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Vulnerability to extreme weather events in cities: implications for infrastructure and livelihoods

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Abstract: Many cities in the Global South are facing challenges as they increasingly experience extreme weather events, which disproportionately affect the urban poor. Focussing on severe heat and surface water flooding, this paper explores how these extreme weather events impact on infrastructure provision and livelihoods in low-income urban communities in Ghana. Climate series, including temperature data recorded in people's homes and workplaces, are linked to qualitative interview data collected in eight neighbourhoods within the cities of Accra and Tamale during 2018. Additional evidence was obtained through key informant interviews with health service, water and electricity supply officials. The paper demonstrates that extreme heat and flooding events are causing disruptions to infrastructure provision and impacting vulnerable populations through loss of goods and property, reduced incomes, restricted mobility, and poorer health, alongside interrupted and increasingly overstretched services. The paper concludes that improved understanding of the climate–infrastructure–livelihoods nexus can reveal entry points for adaptations that reduce the vulnerability of low-income communities to extreme weather events in cities.

Keywords: Flooding, extreme heat, electricity, water, health, livelihood, mobility, Ghana, Accra, Tamale.

INTRODUCTION

Urban populations and built environments are recognised 'hot spots' of vulnerability to climate change (McCarthy *et al.* 2010, Wilby 2007). Many cities in the Global South are facing new challenges as they increasingly experience extreme weather events, which disproportionately affect the urban poor and the localities in which they are concentrated. Across sub-Saharan Africa and beyond, low-income urban communities are facing densification and congestion, and suffer from a lack of basic infrastructure, such as access roads, storm water drains, potable water supply and health facilities (African Centre for Cities 2015, Armah *et al.* 2018). Such poor social and technical infrastructure is contributing to high levels of urban vulnerability and poverty (Kabisch *et al.* 2015). Climate-change-induced extreme weather events are expected to amplify the multifaceted challenges faced by urban dwellers in low-income and environmentally-sensitive communities (Matthews *et al.* 2017, Simon & Leck 2015). Flood and extreme heat vulnerability in cities have become associated with informality, urban poverty, marginalisation and concentrated populations in flood and heat hotspots (Baker 2012, Dodman *et al.* 2019, Douglas 2008, Few 2003, Fischer *et al.* 2012, Magadza 2000, Scott *et al.* 2017). Few studies, however, explore the links between different types of extreme weather weather events and their compound impact in cities.

This paper analyses the impact of flooding and extreme heat on urban infrastructure performance and investigates the implications of this for livelihoods of poor urban residents in Ghana. The climate–infrastructure–livelihoods nexus is explored by analysing when and where indoor air temperatures and surface water flooding are most severe, examining how these extreme weather events affect water, electricity and healthcare provision, and the associated implications for daily life, income-generating activities and mobility. Climate series, including temperature data recorded in homes and workplaces, are linked to qualitative interviews conducted with people living and working in these spaces, supplemented by key informant interviews with health service, water and electricity supply officials. The paper demonstrates that extreme heat and flooding events are causing disruptions to infrastructure provision and impacting vulnerable populations through loss of goods and property, reduced incomes, restricted mobility, and poorer health, alongside interrupted and increasingly overstretched services. In conclusion, a case is made for deepening understanding of the climate–infrastructure–livelihoods nexus to help reduce the vulnerability of low-income communities to extreme weather events in cities.

Ghana was selected as the primary case because it is an example of a country that has a predominantly urban population (52 per cent) and cities that are concurrently vulnerable to two extreme weather types: flooding and extreme heat. According to the Notre Dame Global Adaptation Initiative (ND-GAIN),[1] Ghana is ranked 101 in

[1] The ND-GAIN Country Index summarises a country's vulnerability to climate change and other global challenges in combination with its readiness to improve resilience. See: https://gain.nd.edu/our-work/country-index/rankings/

terms of vulnerability and readiness for climate change, where rank 1 (Norway) and rank 181 (Somalia) are respectively the least and most vulnerable countries in the world. This situates Ghana just below Egypt (rank 98) and above Namibia (rank 103). Ghana is ranked in the lower half of the global table because of expected impacts on national agricultural yields, relatively low capacity to acquire and deploy agricultural technology, the condition of road infrastructure, and particularly low scores for the number of physicians, nurses and midwives per capita.

In the study sites of Accra and Tamale, as in many other African cities, communities are *already* exposed to extreme weather and are ill served by key infrastructure, such as energy, transport, telecommunications and social services that are critical in reducing vulnerability (Pauleit *et al.* 2015, UN-Habitat 2014). Ghana has a long history of flood hazards with several devastating events recorded since the 1950s (Karley 2009, Rain *et al*. 2011), the latest being in June 2015 which killed more than 150 people and displaced over 8,000 in Accra (UN Country Team Ghana 2015). In January 2016, excessive heat in northern Ghana was linked to 140 reported cases of meningitis, claiming the lives of 32 people (*africanews* 2016). As well as loss of life, such extreme weather events severely impact water and electricity services, reduce access to and provision of healthcare, and disrupt/damage livelihoods. Our focus on the impact of extreme weather events is thus directly relevant to many significant development challenges faced by rapidly growing cities in Ghana and beyond.

Following this brief introduction, the next section discusses the concept of vulnerability, indicating how it shaped the project and analysis of the paper. The study sites and methodology are then presented before turning to an exploration of the nature of extreme weather events in Ghana. The impact of these events on urban infrastructure and the livelihoods of urban residents is discussed, before highlighting their interconnectivity and identifying some policy implications in the conclusion.

VULNERABILITY IN CITIES

There are many descriptions of vulnerability and approaches to vulnerability assessment (see Füssel & Klein 2006, IPCC 2013, Kabisch *et al.* 2015, Kelly & Adger 2000). This paper adopts a straightforward definition of vulnerability to climate hazards based on three components: the level and duration of *exposure* of a receptor, the *sensitivity* of a receptor to harm, and the *capacity* of a receptor to adapt (IPCC 2001). We focus on the first two components: 'exposure', which refers to the character, magnitude, extent and rate of climate change and variability experienced by the receptor(s); and 'sensitivity', meaning the degree to which a receptor is affected by a given change in climate, whether adversely or beneficially. Receptors may be different entities (for example, people, livelihoods, infrastructure or natural systems) and cover different scales, including individuals, households, communities and cities (Wilby 2017). Climate vulnerability is geographically and socially differentiated, as are the processes that mediate responses to hazards at the local scale (Brooks *et al.* 2005). Low-income communities are disproportionately exposed and sensitive to extreme weather; hence poverty reduction and improved infrastructure and livelihoods are recognised as pathways to lower climate vulnerability (Adger *et al.* 2003).

In urban settings, the characteristics of the built environment, including structural aspects such as street and building design/materials, significantly modify and condition the climate vulnerability of urban residents (Wilby 2007). In addition, population densities and the presence and effectiveness of urban infrastructure (for example, energy, water, transportation and health services) partly determine the sensitivity of urban populations to climate hazards (Rafael *et al.* 2015, Sharifi *et al*. 2017, Simon 2010). As infrastructure is also affected by climate change, it is important to investigate the vulnerability of urban infrastructure: that is, the degree to which key assets are susceptible to the adverse effects of an increase in climate means and extremes resulting from climate change (Bolitho & Miller 2017, Pregnolato *et al*. 2016).

Vulnerability to climate change is analysed in this paper in relation to the characteristics of urban settings that affect a population's exposure to climate hazards and their sensitivity to these hazards (Amoako & Inkoom 2018, Rafael *et al.* 2015), focussing in particular on the impacts on daily lives and livelihoods. Particular attention is paid to the conditions of neighbourhoods and their residents that can increase exposure and sensitivity to extreme heat and flooding. Poor urban households are amongst the most vulnerable residents in cities, already struggling to make a living and survive in harsh socio-economic and physical environments (Amis 1995, Mitlin & Satterthwaite 2013).

SETTING THE SCENE

Two cities in Ghana were selected for this research: Accra, the capital and largest city located in the south of the country, and Tamale, a rapidly growing intermediate-sized city in northern Ghana. With their differing climates, urban form and size, infrastructure and governance systems, these two cities provide contrasting cases within one national context.

Accra became the capital of Ghana (then called Gold Coast) in 1877. The city's population has increased rapidly from fewer than 400,000 inhabitants in 1960 to almost 1.9 million inhabitants by 2010 (GSS 2012), and is estimated to be 2.4 million today. The majority (69 per cent) of the economically active labour force operates within the informal economy; the 'sales and service worker' group (36 per cent) is the key occupation group, followed by 'craft and related trade workers' (19 per cent) (GSS 2012). Running businesses from the home has been shown to be widespread in low-income areas of the city, providing an especially important income source for women (Gough 2010, Wrigley-Asante & Mensah 2017, Yankson 2000).

Tamale is the capital of the Northern Region of Ghana, created in the first decade of the 20th century when it was made the capital of the British Northern Territories (Fuseini *et al.* 2017). The city hosts many wholesale, retail and informal business activities, and is a centre for agricultural produce and inputs (Yakubi *et al.* 2016). The population has grown rapidly from around 84,000 in 1970 to just over 371,000 in 2010 (GSS 2012). The bulk of Tamale's labour force operates in the informal economy (74 per cent), primarily as self-employed with or without employees (GSS 2013). About 20 per cent of the city's population derives their livelihood from agriculture.

In both cities, considerable pressure on housing results in high-density dwellings in low-income areas. The average amount of space available to households in urban Ghana is 1.7 rooms, resulting in a mean occupancy rate of 2.3 persons per room. The majority of urban households occupy a single room, one third have access to two rooms, but very few homes have three or more rooms (UN-Habitat 2011, Yankson & Gough 2014). High-density, low-income settlements generally have limited infrastructure and service provision, resulting in many self-help solutions (Amankwaa 2017, Bangdome-Dery *et al.* 2014).

In each of the cities, four low-income residential communities were selected (Table 1), two of which are representative of communities that experience severe flooding (Odawna and Bortianor in Accra; Gumani and Ward K in Tamale) and two that are representative of communities exposed to extreme heat (Alajo and Agbogbloshie in Accra; Kukuo and Lamashegu in Tamale). Within each settlement a 'Champion' was selected by the community leaders who became our key contact person, assisting with all stages of the research. An interdisciplinary team of climate specialists, human geographers, civil engineers and health scientists engaged in a range of complementary research methods to collect primary data throughout 2018.

Table 1. Study settlements in Accra and Tamale.

City	Extreme heat	Flooding
Accra	Alajo	Odawna
	Agbogbloshie	Bortianor
Tamale	Kukuo	Gumani
	Lamashegu	Ward K

Recording extreme weather events

The temperatures that are typically used to indicate extreme heat tend to be recordings taken at official weather sites. In order to measure the air temperatures that urban residents actually experience, *Tinytag Transit 2* thermistors were installed in homes and workplaces during January 2018 and subsequently in health clinics from May 2018 (Figure 1). For each settlement, several houses were selected to represent varying structures, building materials and locations. Within each home, one Tinytag was installed in the shade to measure outdoor temperature and one or more (up to four) were located in rooms with various roofing types, of differing usage and size, and inhabited by a differing number of occupants. All Tinytags were sited at least 2 m above ground. In order to cross-check the temperatures with official recordings, Tinytags were also placed at national meteorological weather stations in Accra and Tamale airports. In total, 131 Tinytags were deployed, from which 10 minute air temperature data were downloaded every six weeks. These temperature series provide the basis for quantitative analysis in this paper.

To evaluate surface water and fluvial flood risks, 2 m topographic data were purchased and flood simulations conducted to generate maps of flood depth and extent within some of the most vulnerable communities. Moreover, visual recordings of flood events were made as they occurred. In order to test the quality of the water that residents are drinking, water samples were collected from a range of formal and informal sources within the eight communities studied, following which laboratory analysis of microbial water quality was conducted.

Figure 1. Tinytag housed in a reference meteorological station (left) and within a home (right).

Vulnerability of urban infrastructure

Key informant interviews were held with actors in water, electricity and health provision to investigate how their services are impacted by flooding and extreme heat events. The service providers' current systems for disaster preparedness were also explored, alongside the benefits of being able to accurately forecast extreme weather events. Interviews were conducted in a total of sixteen health facilities, including public and private clinics and hospitals. Within the water and electricity sector a total of five key informant interviews were held, with the Electricity Company of Ghana (ECG), the Northern Electricity Distribution Company (NEDCo) and Ghana Water Company Limited (GWCL).

Vulnerability of urban residents

With the aim of exploring how extreme weather events impact on urban residents' access to water, electricity and health services, and how these in turn affect their income-generating activities and mobility, semi-structured interviews and focus-group discussions were conducted in the study settlements. In order to relate residents' experiences to extreme temperatures, individuals were selected for interview from within the rooms where Tinytags were installed, covering both genders and a range of ages. A total of 124 such interviews were conducted. In each community, three focus-group discussions were held, that is 24 in total: one with older males, one with older females, and a mixed-gender youth group (aged 18–35). All interviews were transcribed verbatim then analysed using NVivo.

EXPOSURE TO EXTREME WEATHER EVENTS IN GHANA

Ghana has three main climatic zones, with coastal savannah in the far south, humid rainforests in the southern half of the country, and the dry, hot Sahel in the north. Nationally, monthly mean temperatures range between 24°C and 30°C throughout the year.[2] Local temperatures are higher in Tamale, however, where daily maximum values average 38°C in March (during the dry season), and 30°C in July–September (during the wet season). In comparison, average daily maximum temperatures in Accra range between 33°C in March and 28°C in July–September.

[2] World Bank Climate Change Knowledge Portal http://sdwebx.worldbank.org/climateportal/index.cfm?page=country_historical_climate&ThisCCode=GHA

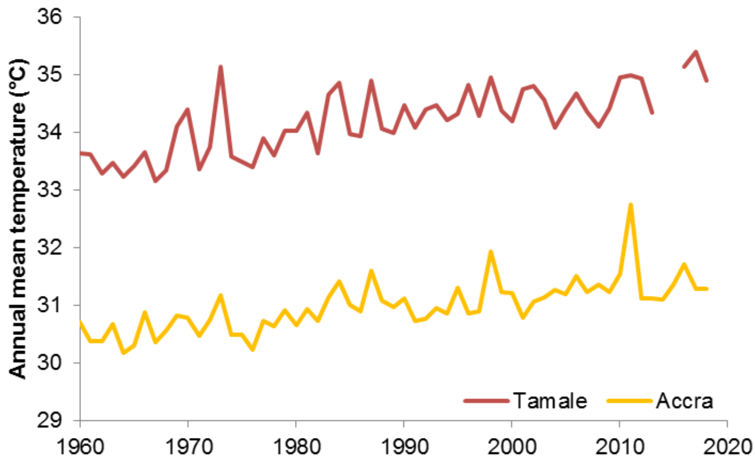

Figure 2. Annual mean temperatures recorded in Accra and Tamale since 1960.

There is evidence of temperature rises in Ghana during recent decades. The mean annual temperature has increased (reports range from +0.4°C over 100 years to +1°C over 50 years), with the largest increase between April and July (+0.27°C per decade) (Figure 2). The rate of increase has been more rapid in the hotter, drier north of the country than in the more humid south. Moreover, the number of 'hot days' and 'hot nights' has increased significantly in all seasons (by 13.2 per cent and 20 per cent, respectively, between 1960 and 2003), while the number of 'cold days' and 'cold nights' has decreased (by 3.3 per cent and 5.1 per cent, respectively, over the same period) (NCEA 2015).

Floods are a perennial concern for Ghana, and there are indications that associated impacts are generally becoming more severe. Evidence of flooding in the country appears to date back to the year 1936, since when flooding has become a recurring phenomenon in Ghanaian cities and urban conurbations (Ahadzie & Proverbs 2011). A chronology of selected flooding events in Ghana since 1968 indicates the location and severity of these (see Table 2). According to the Dartmouth Flood Observatory,[3] Ghana was impacted by fifteen major floods in the period 1988–2010, causing an estimated 244 fatalities and displacing at least 692,700 people. Flooding has become so widespread and complex in urban areas that Ghanaian authorities/stakeholders are overwhelmed by the situation (Amoako & Boamah 2015). There is no systematic forecasting system to warn urban residents of impending floods nor a well-integrated risk management approach to address the safety awareness, evacuation and psychological needs of potential victims (Ahadzie & Proverbs 2011).

[3] http://www.dartmouth.edu/~floods/Archives/index.html

Table 2. Chronology of some floods in Ghana since 1968.

Date	Nature/characteristics	Impact	Regional spread
4 July 1968	Accra recorded heaviest rainfall in nine years	Normal life of the city brought to standstill	Accra
29 June 1971	Downpour started midnight	Houses collapsed, thousands of people rendered homeless	Sekondi–Takoradi
5 July 1991	Downpour started midnight	Flooding of low-lying areas of Accra, commuters and vehicles affected, power installation damaged	Accra
13 June 1997	Intermittent downpour for two days	Flooding of Accra threatened to cut off communities in various parts of the city	Accra
1999	Floods swept through some regions	300,000 people affected	Upper West, East, Northern, Brong–Ahafo, Volta Regions
2007	Floods in some regions	307,127 people affected	Upper West, Upper East, Northern Regions
5 May 2010	Two hours of stormy rain	Parts of the city and its streets submerged in water	Central Accra, Ofankor, Begoro
22 June 2010	Nation's worst flood disaster	35 deaths	Across Ghana
24 June 2010	Floods	3 bridges collapsed	Agona Swedru Central Region,
14 October 2010	Flooding due to torrential rains and opening of Bagre dam in Burkina Faso	161,000 people displaced	Nationwide
18 October 2010	Flooding in Central Gonja District	55 communities submerged following overflow of Lake Volta	Northern Region
2 November 2010	Flooding Afram plains	2,800 people displaced from 120 villages and towns along Lake Volta; 850 buildings, farms, markets and roads affected	Kwahu North, South, East in Afram Plains
24 February 2011	Heavy rains from 9.30PM to 3AM, 71.5 mm of rain	Many communities affected—either submerged or properties washed away	Accra
1 November 2011	Heavy downpour	14 deaths and 43,087 people affected	Accra
31 May 2013	Heavy rains	Flooding in parts of the city	Accra
6 June 2014	More than 10 hours downpour	Flooding of several parts of the city	Accra
4 July 2014	Heavy rains	Several low-lying areas flooded	Accra

Source: Adapted from *Daily Graphic* (2015).

Although reports of flooding in Accra can be found from the 1950s (Twumasi & Asomani-Boateng 2002), major flood disasters have become an annual experience since the early 1990s, with each successive flood generally having a more severe impact than the previous one (Bokpe 2015, *Daily Graphic* 2015). On 3 June 3 2015, Accra witnessed the most devastating flood-related disaster recorded in Ghana when a fire broke out at a filling station where people had sought shelter from torrential rains that had caused widespread flooding, and in the process over 152 people died (Asumadu-Sarkodie *et al.* 2015).

The causes of floods in Accra are many and complex. This is due to the combination of a low coastal elevation, impermeable clay soils, inadequate and undersized drains and culverts (with insufficient conveyance capacity), infrequent maintenance of drainage structures, dumping of refuse into drains and water bodies, and construction in environmentally sensitive areas, such as illegal construction in flood plains (Appeaning & Adeyemi 2013, Okyere *et al*. 2013, Rain *et al.* 2011, Songsore *et al.* 2005, Twumasi & Asomani-Boateng 2002). Our informants also spoke of dams being opened upstream causing flooding in their neighbourhoods. Floods similarly occur annually in the Tamale Metropolis where the flood-prone zones are home to several communities. The causes of flooding in the metropolis are both natural and artificial.

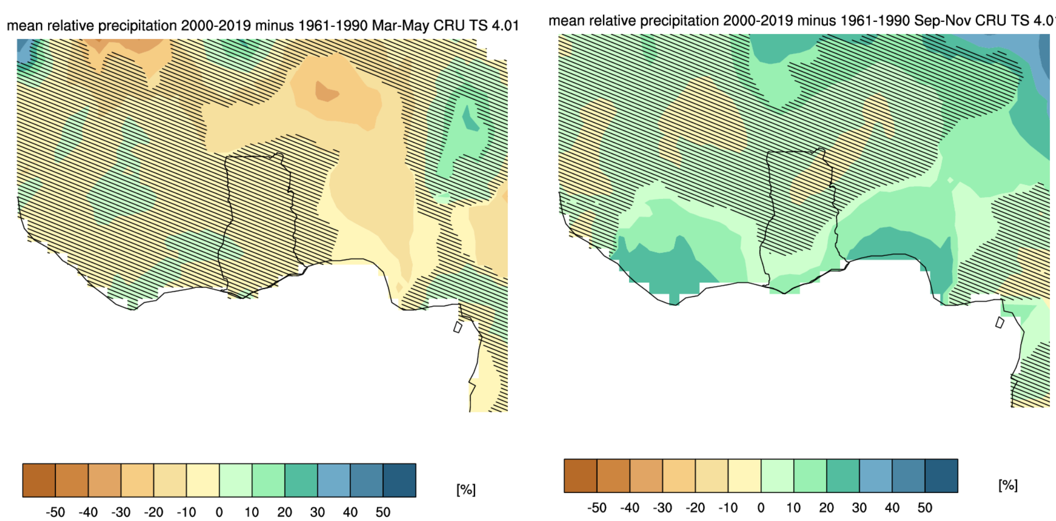

Figure 3. Changes in wet season (March–May and September–November) rainfall across Ghana and West Africa more generally since 1960. Data source: CRU TS 4.01.

Climate change has contributed to an increase in flooding in Ghana through rising annual and seasonal rainfall over at least the last twenty-seven years (Hafiz 2014). Although the seasonal rainfall pattern depicts a relatively weak upwards trend since the 1960s (Nyarko 2000, cited in Yankson *et al.* 2017; UNEP/OCHA 2010), there is evidence that the September–November period has become wetter since the 1960s (Figure 3). Moreover, model-based studies suggest that the frequency of daily intense rainfall events could increase over West Africa in the future (Dunning *et al.* 2018).

VULNERABILITY OF INFRASTRUCTURE

In this section we discuss the vulnerability of infrastructure by examining the exposure of water, electricity and health providers to extreme heat and flooding events, and their sensitivity to these events.

Extreme heat

Extreme heat can influence the supply of electricity and water in various different ways. The electricity service providers for the two cities (the Electricity Company of Ghana (ECG) for Accra and the Northern Electricity Distribution Company (NEDCo) for Tamale) explained that in periods of extreme heat the demand for electricity escalates, as urban residents are using more power in their attempts to cool down: for example, by using fans and air conditioning. Officials also reported that conductors sagging due to extreme heat affected transmission cables. This, coupled with the companys' inability to cope with the peaks in demand, causes a strain on the transformers and other systems, leading to voltage drops and unplanned power cuts, as well as planned load shedding.

As periods of extreme heat coincide with low or no rainfall, the yield from water sources declines and the supply of water available for urban areas is diminished (Benebere *et al.* 2017). In Accra, officials of the Ghana Water Company Limited (GWCL) informed us that they currently produce 600,000 m^3 of water per day against a demand of 730,000 m^3 per day. This shortfall in water production causes the supply in some urban settlements to become more intermittent, especially in periods of extreme heat. The water companies also reported that power fluctuations and power cuts affect their ability to pump water, which further hampers the water supply to urban residents.

Experiences of extreme heat are affecting the operation of health facilities in numerous ways. A key issue is that extreme heat increases the incidence of health-related problems of varying severity, including a rise in respiratory problems,

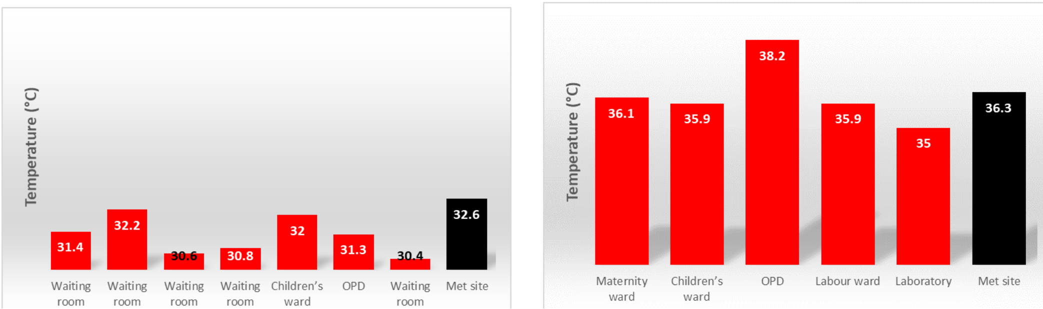

Figure 4. Maxium indoor temperatures recorded in Accra (left) and Tamale (right) health facilities during the period 22 May 2018 to 3 July 2018.

hypertension, strokes, cerebral meningitis and heat rashes. This results in more people seeking the services of health facilities in times of extreme heat. The temperatures that patients and staff experience within the health facilities were found to be disturbingly high. As Figure 4 shows, over the period May–June 2018, the maximum air temperatures recorded in the sampled health facilities in Accra ranged between 30.6°C and 32.2°C, whilst in Tamale they were even higher, ranging from 35.9°C to 38.2°C. As air conditioning is very limited within the health facilities, and fans are considered not to have a cooling effect above 34°C, the temperatures experienced are exceptionally high.[4]

The frequent power cuts in situations of extreme heat have a severe impact on the operation of health facilities, increasing the vulnerability of both patients and staff. Drugs overheat and risk becoming ineffective as a consequence. Staff reported sweating profusely, resulting in an increased chance of spreading infection (Mills *et al.* 2000). Referring patients between health facilities is also a challenge in conditions of extreme heat due to a lack of vehicles, especially any with air conditioning. Perhaps most worrying, hospital staff reported that, in order to keep on operating if a power cut occurs unexpectedly, additional staff are called into the operating theatre to shine their mobile phones on the patient. Health staff lamented the lack of an early warning system for extreme heat and power cuts during these periods, which would enable them to plan accordingly.

Flooding

Flooding events also have severe implications for service provision. ECG and NEDCo officials explained how strong winds preceding the heavy rains that cause flooding can damage electricity poles and cause conductors to join, thereby tripping the

[4] As the monitoring period of the health facilties (May to December 2018) did not include the hottest months of the year, even higher temperatures are likely to be experienced.

electricity supply. During flooding events, the electricity company sometimes disconnects the electricity supply for safety reasons. GWCL reported that their pipelines can be destroyed by flooding, resulting in the water flow being disrupted and the risk of faecal contamination of water. Power cuts during the rainy seasons affect water production levels, and the frequent pipe bursts due to higher pressure also increase physical water losses in the network.

The health facilities reported that the rainy season and associated flooding bring more cases of malaria, respiratory infections, typhoid, cholera, gastrointestinal problems and exacerbation of diabetes (due to the lack of a constant supply of insulin). Consequently, the increase in the number of patients results in there often being insufficient beds. As health staff are not immune to these diseases, and may have problems getting to work during floods, this can result in staff shortages. When drains near clinics become blocked due to the dumping of refuse by local residents, localised flooding is exacerbated. Instances of waist-deep flood waters were reported in and around some of the health facilities, resulting in the loss of medication, the need to move equipment where possible to higher levels and the loss of ground-floor bed spaces. Moreover, staff and patients face challenges when trying to move between buildings within the health facilities and patients have difficulties accessing essential medication and health staff. The increase in the frequency of power cuts during flooding events is a particular concern for health facilities, which is exacerbated when flooding damages generators because of the loss of any electricity supply. Following flooding events, considerable time and money are spent repainting and renovating buildings, and repairing or replacing equipment. Although in a few urban areas, such as Odawna, flood warnings exist, these are not specifically directed to the health services. The lack of any flood warnings in most locations was greatly lamented by the health facilities.

Summary

This discussion of the impact of extreme weather events on infrastructure provision in Accra and Tamale has highlighted how already weak urban services are coming under increasing pressure. When the fragile infrastructure system is exposed to extreme heat or flooding, there is a cascade effect due to the interconnectedness of services: in this case, water, electricity and health. This compounds the sensitivity of infrastructure providers to extreme weather events, increasing the impact on services. Next, we turn to analyse how extreme weather events and reduced infrastructure provision affect residents of low-income urban areas.

VULNERABILITY OF LIVELIHOODS

In this section we explore the vulnerability of poor urban residents by examining their exposure to extreme weather events and their sensitivity to these events, in particular in relation to their ability to continue operating income-generating activities.

Extreme heat

The urban residents interviewed in both Tamale and Accra stressed the multiple ways in which they are affected by extreme heat and flooding in their daily lives and income-generating activities. As expressed by an elderly man in Gumani,

> *There is so much heat here. To give a scenario, when there is water on a fire, the heat that comes out of it is equal to the heat we experience.*

The heat is such that many people spoke of how it was impossible to be in their rooms during the day, even if they have a fan. In the words of a young woman from Alajo, '*Once you enter your room it's as if you have entered an oven.*' This is supported by the temperature data collected, showing temperatures of up to 45.5°C in rooms where people sleep. Even when the temperatures drop at night, as indicated in Figure 4, temperatures in the rooms fall more slowly and remain too high to sleep. A middle-aged woman from Agbogbloshie explained how,

> *Our children are unable to sleep during the period of extreme heat and because they are unable to sleep you also cannot sleep. It becomes worse when there are heat rashes.*

The extreme heat results in urban residents going to bed with windows and doors open, and consequently they reported having a greater fear of experiencing theft while asleep. Many interviewees indicated that they chose to sleep outdoors, although their ability to do so varies according to the layout of the house; those who live in more traditional compound housing where there is an interior courtyard feel much safer sleeping outdoors at night compared with residents of houses with only an exterior courtyard. All urban residents sleeping outdoors at night face an increased chance of being bitten by mosquitoes, scorpions and snakes, and hence a higher risk of contracting malaria and other diseases where mosquitoes are transmission vectors, or death by snake bites. Accessing water was reported to be an issue in periods of extreme heat, with women from Kukuo having to compete with livestock at the community dugout to fetch water for household uses other than drinking. An elderly woman from Kukuo, in a rather understated manner, explained how,

> *In the time of heat the water is not flowing and getting water is difficult. We don't have much water to cool off. This makes living a bit of a challenge.*

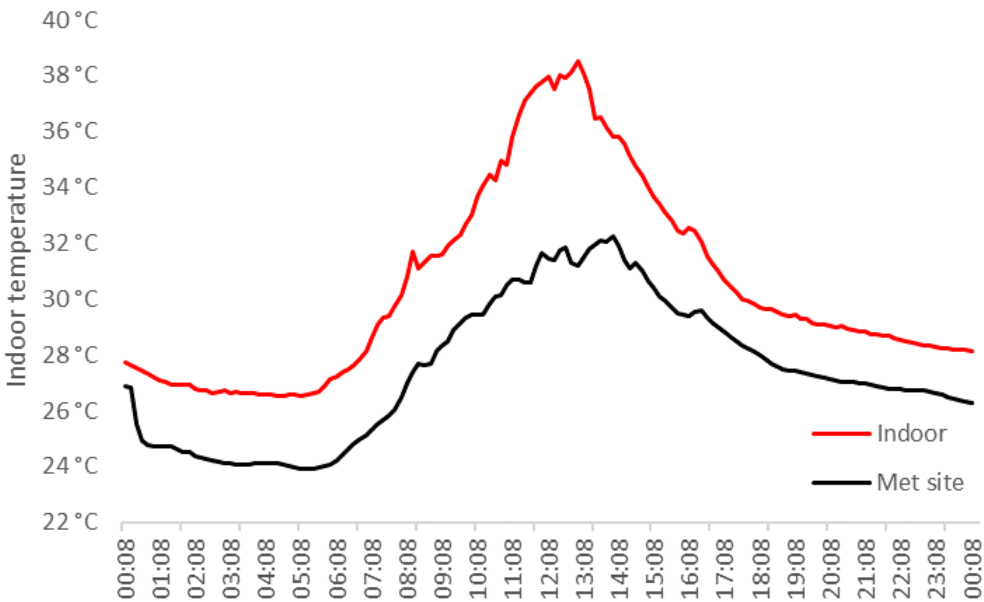

Figure 5. Indoor air temperatures for a house in Alajo compared with reference conditions at the meteorological station on 23 May 2018.

The extreme heat greatly affects urban residents' ability to work and generate an income. As a young woman living in Alajo explained in relation to the heat, '*It makes you tired early. When you do small work you get tired fast.*' The many women who are working from the home in low-income residential areas in Ghana (Gough 2010) find it difficult to operate in their usual workspace, whether there is a room or more commonly a wooden or metal kiosk. The latter in particular can become extremely hot; for instance, a seamstress in Lamashegu was operating from a metal kiosk where temperatures of up to 50.3°C were found. The highest temperature recorded was 61.0°C in a blacksmith's open wooden structure in Lamashegu.

A young seamstress from Ward K reported how in periods of extreme heat she can only produce a quarter of the items compared with when temperatures are lower. Similarly, a middle-aged woman from Agbogbloshie indicated that her ice block production business slows down because it takes much longer to produce the blocks during periods of extreme heat as her freezer is not as effective. In relation to women who sell fresh fruit and vegetables, an elderly man from Lamashegu highlighted a particular problem:

> *Because of the heat, the ripening is hastened and some of it will go bad and they will have to throw it away and that is a loss.*

It is not only individuals who are working from the home who are affected by extreme heat; as Heal and Park (2013) found, extreme heat causes reductions in labour supply, firm- and individual-level production, and macroeconomic output at the regional and national level. The majority of workplaces in Ghana, whether public, private, formal or informal do not have air conditioning, thus increasing the chance of being affected by heat rashes. A middle-aged man from Alajo explained how this can impact on their ability to work,

> *The medicine that is given to us when we visit the hospital* [for heat rashes] *also has an effect on our jobs. It is whiteish and has to be applied on every part of the body. People do not go to work for fear of ridicule.*

The vast majority of schools do not have air-conditioning either, resulting in young people finding it difficult to study in class.

Flooding

Severe flooding events also have a major impact on urban residents' daily activities. Our interviewees talked about problems conducting essential everyday activities, such as eating, when their areas flood; since most low-income urban residents purchase food on a daily basis, they find it hard to access food to buy and cannot cook due to the flood waters. Moving around the neighbourhood is also difficult and can be dangerous, whether on foot, bicycle or using vehicles. This is amplified when the usual means of paid transport, whether motorbikes or *trotros* (mini buses), avoid parts of the city that are experiencing extreme flooding. Fetching children from school can become a hazard and, in a widely reported incident, a woman lost her life in Tamale when she attempted to cross flood waters while driving to pick up her children (GhanaWeb 2017). A young woman from Ward K told us how they have to '*just wait at home and pray that our children come home safely*'. Sleeping at night was also reported to be a problem when there are heavy rains, since people are worried their rooms might be flooded while they sleep.

Many structures and personal items are destroyed in the worst floods, especially if there is no warning. An elderly woman from Kukuo informed us that:

> *The flood was able to breach the walls around the house and part fell off. We also had water all over the rooms and the compound.*

Possessions that urban residents reported being destroyed by flooding included: livestock (goats and fowls), food items, electronic and electrical gadgets, mattresses, cooking utensils, clothes, shoes, furniture, books including those for schoolchildren and important certificates. Replacing these items is expensive and can be very difficult for low-income residents. Several interviewees reported that schoolchildren have to stay at home until the parents can afford to replace their shoes, school uniform and books, which can have a significant impact on their education. Residents also revealed the health consequences of flooding. A young man from Bortianor lamented,

> *The flood carries rubbish to our house. Some people dump faeces into the water and the water smells. That is troubling people here.*

Livelihood activities are also impacted by flooding. As many urban residents in low-income areas are dependent on earning money on a daily basis, and it is common to be engaged in casual work (cf. Gough *et al.* 2016), not being able to work for just one day can be problematic. Thus a young man from Bortianor explained how,

> *Because of the flooding we can't go out and search for work to look for money to look after ourselves so it causes problems.*

For urban residents who run shops, either from their homes or elsewhere in the settlement, flooding can ruin their businesses. Items, such as fridges and TV sets, which cannot easily be moved were reported to have been destroyed by flood waters. Even more moveable items owned by interviewees, such as clothing and food, had been damaged by floodwaters in instances where there was no one to move the items or nowhere to move them to. Customers also stay away during floods, as a young woman from Odawna who was selling the local food *banku* explained,

> *When the flooding comes no one comes to buy it. It will be there so I end up eating it myself.*

Following a flooding event, affected residents spend considerable time (often several days) cleaning, drying and trying to salvage their belongings. As an elderly man from Gumani explained,

> *We spend about three days to clean and dry out our belongings. This affects our work activities and we lose the amount of money that would have been generated in those days.*

This loss of income does not only apply to those who are self-employed but extends to individuals who are formally employed; a young man from Alajo complained how he was fired by his employer after he had to spend time repairing the wall of his room which had collapsed.

Summary

The above analysis of the impact of extreme weather events and impaired service provision on residents of low-income areas in Accra and Tamale has highlighted how the already vulnerable population is highly sensitive to such events. They have a higher exposure to extreme heat and flooding than wealthier households due to the location and nature of their homes and workplaces. Such extreme weather events have a disproportionately large impact on their lives and livelihoods, as many have to earn on a daily basis to cover their basic needs and have no savings they can draw on.

CONCLUSIONS

This paper has shown how the impacts of extreme weather events in Ghana are being widely felt in urban environments, exacerbated by already fragile infrastructure and vulnerable inhabitants. Residents of low-income settlements in the cities of Accra and Tamale are especially vulnerable to extreme heat and flooding events due to the cascading nature of hazard impacts on urban infrastructure, their homes and livelihoods.

The data collected in homes and workplaces demonstrate that residents are actually experiencing temperatures that can be notably higher than the official records from weather stations. This is partly explained by urban heat island effects which can add a few degrees to local *outdoor* temperatures (Mensah 2017). In Accra, however, some homes have *indoor* maximum temperatures that are nearly 10°C warmer than the reference site. As this is the first time, to our knowledge, that such temperatures have been recorded systematically, this reveals how the severity of the problem of extreme heat is likely to be underestimated in Ghana and elsewhere. Our data show how some urban communities are already enduring extraordinary temperatures (>35°C) in homes, workplaces and public spaces. These heat threats are compounded by the disruption to essential infrastructure, including electricity, water and health, caused by high temperatures. Our analysis shows how the impact on the differing services can be amplified, resulting in more severe consequences. Very high temperatures and associated disruption to urban infrastructure are having dire consequences for urban residents' daily lives, mobility and income-generating activities. It is especially the urban poor who are most affected, being unable to afford the means of reducing the temperatures in their homes and workplaces, and being dependent on daily earnings for survival (Ayerakwa 2018).

Flooding is also having a major impact on urban residents. Our model simulations[5] suggest flood depths of around 2 m in some low-lying areas, even for relatively frequent (one in two years) events. Such flooding has a severe impact on urban infrastructure, affecting the supply of water and electricity and disrupting health services. During flooding events, urban residents lose property and personal items, the ability to generate an income, and face considerable costs in replacing/repairing items once the flood waters have receeded. As a consequence, the impact of the flooding extends beyond the extreme weather event itself (Parker & Thompson 2000).

As shown in this paper, the vulnerabilities of urban infrastructure and livelihoods to extreme weather events are highly connected. A deeper understanding of the climate–infrastructure–livelihoods nexus could reveal entry points for adaptation

[5] Not shown in this paper.

measures that reduce the vulnerability of low-income communities to extreme weather events in cities. For instance, forecasting systems for local extreme heat and flooding could be developed such that utilities and urban communities could take steps to limit impacts on human wellbeing, livelihoods and critical infrastructure. Low-cost building design and ventilation solutions are urgently needed for reducing indoor temperatures. Moreover, adaptation actions taken by some communities could be shared more widely. All such activities provide focal points for future research and engagement with city authorities.

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