7 (2026) 100044

Contents lists available at ScienceDirect

Urban Transitions

journal homepage: www.sciencedirect.com/journal/urban-transitions

Impacts of extreme climate events on megacities in West Africa: A case of the Greater Accra Region

Ebenezer Kwadwo Siabi [a,e,*], Amos Tiereyangn Kabobah [b,h], Komlavi Akpoti [c], Geophery Kwame Anornu [d], Peter Donkor [f,g], Samuel Agbavitor [b], Samuel Kofi Mensah [b], Sarah Elikplim Siabi [b]

[a] Earth Observation Research and Innovation Center (EORIC), University of Energy and Natural Resources, P.O. Box 214, Sunyani, Ghana
[b] Department of Civil and Environmental Engineering, University of Energy and Natural Resources, P. O. Box 214, Sunyani, Ghana
[c] International Water Management Institute (IWMI), Accra, Ghana
[d] Department of Civil Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
[e] Regional Center for Energy and Environmental Sustainability, University of Energy and Natural Resources, P. O. Box 214, Sunyani, Ghana
[f] Department of Environmental Management, University of Energy and Natural Resources (UENR), P. O. Box 214, Sunyani, Ghana
[g] School of Public Service and Governance, Ghana Institute of Management and Public Administration, P. O. Box AH50, Achimota, Accra, Ghana
[h] International Relations Office, University of Energy and Natural Resources, P. O. Box 214, Sunyani, Ghana

ARTICLE INFO

Keywords:
Climate extremes
Urban vulnerability
Perception-based risk
Food security
Public health
Energy systems
Water stress
Greater Accra region

ABSTRACT

Rapid urbanization combined with intensifying climate variability is amplifying the vulnerability of megacities across West Africa. Yet, empirical evidence capturing how climate risks are socially perceived and operationalized across critical urban systems remains limited. This study investigates the perceived impacts of extreme climate events particularly floods, heatwaves, and droughts on food security, public health, energy systems, and water resources in the Greater Accra Region (GAR), Ghana. A mixed-methods approach was employed, integrating quantitative survey data from 5800 urban residents with qualitative insights from key institutional stakeholders across climate-sensitive sectors. Results reveal a strong convergence between public and institutional perceptions, highlighting hydroclimatic extremes especially flooding and heat as dominant stressors shaping urban vulnerability. Flooding was most strongly associated with food insecurity and infrastructure disruption, while heat-related conditions were widely perceived to drive increased electricity demand, water consumption, and public health risks. Notably, 46% of respondents linked climate-related health impacts to direct household economic losses, emphasizing the socio-economic burden of climate stress at the household level. The findings further indicate that climate risks are not perceived in isolation but as interconnected pressures across urban systems, reinforcing the existence of a multi-sectoral climate vulnerability nexus in GAR. While the study does not establish causal relationships, it provides critical insight into the social salience of climate risks, which plays a decisive role in shaping adaptation behavior, policy acceptance, and institutional response. In this context, the study directly contributes to advancing Sustainable Development Goal 11 by informing resilient urban planning, and Sustainable Development Goal 13 through evidence-based climate adaptation strategies in rapidly urbanizing African cities. This study advances current knowledge by demonstrating that perception-based evidence can serve as a valuable complement to physical climate and infrastructure datasets, particularly in data-constrained contexts. Findings of the study emphasize the need for integrated urban adaptation strategies that simultaneously address energy, water, health, and food systems. Future research should couple perception-based approaches with observational and model-based datasets to better align perceived and measured climate impacts.

* Corresponding author.
E-mail addresses: ebenezer.siabi@uenr.edu.gh, siabikebenezer@gmail.com (E.K. Siabi).

https://doi.org/10.1016/j.ubtr.2026.100044
Received 17 June 2025; Received in revised form 29 April 2026; Accepted 27 May 2026
Available online 1 June 2026

1. Introduction

Significantly, climate change (CC) has emerged as one of the most pressing global challenges of the 21st century, with increasing frequency and intensity of extreme climate events such as floods, droughts, and heatwaves threatening human health, livelihoods, and ecosystems [1]. Largely, the global community, particularly through the United Nations Sustainable Development Goals (SDGs), has recognized the urgent need to address climate resilience and adaptation, especially in climate-vulnerable regions. Developing countries are disproportionately affected, not due to the scale of emissions, but largely due to limited adaptive capacities and fragile infrastructure [2].

In Africa, the impacts of climate variability and extreme weather events are particularly severe and multifaceted [3]. West Africa, in particular, is witnessing erratic rainfall patterns, rising temperatures, and an alarming increase in hydro-climatic disasters [4]. These climate variances are exacerbating poverty, food insecurity, and water scarcity across the region. Urban areas already grappling with population growth, informal settlements, and inadequate infrastructure are increasingly vulnerable to the adverse effects of extreme weather events [5]. The consequences are especially profound in low-lying coastal cities, where sea-level rise and storm surges compound the risks of flooding and erosion [6].

Ghana is no exception to these regional patterns. As one of the rapidly urbanizing countries in West Africa, it is experiencing the twin challenges of environmental degradation and urban vulnerability. The country has recorded significant climate-induced events in recent decades, with floods being the most recurrent and destructive, particularly in urban centers [7]. Within Ghana, the Greater Accra Region (GAR) the most urbanized and economically active region is increasingly experiencing the adverse impacts of extreme climate events. The region's coastal location, coupled with its dense population, poor drainage systems, and expansive informal settlements, makes it a hotspot for climate-induced disasters, particularly flooding and tidal surges [8].

Notably, the infamous June 3, 2015 twin disaster in Accra, which combined severe flooding with a fuel station explosion, stands as a tragic reminder of the fatal convergence of climate risks and infrastructural fragility. Despite various policy interventions and disaster preparedness strategies, the recurrence of such events raises critical questions about the effectiveness of climate adaptation and urban planning frameworks in the region. Therefore, understanding the localized impacts of extreme climate events in Greater Accra is crucial for informing sustainable urban planning, climate adaptation policies, and disaster risk reduction strategies in Ghana and West Africa at large.

As this study focuses on the GAR, we are presented with an opportunity to contribute significantly to SDG 13 (climate Action), fostering sustainable cities and communities that thrive in the face of an ever-evolving climate reality.

2. Methods and materials

2.1. The study area

The GAR, situated within the boundaries of Ghana, encompasses approximately 370,390.6 hectares of land and is bordered by the Central Region to the west, the Volta Region to the east, the Eastern Region to the north, and the Gulf of Guinea to the south (Fig. 1). Geographically, it spans from 6°6’34.07’’ N and 0°30’28.76’’ W to 5°28’25.76’’ N and 0°37’28.21’’ W. With GAR serving as the national capital, the region is profoundly influenced by formal governmental policies, economic dynamics, and rapid urbanization [9]. Its population stands at approximately 5455,692 million individuals, exhibiting a growth rate of 3.1%, with approximately 75% of residents being migrants [9,10].

Traditionally, the GAR serves as the ancestral home of the Ga/Dangme ethnic group and boasts a network of main drainage systems, including the Korle, Kphesie, Sakumono, and Songo lagoons [11]. Additionally, the region hosts various rivers such as the Akonyador, Ado, Densu, Odaw, Kyekudor, Kyekubor, Nasakyir, Oludor, and Sege,

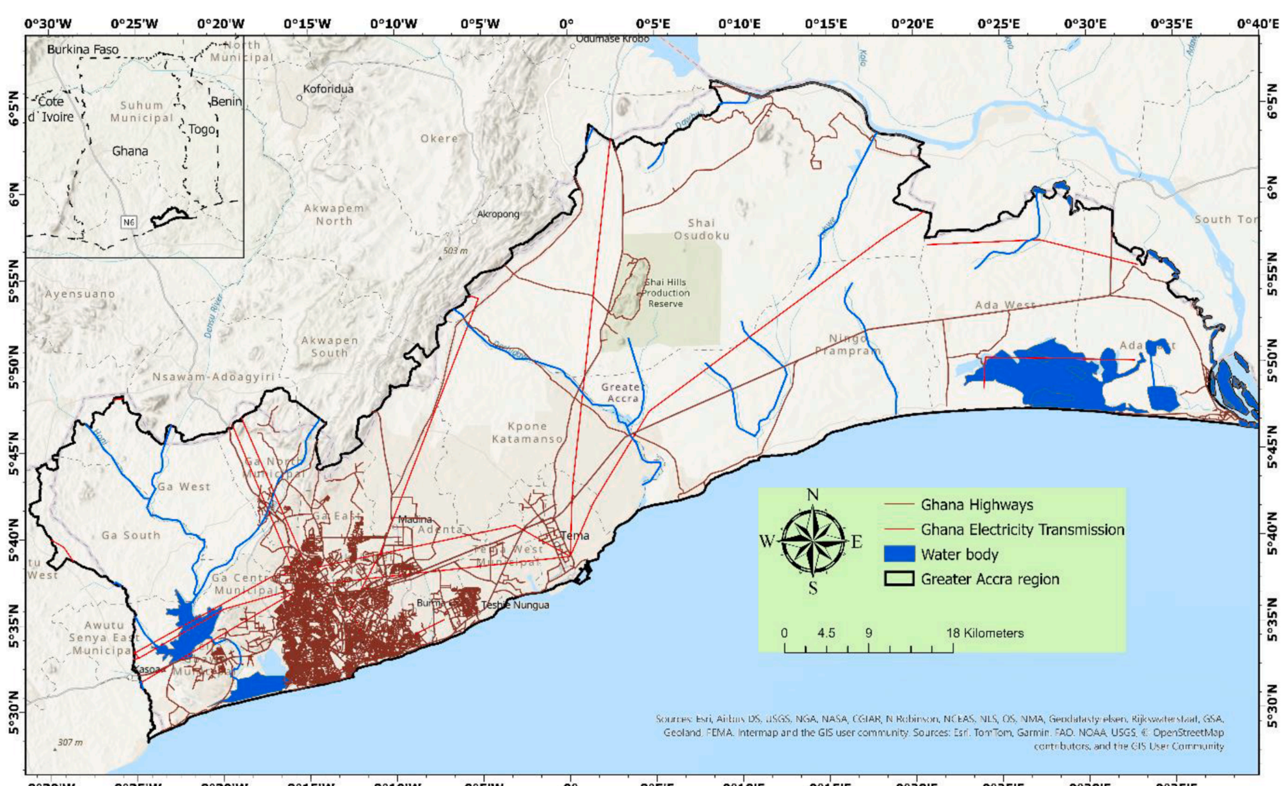

Fig. 1. Map of the study area showing the highways, electricity transmission network, and water bodies.

many of which suffer from degradation and obstruction due to urban development and waste disposal [11]. These waterways traverse geological formations consisting of quartz, schist, fluvial, and lacustrine sediments, particularly prevalent in wetland areas [11]. Predominant soil types in the region include vertisols, solonetz, luvisols, and acrisols [11]. Falling within the Dry Equatorial Climatic Zone, the GAR experiences average annual rainfall ranging from 787 mm to 1200 mm, accompanied by temperatures typically fluctuating between 22 °C and 32 °C, with a mean temperature of 26.5 °C [9,10]. The region's vegetation has adapted to its climatic conditions, characterized by low rainfall and high temperatures, resulting in a coastal savannah landscape dominated by shrubs, grasslands, and sporadic mangrove patches [9,11]. As the economic nucleus of Ghana, the GAR features urban centers primarily dedicated to service-oriented activities, while rural districts focus primarily on agricultural production and fishing [9,11].

2.2. Research design

The study adopted a mixed-methods research design, combining quantitative survey data from residents with qualitative insights from institutional stakeholders. Mixed-methods approaches are widely used in climate impact research because they allow for the integration of public perception data with expert institutional perspectives, thereby providing a more comprehensive understanding of climate-related risks and adaptation challenges.

The quantitative component examined residents' perceptions of climate change impacts on key sectors, including food security, water availability, energy reliability, and public health. The qualitative component captured perspectives from institutional stakeholders responsible for environmental management, meteorological monitoring, public health, water supply, and agricultural services.

2.3. Target population and sampling frame

The conceptual target population for this study consisted of adult residents of the Greater Accra Region as well as institutional stakeholders working in climate-sensitive sectors.

However, due to logistical and operational constraints associated with accessing a complete regional sampling frame, the actual sampling frame comprised residents accessible through tertiary educational institutions and surrounding urban communities within the region. As a result, the respondent pool included a substantial proportion of individuals with higher educational attainment, particularly university students and graduates.

Consequently, the sample does not statistically represent the entire population of the Greater Accra Region. Rather, the data reflect the perceptions of urban residents within the accessible sampling frame, many of whom possess relatively higher levels of formal education. The findings should therefore be interpreted as representing perceptions within this respondent group rather than generalized to all residents of the region.

2.3.1. Inclusion/exclusion criteria

Participants were eligible for inclusion in the study if they met the following criteria:

- Aged 18 years or older.
- Current resident of the Greater Accra Region.
- Willing to provide informed consent.
- Institutional participants working within climate-sensitive sectors in the region.

Individuals below 18 years of age and residents outside the Greater Accra Region were excluded from the study.

2.4. Sampling strategy and participant recruitment

2.4.1. Resident respondents

Given the absence of a comprehensive sampling frame covering all residents of the region, the study employed a non-probability sampling strategy, combining convenience sampling and voluntary participation.

Participants were recruited primarily through:

- tertiary institutions within the region.
- surrounding urban communities.
- voluntary participation during survey administration.

This recruitment approach facilitated the collection of a large dataset but resulted in a sample that is skewed toward individuals with higher levels of education.

While the initial study design referenced simple random sampling, the actual recruitment process corresponds more closely to convenience sampling within accessible populations. Therefore, the findings should be interpreted as reflecting perceptions among accessible urban respondents rather than a statistically representative cross-section of GAR residents.

2.4.2. Institutional stakeholders

For the qualitative component, purposive sampling was used to recruit key informants from climate-sensitive institutions, including:

- Environmental Protection Agency (EPA).
- Accra Metropolitan Assembly (AMA).
- Ghana Health Service (GHS).
- Ghana Meteorological Agency (GMet).
- Electricity Company of Ghana (ECG).
- Ghana Water Company Limited (GWCL).
- Ministry of Food and Agriculture (MoFA).

Three desk officers were selected from each institution based on their professional roles and involvement in environmental governance, climate monitoring, or infrastructure management. Purposive sampling ensured that respondents possessed domain-specific expertise relevant to the research objectives.

2.4.3. Sample size calculation

The total population of the GAR is approximately 5455,692 (GSS, 2021). For the study, a random sample approach was used to pick 5821 respondents from all areas of the region using Yamane's formula (Equation 1).

$$\text{Sample size } = \frac{N}{(1 + e^2 N)}$$

Where:

N = size of the population, e = margin of error or tolerance of 1.31%.

2.5. Survey instrument development

Quantitative data were collected using a structured questionnaire designed to capture respondents' perceptions of climate variability and its impacts across several sectors.

The questionnaire consisted of five main sections:

1. Demographic characteristics.
2. Perceived frequency of extreme weather events.
3. Climate impacts on food security.
4. Water availability and scarcity.
5. Energy reliability and electricity demand.
6. Climate-related health risks.

Questions were primarily structured using binary and Likert-scale response formats, allowing statistical evaluation of perceived climate impacts across sectors.

To ensure accessibility, the questionnaire was translated into local languages where necessary, enabling participation from respondents with varying levels of formal education.

2.6. Data collection

2.6.1. Data collection tools, pretesting and administration

To obtain quantitative data, residents were interviewed employing a structured questionnaire. Three research field assistants and three data entry experts were enlisted and skilled before pre-testing the tools for data gathering. The research assistants received one week of training, which included topics such as community entry and mobilization skills, ethics, rights, privacy, and anonymity of all respondents. The data collection instrument was thoroughly researched and transcribed into the local vernacular so that uneducated respondents could understand it. The pre-test provided the platform to evaluate responses to gain knowledge regarding relevant subjects, concepts, and ideologies, as well as unknown gathering issues. It also provided the chance to strengthen the instruments to produce dependable and well-validated results.

2.6.2. Data management and analysis

To guarantee that all interview questionnaires' work schedules distributed to research assistants were recovered, a variety of procedures were taken. For example, each set of questionnaires was identified using irreversible ink to record a unique identifier. After each day's work, the instrument was cross-checked and updated. The information gathered in the field was corrected, coded, and inputted. The data were analyzed using descriptive and analytical methods and reported in cross-tabulation, frequencies, percentages, and tables.

2.7. Ethical issues

According to Sullivan [12], social researchers are expected to ensure sanctity in their investigations and have respect and value for each respondent selected for a study. The researcher therefore took into consideration respect for respondents' right to privacy as well as being mindful of scientific misconducts such as false information and issues of plagiarism. Additionally, all aspects of the research that had the potential to influence respondents' decision to take part in the survey were disclosed by the researcher. Before commencing the survey across various districts, ethical clearance was secured from the Human Research Ethics Committee (HREC) of the University of Energy and Natural Resources (UENR) under reference CHRE/AP/268/024. Furthermore, a clear presentation detailing the study's overall and specific objectives was provided. Participants' privacy and confidentiality were strictly safeguarded, with their voluntary consent obtained, ensuring they were not obligated to disclose any information. Thus, only individuals who willingly volunteered were included in the study.

2.8. Study limitations

A key limitation of the study relates to the sampling strategy. Because respondents were primarily recruited from tertiary institutions and accessible urban communities, the sample includes a relatively high proportion of individuals with graduate-level education. Consequently, the sample does not represent the full socio-demographic diversity of the Greater Accra Region.

Therefore, the findings should be interpreted as reflecting perceptions among accessible urban respondents rather than the entire regional population. Future studies should employ probability-based sampling strategies, such as stratified household surveys, to enhance regional representativeness.

3. Results

3.1. Respondent profile

Table 1 summarizes the socio-demographic characteristics of the survey respondents. The sample was near gender-balanced, with 51.3% female and 48.7% male respondents. More than half of participants (52.0%) were aged 18–25 years, while 20.4% were aged 26–30 years, indicating that the sample was skewed toward younger adults. The educational profile of respondents was notably high. More than half (54.1%) reported graduate-level education, while 12.2% had post-graduate education and 10.5% had PhD-level education. Only small proportions reported primary (3.1%) or junior high school (3.0%) education. Occupationally, students accounted for 50.0% of the sample, followed by trained professionals (11.0%) and other occupational categories in smaller shares. This profile confirms that the survey largely captured the views of a relatively educated and student-heavy urban respondent group rather than a population-representative sample of all Greater Accra residents. Household size was most commonly 1–4 persons (44.4%), followed by 5–8 persons (34.8%). In terms of income, 39.3% of respondents preferred not to disclose their earnings. Among

Table 1
Sociodemographic characteristics of respondents.

Variable		Frequency	Percentage
Gender	Male	4620	48.7%
	Female	1180	51.3%
	Total	5800	100.0%
Household size	1–4 person household	2580	44.4%
	5–8 person household	2016	34.8%
	Nine and above person household	1204	20.8%
	Total	5800	100.0%
Age	18 - 25	3018	52.0%
	26 - 30	1181	20.4%
	31 - 35	534	9.2%
	36 and above	1067	18.4%
	Total	5800	100.0%
Education	Primary	181	3.1%
	Junior High School	173	3.0%
	Senior High School	992	17.1%
	Graduate	3136	54.1%
	Post Graduate	709	12.2%
	Ph.D	609	10.5%
	Total	5800	100.0%
Income	Below GHC500	419	7.2%
	GHC 500 - GHC 1000	646	11.1%
	GHC1001 - GHC 1500	218	3.8%
	GHC 1501 - GHC 2000	211	3.6%
	GHC 2001 - GHC 2500	749	12.9%
	GHC 2501 - GHC 3000	321	5.5%
	Above GHC 3000	959	16.5%
	Prefer not say	2277	39.3%
	Total	5800	100.0%
Occupation	Skilled Labourer	421	7.3%
	Trained Professional	639	11.0%
	Consultant	105	1.8%
	Researcher	319	5.5%
	Opinion Leader	35	0.6%
	Student	2901	50.0%
	Administrative staff	214	3.7%
	Middle Management	424	7.3%
	Upper Management	105	1.8%
	Other	637	11.0%
	Total	5800	100.0%
Years of experience	1-5 years	3871	66.7%
	6-10 years	425	7.3%
	11-15 years	535	9.2%
	16 years and above	969	16.7%
	Total	5800	100.0%

those who did, the largest category was above GH₵3000 (16.5%), followed by GH₵500–1000 (11.1%). Most respondents (66.7%) reported 1–5 years of work experience, consistent with the relatively young age structure of the sample.

3.2. Perceived perceptions of climate-related impacts on food security

A substantial proportion of respondents perceived floods to be associated with food scarcity, with 64% agreeing or strongly agreeing with this statement. Similarly, 38% associated drought with food scarcity, and 37% linked low rainfall to food shortages. By contrast, opinions were more divided for heatwaves, where 34% were uncertain, 33% agreed, and 23% disagreed (Fig. 2). Perceptions of high night-time temperatures were also marked by uncertainty. For heavy rainfall, the largest share of respondents (41%) disagreed that it contributes to food scarcity, although 31% agreed, suggesting no clear consensus on this specific pathway. Taken together, these findings suggest that respondents most readily associate food insecurity with water-related extremes, especially flooding, drought, and insufficient rainfall, rather than with all forms of temperature and precipitation anomalies.

Institutional interviews were broadly consistent with these perceptions. Officials from the AMA emphasized drainage improvement, enforcement against construction in waterways, and green infrastructure as part of broader efforts to manage flood impacts while supporting urban agriculture. Likewise, officers from the MoFA described ongoing responses to drought and heat stress, including the promotion of drought-tolerant crops, irrigation efficiency, climate-smart agriculture, extension support, and climate information services for farmers. These institutional accounts support the interpretation that both residents and officials perceive hydroclimatic stressors as central to food system vulnerability in the region.

3.3. Perceptions of climate-related public health risks

Survey responses indicate that many participants perceive extreme climate conditions as contributing to health risks and, in some cases, fatalities in their communities (Fig. 3). The strongest perceptions were reported for floods, heavy rainfall, heatwaves, and high daytime temperatures.

Nearly half of respondents (46.4%) agreed that floods are associated with health risks and fatalities, while 43% expressed similar views for heavy rainfall. Heatwaves were also widely perceived as harmful, with 48% agreeing that they contribute to climate-related health risks. For high daytime temperatures, 39% agreed and about 30% remained uncertain. Perceptions were more mixed for drought, with 39% uncertain, 30% in agreement, and 22% in disagreement. Views on high night-time

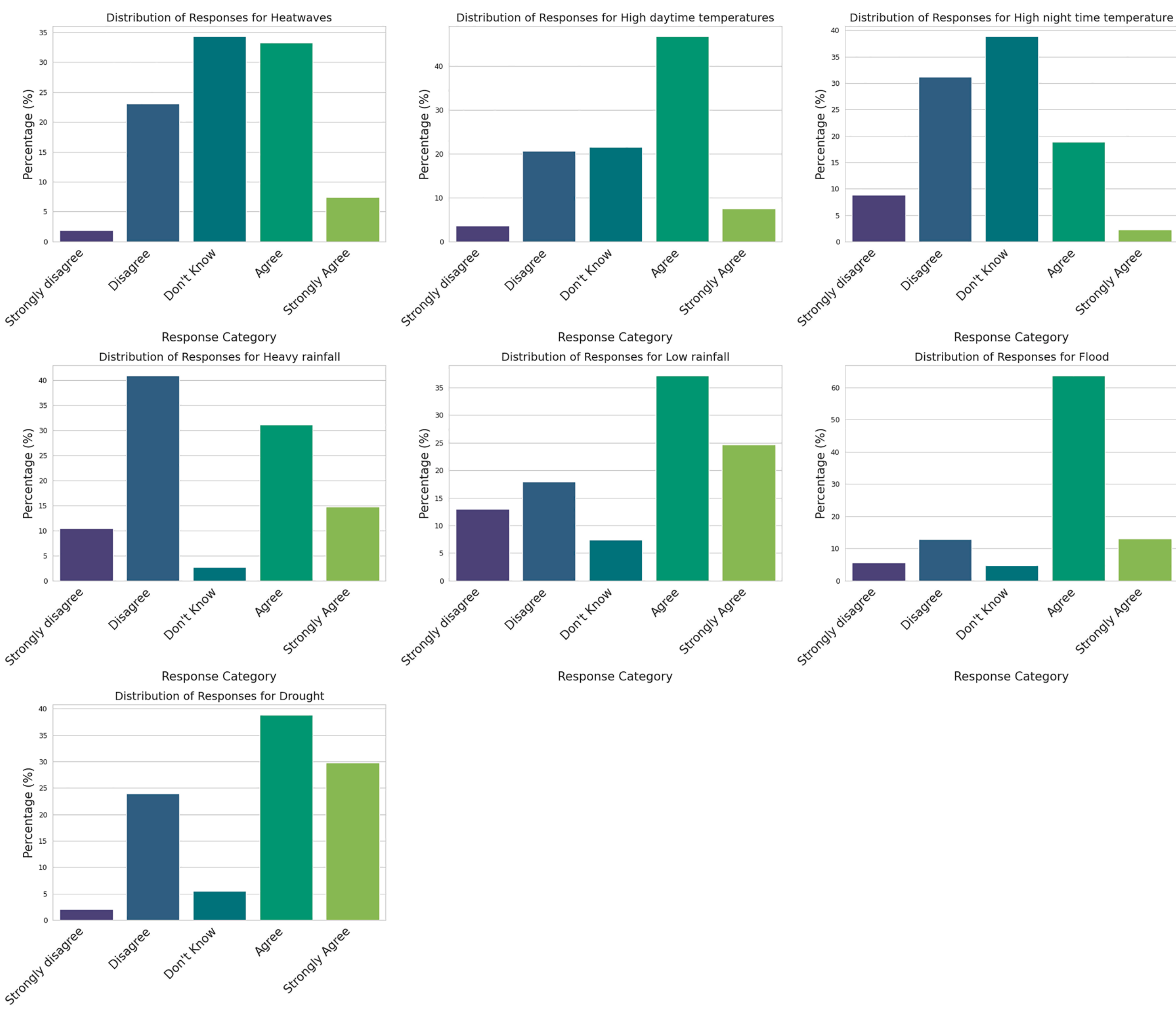

Fig. 2. Respondent's response to climate extreme effects on food scarcity.

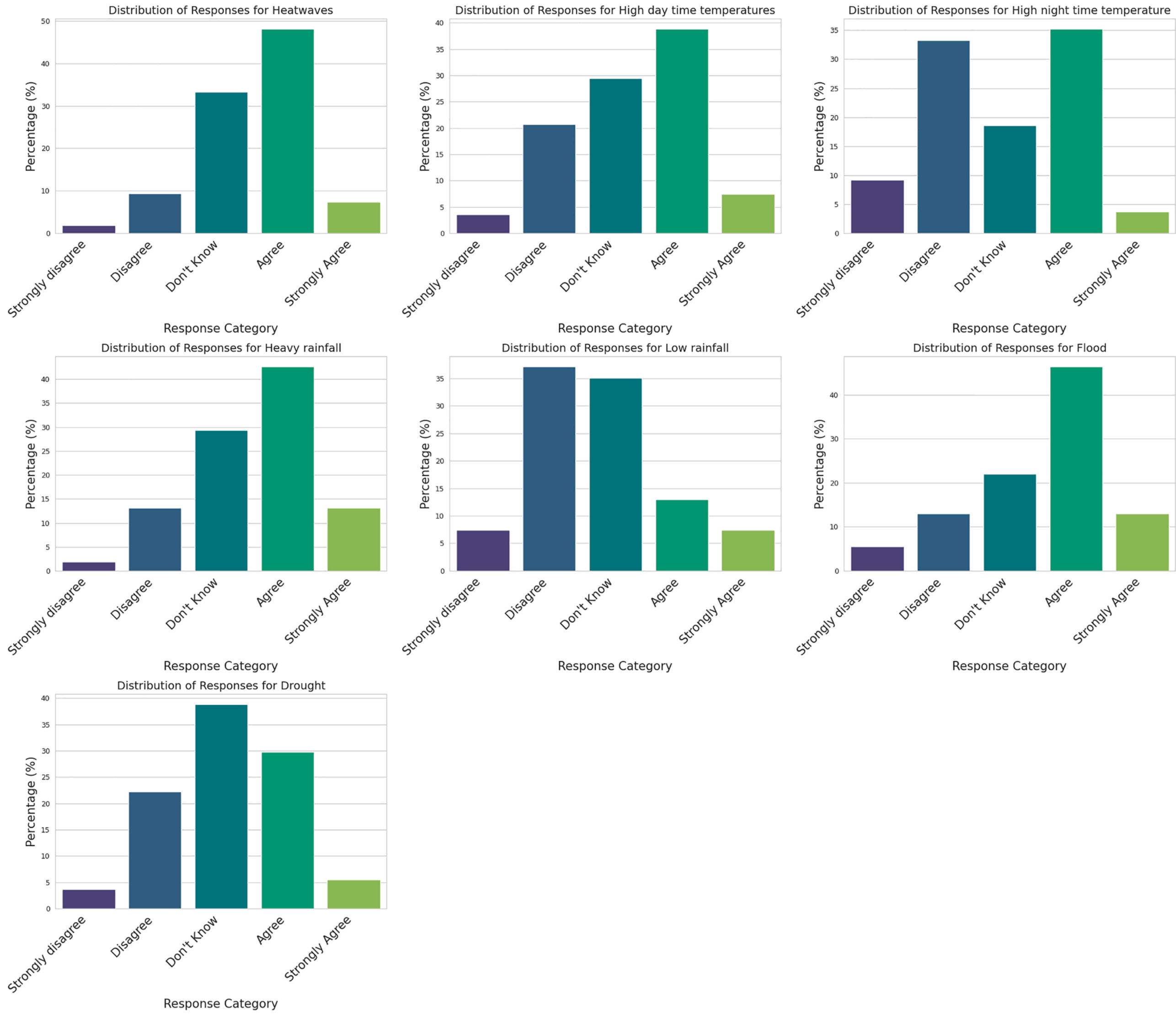

Fig. 3. Respondent's response to climate extreme risk factors for the likelihood of public health hazard.

temperatures were similarly divided.

These results suggest that respondents perceive both hydrological hazards and heat-related conditions as relevant to public health vulnerability in Greater Accra. Importantly, the survey captures how residents interpret and prioritize these risks; it does not establish actual epidemiological or causal relationships.

Respondents also reported substantial economic burdens associated with climate-related illness. The most frequently reported cost category was GH₵100–1000, cited by 46.4% of respondents, followed by GH ₵2001–3000 (18.4%) and GH₵1001–2000 (16.6%) (Table 2). These responses indicate that many participants perceive climate-sensitive health events as having tangible household-level financial consequences.

When asked about adaptation priorities, respondents most frequently identified awareness campaigns (33.2%) and community health education (27.9%) as the most important strategies for reducing disease burden and fatalities under changing climatic conditions (Table 3). Infrastructure strengthening, emergency response capacity, and health system readiness were mentioned less often.

Interviews with institutional stakeholders echoed these priorities. Officials from the GHS highlighted surveillance strengthening, rapid response, public education, and climate-health preparedness,

Table 2
Lost due to climate-related health risks and fatalities.

Cost (GH₵)	Frequency	Percent
100–1000	2693	46.4
2001–3000	1068	18.4
1001–2000	961	16.6
5001 & above	541	9.3
3001–4000	324	5.6
4001–5000	213	3.7
Total	5800	100.0

Table 3
Disease control and prevention ability construction to adapt to climate change are most important.

Disease control and prevention	Frequency	Percent
Awareness campaign	1926	33.2
Community Health Education	1617	27.9
Infrastructure development/refinement (e.g. improve disease surveillance platform, online disease notification system)	864	14.9
Technical know-how for emergency response	748	12.9
Health system readiness	430	7.4
Staff training	215	3.7
Total	5800	100.0

particularly for vector-borne and heat-related illnesses. Officers from the EPA similarly referenced air quality monitoring, public advisories during dust and heat events, cleaner energy promotion, and inter-agency coordination to protect vulnerable populations.

3.4. Perceptions of climate-related changes in household electricity demand

Respondents commonly associated hot conditions with higher household electricity consumption (Fig. 4). The strongest perceptions were reported for high daytime temperatures, followed by high night-time temperatures and heatwaves. For high daytime temperatures, 43% of respondents agreed and 22% strongly agreed that they increase electricity use. Likewise, 31% agreed and 20% strongly agreed that heatwaves contribute to higher electricity consumption. For high night-time temperatures, 33% agreed and 18% strongly agreed. By contrast, heavy rainfall was generally not perceived as a major driver of increased electricity use, with 44% disagreeing. Perceptions of low rainfall, flooding, and drought were less uniform, with relatively high levels of uncertainty.

These patterns indicate that respondents most strongly associate rising electricity demand with heat-related discomfort and cooling needs, rather than with all climate extremes equally.

Reported coping technologies reinforce this interpretation (Fig. 5). Ceiling fans were the most commonly preferred cooling option (44%), followed by standing fans (33%) and air conditioners (13%). Around one-fifth of respondents reported not using any specific cooling appliance. In contrast, most respondents (51%) reported using no heating device during cooler conditions, underscoring the asymmetry between heat-related and cold-related household energy needs in the region.

3.5. Perceptions of climate-related disruptions to electricity supply

Respondents also reported that several climate-related conditions are perceived to contribute to electricity cuts or outages in their communities (Fig. 6). Perceptions were strongest for heavy rainfall, floods, heatwaves, and high daytime temperatures. Approximately 41% of respondents agreed that heavy rainfall results in electricity cuts or outages, while 37% expressed similar views for flooding. Heatwaves and high daytime temperatures were each linked to outages by about 37% of respondents. For high night-time temperatures, views were more divided, with uncertainty and disagreement each accounting for sizeable shares. Low rainfall and drought were also characterized by relatively high uncertainty. In terms of outage duration, 71% of respondents reported typically experiencing outages lasting 1–5 h, followed by 6–10 h (Fig. 7; Table 4). The largest counts of reported outages were recorded in

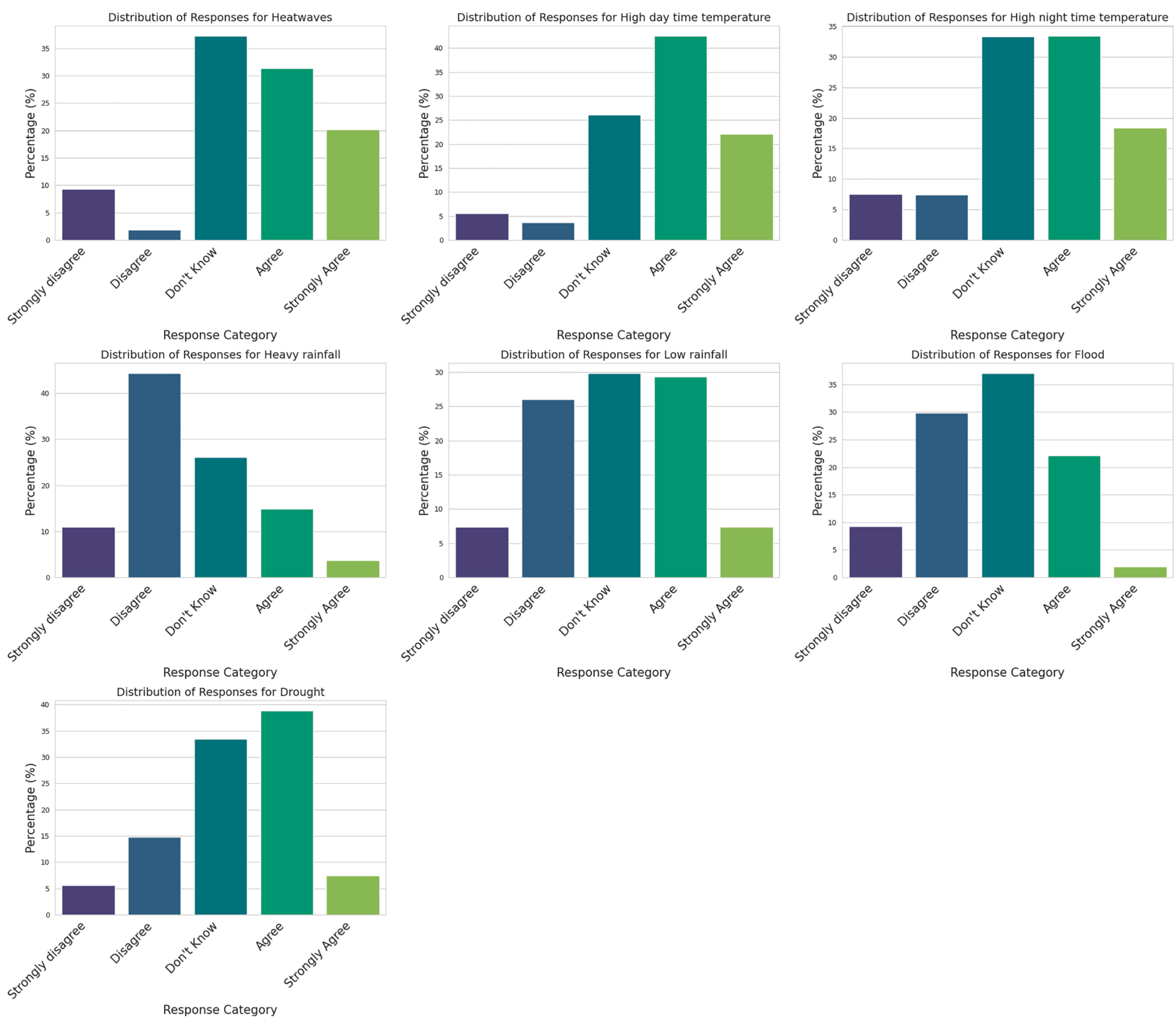

Fig. 4. Respondent's response to extreme climate events that increase electricity consumption.

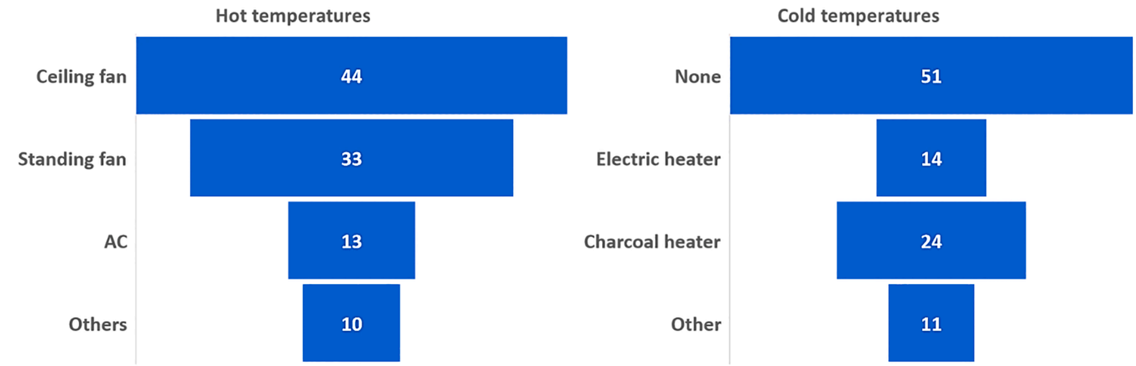

Fig. 5. Cooling and heating solutions in the Greater Accra region.

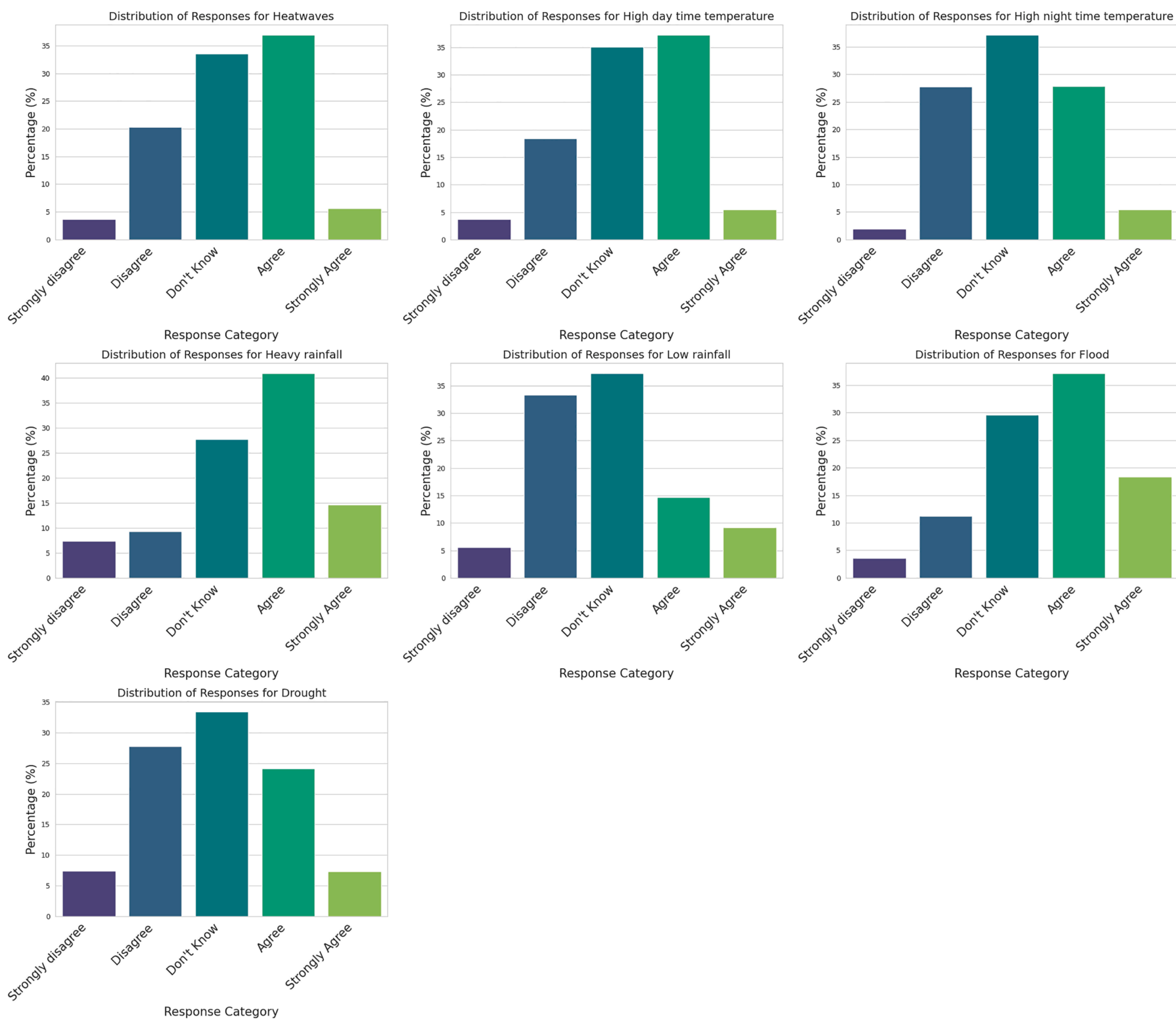

Fig. 6. Respondent's response to extreme climate event that increases electricity cuts or outages.

Ablekuma Central, Weija Gbawe, and Ga South.

Institutional perspectives from the ECG were broadly aligned with these public perceptions. ECG officials noted that heat can increase electricity demand and reduce system efficiency, while floods can damage transformers and transmission lines. They further described ongoing efforts to improve grid resilience through infrastructure upgrades, reinforced transmission systems, smart-grid monitoring, and integration of renewable energy sources.

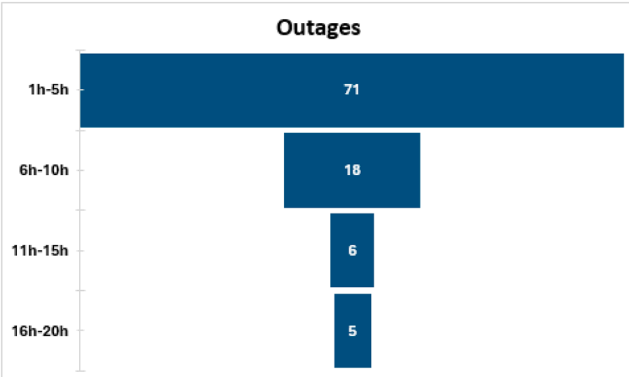

Fig. 7. Duration of power outages in the Greater Accra region.

Table 4
Duration of power outages per district in the Greater Accra region.

District	1–5 h	6–10 h	11–15 h	16 and above	Total
Ga South	358	107	32	27	524
Weija Gbawe Municipal	404	99	34	31	568
Ga Central Municipal	179	43	11	8	241
Ablekuma North	125	33	14	12	184
Ablekuma West Municipal	162	45	10	8	225
Ablekuma Central Municipal	504	155	49	30	738
Accra Metropolitan	118	18	11	14	161
Ablekum South	155	34	15	122	216
Ashiedu Keteke	108	25	6	6	145
Okaikoi South	177	42	9	14	242
Korle Klottey	91	10	7	4	112
Ayawaso Central Municipal	76	26	1	7	110
Ayawaso East Municipal	70	28	5	11	114
Ayawaso North Municipal	88	14	6	9	117
La Dadekotopon Municipal	76	20	7	6	109
Ledzokuku	79	19	9	6	113
Adenta Municipal	82	14	4	3	103
Krowor	80	20	3	3	106
Ayawaso West Municipal	75	29	6	9	119
Okaikoi North	81	26	3	5	115
Ga North	75	24	2	8	110
Ga West	77	20	1	9	109
Ga East	77	26	8	7	118
La Nkwantanan-Madina Municipal	72	22	13	6	113
Kpone Katamanso	76	20	1	3	100
Ashaiman	77	17	7	5	106
Tema West	77	23	2	6	108
Tema Central	78	17	11	10	116
Tema East	80	16	6	5	107
Ningo Prampram	80	21	4	12	117
Shai Osuddoku	80	21	5	9	115
Ada West	82	17	7	3	109
Ada East	72	19	13	8	112
Total	4091	1071	322	316	5800

3.6. *Perceived damage to household appliances during extreme climate conditions*

Respondents further indicated that extreme weather and temperature conditions are perceived to damage household appliances (Fig. 8). Among the conditions presented, heavy rainfall was most strongly linked to appliance damage. More than half of respondents (52%) agreed that heavy rainfall causes major damage to household appliances. High daytime temperatures were also frequently perceived as damaging, with 38% in agreement. Perceptions of heatwaves were more mixed where 36% were uncertain, 33% agreed, and 11% strongly agreed. By contrast, low rainfall and drought were less consistently linked to appliance damage, with large shares of respondents either uncertain or in disagreement.

When asked which appliances were most commonly damaged (Fig. 9), respondents most frequently mentioned televisions (23%), followed by refrigerators (19%) and bulbs (15%). Other cited items included computers, cell phones, air conditioners, and fans.

3.7. *Perceptions of climate-related water stress and household water use*

Survey responses point to a strong perceived relationship between hot weather, household water demand, and water stress in Greater Accra. Respondents reported noticeable differences in bathing frequency, domestic water use, and drinking water consumption between hot and cold conditions (Table 5). During hot periods, 59.4% of respondents reported bathing twice daily, while 25.7% reported bathing three times daily. During colder conditions, the dominant pattern remained twice-daily bathing (65.0%), but the share bathing three times daily dropped substantially (5.5%). A similar pattern was observed for domestic water use. During hot periods, the most common category was 150–250 litres/day (42.6%), whereas during cold periods the largest share of respondents (64.9%) reported lower daily use of 1–125 litres.

Drinking water consumption also increased under hotter conditions. During hot weather, 42.6% of respondents reported consuming 4–6 litres/day, whereas during colder conditions 60.8% reported consuming 1–3 litres/day. These findings suggest that respondents perceive hot conditions as increasing both general household water demand and personal water intake.

Institutional interviews with the GWCL supported these perceptions. GWCL officials emphasized rising demand, treatment and infrastructure expansion, improved filtration, conservation campaigns, alternative sources such as rainwater harvesting and desalination, and emergency response planning for climate-related disruptions.

4. Discussion

4.1. *Interpretation of the evidence and respondent profile*

The findings of the study reveal the social salience of climate risks, the ways these risks are experienced and understood in everyday life, and the extent to which public perceptions align with institutional concerns.

The respondent profile is important for interpreting the results. The sample was nearly gender-balanced, with a slight female majority, and was dominated by younger adults, many of whom had relatively high educational attainment. This pattern is broadly consistent with the urban demographic structure of Greater Accra, where women constitute a slight majority and educational attainment is generally higher than in many rural settings [9]. Household sizes in the present study were also broadly consistent with regional census patterns reported by the Ghana Statistical Service [9]. At the same time, the sample included a substantial proportion of tertiary students and graduates, which suggests that the findings reflect the perceptions of a relatively educated, urban-accessible population rather than a fully representative cross-section of all GAR residents. This distinction matters because education, age, and occupational status can shape climate awareness, risk interpretation, and reported adaptation preferences.

4.2. *Perceived climate-related pressures on food security*

The survey findings indicate that respondents perceived flooding, drought, low rainfall, high daytime temperatures, and water pollution as important contributors to food insecurity in GAR. These are best interpreted as perceived pathways of vulnerability, not as demonstrated causal effects on agricultural productivity or food availability. Nevertheless, the pattern of responses is consistent with the broader literature showing that food systems in climate-sensitive environments are strongly influenced by rainfall variability, heat stress, flooding, and

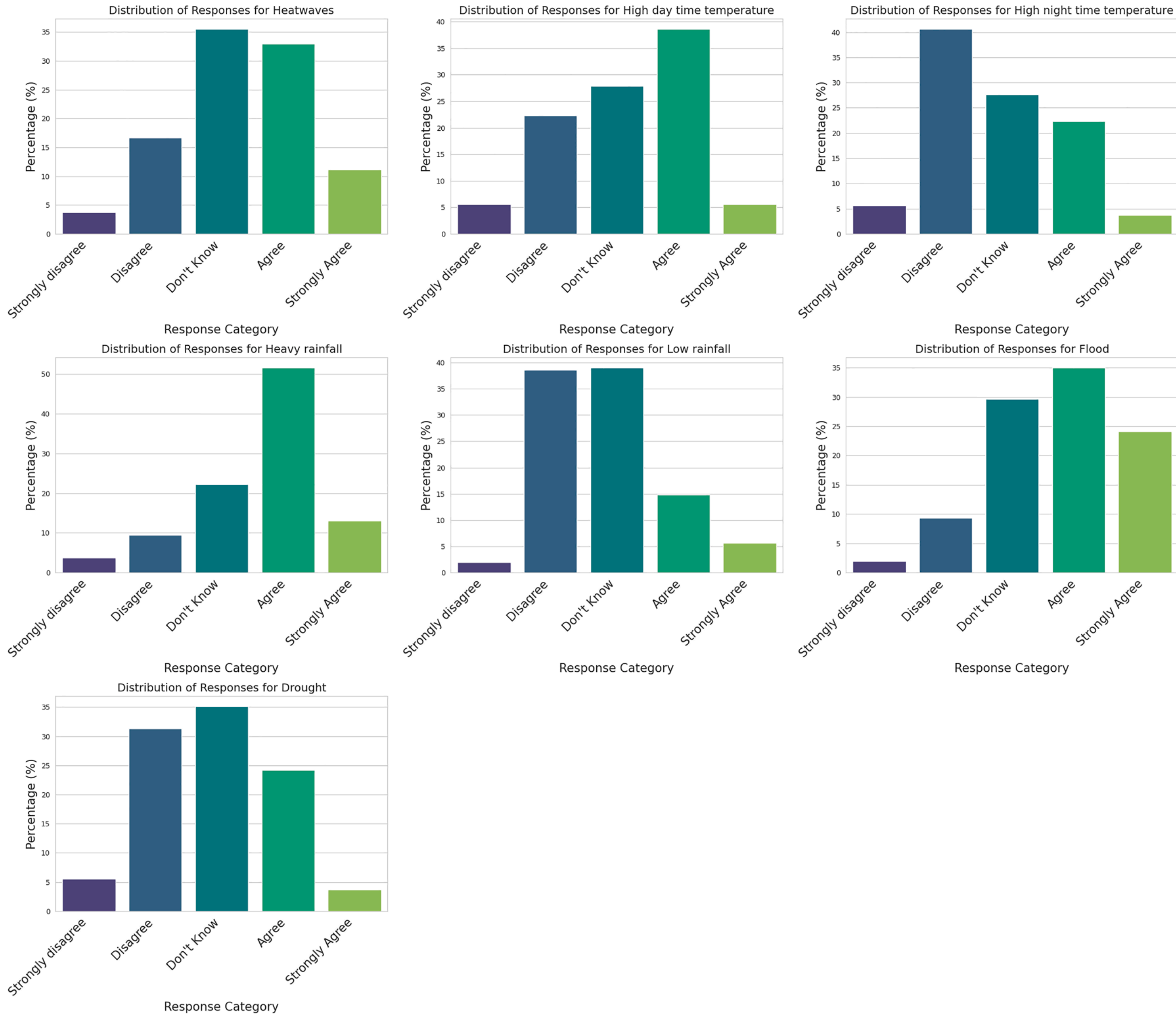

Fig. 8. Respondent's response to the influence of extreme climate on household appliances.

water quality constraints [13–18].

The prominence of low rainfall and drought in respondents' views is unsurprising in the context of southern Ghana's climate sensitivity. Prior work has shown that rainfall deficits and prolonged dry spells undermine soil moisture, reduce crop yields, and intensify household food insecurity, especially where agricultural systems are already resource-constrained [15–21]. In the specific case of GAR, recent scenario-based assessments project increasing thermal stress and altered rainfall patterns, conditions that may heighten concern over food access and production stability [22,23]. Respondents' perceptions therefore appear to reflect a broader awareness that food supply is vulnerable to hydroclimatic stress.

Similarly, the strong association respondents made between flooding and food scarcity aligns with studies showing that urban and peri-urban flooding can damage agricultural land, disrupt food transport and market access, contaminate irrigation water, and reduce the quality and safety of food products [24,25]. In rapidly urbanizing settings such as GAR, these pressures may be particularly visible because climate hazards intersect with informal development, drainage obstruction, and land-use change. The present findings suggest that respondents perceive food insecurity not only as a rural agricultural issue, but also as an urban systems issue connected to flooding, water contamination, and infrastructure stress.

Institutional responses from AMA and MoFA reinforce this interpretation. Their emphasis on drainage management, climate-smart agriculture, irrigation, drought-resilient crop varieties, and extension support suggests that official actors also understand food security through the lens of compound urban-climate vulnerability. Thus, while the present study does not establish actual crop loss or measured food shortages, it demonstrates that both residents and administrators perceive climate variability as a meaningful threat to food-system stability in Greater Accra.

4.3. Perceived climate-sensitive public health risks

Respondents also perceived strong links between extreme climate conditions and a range of public health risks, including heat-related illness, exacerbation of pre-existing conditions, injuries, fatalities, waterborne disease, vector-borne disease, and mental health stress. These findings should again be framed as subjective risk perceptions and reported experiences, but they resonate with established evidence that climate hazards can affect health directly and indirectly through heat exposure, environmental contamination, service disruption, and psychosocial stress [25,26].

The salience of heat-related risks in the survey is consistent with studies from Ghana and elsewhere showing that extreme heat is socially

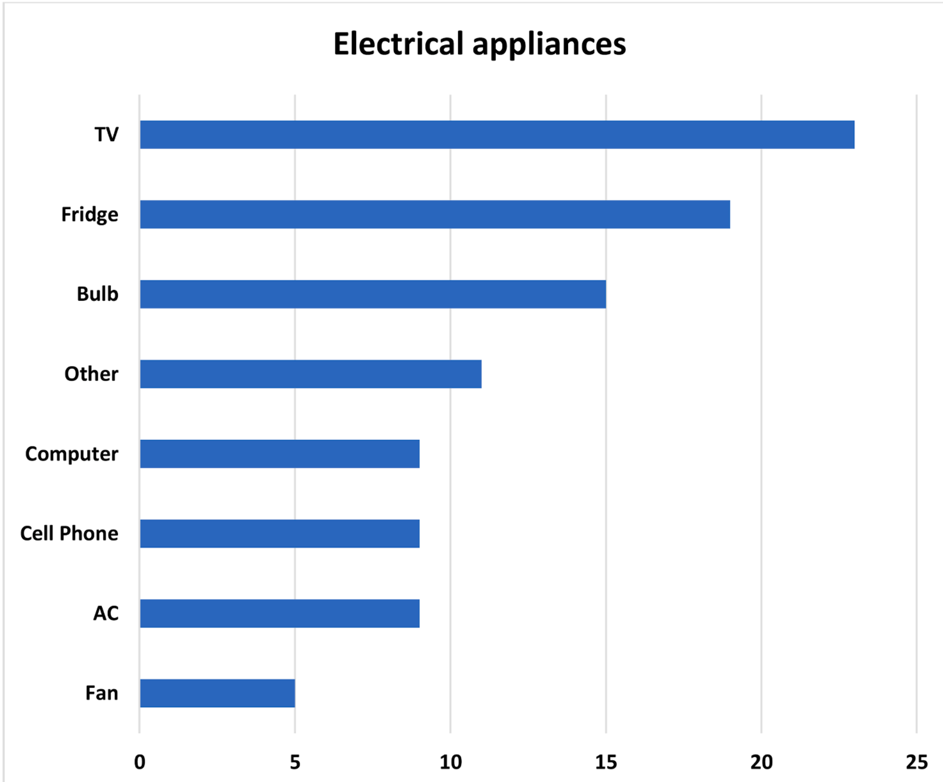

Fig. 9. Electrical appliances damaged by extreme climate extremes.

Table 5
Respondents' water usage in the Greater Accra region.

Variable		Count	Column N %
Bathing frequency in hot temperatures	Once	216	3.7%
	Twice	3448	59.4%
	Three times	1493	25.7%
	Four times	429	7.4%
	Five times	108	1.9%
	Six times	106	1.8%
	Other	0	0.0%
Bathing frequency in cold temperatures	Once	1496	25.8%
	Twice	3768	65.0%
	Three times	321	5.5%
	Four times	215	3.7%
	Five times	0	0.0%
	Six times	0	0.0%
	Other	0	0.0%
Water usage for household keeping in a day in hot temperatures	1–125 (Litres)	1941	33.5%
	150–250	2468	42.6%
	275–375	1177	20.3%
	400–500	214	3.7%
Water usage for household keeping in a day in cold temperatures	1–125 (Litres)	3762	64.9%
	150–250	1285	22.2%
	275–375	431	7.4%
	400–500	322	5.6%
Drinking water consumption during hot temperatures	1–3 (Litres)	1821	32.0%
	4–6	2471	42.6%
	7–10	1168	20.1%
	11–13	322	5.6%
Drinking water consumption during cold temperatures	1–3 (Litres)	3528	60.8%
	4–6	1727	29.8%
	7–10	437	7.5%
	11–13	108	1.9%

disruptive and places pressure on health systems, especially in dense urban areas where housing quality, limited ventilation, and service interruptions magnify exposure [26,27]. Likewise, the perceived influence of flooding and heavy rainfall on health outcomes is compatible with evidence linking such events to injury, displacement, water contamination, diarrheal disease, and vector proliferation [25,28]. The broad agreement among respondents that climate hazards are relevant to health suggests that these risks are already socially legible at the community level, even where respondents may not distinguish between direct climatic drivers and the secondary consequences of poor drainage, sanitation failures, or infrastructure breakdown.

The findings related to mental health are particularly noteworthy. Climate events such as flooding, repeated disruption, household loss, uncertainty, and illness can generate anxiety, distress, and trauma, especially where coping resources are limited. Although this study did not clinically measure mental health outcomes, the fact that respondents identified them as salient suggests that psychosocial impacts may be an important, yet often under-recognized, dimension of climate vulnerability in the urban Ghanaian context. This interpretation is consistent with the expanding literature on the cascading and non-linear health effects of extreme events [25].

Respondents also reported financial losses associated with climate-related ill health, further indicating that perceived health risks are not abstract concerns but are embedded in household economies. This aligns with prior work showing that climate-sensitive disease burdens and flooding can impose medical, livelihood, and service-related costs on affected populations [26,28]. The adaptation preferences identified in the survey especially awareness campaigns, community health education, disease surveillance, and system preparedness suggest that respondents understand health adaptation not only as a matter of clinical care, but also as a function of public information, institutional readiness, and preventive action.

This interpretation is reinforced by the views of GHS and EPA officials, who emphasized surveillance, advisories, pollution monitoring, and inter-agency coordination. The convergence between public and institutional perceptions is important: it suggests that climate-health concerns in GAR are recognized across scales, even if the present study does not measure objective disease incidence or attributable mortality.

4.4. Perceived effects on electricity demand and supply

The results further show that respondents commonly perceived heatwaves, high daytime temperatures, and high night-time temperatures as drivers of increased household electricity consumption. This is best understood as a perception grounded in lived experience, particularly the need for thermal comfort through cooling technologies. The predominance of fans and, to a lesser extent, air conditioners as preferred cooling responses supports this interpretation. Similar patterns have been documented in studies showing that high temperatures increase cooling demand and shift electricity-use behavior in urban households [27].

These perceptions are also consistent with the broader energy-climate literature, which has shown that high temperatures tend to increase electricity demand while potentially reducing generation and transmission efficiency [29–31]. However, it is important to distinguish between this literature-based plausibility and the present dataset: the current study does not quantify electricity consumption, peak load, or appliance-level usage. Rather, it shows that respondents themselves perceive hot conditions as intensifying energy demand and household discomfort.

A related pattern emerged in relation to electricity supply disruptions. Residents associated heavy rainfall, flooding, heatwaves, and high daytime temperatures with outages, while institutional stakeholders from ECG described transformer damage, line failures, and heat-related system stress as important operational concerns. These converging perceptions align with studies showing that flood exposure and coastal hazards can damage critical energy infrastructure, while high temperatures can impair generation performance and raise demand at the same time [27–33]. The present study therefore suggests a socially recognized energy vulnerability nexus, in which both demand-side stress and supply-side fragility are understood as climate-sensitive.

The reported district-level and duration-based patterns of outages add further nuance, but they should not be interpreted as a formal spatial reliability assessment. Rather, they indicate where respondents most frequently reported experiencing climate-linked service interruptions. In this sense, the findings are valuable for understanding how climate stress is perceived at the household level and where service insecurity may be most socially visible.

The findings on household appliance damage also fit within this broader discussion. Respondents particularly associated heavy rainfall and high temperatures with damage to televisions, refrigerators, bulbs, and other electrical devices. Although the study does not technically verify the causes of such failures, these responses suggest that residents perceive climate variability not only as a matter of service interruption, but also as a threat to household assets. This is an important dimension of everyday climate vulnerability because it links infrastructure instability to direct household economic loss.

4.5. Perceived water insecurity under climate stress

Water emerged as another central domain in which respondents perceived climate stress to be consequential. Survey participants reported higher bathing frequency, greater household water use, and increased drinking water consumption during hot conditions, while also identifying low water levels, flood-related pipe damage, and water contamination as perceived drivers of water scarcity. These findings should not be read as hydrological proof of scarcity; rather, they indicate that respondents perceive both demand-side intensification and supply-side disruption during extreme climatic conditions.

The reported rise in water use during hot weather is plausible and consistent with established norms around minimum domestic water needs and thermal comfort. The World Health Organization has long noted that basic household well-being requires adequate access to safe water, typically within a range that varies by use and service conditions [34]. At the same time, development literature has shown that water insecurity is not only a matter of absolute quantity, but also of access, affordability, infrastructure condition, and service reliability [35]. In this regard, the survey findings suggest that respondents experience hot weather as a period of intensified domestic water demand, which may deepen perceptions of scarcity where services are already fragile.

This interpretation is supported by the Ghanaian context. Reviews of national water resources have highlighted the growing stress imposed by population growth, climate variability, infrastructure deficits, and competing sectoral demand [36]. Rising temperatures and prolonged dry conditions can increase evaporation and pressure available supplies, while floods may damage pipelines and contaminate sources, thereby reducing effective access to potable water [27,36]. Respondents' emphasis on flood-related contamination and pipe damage therefore appears to reflect a realistic understanding of how climatic events can interact with aging or overstretched urban water systems.

The perspectives of GWCL officials closely mirrored these public views. Their focus on treatment expansion, infrastructure upgrading, conservation messaging, alternative water sources, and emergency response planning indicates that water managers also perceive climate variability as intensifying the challenge of securing reliable and safe urban supply. The agreement between residents and institutional actors is particularly important here because it suggests that climate-related water stress is not merely a household perception but is also recognized within service governance structures.

Generally, the study indicates that water insecurity in GAR is perceived through two interlinked pathways: higher consumption needs during hot periods and greater risk of service disruption or contamination during floods and other extremes. This framing is especially relevant for adaptation policy because it points to the need for integrated responses that address both demand management and infrastructure resilience.

5. Implications of a perception-based climate risk study

A central contribution of this study lies in demonstrating that climate risk in Greater Accra is already socially articulated across multiple sectors. Residents and institutional stakeholders consistently identified food systems, health, electricity, and water as vulnerable to climate-related stress. This convergence matters for adaptation planning because public risk perception often shapes behavioral responses, trust in institutions, and willingness to support policy interventions.

At the same time, the study also highlights the importance of analytical caution. The findings do not demonstrate direct climatic causality, nor do they quantify the objective magnitude of sectoral impacts. Instead, they capture the perceived associations through which climate change is understood in everyday urban life. This distinction is not a weakness; rather, it defines the contribution of the study. Perceptions are central to adaptation because they influence whether households prepare, whether communities prioritize certain interventions, and whether institutional messaging resonates with public experience.

The results therefore suggest that future research in GAR would benefit from combining perception-based surveys with observational climate records, epidemiological data, infrastructure performance datasets, and geospatial exposure analysis. Such integration would help distinguish between socially perceived risk and measured impact, while also identifying where the two converge or diverge. For policy, the current evidence already points toward practical priorities: flood-resilient urban planning, heat-health preparedness, climate-smart food systems, more resilient electricity infrastructure, and adaptive water supply management.

5.1. Policy implications

Because this study is based on reported perceptions and institutional views, its policy relevance lies primarily in identifying the climate-related risks that are most socially salient in the GAR, rather than establishing the objective magnitude or causal mechanisms of those risks. The results therefore support policy action in areas where residents and institutional stakeholders showed clear convergence, namely heat-related energy stress, flood-related service disruption, perceived health vulnerability, food-system insecurity, and water stress. These findings are particularly valuable for adaptation planning because policy effectiveness often depends not only on physical exposure, but also on how risks are recognized and prioritized by households and service providers [25–27].

5.1.1. Energy

The survey and stakeholder interviews indicate that residents widely perceive high temperatures, heatwaves, flooding, and heavy rainfall as important stressors on household electricity use and supply reliability. The most immediate policy implication is that urban energy planning in GAR should incorporate climate-sensitive demand and service resilience considerations, especially for periods of extreme heat and flood-related infrastructure disruption. This is consistent with evidence that high temperatures can increase cooling demand, while flood exposure and thermal stress can disrupt electricity infrastructure and system performance [27–32].

In practical terms, the data support two priorities. First, demand-side adaptation should focus on household thermal comfort and efficient cooling, given the prominence of fans and other cooling devices in respondents' reported coping strategies. Second, supply-side adaptation should prioritize service continuity during extreme events, particularly in flood-prone and heat-stressed areas where residents reported repeated outages. The present study does not identify the engineering causes of outage events, but it clearly shows that energy insecurity is already perceived as a climate-related concern at household level.

5.1.2. Health

Respondents and institutional stakeholders consistently identified heat, flooding, heavy rainfall, and disease-related exposures as important public health concerns. Therefore, there is the need to strengthen risk communication, community health awareness, and preparedness for climate-sensitive health events. This is especially warranted because awareness campaigns and community health education were the adaptation options most frequently prioritized by respondents. These findings align with existing evidence that climate-related health risks in urban Ghana are shaped not only by hazard exposure, but also by health-system readiness, public information, and service accessibility [25,26].

The findings also suggest that climate-related health risks are perceived to have household-level economic consequences, as many respondents reported financial losses associated with climate-sensitive illness. Policy responses should therefore pay attention to the social and economic burden of health shocks, particularly among already vulnerable groups. However, because this study did not measure clinical outcomes or health expenditure directly, the most defensible implication is not broad health-sector reform, but rather targeted climate-health preparedness, surveillance, and public education, consistent with the concerns raised by both residents and health-sector officials [25,26].

5.1.3. Food

The findings show that respondents most strongly associated flooding, drought, low rainfall, and high temperatures with food scarcity. The main policy implication is that food-security planning in GAR should explicitly recognize that residents perceive food risk through the lens of climate variability and urban environmental stress, rather than through agricultural production alone. This perception is important because it suggests that food insecurity is socially understood as a compound problem involving water availability, flood impacts, market disruption, and environmental degradation. That interpretation is consistent with the literature on drought, rainfall variability, and climate-related food insecurity in African settings [13–24].

The evidence from this study most directly supports policies that improve local food-system resilience to climate stress, particularly through better integration of urban planning, flood management, and climate-smart agricultural support. The interviews with institutional actors further reinforce the relevance of adaptation measures related to irrigation, drought-tolerant crops, and support for urban agriculture. Still, the present dataset does not quantify actual crop losses or food supply deficits, so the policy message should remain focused on perceived vulnerability and adaptation priorities, not measured food-system outcomes.

5.1.4. Water

Water emerged as one of the clearest areas of climate concern in the survey. Respondents reported higher household water use during hot conditions and identified low water levels, flood-related pipeline damage, and water contamination as important perceived contributors to water scarcity. The direct policy implication is that water planning in GAR should account for both climate-sensitive demand pressures and service disruptions during extreme events. This interpretation is consistent with existing evidence that water stress in Ghana is shaped by the interaction of climate variability, infrastructure limitations, and rising urban demand [27,36].

Accordingly, the strongest data-supported priorities include improving the resilience of water supply systems to flood disruption, strengthening public communication on efficient water use during hot periods, and enhancing preparedness for contamination and emergency supply interruptions. These implications are also supported by the stakeholder interviews, in which water-sector officials emphasized infrastructure upgrading, conservation, and emergency response. Since the study did not directly measure hydrological scarcity or treatment capacity, policy conclusions should remain focused on perceived water stress and service vulnerability, rather than absolute water-resource deficits [34–36].

5.1.5. Cross-sector implication

Across all sectors, the most important policy implication is that adaptation in GAR should be designed as a multi-sector urban resilience agenda. Residents do not perceive climate risks in isolated categories; rather, they experience them as interconnected pressures on health, food, water, and energy systems. This mirrors wider evidence from urban Ghana showing that extreme weather can generate cascading impacts across basic services and household well-being [26,27]. For that reason, adaptation planning in GAR is likely to be more effective when service agencies coordinate around shared risks such as heat, flooding, infrastructure failure, and household vulnerability, rather than acting through narrowly sectoral responses.

6. Conclusion

This study examined how surveyed residents and selected institutional stakeholders in the GAR perceive the implications of extreme climate conditions for key urban systems. The respondent pool was predominantly young and highly educated, with many tertiary students, indicating that the findings reflect the perceptions of an urban-accessible and relatively informed population rather than the entire regional population.

Across the survey responses and stakeholder interviews, extreme climate conditions particularly heatwaves, high temperatures, flooding, and drought were widely perceived as contributing to vulnerabilities in food security, public health, electricity reliability, and water availability. Respondents associated hydroclimatic extremes with food scarcity, heat and environmental stress with health risks, high temperatures with increased electricity demand, and extreme weather events with disruptions to energy and water services. Hot conditions were also perceived to increase household water use and reliance on cooling appliances, highlighting the interconnected pressures that climate variability can place on urban infrastructure and household resources.

Importantly, the results should be interpreted as perceived associations and lived experiences, rather than direct evidence of meteorological or causal relationships. Nevertheless, the convergence between resident perceptions and institutional perspectives suggests that climate-related stresses are already recognized across multiple sectors in GAR. This convergence emphasizes the need for integrated urban adaptation strategies that address climate risks across energy, health, food, and water systems simultaneously.

Future research should combine perception-based surveys with observational climate data, infrastructure performance records, and epidemiological evidence to better understand the interaction between perceived and measured climate impacts. Such integrated approaches would strengthen the evidence base for climate adaptation planning in rapidly urbanizing African cities. In the meantime, incorporating community perceptions into adaptation planning remains essential, as public understanding of climate risks plays a critical role in shaping behavioral responses, institutional trust, and the success of resilience interventions.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CRediT authorship contribution statement

Ebenezer Kwadwo Siabi: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Amos Tiereyangn Kabobah:** Writing – review & editing, Writing – original draft, Supervision. **Komlavi Akpoti:** Writing – review & editing, Writing – original draft, Supervision. **Geophery Kwame Anornu:** Writing – review & editing, Writing – original draft, Supervision. **Peter Donkor:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis. **Samuel Agbavitor:** Writing – review & editing, Writing – original draft. **Samuel Kofi Mensah:** Writing – review & editing, Writing – original draft. **Sarah Elikplim Siabi:** Writing – review & editing, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] IPCC. Summary for policymakers. In: climate change 2021: the physical science basis. In: Masson-Delmotte V, Zhai P, Pirani A, Connors SL, Péan C, Berger S, Caud N, Chen Y, Goldfarb L, Gomis MI, Huang M, Leitzell K, Lonnoy E, Matthews JBR, Maycock TK, Waterfield T, Yelekçi O, Yu R, Zhou B, editors. Contribution of working group I to the sixth assessment report of the intergovernmental panel on climate change. U. K. N. Y. NY USA: Camb. Univ. Press Camb; 2021. p. 3–32. https://doi.org/10.1017/9781009157896.001.

[2] Adom PK. The socioeconomic impact of climate change in developing countries over the next decades: a literature survey. Heliyon 2024;10(15):e35134. https://doi.org/10.1016/j.heliyon.2024.e35134.

[3] Wang W, Mensah IA, Atingabili S, Omari-Sasu AY. Climate change as a game changer: rethinking Africa's food security- health outcome nexus through a multi-sectoral lens. Sci Rep 2025;15(1):16824. https://doi.org/10.1038/s41598-025-99276-2.

[4] Khomsi K, El Wakil R, Nwaigwe CO, Mateyisi M, Nangombe SS. Current and projected climate changes in African subregions. In: Saad-Hussein A, Elwakil R, Khomsi K, editors. Impact of climate change on health in Africa. Cham: Springer International Publishing; 2023. p. 21–52. https://doi.org/10.1007/978-3-031-39466-9_2.

[5] Opoku-Boateng E, Agyei F, Asibey MO, Mintah F. Climate change resilience and social capital: Insights from informal urban neighbourhoods in Kumasi, Ghana. Cities 2024;152:105234. https://doi.org/10.1016/j.cities.2024.105234.

[6] Avornyo SY, et al. A scoping review of coastal vulnerability, subsidence and sea level rise in Ghana: assessments, knowledge gaps and management implications. Quat Sci Adv 2023;12:100108. https://doi.org/10.1016/j.qsa.2023.100108.

[7] Asante FA, Amuakwa-Mensah F. Climate change and variability in Ghana: stocktaking. Climate 2015;3(1):1. https://doi.org/10.3390/cli3010078.

[8] Owusu K, Waylen PR. The changing rainy season climatology of mid-Ghana. Theor Appl Clim 2013;112(3–4):419–30. https://doi.org/10.1007/s00704-012-0736-5.

[9] Ghana 2021 population and housing census general report. GSS; 2021.

[10] Ghana. Statistical Service. 2010 population and housing census: post enumeration survey report. Ghana Statistical Service; 2012.

[11] Osman A, Yawson DO, Mariwah S, Dadson IY. Towards a concrete landscape: assessing the efficiency of land consumption in the greater Accra region, Ghana. PLoS One 2022;17(6):e0269120. https://doi.org/10.1371/journal.pone.0269120.

[12] Sullivan M, Kone A, Senturia KD, Chrisman NJ, Ciske SJ, Krieger JW. Researcher and researched-community perspectives: toward bridging the gap. Health Educ Behav 2001;28(2):130–49.

[13] Adjei V. Climate change: threat to agricultural system and food security in Africa. Glob Sci Res Env Sci 2021;1(4). https://doi.org/10.53902/GSRES.2021.01.000518.

[14] Ali S, et al. Climate change and its impact on the yield of major food crops: evidence from Pakistan. Foods 2017;6(6):39. https://doi.org/10.3390/foods6060039.

[15] Asare-Nuamah P. Climate variability, subsistence agriculture and household food security in rural Ghana. Heliyon 2021;7(4):e06928. https://doi.org/10.1016/j.heliyon.2021.e06928.

[16] Ingrao C, Strippoli R, Lagioia G, Huisingh D. Water scarcity in agriculture: an overview of causes, impacts and approaches for reducing the risks. Heliyon 2023;9 (8):e18507. https://doi.org/10.1016/j.heliyon.2023.e18507.

[17] US EPA, "Climate change impacts on agriculture and food supply". Accessed: Jun. 20, 2024. [Online]. Available: https://www.epa.gov/climateimpacts/climate-change-impacts-agriculture-and-food-supply.

[18] US EPA, "Climate impacts on agriculture and food supply", 2020.

[19] Akwango D, Obaa BB, Turyahabwe N, Baguma Y, Egeru A. Effect of drought early warning system on household food security in Karamoja subregion, Uganda. Agric Food Secur 2017;6(1):43. https://doi.org/10.1186/s40066-017-0120-x.

[20] Derbile EK, File DJM, Dongzagla A. The double tragedy of agriculture vulnerability to climate variability in Africa: how vulnerable is smallholder agriculture to rainfall variability in Ghana? Jàmbá J Disaster Risk Stud 2016;8(3):9. https://doi.org/10.4102/jamba.v8i3.249.

[21] Twongyirwe R, et al. Perceived effects of drought on household food security in south-western Uganda: coping responses and determinants. Weather Clim Extrem 2019;24:100201. https://doi.org/10.1016/j.wace.2019.100201.

[22] Siabi EK, et al. Assessment of shared socioeconomic pathway (SSP) climate scenarios and its impacts on the greater Accra region. Urban Clim 2023;49:101432. https://doi.org/10.1016/j.uclim.2023.101432.

[23] Siabi EK, et al. Quantifying future climate extreme indices: implications for sustainable urban development in west Africa, with a focus on the greater Accra region. Discov Sustain 2024;5(1):167. https://doi.org/10.1007/s43621-024-00352-w.

[24] Atanga RA, Tankpa V. Climate change, flood disaster risk and food security nexus in northern Ghana. Front Sustain Food Syst 2021;5:706721. https://doi.org/10.3389/fsufs.2021.706721.

[25] Butsch C, et al. Health impacts of extreme weather events – cascading risks in a changing climate. Robert Koch-Inst 2023. https://doi.org/10.25646/11652.

[26] Codjoe SNA, et al. Impact of extreme weather conditions on healthcare provision in urban Ghana. Soc Sci Med 2020;258. https://doi.org/10.1016/j.socscimed.2020.113072.

[27] Kayaga SM, et al. Cities and extreme weather events: impacts of flooding and extreme heat on water and electricity services in Ghana. Env Urban 2021;33(1):131–50. https://doi.org/10.1177/0956247820952030.

[28] Appeaing Addo K. Changing morphology of Ghana's Accra coast. J Coast Conserv 2011;15(4):433–43.

[29] Cook MA, King CW, Davidson FT, Webber ME. Assessing the impacts of droughts and heat waves at thermoelectric power plants in the United States using integrated regression, thermodynamic, and climate models. Energy Rep 2015;1:193–203. https://doi.org/10.1016/j.egyr.2015.10.002.

[30] Petrakopoulou F. Defining the cost of water impact for thermoelectric power generation. Energy Rep 2021;7:2101–12. https://doi.org/10.1016/j.egyr.2021.04.001.

[31] V.C. Tidwell, "Planning for the electricity-water nexus", 2015.

[32] Koks EE, Le Bars D, Essenfelder AH, Nirandjan S, Sayers P. The impacts of coastal flooding and sea level rise on critical infrastructure: a novel storyline approach. Sustain Resilient Infrastruct 2023;8(sup1):237–61. https://doi.org/10.1080/23789689.2022.2142741.

[33] National Academies, "Vulnerability of US energy infrastructure to coastal flooding | National academies". Accessed: Jun. 20, 2024. [Online]. Available: https://www.nationalacademies.org/event/12-06-2018/vulnerability-of-us-energy-infrastructure-to-coastal-flooding.

[34] WHO, "The human right to water and sanitation", 2003.
[35] UNDP. Beyond scarcity: power, poverty and the global water crisis. Human development report, no. 2006. New York, NY: UNDP; 2006.
[36] Agodzo SK, Bessah E, Nyatuame M. A review of the water resources of Ghana in a changing climate and anthropogenic stresses. Front Water 2023;4:973825. https://doi.org/10.3389/frwa.2022.973825.