669
Welfare	−0.009*	0.005	0.077	0.054***	0.016	0.001
Adoption	0.159***	0.022	0.000	NA	NA	NA
LVI_IPCC	NA	NA	NA	6.271***	0.423	0.000
Constant	26.993	3.024	0.000	−169.267	18.986	0.000
F(9, 289)	27.16			45.75		
R-squared	0.4582			0.5876		
Adj R-squared	0.4413			0.5747		

Note: ***, ** and *indicate significance level at 1%, 5% and 10%, respectively.
Source: Field data, 2019.

their high vulnerability. Other factors that significantly influenced adoption intensity include the age, sex, access to credit, access to extension service, FBO membership, non-farm income and welfare.

4. Conclusions and policy implications

There is a dire consequence of climate change on food systems across the world especially for smallholder farmers in Sub-

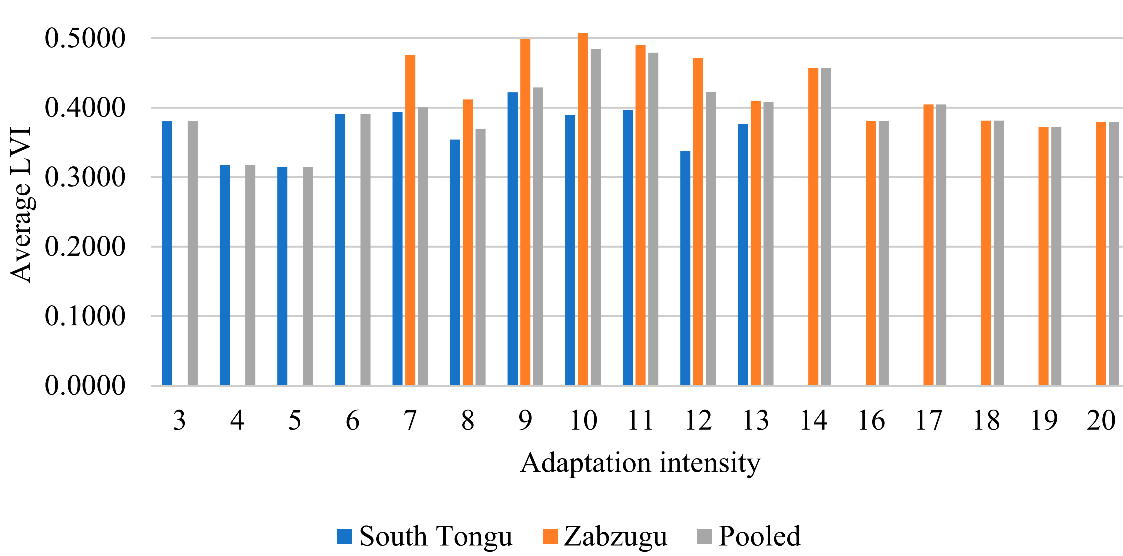

Figure 4. LVI distribution by adaptation intensity. Source: Field data 2019.

Sahara Africa where Ghana is located. Several climate change adaptation strategies have been proposed for farmers to reduce the negative impacts of climate change, and to improve food and nutrition security among farm households. This study presents empirical evidence of the effects of adopting climate adaptation strategies on households' livelihood vulnerability in Ghana, using the indicator approach. The study expanded the literature on livelihood vulnerability by estimating the effect of climate adaptation strategies on households' vulnerability and also compared the livelihood vulnerabilities of the south and north of Ghana.

The major group of factors that contributed highly to climate vulnerability were climate perception and social networks. Similarly, exposure to climate change contributed the highest proportion to climate vulnerability, followed by adaptive capacity and sensitivity. The study concludes that the average farm household in Ghana is moderately vulnerable to the effects of climate change. Therefore, there is the need to address the vulnerability of the farmers to ensure that it does not increase beyond the current levels. Since adaptive capacity can easily be improved at the local level, it is recommended that effective on-farm adaptation practices such as strip cropping to improve the wellbeing of farmers should be promoted among the households. The low contribution of livelihood strategies to adaptive capacity, for that matter high contribution to livelihood vulnerability can be improved through effective livelihood diversification by the farmers and the promotion of local business opportunities among the farmers by the government and non-governmental organizations.

The livelihood vulnerability of the farm households was significantly influenced by both socioeconomic and climate adaptation strategies. For the socioeconomic factors, livelihood vulnerability was lower for male farmers, farmers who belonged to a farmer group, farmers who accessed credit, farmers located in southern Ghana (South Tongu district) and wealthier farmers. The study also established that while the adoption of row planting and early maturing varieties increases livelihood vulnerability, the adoption of refilling, strip cropping, mulching and land rotation decreases livelihood vulnerability. Admittedly, it is not clear the mechanisms through which such important adaptation strategies led to an increase in livelihood vulnerability. Therefore, a further exploratory study is recommended to unravel the underpinning of these findings. Overall, considering the low adoption of strip cropping and its role in reducing vulnerability, farmers are encouraged to adopt this strategy on their farms. To obtain higher result from adoption, MoFA and other organizations working with farmers should consider establishing demonstration farms to educate the farmers on strip cropping. While every farmer is encouraged to join farmer associations, there is the need for financial institutions to consider providing credit facilities to farmers, especially those in groups, to ensure effective utilization and benefits. Generally, it is concluded that there is a positive feedback relationship between livelihood vulnerability and adoption intensity. This supports the call for further research into the identification of appropriate level of combination of on-farm adaptation strategies by the farmers.

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No potential conflict of interest was reported by the author(s).

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