Livelihood Vulnerability Index: An Approach to Assess Vulnerability of Crop Farmers to Climate Variability and Change in Ghana

B. E. Ofori-Kyereh
Researcher
210 Church Road, London, E10 7JQ UK
Email:bofori70@gmail.com

J. F. Morton
Professor of Development Anthropology
University of Greenwich Medway Campus, Natural Resources Institute, Gillingham, UK
Professor of Development Anthropology at the Natural Resources Institute of the University of Greenwich.

T. C. B. Chancellor
University of Greenwich Medway Campus, Natural Resources Institute, Gillingham, UK
A Visiting Fellow at the Natural Resources Institute of the University of Greenwich.

Abstract
Climate change has emerged as a global concern, especially its negative impacts on agriculture, particularly amongst poor subsistence and smallholder farmers because of the sector's dependency on rainfall. The impacts of climate change and climate related extreme events may vary among farmers within the same locality based on the interplay of factors such as differences in households' socio-demographic and economic characteristics. The extent of the impacts of climate change depends on the capacity of farmers and appropriateness of the adaptation measures undertaken to mitigate such impacts. This study adopts the Livelihood Vulnerability Index to assess the vulnerability of the two districts (Atwima Mponua and Ejura-Sekyeredumase) in different agro-ecological zones (Semi-Deciduous Forest and Transition Zone respectively). The study used household questionnaires to collect primary data from150 farming households from each district as well as using secondary data on rainfall and temperature from the Ghana Meteorological Agency. The Livelihood Vulnerability Index was used to assess the vulnerability of the two districts. The overall LVI indicates that Ejura-Sekyeredumase District may be more vulnerable to climate change impacts than Atwima Mponua District. The vulnerability triangle indicates that Ejura-Sekyeredumase District is more sensitive to climate change and variability impacts than Atwima Mponua District. Although Atwima Mponua District may have a higher adaptive capacity than Ejura-Sekyeredumase District, the difference is relatively small. The study found that while it is important to have generic policies that address the main agricultural issues in Ghana, development and implementation of region-specific adaptation policy is crucially important.
Keywords: Climate variability and change, Livelihood Vulnerability Index, exposure, sensitivity, adaptative capacity
DOI: 10.7176/JEES/13-1-03
Publication date: January 31st 2023

1. Introduction

Global climate system is already changing beyond the patterns of natural variability, and there is substantial evidence to suggest that the trends will accelerate, leading to high occurrences of extreme climatic events (Soussana et al., 2010).Climate variability and change present many risks to the well-being of the global populations, especially with its negative impacts on agriculture and food security in many countries, particularly in Africa (Niang et al., 2014). The vulnerability of the agricultural sector, particularly amongst poor subsistence and smallholder farmers, is expected to worsen in Africa (Niang et al., 2014) because of the sector's dependency on rainfall. High poverty levels limit the capacity of rural communities to cope with the impacts of climate change (Olsson et al., 2014; Morton, 2017). Additionally, People who live on arid or semi-arid lands, in water-limited or flood-prone areas, are particularly, vulnerable to climate change impacts Birkmann et al. (2022).

Taking into consideration the increased vulnerability of subsistence and smallholder farmers to the impacts of climate change (Niang et al., 2014; Trisos et al., 2022), this paper aims to adopt Hahn et al. (2009)' s LVI approach to understand farmers' vulnerability to the impacts of climate variability and change in two study areas.

1.1 Impact of Climate Change on Ghanaian Agriculture and Rural Livelihoods

Climate variability and change are important factors that influence societal development for many African countries (Trisos et al., 2022) including Ghana (GSS (Ghana Statistical Services), 2018). Agriculture contributes about 19.2% to the Ghanaian economy and constitutes 60% of the labour force (GSS (Ghana Statistical Services), 2018). The agricultural sector in Ghana is believed to have the potential to grow at rates as high as 6% per annum (World Bank Group, 2017). However, the present level of crop farming and production fails to meet the food demands in Ghana mainly because of challenges posed by climate variability and change in the rural areas where farming is taken as the main occupation (Ministry of Food and Agriculture (MoFA), 2015). There is mounting evidence to suggest that "climate change could potentially inhibit the potential for growth in the agricultural sector, given that the sector is particularly vulnerable to varying temperature and rainfall patterns that characterise climate change and variability" (de Pinto et al., 2012, p. 1). The impact of climate change has resulted in a vicious cycle of high prevalence of poverty, loss of natural resources, isolation and low livelihoods because of neglect by policymakers (Dasgupta et al., (2014). Currently, the impacts of global climate change are felt among the rural populations, especially the subsistence or smallholder farmers (Ofori-Boateng and Insah, 2014). The key factor that contributes to the vulnerability of the rural population in Ghana to climate change can be attributable to the tropical climate and the comparative underdevelopment of Ghana and its rural population (Dasgupta and Baschieri, 2010). Other factors that increase the vulnerability of the rural population and decrease the livelihood include socioeconomic and demographic trends which limit their capacity to adapt (Ha-Mim and Hossain, 2020).

High poverty levels limit the capacity of rural communities to cope with the impacts of climate change (Olsson et al., 2014; Morton, 2017). For example, Akudugu et al. (2012) found that factors such as the types of crops produced, the scale of the operation (commercial or subsistence purposes), and the quality of the natural resource (farmland) determines the extent of vulnerability of crop farmers and their ability to adapt and manage the impact of climate change.

Ghana Environmental Protection Agency (GEPA) (2012) observed that in many rural communities in Ghana, occurrences of intermittent floods and droughts continue to hamper the prospects of agriculture and food security. Mase et al. (2017) assert that in developing countries, including Ghana, crop failure associated with climate change impacts serves as disincentive to crop farmers and the agricultural population is likely to decrease as some go into other forms of non-agricultural diversification. Consequently, food security is negatively affected, with eventual increase in vulnerability of the few remaining crop farmers, leading to increasing poverty level. Measures will need to be introduced to reduce vulnerability imposed by climate variability and change impacts on crop production and livelihoods.

Similar studies have been conducted by different authors. For example in Ghana, Adu et al. (2018) used primary and secondary data to calculate the LVI of maize farmers in Wenchi and Techiman districts (Ejura-Sekyeredumase District). Etwire et al. (2013) assessed the vulnerability of small holder farmers in the Northern, Upper East and Upper West regions (Savannah Zone). All the study areas are located within the same agro ecological zones. Qaisrani et al. (2018) identified factors of livelihood vulnerability in three semi-arid districts of Pakistan. This study extends the knowledge of previous authors to compare vulnerability of communities in two districts with varying climatic and physical characteristics (Semi-Deciduous and Ejura-Sekyeredumase Districts). According to Schipper and Burton (2009) farmers within the different agro-ecological zones are exposed to different levels of climate threats. Hahn et al. (2008) affirm that exposure to climate change is presumed to be location specific; for example, semi-arid regions may be most exposed to drought conditions. Nevertheless, the socio-economic capacity of the affected people determines the extent of vulnerability (O'Brien et al., 2007). This means that this study is relevant in that the findings will inform implementation of region-specific developmental interventions to enhance the adaptive capacity of farmers to climate variability and change impact.

2. Literature Review

Existing literature suggest that vulnerability to climate change has been reviewed and variously defined extensively (Hinkel, 2011; Okpara et al., 2016; Abdul-Razak and Kruse, 2017). The Intergovernmental Panel on climate change (IPCC) (2014) refers to vulnerability as key characteristics of climate change and its effects on geophysical systems, such as floods, droughts, deglaciation, sea level rise, increasing temperature, and frequency of heat waves, as hazards to livelihoods.

IPCC (2007) definition encompasses a variety of concepts and elements including sensitivity or susceptibility of ecological systems to harm and the capacity to cope and adapt to the impacts of and changes to the system. According to the IPCC (2007), the vulnerability of a system is a function of three elements: (1) exposure to climate change effects (2) sensitivity and (3) adaptive capacity.

Thus, Vulnerability (V) = f (exposure, sensitivity and adaptive capacity).

The IPCC (2007) defines **exposure** as "the nature and degree (magnitude and duration) of climatic variations (e.g. drought and change in precipitation) to which a system is exposed to significant climatic variations. **Sensitivity** is the degree to which a system is affected, either adversely or beneficially by climate related stimuli" and **adaptive capacity** is the system's ability to withstand or recover from the exposure.

From the IPCC definitions, climate change is considered as the main cause of vulnerability and the degree of vulnerability is determined by the socio-economic capacity of the affected people to cope and adapt (Füssel, 2007; O'Brien et al., 2007; Dumenu and Obeng, 2016). Adaptive capacity is inversely linked to vulnerability. Thus, the higher the adaptive capacity, the lower the vulnerability of the community concerned and vice versa. An understanding of the relationship between vulnerability and adaptive capacity will assist in the selection and implementation of suitable adaptation for a community or household to moderate the impacts of climate variability and change on farming activities (Hahn et al., 2009). Thus, the IPCC definitions consider both the socioeconomic and the biophysical approaches in measuring vulnerability. Dasgupta et al. (2014) and Morton et al. (2014) assert that climatic vulnerability of a system or social group is exacerbated by political and socioeconomic factors. Social vulnerability provides a means through which to assess the potentially unequal impacts that climate change may have on individuals and societies. A few authors suggest socioeconomic factors (wealth or poverty, economic assets, financial means and technological advancement) and demographic factors (such as gender, age, special needs of the populations, race and ethnicity) for measuring social vulnerability (Birkmann, 2013); Emrich and Cutter, 2011). Thus, these factors either increase or minimise the impacts of hazard events on a society and show the level of social inequalities.

2.1. Theoretical framework of the Livelihood Vulnerability Index

According to Hahn et al. (2009), the LVI uses seven major indicators to measure exposure to natural disasters and climate variability: (i) Socio-Demographic Profile (SDP), (ii) Livelihood Strategies (LS), (iii) Social Networks (SN), (iv) Health (H), (v) Food (F), (vi) Water (W), and (vii) Natural Disasters and Climate Variability (NDCV). The LVI designed by Hahn et al. (2009) has been adopted for this study because it is widely cited (e.g., Etwire et al., 2013; Madhuri et al., 2014). Although the method was originally applied in Mozambique, its suitability for use in research in Ghana has been established because farmers in Ghana and Mozambique share similar impacts from climate change. Besides, Hahn et al.'s method has been adopted by many Ghanaian researchers to successfully measure vulnerability through a single index (see Etwire et al., 2013; Adu et al., 2018). According to Hahn (2008), the choice of indicators is subjective to the researcher. In this study, the selection of the sub-components was based on Hahn et al.'s method of selection of indicators but with some amendments for Ghanaian conditions, based on literature on climate studies on factors that affect exposure, sensitivity and adaptive capacity.

Hahn et al. (2009) adopted a mathematical approach to constructing the LVI and is summarized here for completeness. The vulnerability is calculated following the steps below adopting Hahn et al's, 2009 method.

Step 1: Standardising each of the sub-components as an index using equation (Hahn et al., 2009):

$$\text{"Index}S_a = \frac{S_a - S_{min}}{S_{max} - S_{min}} \quad (1)$$

where S_a is the observed sub-component for households in district a; and
S_{max} and S_{min} are the maximum and minimum sub-component values respectively for households.
These minimum and maximum values were used to transform this indicator into a standardized value between 0 and 1 so that it could be integrated into the adaptive capacity of the LVI. For variables that measure frequencies, such as the 'percent of households reporting vulnerability, the minimum value was set at 0 and the maximum at 100 per cent.

Step 2: Working out the averages of the sub-component indicators using Equation (2) to obtain the index of each major component:

$$M_a = \frac{\Sigma^n_{i-1} \; Index_{sai}}{n} \quad \text{Equation (2)}$$

M_a represents one of the seven major components for district 'a'.
$Index_{sai}$ is the sub-components, indexed by i, that make up each major component; and
n stands for the number of sub-components in each major component.

Step 3: Equation (3) is used to work out the mean of the seven major components for district 'a' to find the score for the LVI:

$$LVI_a = \frac{\Sigma^7_{i=1} w_{Mi} M_{ai}}{\Sigma^7_{i=1} w_{Mi}} \quad \text{Equation (3)}$$

This can also be expressed as:

$$LVI_a = \frac{W_{SDPa}+SDP_a+w_{LS}+LS_a+w_{SN}+SN_a+w_H H_a+w_F F_a+w_w W_a+w_{NDC}NDCV_a}{w_{SDP}+w_{LS}+w_{SN}+w_H+w_F+w_w+w_{NDC}} \quad (3)$$

where LVI_a is the Livelihood Vulnerability Index for district 'a',

W_{SDP}, SDP_d, w_{LS} etc are the weighted mean of the seven major components".
From equations (1) – (3), Hahn et al. (2009) calculated a new variable, LVI–IPCC; which takes into account 'vulnerability' as defined by the IPCC. The LVI–IPCC diverges from the LVI of households when the major components are combined.

Instead of combining the major components into one weighted average as the LVI in equation (3), the major components are first combined based on the three contributing factors- **exposure**, **sensitivity** and **adaptative capacity** using the following equation:

$$CF_a = \frac{\sum_{i=1}^{n} w_{Mi} M_{di}}{\sum_{i=1}^{n} w_{Mi}} \quad (4)$$

where CF_a represents an IPCC-defined contributing factor (exposure, sensitivity, or adaptative capacity) for district 'a'.
M_{di} represents the major components for district 'a' indexed by 'i';
w_{Mi} stands for the weight of each major component; and
n represents the number of major components in each contributing factor.
After the contributing factors-**exposure**, **sensitivity**, and **adaptation capacity** are calculated using Equation 4, they are combined using Equation (5)

$$LVI\text{-}IPCC_a = (e_a - a_a) X\ S_a \quad (5)$$

Where LVI–IPCCa is the LVI for district 'a' expressed using the IPCC vulnerability formula;
e is the calculated value for exposure for district 'a' (equivalent to the Natural Disaster and Climate Variability major component);
a is the calculated value for adaptive capacity for district 'a' (calculated average score of the Socio-Demographic, Livelihood Strategies, and Social Networks major components); and
s is the calculated value for sensitivity for district 'a' (calculated average value of the Health, Food, and Water major components).
The calculations are repeated for the second district 'b'.

3. Materials and methods

3.1 Study areas

Atwima Mponua and Ejura-Sekyeredumase districts of Ashanti Region of Ghana were selected as the study locales (See Figures 1 and 2).

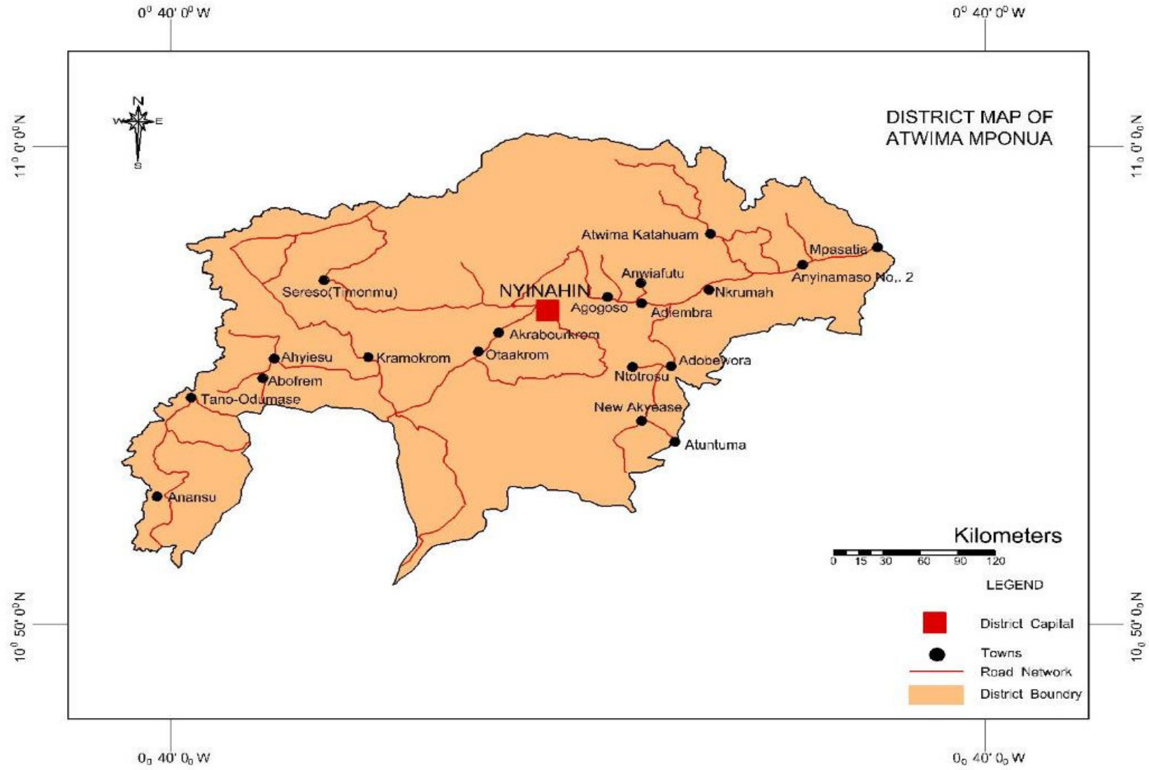

Figure. 1. Study communities in Atwima Mponua District in Ashanti Region of Ghana.
Source: Author's construct.

Ejura-Sekyeredumase is in the northern part of Ashanti Region, with Ejura as its capital town. (Figure 2).

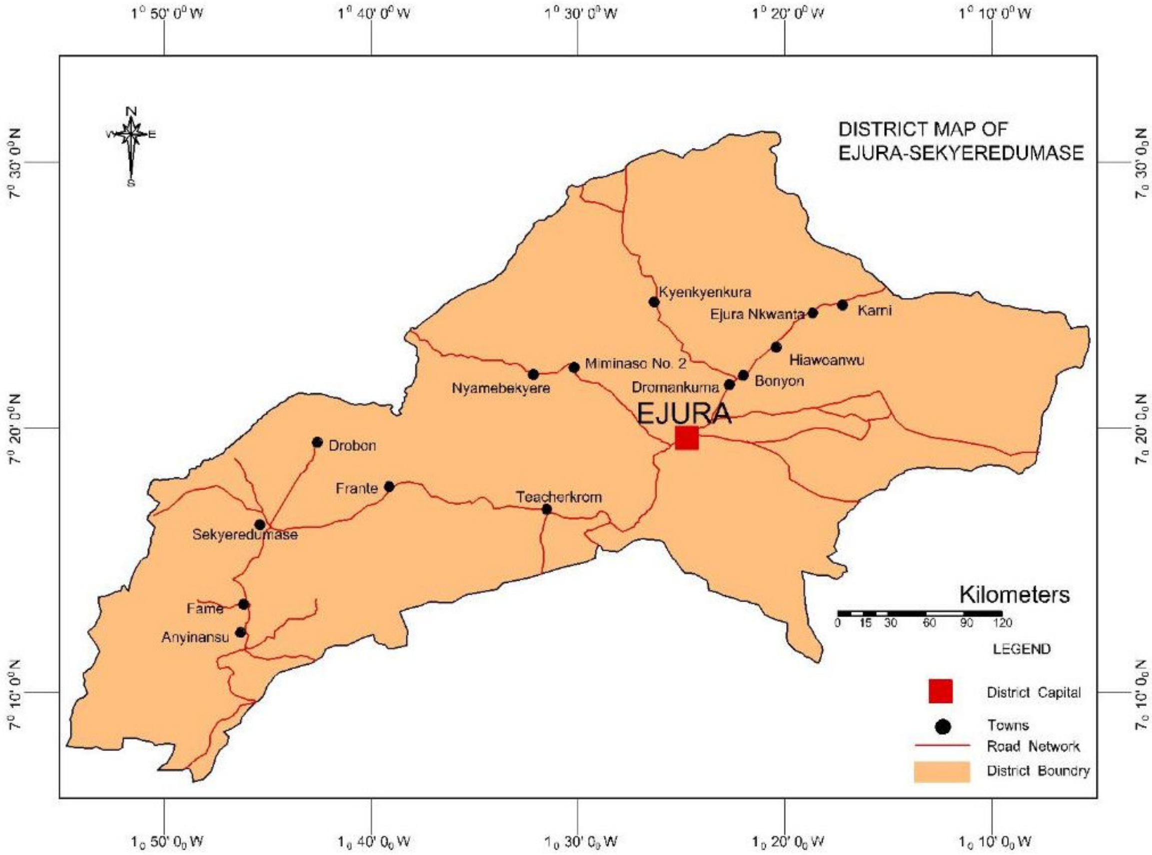

Figure. 2. Study communities in Ejura-Sekyeredumase District in Ashanti Region of Ghana.
Source: Author's construct.

The choice of the study areas is based on being one of the major food producing centres, which is rainfed, making agriculture susceptible to the impact of climate variability and change. Meanwhile, studies have concluded that climate variability and / or change is evident in the study areas and its effect on crop yield is severe (Cudjoe et al., 2021; Fosu-Mensah et al., 2012).

3.2 Profile of the study areas

Atwima Mponua District lies within latitude 6^0 35'59.99'N and longitude 2^0 06'60.00′W Ghana Statistical Services, 2014). The district is characterized by bi-modal annual rainfall pattern - (March to July: 1700 – 1850 mm) and (August to November: 1000 - 1250 mm), with mean annual temperature range between 27 ^{0} C in August and 31 ^{0} C in March (GSS, 2014).

Ejura-Sekyeredumase District lies within latitudes $7^0$9' N and $7^0$36'N and longitudes $1^0$5'W and $1^0$39' W. The district experiences bi-modal annual rainfall pattern in the south and a unimodal pattern in the north with mean annual rainfall of 1430 mm, with temperature range of 21 ^{0}C in August and 35 ^{0}C in March (GSS, 2014).

3.3 Research design

A comparative-case research design (quantitative tools) was used to collect socio-economic data of the participants.The communities selected in Atwima Mponua District were Nyinahin, Adiembra, Otaakroom, Anansu and Kramokrom. In Ejura-Sekyeredumase District, the communities were Ejura, Sekyeredumase, Frante, Anyinasu and Drobon. Stratified random sampling was adopted to select farmers based on age, gender, and years of experience followed by a simple random sampling using a computer - generated random number table to select 150 household heads from each district.

3.3.1. Sample size

The binomial sampling size calculator (http://www.surveysystem.com/sscalc.htm) was used to calculate the sample size using the formula:

$$Cl^1 = \sqrt{\frac{\hat{p} + z \times p\ (1-p) \times (N-n')}{N-1}}$$

where:
Cl[1] = sample size
z = z score
p̂ = the population proportion
n, n' = sample size (Atwima Mponua District = 18,281; Ejura-Sekyeredumase District = 15,761 (GSS, 2014)
N = population size (Atwima Mponua District = 108,235; Ejura-Sekyeredumase District = 88,753) (GSS, 2014)
Confidence interval = 8%
Confidence level = 95%

3.4 Data collection

Data collection started with a reconnaissance visit to the study locales to identify prospective participants, see the topography, and learn about the weather patterns and agricultural activities. A pilot study was carried out to test the research questionnaires with small groups of participants, followed by the main data collection. A structured questionnaire was used to collect socio-economic through a household survey. Secondary data on the climate (rainfall and temperature) for the period 1992 - 2014 were collected from the Statistical Division of the Ghana Meteorological Agency.

4. Results and Discussion

The analysis of the vulnerability of households in the two study areas was based on Hahn et al. (2009) framework. Table 1 presents the LVI sub-component, the major component values and the composite LVI-IPCC values for each district. See Appendix 1 and 2 for details of calculations and Appendix 3 for explanations for sub-components. Hahn et al. (2009) assert that the LVI-IPCC is scaled from -1 (least vulnerable) to 1 (most vulnerable).Microsoft Office Excel 2016 software was employed in estimating the livelihood vulnerability index.

Table 1. Summary of LVI Results for Indexed Sub Components and Major Components for Atwima and Ejura-Sekyeredumase Districts

Sub-component Socio-demographic Profile	Units	District				Indexed SD		Major Component	Index Value for Major Component	
		Atwima Mponua District N=150	Ejura-Sekyere dumase District N=150	Maximum value in both districts	Minimum value in both districts	Atwima Mponua District	Ejura-Sekyered umase District		Atwima Mponua District	Ejura-Sekyered umase District
Female-headed households	Percent	17.300	21.300	100.000	0.000	0.173	0.213	Socio-demographic profile	0.410	0.648
Average age of female head of household	1/Years	0.018	0.019	0.014	0.032	0.70	1.050			
Percentage of household heads with no formal education	Percent	35.600	68.000	100.00	0.000	0.356	0.680			
Livelihood Strategies										
Percentage of households dependent solely on agriculture	Percent	74.700	76.900	100.00	0.000	0.747	0.769	Livelihood Strategies	0.457	0.572
Average livelihood diversification index	1/ average no. of livelihood per household	0.333	0.500	1.000	0.200	0.166	0.375			
Social Network										
Average borrow: lend money ratio	Ratio	1.030	1.000	2.000	0.500	0.353	0.300	Social network	0.602	0.480
Percentage of households that have not received any form of assistance from non/government organisations in the past 12 months	Percent	85.000	66.000	100.000	0.000	0.850	0.660			
Average time to health facility	Minutes	52.850	66.100	120.000	5.000	0.416	0.531	Health	0.256	0.419
Percentage of households with a member with chronic illness	Percent	21.300	21.500	100.000	0.000	0.213	0.215			
Percentage of households where a family member had to miss school or work in the past 6 months due to illness	Percent	14.100	51.000	100.000	0.000	0.141	0.510			
Food										
Percentage of households dependent solely on family farm for food	Percent	85.200	95.20	100.000	0.000	0.852	0.952	Food	0.329	0.354
Average number of months households struggle to find food	Months	3.000	3.500	7.000	0.000	0.030	0.035			
Average crop diversity index	1/no. of crops	0.250	0.300	1.000	0.100	0.160	0.200			
Percentage of households that do not save crops	Percent	34.200	36.100	100.000	0.000	0.342	0.361			
Percentage of households that do not save seeds	Percent	26.000	22.000	100.000	0.000	0.260	0.220			

Sub-component Socio-demographic Profile	Units	District				Indexed SD		Major Component	Index Value for Major Component	
		Atwima Mponua District N=150	Ejura-Sekyere dumase District N=150	Maximum value in both districts	Minimum value in both districts	Atwima Mponua District	Ejura-Sekyered umase District		Atwima Mponua District	Ejura-Sekyered umase District
Percentage of households reporting of water availability problem	Percent	43.30	89.30	100	0.000	0.433	0.893	Water	0.559	0.789
Percentage of households that utilise a natural water source	Percent	100	100	100	0.000	1.000	1.000			
Percentage of households that do not have consistent water supply	Percent	36.000	54.200	100.000	0.000	0.360	0.540			
Average time households take to fetch water	Minutes	48.200	69.100	90.000	15.000	0.443	0.721			
Natural Disasters and climate variability										
Average number of floods and droughts for the past 6 years	Count	6.500	8.300	15.000	0.000	0.430	0.553	Natural disasters and climate variability	0.400	0.764
Percentage of household that did not receive a warning about pending natural disasters	Percent	97.300	92.000	100.000	0.000	0.970	0.920			
Mean standard deviation of monthly average of average maximum daily temperature (years: 2009–2015)	Celsius	0.016	0.128	0.140	0.050	0.370	0.860			
Mean standard deviation of monthly average of average minimum daily temperature (years: 2009–2015)	Celsius	0.045	0.315	0.320	0.030	0.052	0.983			
Mean standard deviation of monthly average precipitation (years: 2009–2015)	Millimetres	14.350	33.330	62.450	3.800	0.180	0.504			
LVI									**0.417**	**0.585**
LVI- IPCC									**-0.038**	**0.102**

Source: Computation from Field Survey, 2016

4.1. Analysis of Vulnerability

Exposure to climate change is presumed to be location specific; for example, semi-arid regions may be most exposed to drought conditions (Hahn et al. 2008). Nevertheless, the socio-economic capacity of the affected people determines the extent of vulnerability (O'Brien et al., 2007). Thus, the major components of vulnerability and their indexes presented in Table 1 provide information on which household socio-economic characteristics contribute to climate change vulnerability in each study area. The higher the figure for vulnerability, the less capable the farmers are in adapting to the impacts of the changing climatic conditions.

4.1.1. Vulnerability in terms of Socio-Demographic Profile

Out of the 300 participants, the percentage of female headed households is higher in Ejura-Sekyeredumase District (21.3%) than Atwima Mponua District (17.3%). In terms of level of education attained, 36.0% of the household heads in Atwima Mponua District had no formal education; whilst in Ejura-Sekyeredumase District, the number of illiterate household head is 68.0%. Overall, Ejura-Sekyeredumase District shows greater vulnerability (0.648) with respect to the Socio-Demographic Profile index than Atwima Mponua District (0.410).

The study revealed that female-headed households inclined to be more vulnerable than male-headed households because they (female-headed households) tend to engage in non-agricultural activities to raise extra income. Also, most of the female-headed households engage in farming activities mainly for household consumption. Furthermore, some of the adaptation strategies such as hand irrigation is labour-intensive. Consequently, female-headed households tend to pay less attention to farming activities and are unable to adopt appropriate adaptive methods to manage the negative impacts of climate change and/or variability. The research outcomes agree with Antwi-Agyei et al. (2013) and Egyir et al. (2015)'s findings in similar studies.

It could also be inferred that since household heads in both districts had some form of level of education, this could enable them to manage information (Milner and Dietz, 2015) and facilitate technology transfer, which could enhance their adaptive capacity in implementing effective adaptation strategies (Silvestri et al., 2012). Nevertheless, the higher number of literate household heads in the Atwima Mponua District implies they are more likely to have higher adaptive capacity to implement effective adaptation strategies than those in the Ejura-Sekyeredumase District.

4.1.2. Vulnerability in terms of Livelihood Strategies

A higher proportion of farmers in Ejura-Sekyeredumase District (76.9%) depend on agriculture as their main source of income than those in Atwima Mponua District (74.7%). However, in both districts, all the respondents indicated that their main source of households' income is farming. The results indicate that farmers in both districts have other forms of livelihood diversification i.e. index values of 0.166 in Atwima Mponua District and

0.375 in in Ejura-Sekyeredumase District. The overall index value for major component indicates that in Ejura-Sekyeredumase District shows greater vulnerability in terms of Livelihood Strategies (0.572) than Atwima Mponua District (0.457).

The study observed that farmers in both districts engage in non-agricultural activities such as wage labour, petty trading and running shops. Aside from these, farmers in the Ejura-Sekyeredumase District engage in charcoal production, which destroys the natural resource base due to fire outbreak. Hence, contributing to the vulnerability of the households in the Ejura-Sekyeredumase District. Likewise, the adoption of slash and burn as a land preparation method in the Atwima Mponua District also contributes to the destruction of the natural resource base, hence increasing the vulnerability of households. Nevertheless, the vulnerability of the Ejura-Sekyeredumase District could be exacerbated by its semi-arid conditions.

4.1.3. Vulnerability in terms of Social Networks

Social networks can reduce households' vulnerability to climate change impacts (Barnes et al., 2020). Thus, the more community groups a household belongs to, the less likelihood it is for that household to be more vulnerable to climate threats. The overall components of social network indicate that Atwima Mponua District (0.602) may be more vulnerable than Ejura-Sekyeredumase District (0. 480).

Interviews with the Agricultural Extension Officers (AEOs) revealed that the Ejura-Sekyeredumase District attracts most development/research projects, which often prefer working with farming groups rather than individuals. Hence, fostering strong social networks enhance the adaptive capacity of households in the Ejura-Sekyeredumase District. In the Atwima Mponua District also, interviews with the AEOs showed that similar to the Ejura-Sekyeredumase District, there were existing farming groups. Comparison could not be made between the two study areas in terms of the number of existing social networks established within the districts in order to assign reasons for higher vulnerability score for the Atwima Mponua District, as this was beyond the scope of the study.

4.1.4. Vulnerability in terms of Health

The proportion of households where a member has chronic disease was similar in both study areas- Atwima Mponua District (21.3%) and Ejura-Sekyeredumase District (21.5%). Meanwhile, the proportion of households where a member missed school due to illness was reported lower in Atwima Mponua District (14.1%) than in Ejura-Sekyeredumase District (51.0%). The households in Atwima Mponua District reported travelling an average of 52.85minutes to the nearest health facility while in Ejura-Sekyeredumase District, households take an average of 66.10 minutes. The major components score indicates that the health vulnerability score for Ejura-Sekyeredumase District (0.419) is higher than that for Atwima Mponua District (0.256).

The study found that malaria is the common disease reported in both districts. In the Ejura-Sekyeredumase District, interview feedback indicates that most households usually depend on traditional medicine when they are not well and would go to the local chemists for self-medication when the traditional medicines seem to fail to treat the disease. They claim that going to the Community Heath Centre is considered the last option. The main reason assigned was due to financial burden, as well as long waiting time. In the Atwima Mponua District however, feedback on interviews indicates that most of the households use traditional medicine alongside the orthodox medicine from the local chemist shops. The traditional medicines may have active ingredient to treat a disease, yet the dosage is usually not quantified properly. Hence, the traditional medicine may not be able to treat the disease effectively. This situation may contribute to the higher vulnerability score of households in the Ejura-Sekyeredumase District with respect to health. In the case of the Atwima Mponua District, lower vulnerability score could be attributed to additional intake of the orthodox medicine, which eventually treats the disease.

4.1.5. Vulnerability in terms of Food

More households in Ejura-Sekyeredumase District (95.2%) depend solely on family farm than those in Atwima Mponua District (85.2%). Again, households in Ejura-Sekyeredumase District struggle to find adequate food supply for at least 4 months between the months of February to May whilst in Atwima Mponua District, scarcity of food is experienced on average for 3 months (March-May). A higher proportion of households in Ejura-Sekyeredumase District (36.1%) do not save crops relative to Atwima Mponua District (34.0%).

Interviews with the households revealed that the main sources of income of households in the Ejura-Sekyeredumase District is from the sale of maize and cassava crops. Most households prefer cultivating improved maize seed for the next farming season in order to get more yield. In the Atwima Mponua District, maize crops are mainly for household consumption, and they normally use the stored seed for the next farming season. Hence, there is a greater proportion of households in the Atwima Mponua District (26.0%) that save seeds for the next farming season than those in the Ejura-Sekyeredumase District (22.0%). Thus, inability of most households in the Ejura-Sekyeredumase District (0.354) to save seed contributes to their vulnerability in terms of food more than that for the households in the Atwima Mponua District (0.329).

4.1.6. Vulnerability in terms of Water

Regarding water availability, households in Ejura-Sekyeredumase District have a higher vulnerability score (0.789) than those in Atwima Mponua District (0.559). This is mainly due to scarcity of rainwater or water from the rivers and streams which tend to dry out as a result of high levels of evaporation because of high temperature. Meanwhile, in both districts all the households utilise natural sources of water. Water is stored in containers with capacity of about 2000 litres by households in both districts, however on average households reported that they hardly get the containers filled to its full capacity especially in the dry season (December-March). In both districts, apart from fetching water from a natural source, the households also harvest rain water. The study revealed that apart from streams and rain harvest as sources of water, there were bore holes installed in the communities in both districts.

In addition to these, a few wells were observed in the communities in the Atwima Mponua District. Interviews with the key informants revealed that whereas the bore holes were installed by either the Local Government or NGOs, the wells were individually owned. This means that relatively, the households in the Atwima Mponua District would have more consistent water supply than those in the Ejura-Sekyeredumase District. Access to relatively more sources of water contributes to less time taken for the households in the Atwima Mponua District (48.20 minutes) to travel to fetch water than those in the Ejura-Sekyeredumase District (69.10 minutes). Meanwhile, in the Ejura-Sekyeredumase District, 89.3% of households had reported water conflict compared with 43.3% in the Atwima Mponua District. Thus, these factors might have contributed to the overall higher vulnerability score (0.797) in the Ejura-Sekyeredumase District in terms of water than the Atwima Mponua District (0.575).

4.1.7. Vulnerability in terms of Natural Disasters, Warning and Impact

Households in both districts had observed changes in climate variables (temperature and rainfall) over the past 20-30 years. Observed changes include erratic rainfall patterns; high intensity of sunshine; high occurrence of flood; increased severe hot days and nights although the temperatures are relatively low during rainy seasons.

4.2. Analysis of Vulnerability Summarized as Spider Diagrams

The results of the seven major components are summarized in Figure3. The vulnerability spider diagram ranges between 0 (least vulnerable) and 0.8 (Most vulnerable).

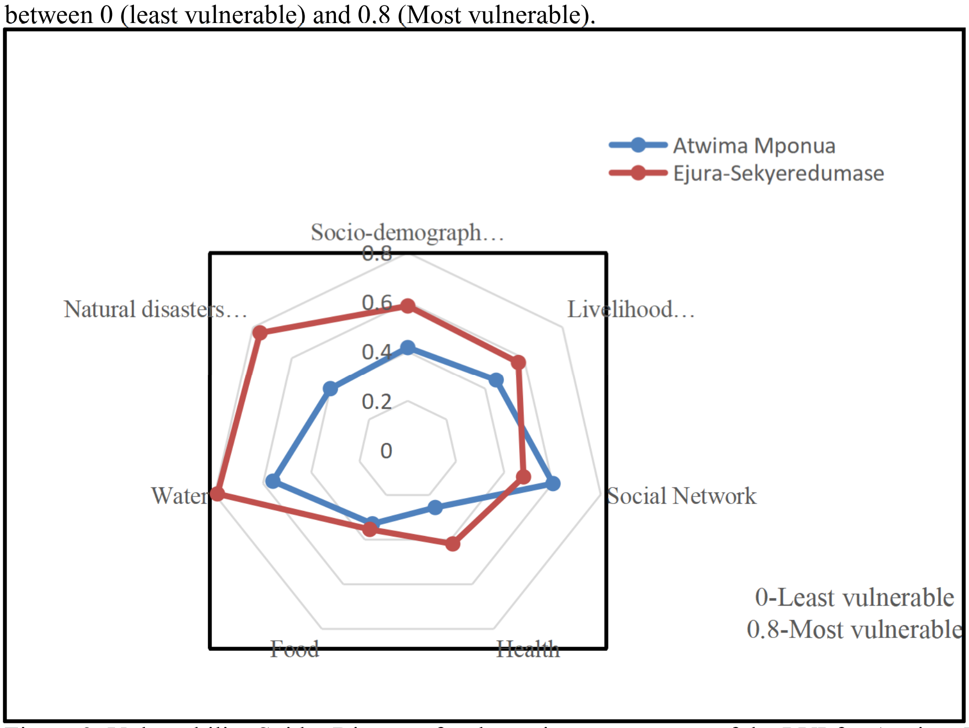

Figure.3. Vulnerability Spider Diagram for the major components of the LVI for Atwima Mponua and Ejura-Sekyeredumase Districts

The diagram shows that the Ejura-Sekyeredumase District may be more vulnerable than the Atwima Mponua District in terms of socio-demographic profile, livelihood strategies, health, food, water and natural disasters. However, the Atwima Mponua District may be more vulnerable than the Ejura-Sekyeredumase District in terms of social network. The findings from the Atwima Mponua District indicated that there had been 5 floods and 2 droughts in the past 6 years, and the latest drought occurred in 2012. In the Ejura-Sekyeredumase District, the case was different. There had been 5 droughts, and 3 floods within the past 6 years. Nevertheless, the vulnerability scores indicate that households in the Ejura-Sekyeredumase District (0.764) are more vulnerable than those in the Atwima Mponua District (0.400). Water availability is as important as climate variability with regard to farmers vulnerability and ability to develop adaptive strategies to improve their livelihood. Water availability in the Atwima Mponua District was higher than in the Ejura-Sekyeredumase District. However, the findings indicated that water availability was reducing.

4.3 Contributing Factors to Livelihood Vulnerability Index

The LVI-IPCC is computed by grouping the **seven** major components into three categories: exposure, sensitivity and adaptive capacity. **Exposure** is the sum of scores from natural disasters and climate variability; **adaptive capacity** is a composite of aggregate score from socio demographic profile, social network and livelihood strategies whereas **sensitivity** is made up of aggregate scores from health, food and water. This index, which takes into consideration **exposure**, **sensitivity** and **adaptive capacity**, is represented in the vulnerability triangle as shown in Figure 4.

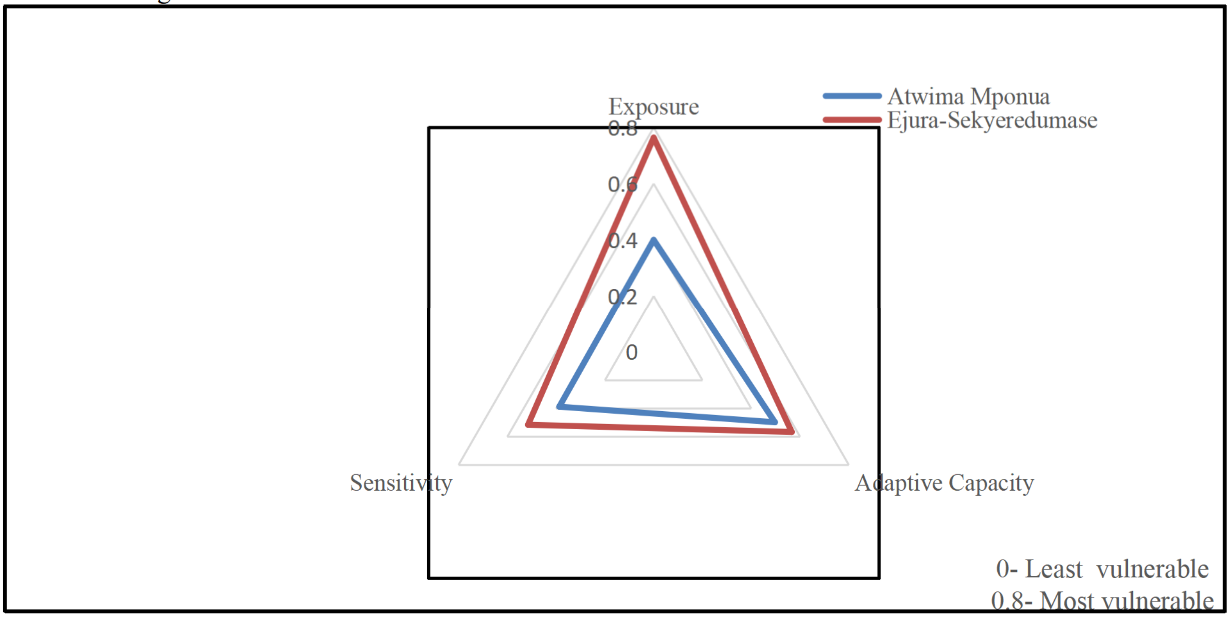

Figure. 4. Vulnerability Triangle Diagram of the Contributing Factors to LVI for Atwima Mponua and Ejura-Sekyeredumase districts

The vulnerability triangle indicates that the Ejura-Sekyeredumase District (0.515) is more sensitive to climate change and variability than the Atwima Mponua District (0.387). In the Ejura-Sekyeredumase District, farming systems are relatively more dependent on maize. Maize is also cultivated in the Atwima Mponua District; however, it shares its role as staple with cassava. Maize is less drought-tolerant than cassava.

The Ejura-Sekyeredumase District also has a higher exposure to climate threats as indicated by the exposure values (the Ejura-Sekyeredumase District – 0.764; the Atwima Mponua District – 0.400). Nevertheless, in terms of adaptive capacity, although the Ejura-Sekyeredumase District (0.566) may be more vulnerable than the Atwima Mponua District (0.497), there is very little difference among the households in both districts (0.069). The overall LVI- IPCC estimates for the two districts indicate that in terms of climate change and variability, the Ejura-Sekyeredumase District (0.102) may be more vulnerable than the Atwima Mponua District (-0.038).

6. Conclusions

This study adopts the Livelihood Vulnerability Index (LVI) to assess the vulnerability of Atwima Mponua and Ejura-Sekyeredumase districts in different agro-ecological zones (Semi-Deciduous Forest and Transition Zone respectively). Socio-economic data was based on household questionnaires from farming households and secondary data on rainfall and temperature from the Ghana Meteorological Agency was used to calculate the LVI. The overall LVI indicates that Ejura-Sekyeredumase District may be more vulnerable to climate change impacts than Atwima Mponua District. However, in terms of the assessment of sensitivity to climate change and variability, using the vulnerability triangle, it was concluded that Ejura-Sekyeredumase District is more sensitive to climate change and/or variability than Atwima Mponua District. Further analysis in term of farmers adaptive capacity in relation to livelihood assets such as human capital; households' dependence on family farm for food consumption, sale of crops at the local/urban markets; and households' consistency of water supply, concluded that farmers in Ejura Sekyeredumase are more vulnerable to climate change and variability impacts. The vulnerability triangle indicates that Ejura-Sekyeredumase District is more sensitive to climate change and variability impacts than Atwima Mponua District. Atwima Mponua District may have a higher adaptive capacity than Ejura-Sekyeredumase District, although the difference is relatively small.

Thus, the findings presented in the chapter point to the fact that smallholder farmers are vulnerable to climate change and/or variability impacts in Ghana. Evidence from this study indicates that farmers' vulnerability is spatially, socially and economically differentiated. Different ecological zones in Ghana have peculiar demographic, physical and socioeconomic characteristics that define their sensitivity and resilience to the impacts of climate change and variability.

7. Policy Recommendation

This study contributes to research on climate change vulnerability by providing empirical evidence to deepen our understanding of the socio-economic factors that enhances smallholder crop farmers vulnerability to the negative impacts of climate variability and change impacts. The findings of this study contribute to literature on climate change in both districts, especially Atwima Mponua district with limited research on climate change relative to Ejura-Sekyeredumase District.

The policy implications that aim at minimising farmers' vulnerability to negative impacts of climate change impacts in the study areas and sub-Sahara Africa are more widely outlined.

It is recommended that local projects and policies support such as micro credit should be made accessible at an affordable interest rate to small holder crop farmers to enhance diversification of livelihood strategies.

Access to essential facilities such as health and water should be made a top priority by the Local Authorities in the communities. Also, education campaign on the essence of seeking medical assistance rather than reliance on traditional medicine should be a key priority.

The study focused on some selected communities in both study areas, hence the interpretation of the results should be limited to these districts. However, it is recommended that this study could be replicated to other regions of Ghana to help identify vulnerable communities, so specific policies can be implemented to manage the vulnerability due to the negative impacts of climate variability and change.

Disclosure statement

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

References

[1] Abdul-Razak, M. and Kruse, S. (2017). 'The adaptive capacity of smallholder farmers to climate change in the Northern Region of Ghana', *Climate Risk Management,* 17(17), pp. 104-122, https://doi.org/10.1016/j.crm.2017.06.001.

[2] Adu, D. T., Kuwornu, J. K. M, Anim Somuah, H., and Sasaki, N. (2018). 'Application of Livelihood Vulnerability Index in assessing smallholder maize farming households' vulnerability to climate change in Brong-Ahafo region of Ghana', *Kasetsart Journal of Social Sciences,* 39(1), pp. 22-32, doi:10.1016/j.kjss.2017.06.009.

[3] Akudugu, M. A. (2012). 'Estimation of the determinants of credit demand by farmers and supply by rural banks in Ghana's Upper East Region', *Asian Journal of Agriculture and Rural Development*, 2 (2), pp. 189-200.

[4] Antwi-Agyei, P., Dougill, A. J., Fraser, E. D. G and Stringer, L. C. (2013). 'Characterising the nature of household vulnerability to climate variability: empirical evidence from two regions of Ghana', *Environmental Development Sustainability,* 15(4), pp. 903–926, doi:10.1007/s10668-012-9418-9.

[5] Barnes, M. L., Wang, P., Cinner, J. E., Graham, N. A. J., Guerrero, A. M., Jasny, L., Lau, J., Sutcliffe, S. R. and Zamborian-Maison, J. (2020). 'Social determinants of adaptive and transformative responses to climate change', *Nature Climate Change*, (10), 823–828, doi: 10.1038/s41558-020-0871-4.

[6] Birkmann, J., E. Liwenga, R. Pandey, E. Boyd, R. Djalante, F. Gemenne, W. Leal Filho, P.F. Pinho, L. Stringer, and Wrathall, D. (2022). Poverty, Livelihoods and Sustainable Development. In: climate change 2022: *Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1171–1274, doi:10.1017/9781009325844.010.

[7] Cudjoe, G. P., Antwi-Agyei, P., Gyampoh, B. A. (2021). "The Effect of climate variability on maize production in the Ejura-Sekyedumase Municipality, Ghana". *Climate*, 9, 145. https://doi.org/10.3390/cli9100145.

[8] Dasgupta, P., Morton, J., Dodman, D., Karapinar, D., Meza, F., Rivera-Ferre, M.G., Toure Sarr, A. and Vincent, K.E. (2014). 'Rural areas'. In: Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, R.C., Genova, B., Girma, E.S., Kissel, A.N., Levy, S., MacCracken, P.R., Mastrandrea, Y.O. and White, L.L. (eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* Cambridge, UK and New York, NY,

USA: Cambridge University Press, pp. 613–657.
[9] Dasgupta, A. and Baschieri, A. (2010). 'Vulnerability to climate change in rural Ghana: Mainstreaming climate change in poverty -reduction strategies', *Journal of International Development* 22(6):803- 820, DOI:10.1002/jid.1666.
[10] Dumenu, W.K. and Obeng, E.A. (2016). Climate change and rural communities in Ghana: Social vulnerability, impacts, adaptations and policy implications. *Environmental Science and Policy*, 55, Pp. 208-217, doi:10.1016/j.envsci.2015.10.010.
[11] Egyir, I.S., Ofori, K., Antwi, G., Ntiamoa-Baidu, Y. (2015). 'Adaptive capacity and coping strategies in the face of climate change: a comparative study of communities around two protected areas in the coastal savanna and transitional zones of Ghana', *Journal of Sustainable Development.*, 8 (1), pp. 1-15, doi:10.5539/jsd.v8n1p1.
[12] Emrich, C. T. and Cutter Susan (2011). 'Social vulnerability to climate – sensitive hazards in the Southern United States, *AMS Journal*, 193–208, DOI: https://doi.org/10.1175/2011WCAS1092.1.
[13] Etwire, P.M., Al-Hassan, R.M., Kuwornu, J. K. M. and Osei-Owusu, Y. (2013). 'Application of Livelihood Vulnerability Index in assessing vulnerability to climate change and variability in Northern Ghana', *Journal of Environment and Earth Science,* 3(2), https://doi.org/10.1016/j.kjss.2017.06.009.
[14] Fosu-Mensah, B.Y., Vlek, P.L.G. and MacCarthy, D.S. (2012). "Farmers' perception and adaptation to climate change: A case study of Sekyedumase District in Ghana". *Environment, Development and Sustainability*,14, 495–505, https://doi.org/10.1007/s10668-012-9339-7.
[15] Füssel, H.-M. (2007). Vulnerability: 'A generally applicable conceptual framework for climate change research', *Global Environmental Change*, 17 (155-167), Pp. 156-164, doi:10.1016/J.GLOENVCHA.2006.05.002.
[16] GEPA (2012). *Climate change and agricultural policy processes in Ghana,* Accra: Ghana.
[17] Ghana Statistical Service (2018). *Quarterly Gross Domestic Product (QCDP), Third Quarter,* Accra: Ghana.
[18] Ghana Statistical Service (2014). *2010 Population Projection by Sex, 2010-2014 national*, Accra: Ghana.
[19] Ha-Mim, N. M. and Hossain, M. Z. (2020). Differential climate change vulnerability among different poverty groups in southwestern Bangladesh: lessons for adaptation planning, *Recent Research in Science and Technology*, 12: 6-10 doi: 10.25081/rrst.2020.12.6084.
[20] Hahn, M.B. (2008). *The livelihood vulnerability index: A Pragmatic Approach to Assessing Risks from Climate Variability and Change,* Unpublished Dissertation (PHD), Department of Environmental and Occupational Health and Hubert Department of Global Health, Rollins School of Public Health, Emory University, Atlanta, Georgia.
[21] Hahn, M.B., Riederer, A.M., Foster, S.O. (2009). 'The Livelihood Vulnerability Index: A Pragmatic Approach to Assessing Risks from Climate Variability and Change - A Case Study in Mozambique', *Global Environmental Change*, 19, pp. 74-88, https://doi.org/10.1016/j.gloenvcha.2008.11.002.
[22] Hinkel, J. (2011). 'Indicators of vulnerability and adaptive capacity: Towards a clarification of the science-policy interface', *Global Environmental Change,* 21, 198-208, https://doi.org/10.1016/j.gloenvcha.2010.08.002.
[23] IFAD (2009). 'Response to climate change through Support to Adaptation and Related Actions', Comprehensive Report: Final version, Washington, DC: World Bank, pp. 160.
[24] IPCC (2007). *Climate change 2007: The physical science basis, contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. M (eds.)]. Cambridge: Cambridge University Press, pp. 866-867, 872, 873.
[25] IPCC (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)], Geneva: IPCC, pp. 121-30.
[26] Madhuri, Tewari, H.R. and Bhowmick, P.K. (2014). 'Livelihood vulnerability index analysis: An approach to study vulnerability in the context of Bihar', Jàmbá, *Journal of Disaster Risk Studies* 6(1), 127, pp. 13. Mase, A.S., Benjamin, G. and Prokopy, L. S. (2017) Climate change beliefs, risk perceptions, and adaptation behavior among Midwestern U.S. crop farmers, *Climate Risk Management,* 15 (2017), Pp. 8-17, doi:10.4102/jamba.v6i1.127.
[27] Millner, A. and Dietz, S. (2015). 'Adaptation to climate change and economic growth in developing countries', *Environment and Development Economics,* 20(3), pp. 380-406, doi: https://doi.org/10.1017/S1355770X14000692.
[28] MoFA (2015). *Climate change finance in Ghana,* Accra- Ghana.
[29] Morton, J., Kisauzi, D., Ohiomoba, I., Demby, D., Mangheni, M., Moumouni, I., Parkinson, V., Suale, D., Lamboll, R., Nelson, V. and Quan, J. (2014). 'Climate, agriculture and knowledge in Africa: agricultural

research and advisory services in the face of climate change', *Final Synthesis Report of the Climate Learning for African Agriculture Project*, Chatham Maritime: Natural Resources Institute, University of Greenwich, Pp. 3.

[30] Morton, J. F. (2017). 'Climate change and African agriculture: unlocking the potential of research and advisory services'. In: F. Nunan (ed.) *Making Climate Compatible Development Happen*, Routledge, Pp. 87-113. ISBN 978-1138657021.

[31] Niang, I., Ruppel, O., Abdrabo, M., Essel, A., Lennard, C., Padgham, J. and Urquhart, P. (2014). 'Africa'. In: Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R. and White, L.L. (eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* Cambridge, UK and New York, NY, USA: Cambridge University Press, pp. 1199–1265.

[32] Olsson, L., Opondo, M., Tschakert, P., Agrawal, A., Eriksen, S.H., Ma, S., Perch, L.N. and Zakieldeen, S.A. (2014) 'Livelihoods and poverty', in Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R. and White, L.L. (eds.), *Climate Change 2014:Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* Cambridge, UK and New York, NY, USA: Cambridge University Press, Pp. 793–832.

[33] O'Brien, K., Eriksen, S., Nygaard, L.P. and Schjolden, A. (2007). 'Why different interpretations of vulnerability matter in climate change discourses', *Climate Policy*, (7) Pp. 73–88, doi:10.1080/14693062.2007.9685639.

[34] Ofori-Boateng, K. and Insah, B. (2014). 'The impact of climate change on cocoa production in West Africa, *International Journal of Climate Change Strategies and Management,* 6(3), pp.296-314, doi:10.1108/IJCCSM-01-2013-0007.

[35] Okpara, U. T., Stringer, L. C. Dougill, A. J. (2016). 'Perspectives on contextual vulnerability in discourses of climate conflict Earth System'. *Dynamics,* 7, Pp. 89–102, doi:10.5194/esd-7-89-2016.

[36] Schipper, E. L. F. and Burton, I.(eds), (2009). *The Earthscan Reader on Adaptation to Climate Change,* London: Sterling, Pp 1-49. 91-373.

[37] Silvestri, S., Bryan, E., Ringler, C., Herrero, M. and Okoba, B. (2012). 'Climate change perception and adaptation of agro-pastoral communities in Kenya', *Regional Environmental Change,* 12: 791– 802, doi:10.1007/s10113-012-0293-6.

[38] Soussana, F.J., Graux, I.A. and Tubiello, F.N. (2010). 'Improving the Use of Modelling for Projections of Climate Change Impacts on Crops and Pastures', *Journal of Experimental Botany,* (61), 8, pp.2217– 2228, doi: 10.1093/jxb/erq100.

[39] Trisos, C.H., Adelekan, I.O., Totin, E., Ayanlade, A., Efitre, J., Gemeda, A., Kalaba, K., Lennard, C., Masao, C., Mgaya, Y., Ngaruiya, G., Olago, D., Simpson, N. P. and Zakieldeen, S. (2022). 'Africa'. In: Pörtner, H.-O., Roberts, D.C., Tignor, M., Poloczanska, E.S., Mintenbeck, K., Alegría, A., Craig, M., Langsdorf, S., Löschke, S., Möller, V., Okem, A. and Rama, B (Eds.), Climate change 2022: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on climate change. Cambridge University Press, Cambridge, UK and New York, NY, USA, 1285–1455, doi:10.1017/9781009325844.011.

[40] Qaisrani, A., Umar, M. A., Siyal, K. M. S. (2018). 'What Defines Livelihood Vulnerability in Rural Semi-Arid Areas? Evidence from Pakistan', *Earth Systems and Environment*, (2), 455–475, https://doi.org/10.1007/s41748-018-0059-5.

Appendix 1: How to calculate the sub-component values

Calculating the sub-component values
Step 1

$$\text{index}_{SDP1} = IndexS_f = \frac{S_f - S_{min}}{S_{max} - S_{min}} \text{ .... Equation (1)}$$

$$= \frac{17.3-0}{100-0} = \mathbf{0.731}$$

Where s_d is the original sub-component for district (F), and s_{min} and s_{max} are the minimum and maximum values respectively, for each sub-component determined using data from both districts. For example, if the 'average time to travel to primary water source' subcomponent ranged from 1 to 1500 minutes in the two districts, these minimum and maximum values were used to change this indicator into a standardized index so it could be integrated into the water component of the LVI. For variables that measure frequencies such as the 'percentage of households reporting having heard about conflicts over water resources in their community,' the minimum value was set at 0 and the maximum at 100% (Hahn et al.2009):
Step 1 was repeated for all sub components

Step 2.1: The average of all the sub-components was worked out to get the value for the major sub-component. Step 2 was repeated for all study areas.

$$LVI_{AMDSDP} = \Sigma i = \text{index}_{sd} = \frac{SDP1 + SDP2 + SDP3 + SDP\ 4 + SDP5}{n}$$

$$= \frac{0.173 + 0.70 + 0.356}{3} = \mathbf{0.410}$$

Step 2.2:

Atwima Mponua District:

$$LVI_{AMD} = \frac{\Sigma^7_{i=1} w_{Mi} M_{di}}{\Sigma^7_{i=1} w_{Mi}}$$

$$LVI_{AMD} = \frac{3(0.410) + 2(0.457) + 2(0.602) + 3(0.256) + 5(0.329) + 4(0.559) + 5(0.400)}{3 + 2 + 2 + 3 + 5 + 4 + 5}$$

$$= \frac{1.230 + 0.914 + 1.204 + 0.768 + 1.645 + 2.236 + 2.00}{24} = \frac{9.997}{24}$$

$$LVI_{AMD} = \mathbf{0.417}$$

Ejura-Sekyeredumase District:

$$LVI_{ESD} = \frac{\Sigma^7_{i=1} w_{Mi} M_{di}}{\Sigma^7_{i=1} w_{Mi}}$$

$$LVI_{ESD} = \frac{3(0.648) + 2(0.572) + 2(0.480) + 3(0.419) + 5(0.354) + 4(0.789) + 5(0.764)}{3 + 2 + 2 + 3 + 5 + 4 + 5}$$

$$= \frac{1.944 + 1.144 + 0.96 + 1.257 + 1.77 + 3.156 + 3.82}{24} = \frac{14.051}{24}$$

$$LVI_{ESD} = \mathbf{0.585}$$

Step 3: Calculating the contributing factors
Exposure

Atwima Mponua District:

$$CF_d = \frac{\Sigma^n_{i=1} w_{Mi} M_{fi}}{\Sigma^n_{i=1} w_{Mi}} = \frac{5(0.400)}{5}$$

$$= \mathbf{0.400}$$

Ejura-Sekyeredumase District:

$$CF_d = \frac{\Sigma^n_{i=1} w_{Mi} M_{fi}}{\Sigma^n_{i=1} w_{Mi}} = \frac{5(0.764)}{5}$$

$$= \mathbf{0.764}$$

Adaptive Capacity

Atwima Mponua District:

$$CF_d = \frac{\Sigma^n_{i=1} w_{Mi} M_{Ti}}{\Sigma^n_{i=1} w_{Mi}} = \frac{3(0.419) + 2(0.457) + 3(0.602)}{3+2+3}$$

$$= \frac{1.257 + 0.914 + 1.806}{8} = \frac{3.977}{8}$$

$$= \mathbf{0.497}$$

Ejura-Sekyeredumase District:

$$CF_d = \frac{\Sigma^n_{i=1} w_{Mi} M_{di}}{\Sigma^n_{i=1} w_{Mi}} = \frac{3(0.648) + 2(0.572) + 3(0.480)}{3+2+3}$$

$$= \frac{1.944 + 1.144 + 1.440}{8} = \frac{4.528}{8}$$

$$= \mathbf{0.566}$$

Sensitivity
Atwima Mponua District:

$$CF_d = \frac{\Sigma^n_{i=1} w_{Mi} M_{Fi}}{\Sigma^n_{i=1} w_{Mi}} = \frac{3(0.256) + 5(0.329) + 4(0.559)}{3+5+4}$$

$$= \frac{0.768 + 1.645 + 2.236}{12} = \frac{4.649}{12}$$

$$= \mathbf{0.387}$$

Ejura-Sekyeredumase District:

$$CF_d = \frac{\Sigma^n_{i=1} w_{Mi} M_{Ti}}{\Sigma^n_{i=1} w_{Mi}} = \frac{3(0.419) + 5(0.354) + 4(0.789)}{3+5+4}$$

$$= \frac{1.257 + 1.77 + 3.156}{12} = \frac{6.183}{12}$$

$$= \mathbf{0.515}$$

Calculating LVI-IPCC:
Atwima Mponua District:

LVI-IPCC $= (e_{AMD} - a_{AMD}) \times S_{AMD}$
$= (0.400 - 0.497) \times (0.387)$
$=$ **-0.038**

Ejura-Sekyeredumase District

LVI-IPCC $= (e_{ESD} - a_{ESD}) \times S_{ESD}$
$= (0.764 - 0.566) \times (0.515)$
= 0.102

Appendix 2: Summary of Calculations of the Contributing Factors

Ecosystem	IPCC contributing factor to vulnerability major components		Major components values for Districts	Number of sub components per major component for Districts	Contributing factor values	LVI-IPCC value for Atwima Mponua District	LVI-IPCC value for Ejura-Sekyeredumase District
Atwima Mponua	**Exposure**	Natural disasters and climate variability	0.400	5	0.400	**-0.038**	**0.102**
Ejura-Sekyeredumase			0.764	5	0.764		
Atwima Mponua	**Adaptive capacity**	Socio-demographic profile	0.417	3	0.497		
		Social networks	0.778	3			
		Livelihood strategies	0.380	2			
Ejura-Sekyeredumase		Socio-demographic profile	0.585	3	0.566		
		Social networks	0.480	2			
		Livelihood strategies	0.441	3			
Atwima Mponua	**Sensitivity**	Health	0.256	3	0.387		
		Food	0.329	5			
		Water	0.575	4			
Ejura-Sekyeredumase		Health	0.419	3	0.515		
		Food	0.354	5			
		Water	0.797	4			