Assessing the Vulnerability of Rice Production to Climate Change in the Upper East Region of Ghana

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ABSTRACT

This study assesses the vulnerability of rice production to erratic climatic patterns in the Upper East Region of Ghana. This region is known to be the most vulnerable to climate change in the country. However, no study has found any local variations as the study tended to be defined by administrative boundaries. To assess rice production vulnerability to biophysical aspects of climate change (e.g., rainfall, temperature), we applied a multiple regression and crop vulnerability index analyses. The vulnerability index was used to determine the yield loss sensitivity and exposure. The multiple regression analysis aimed to assess the impact of maximum and minimum temperatures on rice yields with negative relationship to rainfall variability. The results of rice yield sensitivity and overall vulnerability highlighted local differences. For example, we found that farmers in Talensi district were the most vulnerable in terms of exposure to erratic rainfall patterns. Also, our multiple regression analysis showed that a local variation of vulnerability was linked to residents' socioeconomic status, including poverty, literacy/education, and economically active population. These results suggest that highly localized adaptation strategies are needed through technical and institutional support to improve the resilience of food production systems.

Keywords: Vulnerability, Climatic variability, Rainfall and temperature patterns, Rice production

1. Introduction

Crop vulnerability can be understood in terms of how the crop production system sensitively responds to climate change, including adaptive capacity (IPCC 2001b, p. 89). The Upper East Region of Ghana has experienced extreme climatic hazards, including erratic rainfall, drought, flood and high temperature (Antwi-Agyei, 2012; Nkrumah et al., 2014). Smallholder rice farmers here perceived decreasing rainfall, increasing temperature, and reduced crop yields (Abdul-Razak and Matsui, 2018). These unstable climate conditions affected rice production and productivity.

To determine crop vulnerability to weather and climate conditions past studies focused on process-based models (Challinor et al., 2009; Wheeler et al., 2000) and inter-regional variations (Issahaku et al., 2009, Antwi-Agyei, 2012). While these overall impact studies on agriculture is viable, it is also important to look at specific crop response so that our overall understanding can be further refined. This paper aims to determine the impact of climate change on rice production and smallholder farmers' adaptation measures that are needed to reduce crop vulnerability. We explore and quantify the sensitivity and exposure of rice yields to climatic hazards.

2. Study Area

The Upper East Region is located in the northeastern part of Ghana. It lies in semi-arid Guinea and Sudan savannahs. The mean annual rainfall ranges between 800mm and 1,100mm although the rainfall pattern is erratic spatially and in duration. Annual average temperatures range from 14 ^{o}C to 35 ^{o}C (Ghana Statistical Service, 2014). Agriculture employs 80% of the population in this Region. The Region is the third largest rice producer among five rice-producing regions in Ghana. About 90% of farm holdings in this Region are less than two hectares in size. Farmers here mainly use hoe and cutlass to cultivate. In some cases, they use bullocks. Rice farming is predominantly rainfed. Only limited locations like Tono and Vea dam sites are under irrigation. This means that rice yields depend on rainfall and are vulnerable to climate change (MOFA, 2016).

3. Methodology

3.1 Regression analysis

We collected the Region's climate data, including annual rainfall, maximum temperature and minimum temperature for the period (1991 to 2017) from the Savanna Agricultural Research Institute (SARI-Manga) and Ghana metrological agency (Gmet. -Navrongo). Annual rice yield data for over 27 years (1991 to 2017) were collected from the Statistics, Research and Information Directorate of the Ministry of Food and Agriculture (SRID-MOFA). We carried out a multivariate regression analysis to determine the relationship between rice yields and climatic variability. This helps to confirm the significant impact of rainfall and temperature anomalies on rice yields anomalies.

3.2 Rice yield vulnerability index analysis

Rice yield vulnerability analysis was conducted concerning Pusiga, Garu tempani, Talensi and Builsa districts. The study districts were purposively chosen based on their rainfed rice production potential mostly at valley bottoms (MOFA, 2016). Rice yield data of the four selected districts over 27-year period (1991 to 2017) were detrended using auto regression with a 3-year lag. The auto-regression removes the effect of increased technology and allows to calculate an expected yield (Smilton et al., 2009). The expected yield was divided by the actual yield to determine the yield loss sensitivity index.

$$\text{Sensitivity Index (S)} = (\text{Expected yield})/(\text{Actual yield})$$

Average seasonal rainfall data of the selected districts from 1991 to 2017 within rice cropping months of May to October was divided by each year's average growing season rainfall for the same period to determine the exposer index.

$$\text{Eposer Index(E)} = \frac{\text{Average long term growing seasonal rainfall } (1991 - 2017)}{\text{Average growing season rainfall for each year}}$$

To determine the vulnerability of rice yields to erratic rainfall pattern we divided the yield loss sensitivity index by the exposer index in line with (Antwi -Agyei, 2012)

$$\text{Vulnerability index} = \frac{\text{Yield loss sensitivity Index(S)}}{\text{Eposer Index (E)}}$$

4. Results and Discussion

4.1 Rice yield response to climatic variability

Table 1 shows the results of the regression analysis regarding the impact of climatic variabilities on rice yields. It indicates that rainfall and temperature anomalies significantly affected rice yields over time. Rice yields variation had a coefficient of (-8.814) significant at 5%. This indicates that yields of rice significantly decreased with time. Rainfall trends in the UER had varied (28%) and decreased by 44.6% for the past decade (Abdul-Razak and Matsui 2018). This finding conforms with the negative relationship observed between rainfall and rice yields in our regression analysis. The overall results show an R–square value of 0.472, implying that the impact of climatic variabilities accounted for (47%) of the total variations in rice yields as observed in the study region.

Table 1 Results of multiple regression for Yield(t)

Variables	Coefficient	Std Err	t-value	p-value	Lower limit	Upper limit
Constant	-8.814	3.649	-2.415	0.024	-16.362	-1.265
Rainfall(mm)	-0.001	0.000	-2.491	0.020	-0.002	0.000
Temp (Mini)	0.215	0.106	2.023	0.055	-0.005	0.435
Temp (Max)	0.207	0.053	3.879	0.001	0.097	0.318

NB: Summary measures

Multiple R	R-Square	Adj R-Square	StErr of Est
0.687	0.472	0.403	0.387

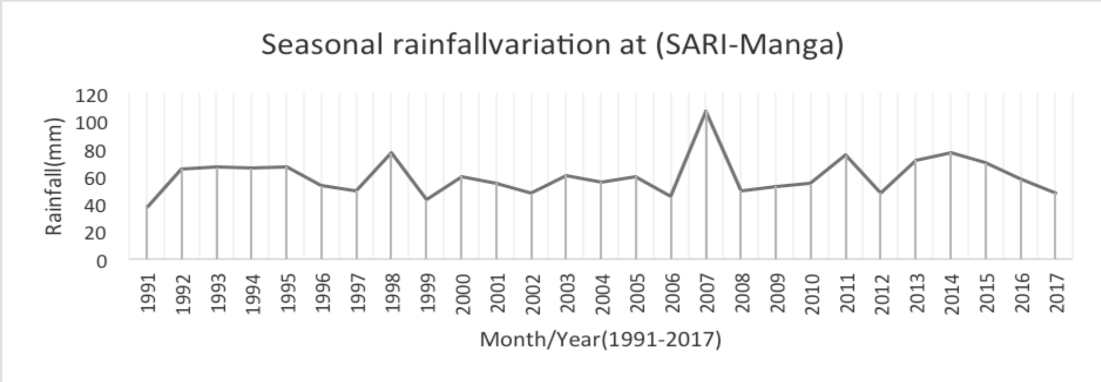

Figure 1 Observed seasonal rainfall variability for the Upper East Region

4.2 Rice yield sensitivity and vulnerability to erratic rainfall pattern

Figure 2 shows the overall sensitivity and vulnerability of rice production to climatic variability. The results indicate that Talensi district had the highest vulnerability index (1.113) followed by Pusiga district (1.104) and Garu tempani district (1.042) respectively. Builsa district was the least sensitive. Geographically the most exposed and sensitive districts were located in the Sudan savannah zone. This zone receives the lowest average rainfall of 958mm per annum (Armah et al., 2010). Upland rice farming in the Sudan savannah is prone to drought, with some farms located at riverbanks and valley bottoms least sensitive and resilient to drought conditions. Districts located within the Guinea savannah (Talensi and Builsa North) are more exposed to climatic stresses. Rice farming in this zone are vulnerable to flooding especially at valley bottoms but least sensitive to drought conditions, attributed to the water retention and soil fertility of these areas.

The main cause of high sensitivity is attributable to the increase in average yearly temperature, decreased rainfall and high incidence of extreme climatic conditions. The projection study shows that the Upper East Region would further experience decreasing rainfall and increasing temperature in the future (Issahaku et al., 2016).

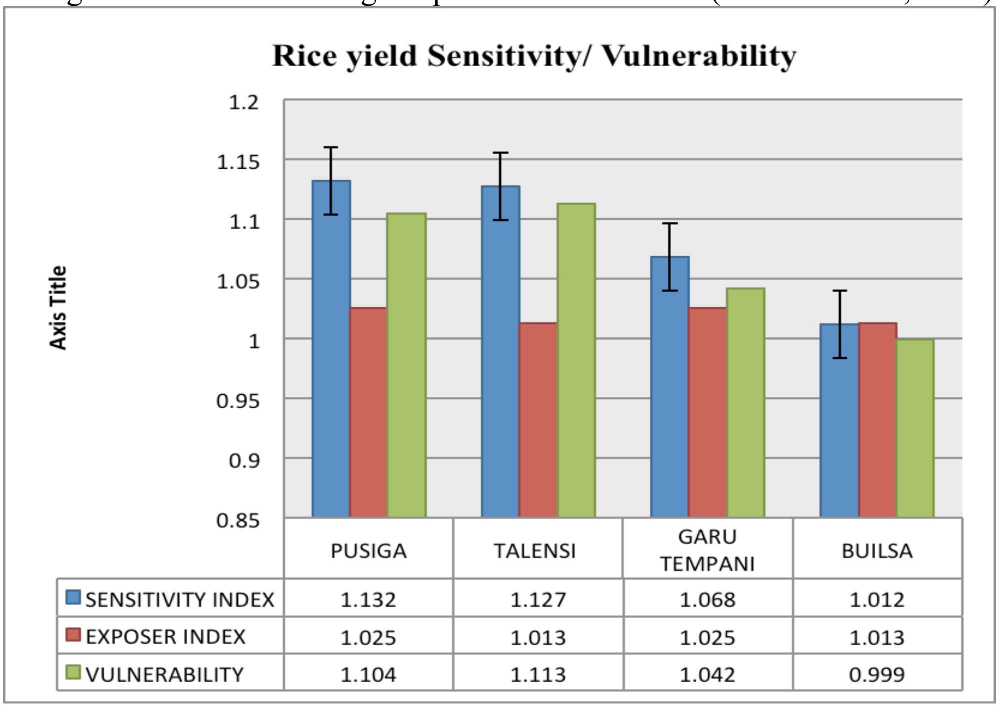

Fig 2: District scale rice yield sensitivity/vulnerability

(Scale 0.0 to 2.0) , < 1.0= Normal , > 1.0 = Sensitive/Vulnerable

4.3 Socio-economic factors that influence vulnerability and coping capacity

The results of our multiple regression analysis indicated that the vulnerability of Talensi, Pusiga, Garu tempani and Builsa south districts was linked to low socioeconomic status, such as low economically active population, illiteracy and poverty (Tables 2). According to UNISDR (2014) the capacity to cope requires continuous awareness, skills, resources and good management. The low literacy rate limits an access to climate information, limited knowledge on adaptation strategies. Insufficient economically active population limits labor availability, leading to weak farm coping capacity. Also, weak asset base as a result of poverty reduces the capacity to cope with climate change hazards. Low-income smallholder rice farmers face a shortage of agricultural inputs (Dow, 1992).

Table 2 Multiple regression analysis of socio-economic status and climatic vulnerability

Variables	Coefficient	Std Err	t-value	p-value	Lower limit	Upper limit
Constant	0.00170	0.02635	0.06434	0.95120	-0.06604	0.06943
Poverty Incidence	0.00817	0.00179	4.55972	0.00606	0.00356	0.01278
Literacy rate	-0.01577	0.00411	-3.83858	0.01214	-0.02632	-0.00521
Active population	0.01626	0.0255	6.38208	0.00140	0.00971	0.02281

5. Conclusion

This paper assessed the vulnerability of rice production to climate change in the Upper East Region of Ghana. Our results showed that climatic variabilities significantly impacted rice yields in the study area. Our analysis showed that the vulnerability of rice production spatially varied, depending partly on the adopted production system. These results support Agyei's (2012) findings on the vulnerability of crop production to drought in Ghana. This study showed a strong need for districts to make crop-specific adaptation strategies in the study area. Therefore, we recommend further studies for a localized adaptation strategy. Research and extension support (e.g., climate information, technology transfer and farmer networking) can buttress farmers. To enhance resilience, these farmers may adopt livelihood diversification strategies (e.g., livestock rearing, dry season irrigation farming, pitty trading).

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