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ORIGINAL ARTICLE

Mapping vulnerability to multiple hazards in the savannah Ecosystem in Ghana

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Abstract The interior savannah ecosystem in Ghana is subjected to a number of hazards, including droughts, windstorms, high temperatures and heavy rainfall. The frequency and intensity of these hazards are projected to increase during the twenty-first century as a result of climate variability and change. Vulnerabilities to these hazards vary, both spatially and temporally, due to differences in susceptibilities and adaptive capacities. Many mapping exercises in Ghana have considered the impacts of single hazards on single sectors, particularly agriculture. But the hazards often occur concurrently or alternately and have varying degrees of impacts on different sectors. The impacts also interact. These interactions make mapping of the vulnerabilities of multiple sectors to multiple hazards imperative. This paper presents an analysis of the spatial dimension of vulnerabilities by mapping vulnerability of sectors that support livelihood activities at a single point in time, using the Upper East Region of Ghana as a case study. Data collected to develop the maps were largely quantitative and from secondary sources. Other data drew on fieldwork undertaken in the region from July to September 2013. Quantitative values were assigned to qualitative categorical data as the mapping process is necessarily quantitative. Data were divided into susceptibility and adaptive capacity indicators and mapped in ArcGIS 10.2 using weighted linear sum aggregation. Agriculture was found to be the most vulnerable sector in all districts of the Upper East Region and experienced the greatest shocks from all hazards. Although all districts were vulnerable, the Talensi, Nabdam, Garu-Temapane and Kassena-Nankana West Districts were most vulnerable. Findings highlight the need for more targeted interventions to build adaptive capacity in light of the spatial distributions of vulnerabilities to hazards across sectors.

Keywords Vulnerability analysis · Spatial analysis · Multi-hazards · Savannah ecosystem

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Introduction

The climate is warming, a trend that is projected to continue with increasing frequency and intensity of climate-related hazards (i.e. droughts, dry spells, high temperatures, heavy rainfall, floods, sea level rise, coastal erosion and windstorms) (Niang et al. 2014). Vulnerability to these hazards is greatest in developing countries, especially in sub-Saharan Africa, because of their dependence on climate-sensitive livelihood activities and their poverty (Niang et al. 2014). Climate hazards occur independently of each other, alternately or concurrently, in sub-Saharan Africa. Many studies have concentrated on impacts or vulnerabilities of single hazards on single sectors (e.g. Damm 2010; Schlenker and Lobell 2010; Blanford et al.

2013) or multiple hazards on single sectors, and some have sought to map vulnerability (Kienberger et al. 2009; Antwi-Agyei et al. 2012; Lopez-Carr et al. 2012; Yaro 2013). Blanford et al. (2013), for example, focused on the health sector and showed that malaria parasite development has both spatial and temporal variation across Africa in relation to temperature changes, while Antwi-Agyei et al. (2012) demonstrated that the agriculture sector is vulnerable to climate variability and change.

Studies have also focused on adaptation, especially to climate change, aimed at reducing the potential impacts on humans and ecosystems. These studies include a focus on: adaptation to climate change by the poor (e.g. Kates et al. 2012; Maslin and Austin 2012; Sovacool et al. 2015); the adaptive capacities of vulnerable communities (e.g. Bryan et al. 2015; Sherman et al. 2015; Williams et al. 2015); and barriers to adaptation (e.g. Antwi-Agyei et al. 2014; Islam et al. 2014), amongst others. Most call for concerted efforts to address the impacts of climate change (see Niang et al. 2014) and predict severe negative impacts in the future. It is nevertheless clear that while people in these communities and ecosystems are vulnerable, they are still adapting, albeit with some challenges.

Despite these insights from the literature, it remains unclear as to how people are vulnerable to multiple stressors, particularly if they are frequently exposed and/or sensitive to multiple hazards, alternately and concurrently. Yiran and Stringer (2016) showed that, in the Upper East Region (UER) of Ghana, there are either dry spells, droughts, flooding or a combination of these events every season or year since 2000, and sometimes these events occur in the same season with severe effects on lives and properties. The years 2007 and 2010 recorded very high impacts where droughts and floods occurred in the same season (Yiran and Stringer 2016). Nevertheless, often missing in these studies in Ghana and the wider region is assessment of the interaction of the impacts of the hazards on different sectors. While some studies have shown high malnutrition and linked this to low agricultural production (e.g. Ghana Statistical Service et al. 2009; Yiran 2014), others have linked high poverty levels to low agricultural production (e.g. MOFA 2007; Antwi-Agyei et al. 2012; Ghana Statistical Service 2012) which invariably affects finances in the other sectors. Ghana's agriculture policy recognises the importance of a healthy population for agricultural production and includes a health objective (MOFA 2007). Yet, previous studies do not necessarily consider multi-sector impacts of hazards. Fewer studies still have looked at both multiple climatic hazards and multiple sectors.

This leaves a major research gap and calls for a holistic approach to better understand the situation, particularly as climatic hazards are projected to increase in frequency and intensity in the savannah (IPCC 2014) and will impact upon multiple sectors. This paper therefore extends existing knowledge by presenting a multi-hazard and a multi-sector mapping and analysis focusing on the vulnerability of the savannah ecosystem (hereafter referred to as the interior savannah) of Ghana. It highlights locations and sectors requiring more targeted interventions to enable more effective adaptation to the hazards. Such a spatial mapping approach is useful because it gives a pictorial view of the scale of the vulnerabilities and factors accounting for such vulnerabilities at various locations across space.

Methodology

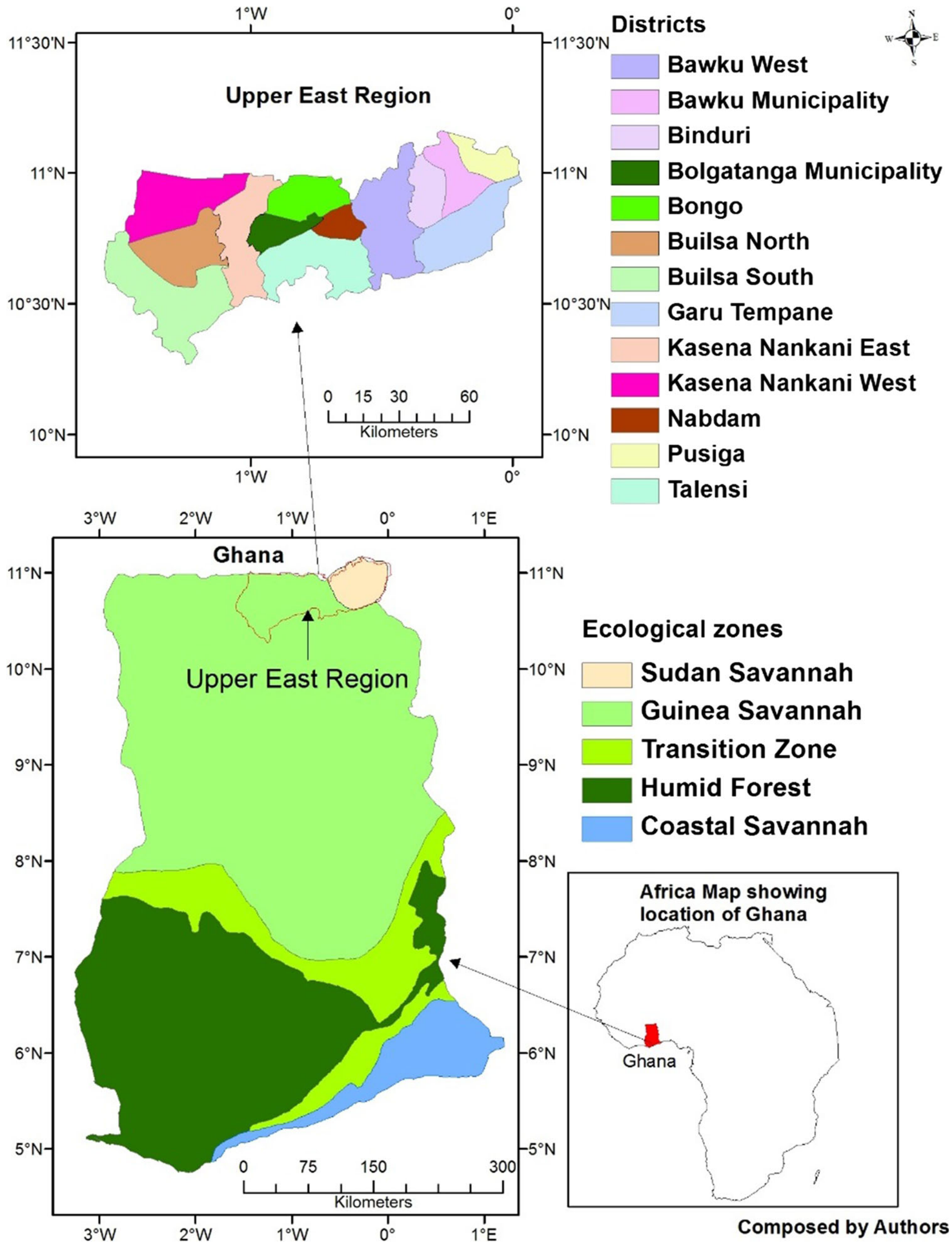
Vulnerability to climatic hazards is a function of exposure, sensitivity and adaptive capacity (IPCC 2007). Variables used as indicators of exposure, sensitivity and adaptive capacity were identified and quantified from both primary and secondary sources and grouped according to the prevalent hazards (see Yiran 2014) and key sectors in the area. We focus specifically on agriculture, health, housing, road and water as the main climate-sensitive sectors that support livelihoods. Grouping reduced double counting (correlation effect) between indicators, in forming composites (see Nardo et al. 2005). The vulnerability of the water sector was not mapped due to insufficient information to determine its susceptibility to these hazards. This is not expected to affect the results as we assessed its vulnerability from participants. Methods used to collect primary data included household surveys, focus groups and interviews. Secondary data were acquired from institutions and other published sources. Data sources and methods used are outlined in detail in the following subsections, after outlining the study area.

Study area

This study mapped vulnerabilities to hazards in the interior savannah of Ghana, focusing on UER (Fig. 1).

UER was chosen because it experiences all hazards in the interior savannah, has the highest proportion of poor people in the country who depend on climate-sensitive livelihoods, especially agriculture (Ghana Statistical Service 2012) and receives the lowest amount of rainfall in the interior savannah (Logah et al. 2013). It is the only region that has two variant savannahs; the Guinea savannah and the Sudan savannah (a degraded form of the Guinea savannah) as shown in Fig. 1. UER borders Burkina Faso and is the first area to flood following the opening of Burkinabe dams which occur almost every year. It has also been shown to be more vulnerable to single hazards and

Fig. 1 Map of the UER and its location in the Savannah Ecological Zone of Ghana



less food secure than other parts of Ghana (e.g. Antwi-Agyei et al. 2012; WFP 2012).

Methods

Indicators to quantify exposure, sensitivity and adaptive capacities were derived from interviews with local people and institutional representatives and were verified from the literature. A multi-stage sampling procedure was adopted. First, a town/village in each of the 13 districts[1] was selected using a procedure similar to restricted random sampling (Stevens and Olsen 2004). Thus, the three big towns (Bolgatanga, Bawku and Navrongo) were purposively selected, ensuring the study captured varying urban characteristics. The remaining 10 villages were randomly selected from a list of villages in each district. Selected villages were at least 10 km from another by road, ensuring a good spatial distribution of sampling areas. Districts are divided along major ethnic groups, and therefore values and norms derived from one village will generally reflect that of the entire district.

The next stage involved randomly selecting households and representatives of government institutions and NGOs

[1] A district in Ghana is the smallest administrative unit of the local government system.

for the questionnaire survey (see Section 1 of the supplementary material for the sample size calculation and distribution). In the household survey, a total of 210 households were sampled. The institutional representatives were interviewed with a slightly modified questionnaire with more in-depth discussions. Only 25 out of the intended 36 institutional representatives were available. These included district officers of the Ministry of Food and Agriculture (MOFA), National Disaster Management Organisation (NADMO) and some NGOs. Two representatives agreed but could not respond after scheduling to meet twice. Six individuals in each district (largely people who had experienced a hazard) were contacted for in-depth interview (IDI). Additionally, five focus group discussions (FGD) were held with village/town members: four in rural districts and one in an urban district. IDI and FGD participants reflected the main social groupings of the villages/towns, identified following discussions with local opinion leaders. No interviewee participated in more than one interview. All these methods were employed together with the use of secondary data to ensure that weaknesses in any method were compensated.

Factors identified as indicators through the interviews, especially those that did not have a geographic reference system, were georeferenced, mostly using district boundaries as the data sets for these variables were collected at district level. Indicators were divided into susceptibility and adaptive capacity categories for different sectors supporting people's livelihoods and were weighted. Interviewees ranked the indicators, so we could obtain a picture of the effects of each hazard on each indicator and sector. This was done on scale of 0–10, with the highest number given to the indicator or sector hit hardest. Ranks were compared with the weights obtained from the institutional interviewees and found to be comparable, so average weights were used. Adaptive capacity indicators were difficult to rank based on their contributions to countering the susceptibilities, so were given equal weights.

Quantitative data for the indicators were obtained from secondary sources (reports and documents, etc.) from relevant institutions. Other data such as crop failure index, size of grassland and land availability were computed from other data sets (see Supplementary Material, Sections 2.1.1, 2.3 and 3.5). Qualitative data were scored by respondents and averaged in similar fashion to other studies (see Morrissey et al. 2005; Nardo et al. 2005; Yiran 2016). To minimise errors that might have arisen as a result of the subjective scoring of the qualitative indicators, we averaged the individual scores as has been done in Yiran (2016). These geographical data sets were then converted from vector data to raster data which is more suitable for spatial analysis (Malczewski 2000). After rasterisation, population, area and distance (i.e. length) data and all other absolute values (e.g. number of dams/dugouts) were divided by the number of grid cells (400 × 400 m^2) to obtain the value per grid cell. The percentage values, crop sensitivity index and scored values, particularly those below 100, were not converted to number per grid because these are relative values. See Supplementary Material for maps (Figs. S1–S13) of the indicators showing the quantities and measurement units.

Aggregation

To aggregate the data at sector level for each hazard, the definition of vulnerability as the algebraic sum of susceptibility and adaptive capacity (IPCC 2014) was operationalised using the weighted linear sum overlay operation in ArcGIS 10.2. Susceptibility is considered as the combination of exposure and sensitivity to hazards (see Kienberger et al. 2009). Many mapping exercises have negated adaptive capacity indicators when aggregating (e.g. Davies and Midgley 2010; Kienberger et al. 2009). However, we argue that vulnerability connotes adverse effects and increases with increasing susceptibility but decreases with increasing/enhanced adaptive capacity. Thus, susceptibility is negated (Eq. 1):

$$Vulnerability = -(Susceptibility) + (Adaptive\ capacity) \quad (1)$$

This conceptualisation results in negative values for grid cells having larger susceptibility values than adaptive capacity and positive values where the susceptibility values are smaller than adaptive capacity. The aggregation was operationalised using Eq. 2 in ArcMap 10.2.

$$\mathrm{CI} = \sum_{q=1}^{Q} W_q I_q \quad (2)$$

(Nardo et al. 2005) where CI = composite index, q = indicator, Q = number of indicators, w = weight and I = normalised indicator.

The methods and indicators were evaluated to test the robustness of the methods and sensitivities of the indicators (Refer to the Supplementary Material for the evaluation process and results). In sum, we identified the indicators through interviews, quantified the indicators using secondary data and scoring and obtained weights for them from interviews and then mapped in ArcGIS 10.2.

Results

Findings are presented considering the indicators and their weights, the output of the uncertainty analysis and the vulnerability maps.

Indicators and weights

Indicators identified through the field survey and verified with literature were grouped into sectors for each hazard. Hazards were grouped into drought/high temperatures, floods/heavy rainfall and windstorms because interviewees had difficulty separating the effects of these hazards as they occur concurrently. For example, in all focus group discussions, the participants noted that floods occur following a heavy downpour. Thus, we grouped the hazards into dry and wet conditions. However, some indicators were identified to represent specific hazards (e.g. Cerebrospinal Meningitis (CSM) for high temperature). As such, references are made to specific hazards where data permit. Table 1 shows the susceptibility indicators and their weights.

Adaptive capacity indicators are in Table S4 in the Supplementary Material, as are data sets for the quantification and mapping of the indicators.

Results of evaluation

Robustness tests were done for all sectors and hazards, but for illustrative purposes, we present the results for the agriculture sector. Tests show similarity in the indices for all methods (i.e. normalisation, weighting and aggregation procedures), with only small variations in magnitudes (Fig. S14). Mean volatility between the various methods was computed to determine the significance of the variations. Volatilities are small, ranging from 0.165 for the weighting procedure to 0.24 for the normalisation procedure and with an aggregated value of 0.17, indicating that the procedures were robust. The composites were also not sensitive to each indicator as the mean volatilities after excluding each in turn ranged between 0.17 and 0.21.

In the vulnerability maps discussed below, we assumed that vulnerability and resilience are opposite of each other (see Bahadur et al. 2010) to denote the negative values as vulnerability and positive values as resilience. Though we recognise that people could have high adaptive capacity and still be vulnerable and that the reality is more complex, the division between resilience and vulnerability was made here to expedite our analysis. Maps are presented sector by sector for each hazard.

Vulnerability to droughts/high temperatures

The three main sectors identified to be vulnerable to drought/high temperatures are shown in Fig. 2. The agriculture sector is most vulnerable. It has the largest negative value, and all values in the range are negative. The second most highly vulnerable sector is water, with the next largest negative values but shows higher resilience than the health sector. Spatially, the highest vulnerability indices for the agriculture sector occur in Talensi-Nabdam, Garu-Tempane and Kassena-Nankana West Districts where values

Table 1 Weights of susceptibility indicators

Drought/high temperature		Flood/high precipitation	
Sector/indicators	Weight	Sector/indicators	Weight
Agriculture		Health	
Crops	0.6	Displacement	0.1
Livestock (pasture)	0.3	Casualties	0.2
Water holding capacity	0.1	Malaria	0.3
Health		Vulnerable group	0.4
Food insecurity	0.4	Agriculture	
Population distribution	0.1	Crops	0.6
CSM	0.2	Soil loss	0.3
Employed in agriculture	0.3	Erosion	0.1
Water		Housing	
Surface water	0.8	Buildings destroyed	0.2
Ground water	0.2	Proximity	0.4
		Flash flood	0.3
		Type of building material	0.1
Windstorm		Roads	
Housing		First class	0.2
Roofing material	1	Second class	0.3
		Third class	0.5

Source Authors N.B: Sum of the weights is equal to one (1) (Malczewski 2000)

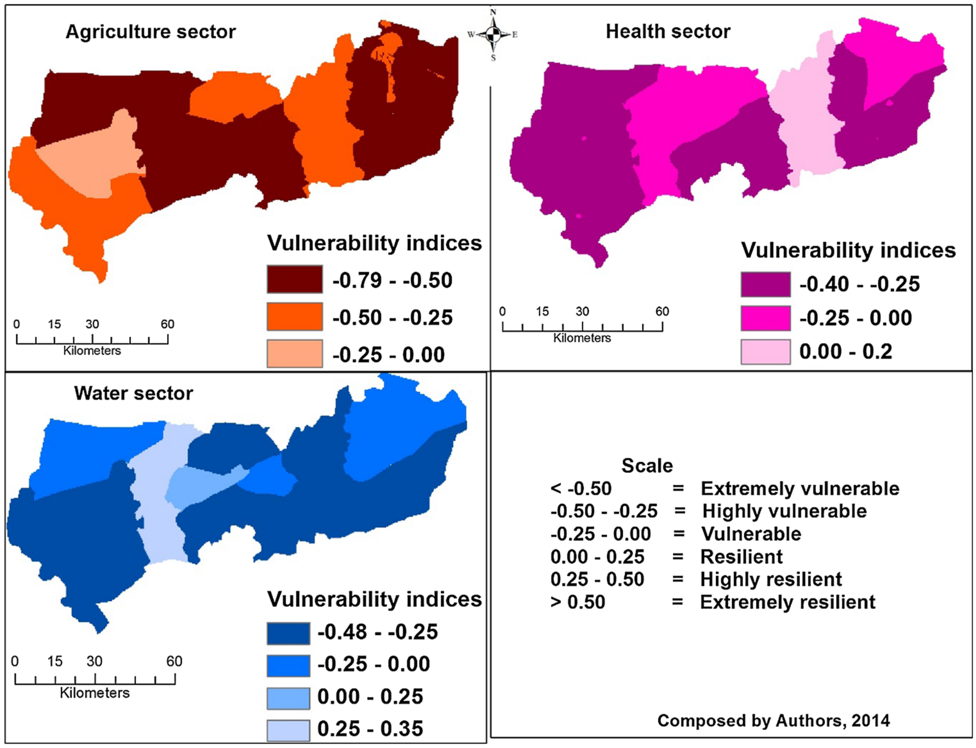


Fig. 2 Vulnerability of sectors to drought/high temperatures

are above -0.6. The next most vulnerable set of districts included Bolgatanga Municipality, Kassena-Nankana East, Pusiga, Binduri and Bawku Municipality, while Builsa North is least vulnerable. In the water sector, the Kassena-Nankana East District is highly resilient, Bolgatanga is resilient, Bawku, Nabdam, Binduri and Pusiga Districts are vulnerable, while the rest are highly vulnerable to droughts.

From the household survey, all participants agreed that agriculture is the most vulnerable sector to dry spells/-droughts and cited the frequent occurrence of the hazards as a major reason. According to them, dry spells/droughts coupled with high temperatures kill plants or affect their growth and seeding. For water, more than 85 % of participants observed that they have good supply of water since they started using boreholes and/or mechanised wells. However, all participants in Pwalugu noted that access to water is a problem, especially in the dry season, since it is not possible to sink boreholes because the settlement is on rocky ground.

The health sector shows low vulnerability due to good adaptive systems. For example, remittances from relatives were used to buy food and finance healthcare. One respondent noted: “My son is working in Accra and each month, he sends me some money which I use to buy food, medicine and take care of other needs.” Many rural communities reported some form of a healthcare system. A Health Nurse in the Talensi district noted that: “since I came here, I have managed a lot of minor ailments that could lead to more severe outcomes from CSM and malaria cases and I can say that there is improvement in the health status of the people in this and surrounding communities,” an indication of reduced vulnerability through provision of health facilities. The districts that are highly vulnerable to droughts/high temperatures in the health sector are Kassena-Nankana West, Builsa North and South, Talensi-Nabdam, Binduri and Garu-Tempane. The rest show low vulnerability, while Bawku West is resilient to dry and hot conditions. The highly vulnerable districts in this sector to droughts/high temperatures possess high susceptibility indicators (see Section 2.1.2 of Supplementary Material).

Vulnerability to floods/heavy rainfall

Four sectors were vulnerable to floods: agriculture, health, housing and roads. Figure 3 shows the agriculture and housing sectors as highly vulnerable to flooding/heavy rainfall. The agriculture sector is most vulnerable. Builsa North and South and Binduri Districts are highly vulnerable to floods (Fig. 3).

Bolgatanga Municipality is least vulnerable. High vulnerability of the Builsa districts is due to high and frequent exposure to flooding. The housing sector is also vulnerable to flooding, especially those houses close to rivers/streams (see Supplementary Material, Section 2.2.3). The health sector is vulnerable in Bolgatanga and Bawku Municipalities, Bawku West, Binduri and Pusiga Districts, while the rest are resilient. These districts have a high malaria burden, a high number of displaced and injured people and/or

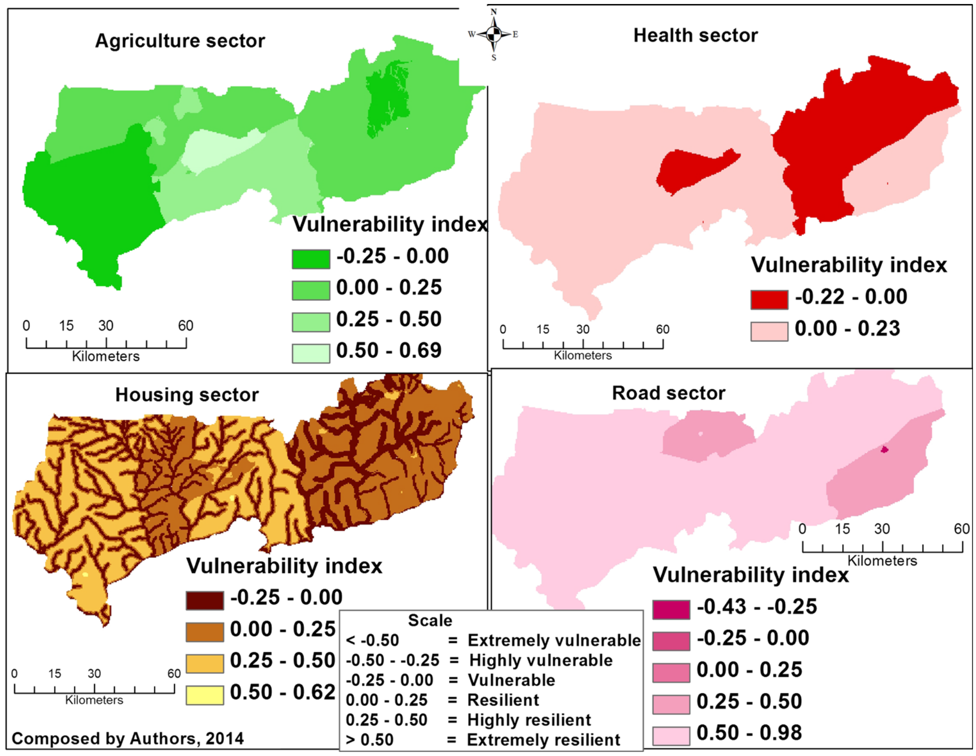


Fig. 3 Vulnerability of sectors to floods/high rainfall

properties destroyed due to flooding, high numbers of dependent people (disabled and children) and low adaptive capacities (see Supplementary Material, Section 2.2.2 and 3). The road sector is also generally resilient across the study area with only Bongo and Garu-Tempane showing vulnerability.

Vulnerability to windstorms

The vulnerability to windstorms map (Fig. S17 of the Supplementary Material) shows the entire region is resilient to wind, especially the urban areas. From the questionnaire survey, over 70 % of the people indicated windstorms hardly occur. Nearly all respondents stated that storm damage is usually to roofs and they are able to re-roof immediately or in the following dry season. An old lady said: “when my roof was ripped off, I stayed with my nephew’s wife until it was fixed for me after the rainy season.”

Discussion

This section discusses spatial variations sector by sector for each hazard and then considers aggregate vulnerability. In discussing the vulnerabilities, we refer to the original indicators in the Supplementary Materials due to loss of information resulting from the normalisation process (see Nardo et al. 2005).

Agriculture

The agriculture sector is the most vulnerable to nearly all hazards. This is because agriculture in the region is still largely rainfed, so is moderated by the climate system. Droughts/dry spells and excessive heat are increasing in frequency and intensity (Logah et al. 2013; Yiran 2014; Yiran and Stringer 2016). Coupled with high temperatures, this greatly affects soil moisture, which in turn affects crop production. Many studies show a negative correlation between increasing temperatures and yields of major crops in Africa (e.g. Schlenker and Lobell 2010; Sultan et al. 2013). The WHC of soils and crop sensitivity varied, and these contributed to the spatial variations in vulnerability we observed. Highly to extremely vulnerable districts were mostly those with few irrigation facilities (dams/dugouts for farming), while least vulnerable areas are where dependence on rainfed agriculture is reduced. This is in line with the findings of Boko et al. (2007) who note that the vulnerability of the African crop production system is due to extensive reliance on rainfed crop production, high intra- and inter-seasonal climate variability, recurrent droughts and floods that affect crops and livestock.

According to Thomas (2008), rural people in dry areas require different options to manage climate change. These include changing cropping systems and patterns, changing from cereals to cereal–legume systems, diversification towards higher value production systems and more water efficient practices. We found that changing crop systems and cereal–legumes, crop diversification, application of fertilisers, and mixing cropping with production are already practiced, yet yields remain low. Several factors could account for this (see Aniah et al. 2013; Bawakyillenuo et al. 2015; Yiran and Stringer 2015), yet interventions to enhance adaptation need to be targeted considering the relative susceptibilities of each district. Efficient use of irrigation systems and practices and water harvesting technologies have been recommended for dry land areas in Asia (Thomas 2008) and could increase agricultural production in the interior savannah, particularly in highly vulnerable districts.

Droughts/dry spells have affected the growing season length for annual crops. Sowing has shifted from April to May/June (Yiran 2014). Late planting pushes crop maturing to August, the month with heaviest rainfall and flooding, resulting in crop losses (Yiran 2014). Reduced growing seasons coupled with increased frequency and prevalence of failed seasons may shift the farming system towards more livestock production (Jones and Thorton 2009; Thornton et al. 2010). Climatic and other environmental changes have also affected livestock production (Thornton et al. 2010; Dougill et al. 2010; Descheemaeker et al. 2011; Freier et al. 2012; Schilling et al. 2012). Although short-duration crops are being introduced, these are largely maize varieties (Yiran 2014). This is changing the taste and food preference of the people as they largely eat their own produce (Yiran and Stringer 2015). Cultivation of a single crop has been found to also negatively affect biodiversity (Olschewski et al. 2006, cited in Stringer et al. 2009). Again, this highlights the interlinked nature of dealing with vulnerability to climate hazards, as actions in one sector impinge on activities and outcomes in other sectors.

Districts with lower adaptive capacities exhibited higher vulnerabilities, though susceptibilities also varied. Low adaptive capacity stems from low agricultural productivity, the main economic activity of the people. Despite its vulnerability, agriculture is still seen as a means for rural growth and poverty reduction (MOFA 2007). Although all districts experience low productivity, those with irrigation facilities or where some people use groundwater for dry season gardening are better off than those without. This was also found by Antwi-Agyei et al. (2012). Other local practices reported by respondents (e.g. flood recession agriculture, seed stocking, remittances, dry season gardening using groundwater with water cans and pumps) increased productivity and hence adaptive capacity in some districts.

Frequent losses in agricultural production are thwarting efforts to reduce poverty (UNDP 2012). From Niang et al. (2014) projections, and Africa's agricultural sector is expected to face significant challenges in adapting to climate change by 2050. This may increase poverty in already highly vulnerable districts and affect Ghana's ability to achieve the Sustainable Development Goals. Indeed, official figures show that 9 out 10 people in the region are poor (Ghana Statistical Service et al. 2009). Although Ghana has already halved poverty nationally since 2010, there is no improvement in the three regions in northern Ghana which occupy the interior savannah (UNDP 2012) as a result of frequent production losses. According to the UNDP (2012), these regions are in deficit and that of the UER is about 32 percentage points from the 2006 poverty incidence. Low levels of agricultural production and attendant poverty have implications for public health. This is discussed in the next section.

Health

The health sector is highly vulnerable, particularly to droughts/dry spells, high temperatures, floods/heavy rainfall. These hazards directly or indirectly cause illnesses such as CSM, malaria, headaches, cholera, rashes, amongst others, as well as injuries and loss of life to humans and livestock. Spatial vulnerabilities vary due to differential exposures to factors that cause these illnesses and injuries and differences in the availability and capacity of health facilities. High susceptibility to the diseases and low adaptive capacity in terms of inadequate health infrastructure and health personnel, weak health insurance scheme and lack of financial resources (Ghana Health Service 2012) explain the high vulnerability of the health sector. Daily maximum temperatures are very high and are increasing (Yiran and Stringer 2016), and these create conditions that expose the people to heat-related diseases such as CSM, headache, rashes and fever. Studies in other regions have estimated increases in diarrhoea, malaria and malnutrition by 3, 5 and 10 %, respectively, due to climate change (e.g. McMichael et al. 2004; Ebi 2008). Although malaria occurs all year, its occurrence and that of cholera and diarrhoea increase during the rainy season. Yet, health facilities and financial resources to timely seek health care are limited.

Diseases and injuries, as well as destruction to property and life, have serious socio-economic implications, especially where health facilities are limited. Increased CSM, malaria and injuries due to the hazards require substantial financial outlays for people to seek health care. Lack of resources negatively influences people's health-seeking behaviour and results in high fatalities. UNDP (2012) also found high incidences of malaria, CSM and other climate-related diseases place untold health burdens on the people. These diseases also require financial and logistical support from central government to acquire and distribute vaccines and medicines. These financial requirements, according to Whitson (2005), bring about disruption to normal health services in the affected areas as resources are redirected.

The health sector is more vulnerable to drought/high temperatures than to floods and other hazards. Impacts of droughts/high temperatures are more severe than those from floods/heavy rainfall due to high incidences of heat-related diseases affecting a wide area (as is evident in the records of the regional health directorate), whereas adaptive capacities are the same for all hazards. Variations in impacts according to hazards have also been recognised by WHO (2008).

Vulnerability to hazards in one sector may have implications for other sectors. As shown in Sect. 4.1, low agricultural production has serious implications for food security and malnutrition where most people depend on their own production for household food consumption. High food insecurity (WFP 2012) and malnutrition (Ghana Statistical Service et al. 2009) in the area are largely attributed to low crop production (Yiran 2014). Other studies on the relationship between climate change and health show a correlation between weather variables and stunting (Grace et al. 2012; Jankowska et al. 2012), an indicator of malnutrition. Projections into the 2050 s show climate change, and variability will increase the relative percentage of the severely stunted by 31–55 % reversing benefits derived from socio-economic development (Niang et al. 2014). This will further worsen the health status of those in already highly vulnerable (and food insecure) districts. High incidences of malaria, CSM and other diseases reduce labour outputs and thus affect agricultural production. Interactions between health and agriculture sectors can worsen poverty, especially for smallholder farmers. The next section discusses the water, housing and road sectors and how they interact with health and agriculture sectors in the face of increasing occurrence of climatic hazards.

Water, housing and road sectors

Droughts and high temperatures can result in water scarcity, especially for domestic use, irrigation and watering of animals, as well as the over-heating of housing units. Liebe et al. (undated, cited in Yiran and Stringer 2016) reported high evapotranspiration rates in the region. As temperatures increase, evapotranspiration will increase. The resulting drying of water bodies and lowering of groundwater tables during these hot conditions often result in acute water problems in the dry season in parts of the Talensi, Builsa, Bawku West and Garu-Tempane Districts. These areas are on rocky ground where it is difficult to sink boreholes (Yiran 2014). In some areas in these districts and in Nabdam, Binduri and Pusiga which have boreholes, yields are reduced in the dry season (Yiran 2014). A study by the UNEP-GEF Volta Project (2013) showed that borehole yields in the Volta basin are very low (2.1–5.7 m^3/depth). In other areas, shallow wells, used to harness groundwater for both domestic and agricultural purposes (Namara et al. 2011), dry up. According Obuobie et al. (2012), rainfall is the main source of groundwater recharge and also the main source of surface water recharge (UNEP-GEF Volta Project 2013). Thus, increasing occurrences of dry conditions will likely affect water availability in the area. All districts are vulnerable in the water sector, except Kassena-Nankana East and Bolgatanga Municipal. Vulnerability is lower here due to the presence of many dams/dugouts.

Conversely, extreme wet conditions recharge the water system and have been predicted to increase (Niang et al. 2014). Numerous dams and reservoirs could benefit from this; however, studies indicate high siltation of water bodies due to increased run-off and erosion (Obuobie 2008; Adwubi et al. 2009), thereby decreasing the storage capacity of reservoirs. This means that reservoirs and dams could collapse leading to flooding downstream, or store less water and dry quickly in the dry season, increasing the vulnerability of people and property. When water becomes less available, it affects agricultural production and people's health. Eroded material also pollutes the water making it unsuitable for use. Studies have found most surface water bodies contain deadly chemicals and have advised people to desist from drinking it (Pelig-Ba 2011; Boah et al. 2015). Water scarcity also increases time spent searching for water, and few options can lead people to use unsuitable sources. This exposes them to diseases, reduces labour output, as well as requiring financial resources to treat. Studies have related the increasing prevalence of waterborne diseases and migration of humans to water scarcity due to climate change (see UNDP 2012; Niang et al. 2014).

In the housing and roads sectors, increased rainfall and subsequent flooding damage infrastructure. The situation is more serious as increasingly, infrastructure finds its way into valleys and close to rivers due to urbanisation. This is particularly problematic as towns grow and villages consolidate into towns, while competing demands for land, especially for residential purposes, push people to settle in flood-prone areas. Records from NADMO between 2005 and 2011 show more destruction to properties and casualties in the big towns, particularly Bolgatanga and Navrongo and districts (Binduri, Bawku West, Builsa North and South) that have more river/stream networks. Families and individuals are affected financially as they lose property and require financial resources to reconstruct or renovate the affected properties. Similar findings are present in other studies (e.g. Whitson 2005; Oteng-Ababio 2011;

Yiran 2014; Yiran and Stringer 2015). Indeed, many African cities are experiencing the consequences of floods due to urbanisation (Oteng-Ababio 2011; UN-Habitat 2011; Gyasi et al. 2014). Urbanisation creates excessive demand for housing and roads in towns and may increase the number of people vulnerable to climate impacts (Seto 2011). However, Yiran and Stringer (2015) found that weakness in the enforcement of building and land use regulations in the study area also contributes to the vulnerability of the housing sector.

Windstorms affect buildings. Combined effects of extreme wet conditions and windstorms have caused people to shift to use concrete and metal roofing sheets, although interviews suggested modernity and taste are also increasing use of these materials. These materials trap heat and increase the risk of CSM. Rural roads suffer the consequences of flooding/heavy rains because they are largely untarred and easily eroded, and in some cases, bridges and culverts are washed away. This leaves the roads in very deplorable conditions, making delivery of goods and services, especially emergency services, both difficult and expensive. Spatial variations in vulnerabilities here are largely due to differences in susceptibilities as adaptive capacities are fairly similar across the region (Yiran 2014).

Conclusions and recommendations

We have shown that Ghana's interior savannah is highly vulnerable to multiple hazards. Vulnerabilities vary sectorally and spatially from hazard to hazard and the vulnerabilities of different sectors interact. Vulnerabilities are high because of high susceptibilities and low adaptive capacities. We therefore recommend a reduction in the susceptibilities while enhancing adaptive capacities. We therefore recommend the provision of interventions to reduce the vulnerabilities. Interventions to reduce susceptibilities and increase adaptive capacities will have to compete for funding from limited national budgets and resources, so we envisage that our work will serve as a guide to policy makers, especially at the district level, to prioritise interventions to maximise adaptations to the hazards. We propose more attention be paid to reducing susceptibilities to droughts/high temperatures and that interventions should be targeted, considering the strengths and weaknesses of various districts. We have segregated the recommendations into sectors which we believe if integrated/mainstreamed into the sectoral policies could reduce susceptibilities and at the same time increase adaptive capacity and thereby decrease the vulnerabilities to the hazards.

We have shown the spatial variations in the agricultural sector and therefore offer an opportunity for development agencies to better target interventions to enhance agricultural adaptation. Vulnerabilities of Talensi, Nabdam, Garu-Tempane and Kassena-Nankana West Districts could greatly be reduced by enhancing irrigation facilities, as the few dams/dugouts in these districts are largely for watering animals. Providing or improving irrigation will reduce susceptibilities of the sector to droughts/high temperature, will reduce the reliance on rainfed agriculture greatly and enable all year round farming. This could increase productivity and help to alleviate poverty. Additionally, the various districts have potential (captured as investment opportunities under adaptive capacity) that could be tapped to diversify their economies, reducing dependence on agriculture in order to alleviate poverty and enhance adaptation to all hazards affecting the sector.

There is an urgent need to improve healthcare by increasing health facilities and staffing, and undertaking health campaigns, especially in rural districts. This needs to be coupled with actions to reduce healthcare costs, especially for the poor. Such actions include development of Community-based Health Planning Services (CHPS) compounds and other health facilities, immunisations, vaccinations, distribution of insecticide-treated bed nets, deworming, nutritional treatments, and outreach programs aimed at sensitising the people on preventive measures. In Bolgatanga and Bawku Municipalities, insecticide bed nets could be distributed, while in the rural districts, investment in more health facilities would ease pressure on those in the towns and help to build adaptive capacity. CHPS compounds are particularly important in rural areas as health facilities are inadequate and settlements are dispersed. Incentives could encourage health personnel to take up posts in the rural areas. The health insurance scheme, which is pro-poor, should be strengthened.

Groundwater should be harnessed (for both agriculture and domestic use), but there is need for further research into the sustainability of its extraction to enhance adaptation. The eastern part of the Talensi District in particular has high groundwater recharge rates that could be exploited to enhance adaptation. In the housing sector, building and land use regulations and buffer zones should be enforced in towns/villages along rivers/big streams, ensuring hazard-prone areas are not used for settlements and to protect river banks. This would reduce exposure and sensitivity. Rainwater harvesting technologies in Bolgatanga, Navrongo and Bawku and included in the building codes should be introduced to reduce run-off, extending also to the capitals of the rural districts, as these will soon develop into bigger towns. Roads need improving to increase the movement of goods and services, particularly agricultural goods and emergency services. These efforts can together enhance the adaptive capacity of the area and ultimately reduce vulnerability as they will also invariably reduce susceptibilities.

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