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Climate and Food Insecurity Risks: Identifying Exposure and Vulnerabilities in the Post-Food Production System of Northern Ghana

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Climate and Food Insecurity Risks: Identifying Exposure and Vulnerabilities in the Post-Food Production System of Northern Ghana

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Abstract: Evidence shows how food system activities from production to consumption underpin food security. However, studies exploring climate impacts on food security in northern Ghana have overly focused on production systems, neglecting post-production activities that loom large in food security. This paper addresses the research need to comprehensively analyze how climate change affects post-production activities and exacerbates food insecurity risks in northern Ghana. The study collects and analyzes data on climate hazards, impacts, and food system vulnerabilities using questionnaires and participatory engagement with farming households in northern Ghana. Results show that climate-induced food insecurity risks in northern Ghana are not just products of persistent climate impacts on food production in the region. Instead, risks are inextricably connected to the vulnerability contexts within which food is harvested, processed, stored, and marketed. Specifically, the results reveal that climate hazard events such as floods, extreme temperatures, and droughts damage stored grain, disrupt food supply to the market, and cause seasonal volatilities in food prices. However, these impacts are not solely externally generated circumstances. The food system is highly vulnerable; most households lack access to threshing and grinding machines, warehouse storage, post-harvest management information, and transportation services. These underlying characteristics of the post-food-production system of northern Ghana, which is ultimately quite remote from climate change, exacerbate household-level food insecurity risks.

Keywords: climate change; food security; food system; risk; vulnerabilities; Northern Ghana

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1. Introduction

Climate change is increasingly recognized as a key driver in global hunger. Rising temperatures, changing precipitation patterns, and frequent extreme weather events are affecting agricultural yields, disrupting food supply chains, and reinforcing other underlying causes of food insecurity (Fanzo et al., 2018; FAO et al., 2018). The increasingly erratic rainfall and prolonged dryness intensify food crop susceptibility to pests and diseases, causing yield losses (Armah et al., 2011; FAO, 2016). The rise in temperatures and water shortages create problems for food quality and safety, including the outbreak of food-borne pathogens and mycotoxins, more food spoilage, and high food waste and losses. (Vermeulen et al., 2012). It is estimated that by 2050, the global climate change phenomenon will put millions of people at risk of acute hunger, malnutrition, and poverty (Swinnen et al., 2022). The brunt of these climate-induced hunger will fall highly on poor households in developing countries, especially across sub-Saharan Africa, South Asia, Small Island States, and Southeast Asia (Intergovernmental Panel on Climate Change, 2014). Smallholder farmers in rural areas are expected to be overrepresented in climate-induced hunger situations because of their high vulnerability relating to limited access to climate information, lack of early warning systems, high levels of poverty, and dependency on climate-sensitive food systems and livelihood activities.

In Ghana, an emerging volume of climate change studies pays specific attention to the fragile and climatically vulnerable semi-arid northern region. In particular, the studies present empirical assessments of climate change impacts on the agricultural calendar, land suitability, food production diversity, and yields (Armah et al., 2011; Hjelm & Dasori, 2012; Yiran et al., 2016). For example, Armah et al. (2011) modelling of the historical and predicted climate changes demonstrates how early onset and delayed rains during the rainy season affect the timing of sowing and the variety of crops cultivated. Armah and colleagues' study further presents evidence showing that the increasingly drier conditions due to the rising temperature and reduced rains would likely lead to a decrease in the suitability of agricultural lands for crop cultivation with consequences for the region's overall food production potential. Additional studies, including (Antwi-Agyei et al., 2018; Balana et al., 2020; Setsoafia et al., 2022) have explored how the adoption of climate-adaptive responses (e.g., irrigation, improved seeds and fertilizer, soil and water conservation, and flood recession agriculture) can reduce agricultural livelihoods vulnerability and strengthen household food security.

Despite the robust knowledge contributions, these available studies overly focused on food production-related aspects of food security (Armah et al., 2011; Atanga & Tankpa, 2021; Baffour-Ata, 2021). However, climate impacts on food security extend beyond food cultivation systems to other equally important post-production activities of harvesting, storing, and marketing food crops (Fanzo et al., 2018). In fact, seasonal flooding, erratic rains, and increased temperatures can create problems for food transportation, pricing, and safety. For example, flood waters overflowing narrowly constructed roads of rural communities can impede the safe transport of crop harvest and access to retailers and consumers in the market centers. Rains intermittently occurring during harvesting and post-harvesting months can be a great disincentive to farmers preparing to harvest and store crops for future use. Crop losses due to climate impacts on transport networks, harvesting, and storage are significant food insecurity risks as they can amount to reducing weeks of a household's food supply. This paper, therefore, addresses the research need to explore a detailed analysis of how climate change effects on the post-food production activities induce food insecurity risks in northern Ghana. The specific objectives are to (1) identify key climatic hazards affecting post-production level activities in rural areas of northern Ghana; and (2) assess how the combined community-level exposure to climate hazards and vulnerabilities in post-production level activities exacerbates food insecurity risks.

Based on the integrated analysis of climate hazard exposure and food system vulnerability at the micro-level, this research demonstrates that climate-induced food insecurity risks in northern Ghana are not just products of persistent climate change impacts on food production. Instead, risks are also inextricably connected to the vulnerable situations within which food is harvested, processed, stored, and marketed in rural communities. The findings reveal that climate hazard events such as flooding and droughts damage stored grain, disrupt food supply to the market, and cause seasonal volatilities in food prices. However, these impacts are not solely externally generated circumstances. The food system is highly vulnerable; most households lack access to threshing and grinding machines, warehouse storage, post-harvest management information, and transportation services. These underlying characteristics of the post-food-production system of northern Ghana, which is ultimately quite remote from climate change, exacerbate household-level food insecurity risks. Overall, this paper is not intended to understate the direct impacts of climate hazards on food production and the environment. Instead, it broadens the knowledge base on the connection between climate risks and food insecurity by providing the first direct empirical evidence showing climate impacts on the food system and emphasizing activities at the post-production level as they are also critical for households and communities to maintain physical and economic access to food in northern Ghana.

2. Literature review

According to the United Nations, food security is a situation "when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (United Nations, 1996, p.3). From this definition, food security rests on four pillars: availability, access, utilization, and stability (Gross et al., 2000: Sassi, 2018). Food availability is the quantity of appropriate food available for consumption through production output, stock levels, and net trade. Food accessibility is the ability of individuals, communities, and countries to access the required type, quality, and quantity of food for consumption through the various legal, social, economic, and political means available. Food utilization refers to the proper biological use and benefits from food, which is determined by care and feeding practices, food preparation methods, dietary diversity, and nutrient distribution. The fourth pillar, food stability, is a recently added dimension of food security amidst the rising impacts of weather conditions, political instabilities, and economic uncertainties on physical and economic access to food commodities (Sassi, 2018). Food stability describes the adequacy and reliability of food supplies for all people "at all times" without risking deteriorating nutritional status. Therefore, food availability, access, and utilization are necessary for food security but not enough without stability; there should be enough food for everyone, not periodically but throughout the year.

In rural communities, most households produce a significant proportion of the food they consume. To ensure stable access to food, however, households must thresh, dry, process, and store harvested crops for out-of-the-season months; they must also buy from the market to supplement production in times of crop losses or productivity decline. Thus, food production is important for rural households, but that alone cannot guarantee the stability of household food supply, access, and equitable use and benefit for all members. Other equally important food system activities beyond food production need critical attention.

Eriksen (2008) conceptualized a food system as comprising a set of activities ranging from production to consumption. These activities are often expressed with phrases like "farm to fork," "field to table," and "land to mouth" (Sobell et al., 1998; Heller & Keoleian, 2002). Ericksen further broadly categorizes four groups of food system activities: (i) food production; (ii) food processing and packaging; (iii) food distribution and retailing; and (iv) food consumption. Food production involves various practices, from accessing and buying farm inputs to preparing the land, planting, caring for crops/animals and harvesting. Processing and storage activities involve transforming food into finished or semi-finished products, together with quality control and labelling for safety in packaging. Distributing and retailing include transportation, trading, and selling food to consumers, while consumption consists of deciding, selecting, preparing, eating, and digesting food.

It is important to note that Ericksen's categorization generally represents the chains of 21st-century food system activities. However, there might be slight differences for specific locations, communities, and households. In rural areas of northern Ghana, for instance, the most relevant food system activities include the production, harvesting, processing and storage, and marketing of maize, cereals, legumes, and vegetables. The adverse impacts of climate change and weather variabilities on these food system activities in northern Ghana predispose households and communities to food insecurity risks.

The IPCC's Special Report on "Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation" defines risk as "the likelihood over a specified period of severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, or environmental effects…." (IPCC, 2012, p. 4). This definition indirectly relates the probability of negative impacts from climate change to the occurrence of a hazard and its interaction with the underlying social processes (such as class differentiation, gender, and power relations). In this context, climate-induced food insecurity risk can be conceptualized as a function of a climate hazard event and food system vulnerability (see Welle & Birkmann, 2015).

A climate hazard is often understood as any threatening event or the probability of a potentially damaging event from weather-related hydro-meteorological sources such as droughts, floods, bushfires, windstorms, and extreme temperatures. Generally, climate and weather-related hazards are due to natural causes, but human actions may influence their deliberate or unintended outcomes (Epule et al., 2013). Comprehensive knowledge of the physical causal mechanisms of natural hazards is often considered very limited. However, the Emergency Event Database (EM-DAT) records provide enough information to specify the likelihood of a particular hazard occurring at a specific time and space. Most researchers assess threats from natural hazards by identifying the frequency and likelihood of occurrence (see Ahulu et al., 2018; Kadiri & Kijko, 2021). Others also often focused on an entity's exposure and the severity of impacts expressed in terms of the losses and damages generated (see Agada and Nirupama, 2015; Zhang & Zhang, 2016; Prabnakorn et al., 2019). Assessing the exposure of communities, households, and resources in hazard-prone environments is particularly useful for understanding the extent of damaging impacts they are likely to face. Such analysis also presents significant contributions to identifying adaptation and resilience mechanisms.

Vulnerability is the degree to which a system is likely to suffer harm from a hazard (Forbes-Mewett & Nguyen-Trung, 2019). The literature consistently identifies the vulnerability of a socio-ecological system or an entity as a function of three elements: exposure to a particular hazard, sensitivity to that hazard, and capacity of the system to cope, adapt, and recover from the effects or consequences of the hazard (Adger, 2005; Smit & Wandel, 2006). Exposure denotes the degree and extent to which a system is in contact with or falls within the geographical range of a hazard. Sensitivity describes the degree to which a system will likely suffer harm or significantly change its state when a hazard strikes. Capacity to adapt or cope is the ability to take advantage of, accommodate, or recover from the consequences of a hazard. An example of how these elements combine to determine vulnerability can be given in the case of subsistence households in semi-arid environments. By their location, these households are likely to experience dry spells or droughts (exposure); those highly dependent on a rainfed scheme will suffer significant losses whenever dry spells occur (sensitivity); and those with alternative livelihoods and income sources outside of the agricultural sector are in a better position to purchase food to supplement losses from their farms (capacity to adapt). All these three elements are usually incorporated into climate vulnerability assessments in one way or another (e.g., IPCC, 2001; Antwi-Agyei et al., 2012; Acheampong et al., 2014; William et al., 2020; Segnon et al., 2021).

There are many frameworks and approaches to assessing the vulnerability of households to climate change. One such is the sustainable livelihood framework, widely rooted in household-level poverty studies and focused on the critical aspects of poor people's livelihood. Key components of the livelihood framework include access to assets (e.g., natural, human, social, physical, and financial capital) to pursue income-generating activities and the vulnerability context of exposure to shocks and threats that are likely to affect earnings from livelihood activities. This framework is particularly relevant because it provides a basis for understanding the proneness of activities that poor households pursue daily, including food production, storage, and marketing activities that underpin food security. Notably, the asset-based concept of the livelihood framework helps identify how asset profiles can influence the susceptibility of livelihood activities to harm and the potential for building adaptive capacities and resilience to unforeseen future climatic changes and weather variabilities (e.g., financial capital to purchase crop insurance). Various researchers, including Hahn et al. (2009), Etwire et al. (2013), Antwi-Agyei et al. (2013), Opiyo et al. (2014), and Panthi et al. (2016), have applied the asset-based approach to determine household vulnerability to climate change. This research draws on these existing studies to analyze post-food-production system vulnerability to climate hazards in Kassena Nankana Municipality. Adopting this approach allows the research to integrate the underlying socio-economic characteristics of the study communities for a nuanced understanding of climate and food insecurity risks in northern Ghana.

3. Materials and Methods

3.1. Study Context

The northern part of Ghana is administratively divided into the Upper West, Upper East, Northeast, Northern, and Savannah regions. These regions experience above-average mean temperatures, usually reaching 29°C or more in the dry season, compared to 25-26°C in the southern regions (EPA, 2015; World Bank, 2022). Average precipitation rate in the north is often less than 1000mm compared to 1200mm in the south and even up to 1500mm in the far southeast. This study was conducted in the Kassena Nankana Municipality in the Upper East region of Ghana, where mean annual rainfall over the past few decades has been sporadic with frequent surges and relapses (see Figure 1a). One of the highest mean annual rainfalls occurred in 2007 (1203.8mm), following periods of lower rainfall from 2000 to 2006. However, in the subsequent years, the mean rainfall decreased, reaching as low as 617.3 mm in 2014, before increasing again up to 1363.4mm in 2019. The mean annual temperature of the Municipality also increased by 0.5°C in the two decades, from 29°C in 2000 to 29.5°C in 2020. But this increase is also characterized by significant fluctuations (see Figure 1b). In 2005, the mean temperature increased sporadically by 0.8°C relative to the record in 2000 and remained high until 2008, when the mean temperature dropped by 0.1°C below the record in 2000. The mean temperature has since risen, reaching as high as 29.8°C and 29.5°C in 2014 and 2020, respectively.

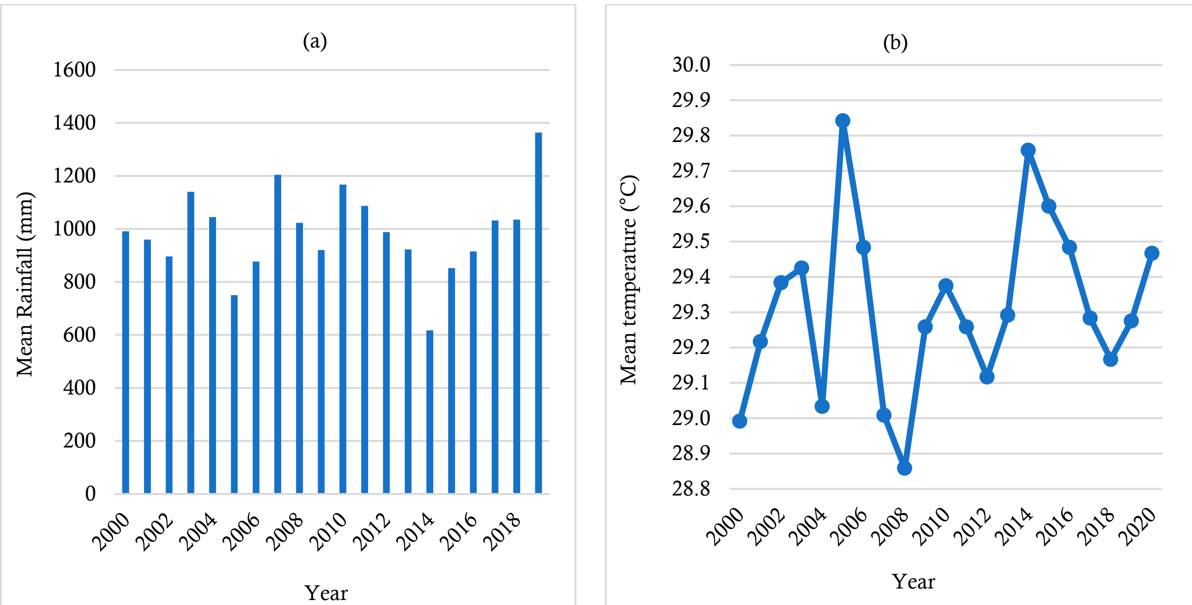

Figure 1. (a) Mean annual rainfall variability for the Kassena Nankana Municipality and (b) Mean annual temperature variability for Kassena Nankana Municipality. Source: Author's construct based on data from Ghana Meteorological Agency.

The Kassena Nankana Municipality has a population of 99,895 people, out of which 48,658 (48.7%) are male and 51,237 (51.3%) are female (GSS, 2021). The average household size of approximately 4.1 persons (GSS, 2021). Ethnicity is mainly Nankani and Kasem. Economic activities are predominantly agricultural – more than 80% of the households earn their livelihoods from overlapping food cropping and livestock rearing (UNDP, 2011; GSS, 2014). Households mainly cultivate maize, rice, millet, guinea corn (sorghum), beans and groundnuts on farm plots ranging from 0.4 to 4.0 hectares (1-10 acres). Farmers cultivate for subsistence and store their harvest in heaps in the barns or sacks packed in their rooms. Post-harvest losses are widespread because of the poor storage facilities and handling of stored crops which attract rodents, birds, weevils, and grain borers. In addition to agriculture, households in some communities trade in food crops, semi-processed foods, and crafts. The buying and selling mainly occur in the Municipality's only central market in Navrongo and satellite markets in a few communities.

3.2. Research Methods

Data for this research was collected over six months from January-June 2021. The Kassena Nankana Municipality comprises six major communities/townships representing the zonal divisions for local government administration: Navrongo, Doba, Manyoro, Pungu, Kologo, and Naaga (see Figure 2). A multi-stage stratified purposive sampling procedure was used to select two villages from the six communities to be representative of the whole Municipality. The villages were selected based on four main criteria; 1) the most exposed to climate change extremes; 2) most food-insecure; 3) accessibility for the research data collection; and 4) willingness to participate.

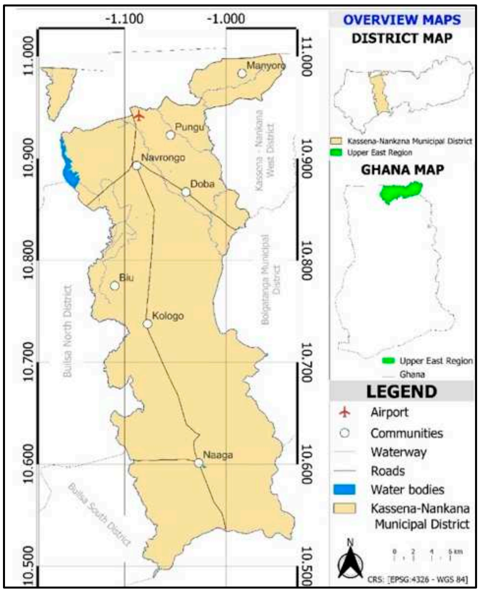

Figure 2. Map of Ghana showing the Kassena Nankana and the study communities.

Scheme 288. smallholder farming households for the questionnaire administration, using a mix of random and snowballing methods to reach many potential research respondents for a high response rate (Bryman, 2008). Following the household survey, two focus group discussions were organized in each of the six communities for more detailed explanations to help situate the survey results on climate hazard occurrences, impacts on post-food production activities, and households' asset capacities to protect these activities from harm. In all, the discussions brought together 95 participants in twelve separate focus groups, each consisting of six to twelve people. Discussions lasted 80-120 minutes and consisted of adults over 20 years but not more than 70 years of age.

Quantitative data were analyzed with SPSS Version 21.0 using descriptive statistics, including frequencies and custom tables. Tables and graphs were generated from these statistical tools to show the results. Qualitative data from focus groups and field notes were analyzed following the methods outlined by Miles and Huberman (1994) and Berg (2004). This involved summarizing, hand-coding, and categorizing field notes into quotes and relevant themes.

4. Results

4.1. Perceived Exposure to Climatic Hazards

Available assessments of climate change in the northern part of Ghana identify communities' exposure to five key hazard events: extreme temperature, drought/dryness, floods, windstorms, and erratic rains (see Barry et al., 2018; Yiran et al., 2016; Osman 2020; Ogunrinde et al., 2021; Antwi-Agyei & Nyantakyi-Frimpong, 2021). This study assesses the study communities' exposure to climate hazards by including a YES/NO question in the survey questionnaire for respondents to confirm the hazard occurrences in their communities.

The results presented in Table 1 indicate that almost all the research participants reported in the affirmative that they are exposed to all five climate hazards. More households confirmed exposure to windstorms (92%), floods (90.6%), and drought/dry spells (90.2%) than extreme temperatures (86.12%) and erratic rains (86.48%). Further discussions in the focus group confirm the frequency and intensity of their exposure to windstorms. For example, the following comments come up repetitively in the discussions:

Table 1. Perceived exposure to climate hazards in Northern Ghana.

Climate hazards	Study communities						Total
	Doba	Manyoro	Kologo	Naaga	Navrongo	Pungu	
Extreme temperature	89.60%	93.80%	83.30%	87.50%	85.40%	77.10%	86.12%
Droughts/dry spells	89.60%	95.80%	97.90%	95.80%	83.30%	79.20%	90.27%
Windstorms	93.80%	93.80%	91.90%	92.00%	90.90%	89.60%	92.00%
Floods	92.80%	95.80%	95.50%	91.70%	88.80%	79.20%	90.63%
Erratic rains	89.60%	91.70%	79.20%	68.80%	97.90%	91.70%	86.48%
Total	91.08%	94.18%	89.56%	87.16%	89.26%	83.36%	89.10%

Windstorms are widespread and occur throughout the year. We experience both dusty and moist windstorms. In particular, the dusty harmattan windstorms are a frequent phenomenon in November-March, whilst the moist windstorms occur in August-October. The moist windstorms are usually heavy, noisy, destructive, and associated with intense but short-duration rains. Here in the north, there is always a heavy windstorm preceding the intense rains in August-September. It's not possible for the rains to occur without the windstorm before the rain there is always a windstorm (Male Farmer, Doba).

Most of the participants reported exposure to floods because of the frequent occurrence of torrential rains, leaving behind excess water in land areas beyond the crest of river plains, canals, and dugouts. Discussions with communities located near the Tono Irrigation Dam canals reiterated the increasing rate of flood occurrences. As one farmer reported:

Heavy rains and floods are very common in the rainy season. There is always a flood any time it rains, especially in the months of August and September – every little rain can even cause flooding. Last year, there was three day of consecutive rains that left behind excess water on our farms and even our homes for days. We are used to it; whenever the rainy season is approaching, we know that floods are also ready to occur. (Male Farmer, Navrongo).

The results presented in Table 1 show variations in overall exposure to climate hazards across the study communities. More households in Manyoro (94.2%) and Doba (91.3%) reported greater exposure to climate hazards than those in other communities (see Table 1). The general biophysical characteristics of Kassena Nankana Municipality, consisting of large tracts of bare lands, sparse vegetation cover, and non-porous soils, explain the study communities' overall exposure to climate hazards. However, the higher exposure of households in Manyoro and Doba to climate hazards can be attributable to the increasing rates of land degradation, desertification, and their relative geographical location. During field observation, it was noticeable that these two communities have tracts of dry land without vegetation cover. Some pieces of land consist of baked soil surfaces, forming hardpans that render lands uncultivable. Additionally, Manyoro lies in the northernmost part of the district, bordering the Sahel region of Burkina Faso. This means it experiences relatively more extreme heat conditions than the rest of the study communities.

4.2. Impacts of Climate Hazards on Post-production Activities

Climate change hazards affect food security through the impacts on food system activities, including those relating to food processing, storage, and marketing. From the review of literature and interactions with the research participants, twelve main directions of climate impact on post-food production system activities were identified: four for food processing and storage, and three for food marketing. During the survey, participant farmers were asked to indicate which one of the identified challenges they perceived as having the most adverse impact on post-food production system activities. The results of their response are presented below in Figures 3a,b.

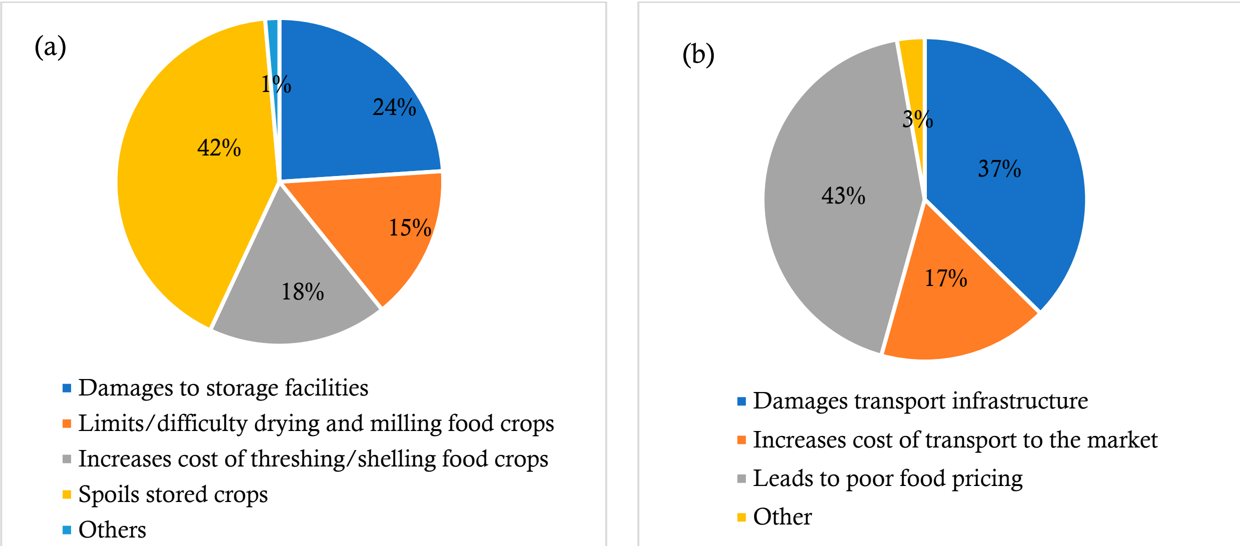

Figure 3. (a) Climate hazard impacts on food crop processing and storage, (b) Climate hazard impacts on food crop marketing and transportation.

Figure 3a presents results on the impacts on food crop processing and storage activities. Over one-third of the respondents reported crop spoilage/losses (42%). This impact is significantly felt by the majority of the farmers because the unpredictable rains occurring in September-November coincide with the harvesting season, often leading to dampness in ready-to-harvest crops and consequently increasing the susceptibility of stored grains to mould attack. Additionally, about one-fourth of the participants (24%) reported damages to crop storage facilities due to climate change. According to the focus group participants, damage to barns is very common when windstorms occur and can further cause losses in grains. The following concern from one of the focus group discussion participants summarizes the farmers' perception of the impacts of climate hazards on storage facilities:

When windstorms occur, they can easily blow away roofs, create cracks, and collapse the barns where we mostly store our millet and guinea corn. So, if the structure is not well roofed or properly checked and repaired, there can be a huge problem. As soon as it rains, water can easily leak into the barn. This can cause stored grains to regerminate and then rot. One can lose good seeds from the rainwater leaking into the barn and storage rooms (Male Farmer, Manyoro).

Figure 3b illustrates the results of climate impacts on food marketing activities. Nearly half of the participants (43%) indicated poor food pricing due to climate hazards. This impact on food prices is often experienced by farmers in their statuses as sellers in the harvesting season and buyers purchasing to supplement own production in the dry season. Across the study communities, farmers generally face weather-induced losses, often translating into low stocks in the out-of-the-season months and pushing food prices higher to levels unfordable to poor households. Nonetheless, the research participants seemed more concerned about the weather-induced damages limiting farmers' ability to bargain for better farmgate prices. One of the focus group participants indicated that:

The unpredictable rains occurring in the early harvesting period usually cause cosmetic damage and rot in food crops, especially beans and maize. When you take a bag of black-eyed beans to the market and it has a lot of moisture-damaged pieces, you cannot bargain for fair farmgate prices. You just have to accept the low-price offers. Sometimes, the prices are as low as half the price of the good-looking ones. If moisture-damaged pieces are too much, no one will even buy them; you are likely to bring them back home for household consumption (Woman Farmer, Pungu).

4.3. Post-food Production System Vulnerability to Climate Hazards

As indicated earlier in section 2, the food system vulnerability assessment in this research draws on the asset-based approach used in existing studies on household and livelihood vulnerability to climate change, including Hahn et al. (2009), Etwire et al. (2013), Antwi-Agyei et al. (2013), Opiyo et al. (2014), and Panthi et al. (2016). Here, the asset-based approach to post-food production system vulnerability assessment is expressed as a composite of resources and services critical for food processing and storage and marketing activities to withstand and recover from adverse impacts of climate hazards. Ten assets were identified as critical for post-food production system vulnerability analysis in the Kassena Nankana Municipality based on the focus group discussions with the participant households. Out of these

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assets, six are for food processing and storage and four are for food marketing activities. The roles of each of these assets are presented in Table 2. The asset index for each food system activity is calculated as follows:

$$\text{Food processing and storage } 1\,\frac{-(\text{PSta1}+\text{PSta2}+\text{PSta3}+\text{PSta4}+\text{PSta5}+\text{PSta6})/n}{\text{Number of assets critical for food processing and storage activities}} \quad (1)$$

$$\text{Food marketing } 2 = \frac{(\text{Mkta1}+\text{Mkta2}+\text{Mkta3}+\text{Mkta4})/n}{\text{Number of assets critical for food marketing activities}} \quad (2)$$

1. PSt_a1, PSt_a2, PSt_a3, PSt_a4, PSt_a5, and PSt_a6 stand for the number of affirmative responses for each of the six food processing and storage assets listed in Table 2. 2. Mkt_a1, Mkt_a2, Mkt_a3, and Mkt_a4 represent the number of affirmative responses respectively for each of the four food marketing assets listed in Table 2.

Using the above equations, the mean asset index score was estimated on a scale of 0 to 1 for food processing and storage and marketing activities in each study community. The estimates are based on the data gathered from the household survey. An overall estimated asset index score of 0 corresponds to the lowest asset capacity and, thus, high vulnerability. Similarly, a score of 1 indicates the highest asset capacity, hence low vulnerability. Interpreting the results in this manner allows for easier understanding by a diverse audience, including policymakers and farmers.

Food crop processing and storage vulnerability analysis for the study communities presented in Table 3 above shows that Manyoro has the lowest mean asset index score for food processing and storage (0.2014) and, therefore, the highest vulnerability. In practical terms, Manyoro has less asset capacity than other communities to protect ready-to-harvest and stored crops from dampness and cosmetic damages often associated with unpredictable and out-of-season rains.

To understand this level of vulnerability, detailed information on the percentage of household access and use of six identified assets critical for food processing and storage activities is presented in Figure 5a. Again, the results here demonstrate that none of the households in Manyoro reported using threshing machines or warehouse services, respectively, for food crop harvesting and storage. Additionally, the households' access to grinding machines and training on post-harvest management is 31.3% and 8.3%, respectively, compared to far more than 50% in other communities. This lower intensity of access and use of timesaving harvesting and post-harvesting resources in Manyoro explains its high vulnerability to climate hazards. Overall, the result here suggests that Manyoro is prone to post-harvest losses, which can directly hinder households' ability to achieve food availability in the out-of-the-season months.

Table 2. Critical assets for food system activities in northern Ghana.

Food system activities	Assets	Role/Importance
Food crop processing and storage	1. Threshing machines	Rice and maize threshers enable farmers to quickly process their harvested crops and prepare for storage without getting damp from uncertain rains.
	2. Warehouse	Enable farmers to safely store and protect food crops against insect pests and theft. Proper warehouse handling allows food crops to be stored throughout the year and beyond. Crops stored in warehouses are usually marked for the market during off-season periods to stabilize seasonal prices and smoothen household consumption.
	3. Chemical storage	Protect food crops against insect pest attacks or suppress the growth of insects in stored grains, allowing farmers to keep crops for up to eight or more months after harvest.
	4. Storeroom	Some households have dedicated rooms for storing threshed grains and paddy. Crops may be kept in the storeroom for up to six months or more, depending on farmers' knowledge of proper storage techniques, the use of chemicals to protect pests, and the conditions of the storeroom.
	5. Grinding mill	Access to a grinding mill provides convenience for a household to mill grains. In communities without access to grinding mills, households may spend hours pounding rice to remove husks.
	6. Education	Access to knowledge and training on proper harvesting and storage techniques helps reduce post-harvest losses and crop damages and helps save a household from days to months' worth of food for consumption.
Food crop marketing	1. Market center	Market centers serve essential roles as converging points for buyers and sellers; households also get access to more diverse food crops than what they produce. More accessible market centers can help lower transaction costs when buying food crops to smoothen consumption in out-of-season months.
	2. Vehicle transport	Access to roads and vehicles linking rural areas to the market centers enables poor farmers to sell their surplus produce at better prices and earn income that can supplement household food needs in the post-harvest season.
	3. Non-farm income	Non-farm works such as trading and day labour jobs in construction, weaving, and pottery are great opportunities for households to shift surplus agricultural labour to earn income during the dry season. Income from non-farm work helps resource-poor households secure money for investment in climate-resilient food production activities.
	4. Migrant income (Remittances)	Remittances from migrant relatives (either in the south or agricultural-rich communities in the north) enable households to buy more food and replenish food stock to deal with insecurities associated with yield losses from climatic hazards and disasters.

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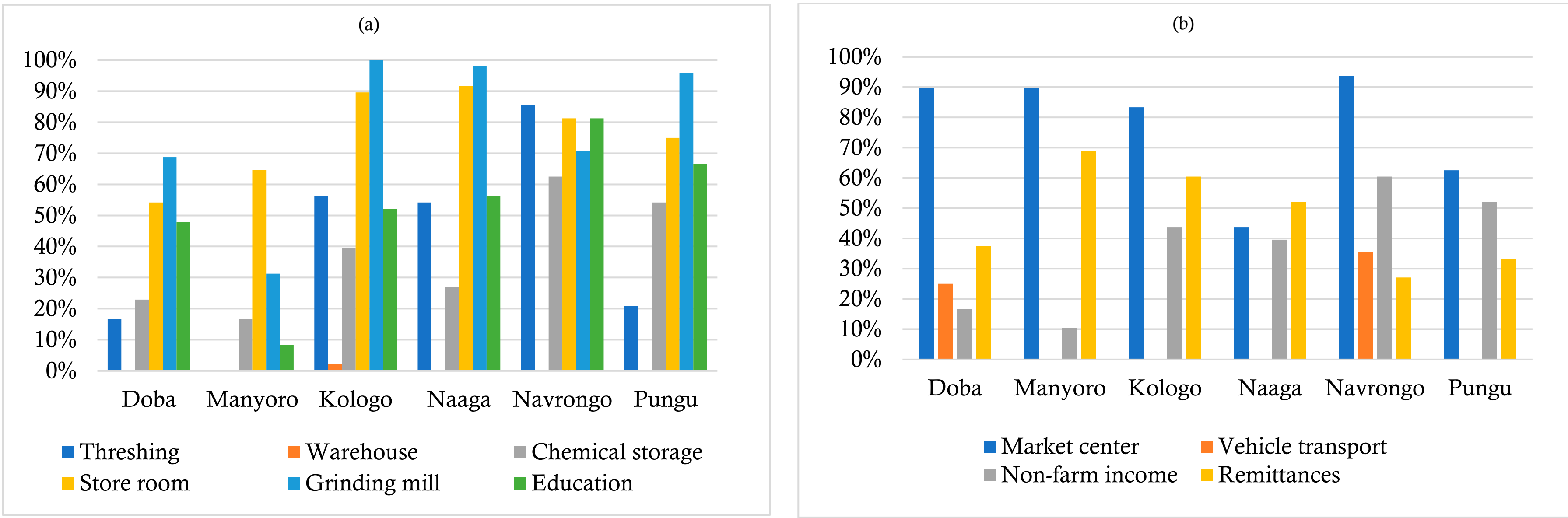

(**a**) (**b**)

Figure 5. (a) Percentage of households with access to assets for food processing and storage activities across the study communities; (b) Percentage of households with access to assets for food marketing activities across the study communities.

Table 3. Mean asset score for post-production activities across communities in the Kassena Nankana Municipality.

Communities	Food processing and storage			Food marketing vulnerability		
	Mean	N	Std. Deviation	Mean	N	Std. Deviation
Doba	0.3507	48	0.16927	0.4219	48	0.20077
Manyoro	0.2014	48	0.13734	0.4219	48	0.17225
Kologo	0.5660	48	0.16751	0.4688	48	0.20385
Naaga	0.5451	48	0.15275	0.3385	48	0.25521
Navrongo	0.6354	48	0.19946	0.5417	48	0.22081
Pungu	0.5208	48	0.22182	0.3698	48	0.21257
Total	**0.4699**	**288**	**0.22959**	**0.4271**	**288**	**0.22062**

Concerning food marketing vulnerability analysis, the results presented in Table 3 show that Naaga recorded the lowest mean asset score for food marketing (0.3385) and, therefore, it is the community with the highest food marketing vulnerability. This implies that compared to the other communities, households in Naaga have limited capacity to deal with food market price, affordability, and accessibility challenges in the dry season.

Additional statistics to help identify the assets with significant contributions and explanations for food marketing vulnerability are presented in Figure 5b, showing the percentage of household access to the four key assets critical for food marketing. Primarily, vehicle transport and non-farm income contribute more to food market vulnerability across all the communities than the other assets. The impacts of these resources are even more pronounced in explaining the higher vulnerability of Naaga, where none of the households (0%) reported access to vehicle transport, and only a few (10.4%) have income opportunities to buy food in the out-of-the-season months.

Overall, the food system vulnerability analysis presented here reveals that post-food production activities of the Kassena Nankana Municipality are generally vulnerable to climate change hazards. However, some communities are more prone to adverse impacts than others. Communities with the most households lacking access to and use of threshers, warehouses, market centers, vehicular transport services, and non-farm income are the most vulnerable to climate hazards and vice versa. This suggests that policy intervention to improve food security must target specific communities or households over others.

4.4. Intensity of Climate Hazards Impacts on Post-Food Production System

Climate change hazards affect food security through the impacts on food crop processing, storage, and marketing activities. During the survey administration process, research participants were asked about their perceived level of climate hazard impact for each post-food production system activity. Participants were requested to indicate whether the impact is low or moderate or high or no impact, or do not know (that is, have no knowledge). Data from the research participants' responses were aggregated for each study community, and results are presented in Figure 9a–c.

Figure 7 (a) presents the results on the intensity of climate impacts on food crop processing and storage activities. It shows that many households in Manyoro (49.6%), Doba (44.2%), Naaga (43.8%), and Kologo (42.9%) reported high impacts of climate hazards on food crop processing and storage. The high impacts in these communities can be attributable to the households' very limited access to proper threshing and storage services (as shown earlier in Figure 5). At one of the focus group discussions, a participant elaborated how challenges in access to threshers and harvesters lead to high climate impacts, explaining that:

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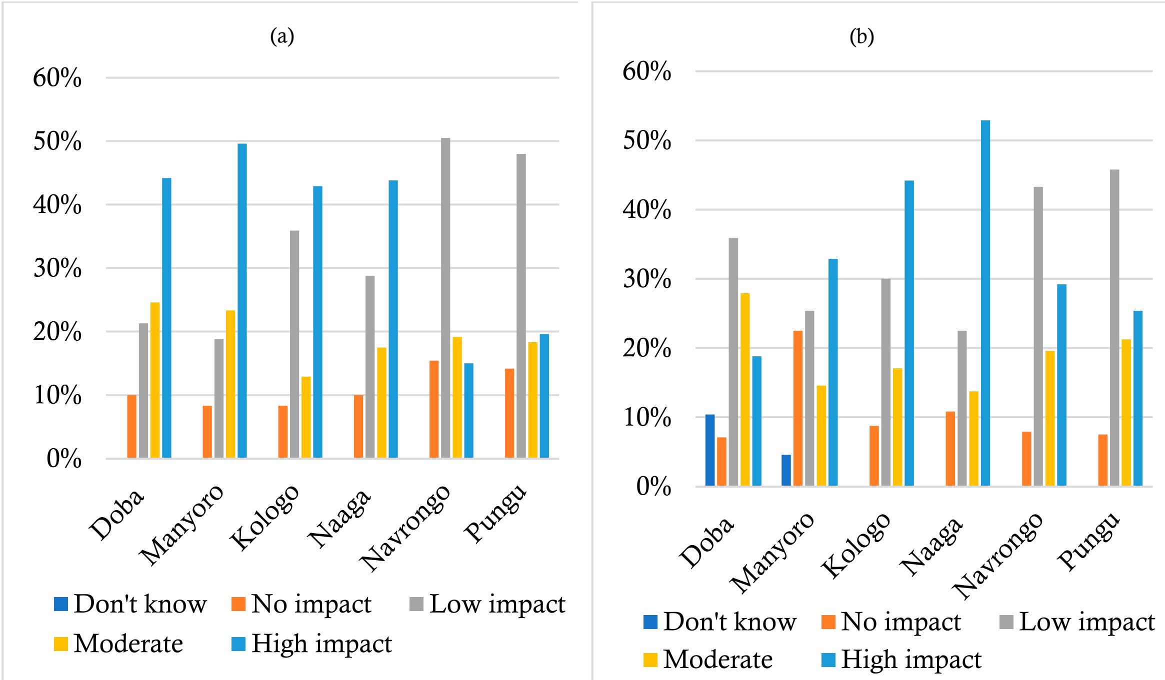

Figure 7. The intensity of climate impacts on (a) food crop processing and storage, and (b) food crop marketing activities across the various communities.

The harvesters only work on rice farms and not all crops. It is also just a few people who can afford the services because there is no money during the harvesting months. The harvesting period is the most challenging time for everyone in our community – no money until we sell the crops. So, we harvest our crops manually, just cut the stalks and stook in heaps. Most farmers rely on organized labour and help one another in rotation. This manual labour is not effective; it takes a longer time to finish the whole farm. So, anytime the rain occurs, it soaks into the crops; they become damp and difficult to thresh. (Female Farmer and group leader, Bonia).

Figure 7 (b) shows variations in the severity of the impact of climate hazards on food marketing activities across the study communities. Many of the households in Naaga (52.9%), Kologo (44.2%), and Manyoro (32.9%) reported high impacts from climate hazards, while those in Pungu, Navrongo, and Doba reported lower impacts. The high impact of climate hazards on food marketing in Naaga, Kologo, and Manyoro could be attributable to these three communities being distant from the central markets in Navrongo and Bolgatanga. On average, farmers in these communities must travel 25 kilometres over rugged, dusty lateritic roads to get to the central markets. Besides, there is limited access to vehicular transport services, as shown in Figure 6 and repetitively expressed by the households. A comment from one of the focus group participants summarizes the concerns of the households:

Our roads are very bad to travel on, but they are even better now (referring to the dry season). When the rains set in it gets worse; our pothole-ridden roads become completely filled with water after every small downpour, consequently blocking farmers from transporting their crops home and market. Also, the bridges we have along the roads are very narrow. The rainwater always overflows the main bridge linking our community to Navrongo. When it happens, no one is willing to travel, not even the tricycles or trucks from Bolgatanga and Navrongo. So, we are unable to transport our produce from the farm and even to the market (Male Farmer, Naaga).

5. Discussion and Conclusions

Climate hazards have a range of adverse impacts on northern Ghana's micro-level food system activities. The research results empirically demonstrate the study communities' high exposure to climate hazard events. Almost all farming households (89%) confirmed the occurrence of windstorms, droughts/dry spells, erratic rains, extreme temperatures, and floods. The evidence presented is consistent with past studies highlighting the persistent climate hazards in the northern regions of Ghana (EPA, 2009; Yiran & Stringer, 2016; Dumenu & Obeng, 2016). For instance, Yiran & Stringer's (2016) spatial, time-series analysis of climate hazards from 1983–2012 identified constant occurrences of high and increasing temperatures, frequency but varied seasonal droughts, dry spells, and floods, and windstorms in the Upper East region of Ghana. Dumenu and Obeng's (2016) study on the social impact of climate change reveals that respondents in northern Ghana frequently mention prolonged drought, erratic rainfall, and flooding as the most observed climate change events in their communities. Indeed, the geographical location of the study communities at the margins of West Africa's environmentally fragile Sahel region explains the high exposure to climate hazards (CILSS (CILSS – Comité Inter-états de Lutte contre la Sécheresse dans le Sahel (The Permanent Interstate Committee for Drought Control in the Sahel)), 2016).

This study demonstrates the adverse impacts of climate hazard events on the post-food-production activities that loom large for household food security in northern Ghana. Previous studies (including Armah et al. 2011; Atanga & Tankpa, 2021; Baffour-Ata, 2021) have reported adverse impacts of climate change on food crop production. Recognizing the need for comprehensive analysis for a nuanced understanding of household-level food security, this study extends attention to the post-production level by revealing the significant impacts of climate change on smallholder processing, storage, and marketing activities. Regarding the impacts on processing and storage, findings show that climate causes damage to smallholder storage facilities and spoilage in stored crops. Likewise, climate change has direct impacts on food crop marketing, including disruptions to transport networks, increases in the cost of transport, and rising food prices. In the context of these climate impacts, households and communities in northern Ghana are predisposed to food insecurity risks relating to high post-production losses, reduced quality and quantity of food crops, declining food stores, disruption in food pricing, and income losses. These risks make it virtually impossible for poor households to maintain their physical and economic access to sufficient food to meet consumption needs. The findings confirm the IPCC's high confidence that observed climate change and frequent extreme events already affect food security in drylands, particularly in Africa, including northern Ghana (Mbow et al., 2019). Besides, the evidence of food insecurity risks presented here reinforces previous studies of climate impact on food production (Antwi-Agyei et al., 2012; File, 2019; Dumenu & Obeng, 2016) with additional pioneering insights on how other food system activities are equally adversely affected by climate change.

The study's results showed the generally low asset endowment influences food system vulnerability to climate change across communities in northern Ghana and other marginal areas of the West Africa Sahel and Savannah regions. The findings resonate with climate vulnerability assessment studies demonstrating that asset endowment shapes the impact of climatic variations, shocks, and trends on households' livelihoods and food security (Antwi-Agyei et al., 2012; Opiyo et al., 2014; Dumenu & Obeng, 2016; Shaibu et al., 2020). The study would have failed to reveal the above-explained results and findings if the research did not focus on the differences in critical resources and services for food system activities in the selected communities in northern Ghana. Notwithstanding this, the study did not reveal the differential vulnerability of various social groups, thus limiting the potential of the analysis and results to show demographic, economic, and social differences in food insecurity risks. Overall, the findings provide compelling evidence for policymakers to facilitate interventions that foster asset building for poorer communities to build safe conditions to protect food system activities against climate change-related extreme events and impacts.

Additionally, the study presents evidence demonstrating how the "pressures" from both climate hazards and food system vulnerability converge to underpin food insecurity risks in northern Ghana. The results show that climate hazards adversely affect all post-food production system activities. However, the severity of impact is greater in communities with higher levels of vulnerability and vice versa. As per the sustainable livelihoods framing, the lack of asset endowment may limit households' or communities' capacities to manage and cope with threatening events. Across the study communities, critical assets for managing climate-induced hazards to post-food production

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activities include threshers, grinding machines, warehouses, and market centers. The research results show that most households in Manyoro harvest food crops without threshing machines. Also, those in Kologo and Naaga are generally far from the district capital, with impassable roads and a lack of vehicular services to connect households to Navrongo town, where they can access the market and purchase food at competitive prices, especially in the dry season. Together, the "pressures" from the high vulnerability situations of households in these three communities and the generally high climate hazard exposure of the entire Kassena Nankana Municipality converge to produce adverse impacts of climate change on food system activities, and consequently high food insecurity risks in the three communities.

Overall, this research has examined how and why climate change and variability induce food insecurity risks in northern Ghana with insights from climate risk, food systems, and livelihood vulnerability research. Using a mixed method approach, the research gathered pieces of evidence demonstrating how the adverse effects of climate change and associated hazard events exacerbate food insecurity risks in northern Ghana. Based on the detailed analysis of results and discussions presented above, the research argues that climate-induced food insecurity risks in northern Ghana are not just products of the persistent climate hazards and impacts on food production as have been conventionally framed. Instead, risks are also inextricably connected to the vulnerable situations within which food is harvested, processed, stored, and marketed in rural communities. The findings reveal that climate hazard events such as flooding and droughts damage stored grain, disrupt food supply to the market, and cause seasonal volatilities in food prices. However, these impacts are not solely externally generated circumstances. The food system is highly vulnerable; most households lack access to threshing and grinding machines, warehouse storage, post-harvest management information, and transportation services. These underlying characteristics of the post-food-production system of northern Ghana, which is ultimately quite remote from climate change, exacerbate household-level food insecurity risks.

Overall, this paper is not intended to understate the direct impacts of climate hazards on food production and the environment. Instead, it broadens the knowledge base on the connection between climate risks and food insecurity by providing the first direct empirical evidence showing climate impacts on the food system and emphasizing activities at the post-production level as they are also critical for households and communities to maintain physical and economic access to food in northern Ghana.

Lastly, this research is not intended to understate the direct impacts of climate hazards on food production activities. Instead, the research seeks to contribute knowledge to the broader scholarship that critically analyzes the concepts of climate risks and food security by revealing some of the climate change impacts on post-food production systems that underpin household-level food security. Additionally, it affirms the importance of integrating varied perspectives and complementing solutions to address climate-induced food insecurity. As policymakers formulate solutions to the social impacts of climate change and hunger, far-reaching results could be achieved with an integrated approach that recognizes the interlinked challenges of climate change and post-food production system vulnerabilities. For example, the growing focus on the "new Green Revolution" in Africa, emphasizing climate-resilient and high-input food production systems, should be matched with increased investment in quality and climate-proof storage and markets for smallholder farmers. In particular, proponents of this revolution could call for more opportunities to develop decentralized farmer-managed warehouses, community-based food reserves, and rural transportation networks to help poorer communities adapt the entire food system to the increasing climate change and weather variabilities.

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