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Frontline knowledge, attitudes, and practices on climate change and its link to zoonotic diseases: a mixed-methods study of healthcare workers in Ada East, Ghana

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Abstract

Introduction Climate change alters patterns of infectious diseases and increases the risk of zoonotic spillover in vulnerable areas. This study examines how frontline healthcare workers (FHWs) in Ghana's Ada East District understand and perceive the relationship between climate change and zoonotic disease transmission.

Methods We conducted a concurrent mixed-methods study in the Ada East District, Ghana. A cross-sectional survey of FHWs evaluated knowledge, attitudes, and practices (KAP) regarding climate change and its link to zoonotic diseases. KAP scores were classified using Bloom's cut-off points; adjusted logistic regression models identified predictors of good KAP. A purposively selected focus group (n=9) explored perceived links between climate change and zoonotic disease, lived experiences, and institutional barriers.

Results Most participants demonstrated good knowledge ($\geq 60\%$ correct; 83.2%) and attitudes ($\geq 60\%$ positive attitudes; 86.8%), but fewer reported good climate-mitigation practices ($\geq 60\%$ of good practices; 62.4%). Clinical staff other than nurses and midwives were associated with higher odds of good knowledge (adjOR = 4.52, 95% CI 1.12–22.76), while those trained on the human monkeypox virus were associated with lower odds of good knowledge (adjOR = 0.24, 95% CI 0.08–0.64). For practices, working in a district/regional hospital was associated with lower odds (adjOR = 0.18, 95% CI 0.05–0.61), as was training delivered by the Ministry/Government authorities (adjOR = 0.44, 95% CI 0.21–0.91) and training on human monkeypox virus (adjOR = 0.39, 95% CI 0.17–0.90). Providers associated land-use change and bushmeat hunting with zoonotic spillover risk. They noted that spiritual beliefs, self-medication, and fear of income loss delayed care-seeking for suspected cases. Institutional preparedness was perceived as reactive. Participants called for climate-resilient infrastructure, integrated early-warning systems, and One Health training.

Conclusion FHWs in Ghana's Ada East District are knowledgeable and motivated to address climate-sensitive zoonotic risks. Yet, structural and sociocultural barriers limit



the translation of frontline commitment into system-wide resilience. Strengthening climate-health education, investing in facility-level preparedness, and integrating FHW's insights into surveillance could enable a shift from reactive outbreak response to proactive, community-based preparedness.

Keywords Climate change, Zoonotic diseases, Knowledge, attitudes, and practices (KAP), Frontline healthcare workers, One Health, West Africa

1 Introduction

Human-induced climate change, defined as long-term alterations in local, regional, and global weather patterns driven primarily by anthropogenic greenhouse gas emissions and land-use changes, has emerged as a key modifier of infectious disease dynamics [1–8]. Such climate stressors are intensifying the emergence and re-emergence of zoonotic diseases by altering environmental conditions that influence pathogen transmission [2, 3, 9–15]. In recent decades, zoonotic outbreaks have increased in both frequency and geographic range, a trend expected to worsen as climate pressures escalate [10, 11, 16, 17]. Over 60% of emerging infectious disease events since 1940 have been zoonotic, with most traced to wildlife reservoirs [10, 18]. These climate-related hazards are already intensifying global health risks [14, 19, 20]. While global evidence links climate stressors to zoonotic emergence, limited research explores how these mechanisms operate in specific regional contexts such as West Africa.

Climate variability amplifies zoonotic spillover risk through disrupted ecosystems and host–pathogen dynamics [21–25]. Species migration, vector expansion, and habitat overlap increase cross-species viral exchange [26–34]. These changes increase the likelihood of new pathogen transmission cycles, especially in biodiversity-rich, rapidly urbanizing regions as in West Africa.

These global patterns in climate change and disease vectors are acutely relevant to Ghana, which is home to 221 species of amphibians and reptiles, 728 bird species, and 225 mammal species [35, 36]. Wetlands in Accra provide stopover habitats for migratory species, further contributing to the region's potential reservoir of zoonotic pathogens [37]. Urban ecosystems like Accra's wetlands host migratory birds and bat colonies, while bushmeat consumption and livestock encroachment into wildlife habitats intensify human–animal interfaces [37–64]. Clearly, much of Ghana's population relies directly on these ecosystems for their livelihoods [37, 39, 40, 46, 47, 65]. Few studies explore how environmental and livelihood changes affect zoonotic disease risks in Ghana, despite its ecological and social vulnerabilities.

Frontline healthcare workers (FHWs)—including community nurses, clinicians, and public health officers—are pivotal to early outbreak detection and climate-resilient health systems in vulnerable regions such as Accra [66–69]. Embedded within their communities, they are trusted communicators who bridge clinical and community knowledge, translating climate–health messages into practical action [66, 67, 70–73]. However, the effectiveness of FHWs in this role depends on adequate awareness, knowledge, and training related to the climate–zoonoses nexus.

The Intergovernmental Panel on Climate Change (IPCC) warns that the severity of climate-related health risks will hinge on how effectively health systems and their staff can anticipate and manage emerging threats [74]. Yet gaps remain between high-level climate–health policy and local implementation [67–69, 73]. In Ghana, limited

climate-specific training and constrained resources remain significant barriers to operationalizing climate–health strategies [75]. Without insight into how FHWs perceive and manage these interconnected challenges, it is difficult to tailor solutions that enhance zoonotic outbreak prevention, preparedness, and resilience at the community level in an era of climate change.

To address these gaps, this study employed a mixed-methods approach to examine how FHWs in Ghana’s Ada East District understand and perceive the relationship between climate change and zoonotic disease transmission. This study (i) quantitatively assessed FHWs’ knowledge, attitudes, and practices (KAP) related to the climate–zoonoses nexus, gauging both their understanding and the extent to which this knowledge informs their practices; (ii) identified predictors of higher KAP, such as sociodemographics, professional experience, and prior training; and (iii) qualitatively contextualized survey findings through a focus group discussion, exploring FHWs’ perspectives on climate–zoonosis dynamics, barriers to climate adaptation in healthcare settings, and recommendations for strengthening zoonotic preparedness in a changing climate.

2 Materials and method

2.1 Study design and population

This study employed a concurrent exploratory mixed-methods design, integrating quantitative cross-sectional survey data with a qualitative, semi-structured focus group discussion. Data collection took place from January 30th to February 7th, 2025, in the Ada East District of Ghana’s Greater Accra Region. Eighteen healthcare facilities were purposively sampled in collaboration with the University of Ghana (Fig. 1). These included district hospitals, local health centers, and Community-Based Health Planning and Services compounds, chosen to reflect the diversity of the regional healthcare delivery system. We describe both the quantitative and qualitative procedures in the following section.

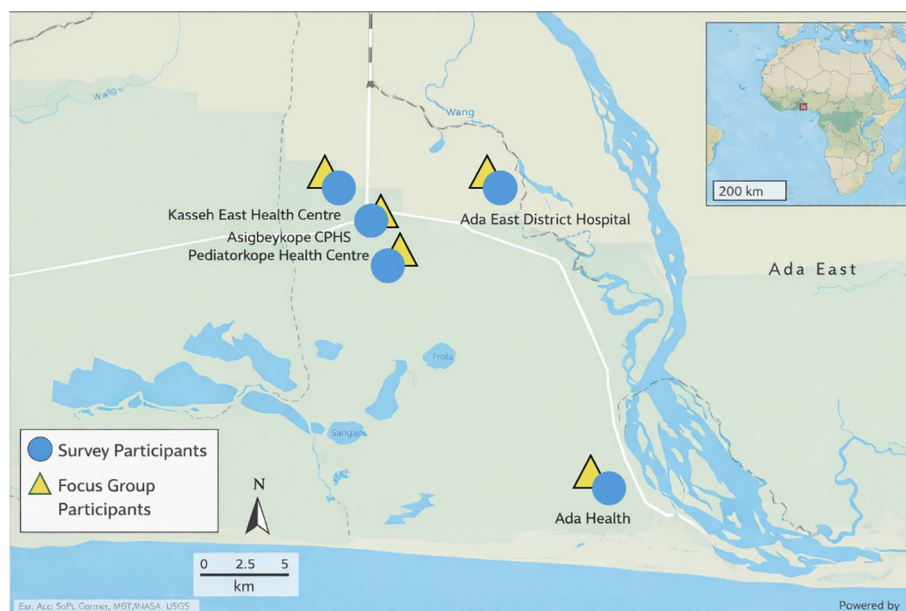


Fig. 1 Geographic distribution of health facilities and frontline healthcare worker (FHW) who answered the survey as well as focus group participants in Ada East District, Ghana

Eligible participants included FHWs employed at the selected facilities who met the following inclusion criteria: (1) age ≥ 18 years; (2) actively involved in direct patient care at the facility for ≥ 3 months; (3) ≥ 6 months post-completion of formal clinical training; (4) proficient in English—the official language of healthcare delivery in Ghana; and (5) able to provide written informed consent. Individuals were excluded if they were not engaged in patient care, were unavailable during data collection, or declined to participate. Eligibility was confirmed at the time of enrollment by trained research personnel.

The required sample size was calculated using a single-population proportion formula, as outlined in a prior manuscript [76]. Due to the absence of existing data specific to the Ada East District, we assumed a 6% prevalence of poor KAP, a 3% margin of error, and a 95% confidence level. This assumption was selected as a conservative estimate based on the expectation that frontline healthcare workers would have relatively high baseline awareness of climate change and zoonotic diseases due to their professional training and routine exposure to public health information. Sample size was calculated using the single-population proportion formula: $n = Z^2 \times p(1 - p)/d^2$, with $Z = 1.96$ (95% confidence), an assumed prevalence of poor KAP $p = 0.06$. The resulting minimum sample size was 241, and we targeted 250 to ensure adequate participation. The margin of error used (3%) in sample size estimation was applied as a planning parameter to guide recruitment rather than to imply population-level statistical precision. Purposive sampling of facilities was employed to ensure inclusion of diverse healthcare settings and cadres, prioritising internal validity and contextual relevance over population-level representativeness.

2.2 Quantitative part

2.2.1 Participant recruitment

Survey recruitment was conducted on-site at each selected healthcare facility. Recruitment involved purposive selection of facilities and all eligible FHWs present during the study period. All eligible frontline healthcare workers present at each facility during the data collection period were invited to participate; however, exact numbers of individuals approached and those who declined participation were not systematically recorded. In total, 250 subjects fulfilled inclusion criteria to this study, and thus, were included in the study. Recruitment at each facility continued until no additional eligible participants remained. Local data collectors coordinated with facility administrators to identify optimal recruitment windows that minimized disruption to clinical activities across day and night shifts. During these time windows, trained research assistants approached eligible staff in common areas to introduce the study and distribute informational leaflets. Interested individuals were escorted to a private area where the study was explained and questions were addressed.

2.2.2 Survey pilot testing

The survey instrument underwent pilot testing with 10 FHWs at a nearby hospital to assess question clarity, survey flow, and technical usability of tablet devices for data collection; pilot participants were not included in the main survey sample. Based on feedback, we refined the instrument by incorporating a standardized definition of climate change at the start of the attitude's module. We clarified select climate mitigation practices to eliminate any ambiguity among participants. Ten research assistants were

recruited and completed a two-day training in Good Clinical Practice, study-specific protocols, informed consent procedures, survey administration techniques, and hands-on instruction using the Research Electronic Data Capture (REDCap) platform. Surveys were administered using REDCap-enabled tablets via structured, interviewer-led sessions conducted in private areas of each facility. Research assistants read each survey question (in English) aloud to the participant and entered the participant's responses into the REDCap-enabled tablet in real time. Each session lasted approximately 45–60 min. No personal identifiers were collected with the survey data. For participants who volunteered for follow-up focus group discussions, a first name and phone number were collected solely for re-contact, stored in a separate password-protected file accessible only to the principal investigator, and were not linked to survey responses in any analytic dataset.

2.2.3 Survey measures

A structured questionnaire was developed to assess FHWs' KAP regarding climate change, its health impacts, and its links to zoonotic diseases such as EVD. Several items were adapted from previously validated KAP surveys and other peer-reviewed information sources on the topics of climate change, its health impacts, and the link to zoonotic diseases [77–81]. The tool included four main sections: sociodemographic and professional background, knowledge, attitudes, and practices related to climate change and health.

2.2.4 Sociodemographic and professional characteristics

Respondents reported age, sex, education, occupational role, facility type, total years of healthcare experience, and years managing infectious diseases. They also indicated prior formal training on infectious diseases (topics covered, training providers), and their frequency and preferred sources of information about climate change and zoonotic diseases (radio, television, internet, social media, or mobile applications).

2.2.5 Knowledge of climate change and its health impacts

Knowledge was assessed using 37 items (true/false and multiple-response) across three domains:

- Climate change (16 items): understanding of definitions, anthropogenic causes (industrial activity, deforestation, greenhouse gas emissions), and environmental effects (temperature rise, altered rainfall, floods, droughts).
- Health impacts (12 items): awareness of climate-related diseases (heat stress, vector- and water-borne diseases, malnutrition, respiratory and mental health conditions) and recognition of vulnerable groups.
- Climate–zoonoses link (9 items): knowledge of how climatic shifts alter pathogen ecology, host migration, and disease emergence.

Each correct answer scored 1 point, incorrect/unsure scored 0, yielding a total score of 0–37, expressed as a percentage. Scores $\geq 60\%$ (≥ 23 points) were classified as *good knowledge*, both overall and by domain.

2.2.6 Attitudes toward climate change mitigation and health

Seven Likert-scale statements (1 = strongly disagree to 4 = strongly agree) assessed attitudes toward:

- Support for climate change mitigation actions,
- Stakeholder responsibility (government, individuals, private sector, donors),
- Health sector's environmental role, and
- Beliefs about human capacity to influence climate outcomes.

For analysis, responses were dichotomized: “agree/strongly agree” = favorable (1); “disagree/strongly disagree” = unfavorable (0). The negatively worded item (“Climate change is an act of God and cannot be controlled”) was reverse-coded. Total attitude scores ranged from 0 to 7, with ≥ 4 indicating *positive attitudes*. Attitude items measured on Likert scales were dichotomised to support interpretability and consistency with common KAP analytic approaches [82].

2.2.7 Climate change mitigation practices

Participants were asked about 13 practice items, divided into:

- Individual-level behaviors (8 items): actions such as energy and water conservation, recycling, clean cookstove use, and low-carbon transport.
- Institutional-level behaviors (5 items): facility-based practices such as reducing medical waste, switching off unused equipment, and promoting sustainability in meetings.

“Yes/No” items were scored 1 for “Yes”; frequency items (“often/always”) were also scored 1. The composite practice score ranged 0–13, with higher scores reflecting *better climate mitigation practices*. Sub-scores for individual and institutional practices were analyzed separately.

2.2.8 Statistical analysis

All analyses were conducted in RStudio v4.3.1. Descriptive statistics were used to summarize participant characteristics. Continuous variables were presented as means and standard deviations (SD), and categorical variables as frequencies and percentages. Composite KAP scores were calculated by summing responses, converting total scores to percentages, and classifying participants according to Bloom's taxonomy, as used in prior KAP research [82, 83]. That is, scores $> 60\%$ were labeled “Good” or “Positive,” while scores $\leq 60\%$ were considered “Poor” or “Negative.” This threshold widely applied in KAP studies to support comparability and interpretability [82, 83]. The study aimed to provide an interpretable assessment of frontline healthcare workers' knowledge, attitudes, and practices using a widely applied categorisation approach in KAP research for comparison and policy translation [84]. Geospatial data visualizing facility locations and participant distributions across Ada East were generated using ArcGIS Online v3.2. Logistic regression was used to identify covariates associated with “Good” knowledge, “Positive” attitudes, and “Good” practices. Covariates included sociodemographic factors (e.g., sex, age), occupational characteristics (e.g., facility type, clinical role, years of experience), training history (e.g., training source, content), and information access (e.g., source type, frequency). Covariates were specified a priori based on prior literature and

substantive relevance and were entered simultaneously in fully adjusted multivariable models to reduce residual confounding and support comparability across outcomes. All covariates were entered as categorical variables (binary or multi-level factors). Univariate models yielded crude odds ratios (ORs) with 95% confidence intervals (CIs), followed by fully adjusted models yielding adjusted odds ratios (AORs) with 95% CIs. Covariates with <5% prevalence or near-zero variance were excluded from modeling (including malaria/sanitation/food-contamination training topics; community/NGO/other climate-information sources). Missing data were minimal (reported under Table 1), and analyses were conducted using complete cases. Statistical significance was set at $\alpha = 0.05$ (highlighted in bold across tables), using two-sided Wald chi-square tests.

2.3 Qualitative part

2.3.1 Focus group discussion

A semi-structured focus group discussion guide was developed to explore FHWs' KAP regarding zoonotic diseases—particularly Ebola Virus Disease—and their perceived links with climate change. The guide covered two domains:

1. Zoonotic disease knowledge and preparedness—beliefs, misconceptions, and management practices.
2. Climate change and health—awareness, perceived impacts, and mitigation or adaptation strategies.

Questions were open-ended, with targeted probes to encourage discussion and clarify survey findings.

2.3.2 Recruitment of focus group discussion

To capture a broad range of frontline perspectives, we employed a maximum-variation purposive sampling approach during the same five-day period as the survey. Survey responses were reviewed in real time to identify interested FHWs and ensure diversity across occupational roles, facility types, sex, experience levels, and training backgrounds. Sampling continued until the target of 7 to 10 participants was reached, which was set a priori based on project scope and resources. Participants in the focus group discussion were either newly recruited from the 18 study sites or selected from among survey respondents. Ultimately, we enrolled 9 FHWs (2 men, 7 women), who were purposively considered for various professional roles to yield a diverse sample for the focus group discussion on climate change and zoonotic disease; no formal comparison with the full survey sample was undertaken. Because the qualitative component comprised a single focus group, thematic saturation was not formally assessed.

2.3.3 Focus group discussion data collection

The focus group discussion was conducted in a private room at Ada East District Hospital to ensure comfort and confidentiality. The session was facilitated in English and Dangme by a trained moderator, supported by a note-taker. Participants were assigned numeric identifiers (P1–P9) for anonymity. The moderator reviewed the study purpose, ground rules, and obtained verbal group consent for recording. The session lasted ~100 min, with member-checking used throughout to confirm interpretations. Audio was transcribed verbatim and translated into English when needed by the

Table 1 Sociodemographic, professional, training, and information-access characteristics of study participants (N = 250), frontline healthcare workers (FHWs)

Characteristic	N (%)
Age (in years)	
20–29	84 (33.6)
30–34	83 (33.2)
35–57	83 (32.2)
Sex–Women	183 (73.2)
Education Level	
SSS/SHS/Technical	11 (4.4)
Higher education	239 (95.6)
Healthcare Facility Type	
CHPS Compound	22 (8.8)
District/Regional Hospital	116 (46.4)
Health Center	112 (44.8)
Occupational Category	
Nurse	153 (61.2)
Midwives	45 (18.0)
Other Clinical Staff	41 (16.4)
Administrative and Support Staff	11 (4.4)
Activities Performed in Job Role	
Provision of clinical services	245 (98.0)
Clinical support group	93 (37.2)
Preventative health services	229 (91.6)
Other	1 (0.4)
Years of Experience in Current Job	
> 5 years	94 (37.6)
5 years	156 (62.4)
Diagnoses and Treats Patients with Infectious Diseases**	156 (63.4)
Received Infectious Diseases Training*	175 (70.3)
Who Provided Infectious Diseases Training	
Experts from the Respondents' Health Facility	121 (48.4)
Experts from the Ministry and the Government Health Authorities	104 (41.6)
Experts from International NGOs	27 (10.8)
Academic or School-Based Training	8 (3.2)
No Training Received/Other	75 (30.0)
What Infectious Diseases Training Provide	
COVID-19	149 (59.6)
Ebola virus disease	64 (25.6)
Marburg virus disease	24 (9.6)
Human monkeypox virus	74 (29.6)
Rabies	72 (28.8)
Anthrax	14 (5.6)
Cholera	45 (18.0)
Tuberculosis	14 (5.6)
Other	13 (5.2)
Current Source of Zoonotic Disease Information	
Electronic media	241 (96.4)
Conventional media	155 (62.0)
Public media	94 (37.6)
Current Source of Climate Change Information	
Electronic media	238 (95.2)
Conventional media	163 (65.2)
Public media	93 (33.2)
Frequency of Engagement with Climate Change Information	

Table 1 (continued)

Characteristic	N (%)
Always or often	26 (10.4)
Sometimes, rarely, or never	224 (89.6)

Missing data were limited to two covariates: Received Infectious Diseases Training (n=1 missing) and Diagnoses and Treats Patients with Infectious Diseases (n=4 missing). Multi-response items (e.g., training topics and information sources) are not mutually exclusive and may exceed 100%. *CHPS* Community-based Health Planning and Services; *SSS/SHS* Senior secondary school/technical school (e.g., secondary); *NGO* non-governmental organization

bilingual moderator and note-taker. All data were de-identified and securely stored by the principal investigator.

2.3.4 Qualitative data analysis

A thematic analysis guided by grounded theory principles was used. A hybrid deductive-inductive approach was employed: a preliminary deductive codebook was developed from the focus group discussion guide, and additional inductive codes were added as concepts emerged from the transcript. Three researchers (one senior, two trained assistants) independently applied the preliminary codebook using line-by-line coding and recorded proposed inductive codes. These researchers had prior experience in public health research, which may have influenced data interpretation; therefore, efforts were made to minimise this through team discussion and reflexive review of emerging themes.

The research team met to compare coding, resolve discrepancies through consensus, and iteratively refine the shared codebook. Themes were generated by clustering related codes and refined through constant comparison to capture variation in perspectives; themes were supported by representative quotations and counterexamples. Formal inter-coder reliability statistics were not calculated.

2.3.5 Research ethics

The study received ethical approval from both the Ghana Health Service Ethical Review Committee (protocol GHS-ERC 024/08/24) and the Pennsylvania State University Institutional Review Board (STUDY00025492). Written authorization to conduct the study was also obtained from the administrative leadership of all eighteen participating health facilities. Then, all survey data were collected anonymously, with no direct identifiers included in the analytic dataset. Participation was voluntary, and individuals were assured that declining or withdrawing from the study would have no impact on their employment or benefits. Written informed consent was obtained from all participants before enrollment. All participants were provided 160 Ghanaian Cedi (13.39 USD) upon completion of the survey. This compensation was approved by the ethics committees and intended to reimburse participants for time/transport rather than to incentivize participation.

Only individuals who expressed interest in the focus group discussion voluntarily provided their name and phone number for recontact. This identifying information was stored in a separate, encrypted, password-protected file accessible only to the principal investigator and was not linked to survey responses. Participants in the focus group discussion signed a separate consent form specific to the qualitative component and consented to recording and transcription. Upon completion of the focus group discussion, all participants were provided with 160 Ghanaian Cedi (13.39 USD).

3 Results

3.1 Study demographics

A total of 250 FHWs (73.2% women) in Ada East completed the survey (Table 1). The mean age was 32.8 years. Most participants were stationed at either district or regional hospitals (46.4%) or health centers (44.8%), while 8.8% worked in Community-based Health Planning and Services compounds. Nurses comprised the largest cadre (61.2%). The most frequently covered diseases included COVID-19, monkeypox, rabies, and Ebola virus disease. Digital platforms were the predominant source of professional information, accessed by 96.4% for zoonoses and 95.2% for climate-related health topics. The majority of FHWs reported engaging with climate change information only occasionally or not at all.

3.2 Knowledge of climate change and its health impacts

Most FHWs (83.2%) met the $\geq 60\%$ threshold for “Good” climate change and health knowledge (Supplementary Table S1). Participants correctly identified major biophysical indicators of climate change, including increased frequency of droughts and floods (94.0%) and changes in temperature and rainfall (89.2%). Key drivers such as deforestation (96.0%), atmospheric pollution from open waste burning (96.4%), industrial emissions (90.8%), and carbon dioxide emissions (86.0%) were widely recognized. However, fewer respondents linked agriculture (56.0%) and methane from livestock (40.8%) to climate change. In the health impacts domain, most FHWs associated climate change with heat-related (91.6%) and air-quality-related illnesses (94.4%).

Recognition of indirect impacts was lower: malnutrition (54.8%), mental health conditions (28.0%), and social conflict (26.0%). Awareness of vulnerable populations was also limited, with fewer than half identifying children (46.4%), older adults (44.4%), or women (11.6%) as especially susceptible to climate-related health risks. Nearly all respondents (96.4%) agreed that climate change increases infectious disease outbreaks, and 98.8% linked it to illness in both humans and livestock. Most participants understood that rising temperatures and shifting rainfall patterns expand vector habitats (93.2%), and many anticipated increased EVD outbreak risk (81.6%) and emergence in new locations (83.2%).

3.3 Attitudes toward climate change

Most respondents expressed strong pro-mitigation attitudes, with 86.8% ($n=217$) meeting the $\geq 60\%$ threshold for a “Positive” climate change attitude (Supplementary Table S2). Support for climate change mitigation was nearly universal; 94.4% agreed it is essential for controlling emerging and re-emerging zoonoses. Most respondents assigned primary responsibility to the Ministry of Health (84.8%) and private citizens (79.6%). Fewer attributed responsibility to international actors such as industrialized nations (57.6%) and donors or NGOs (59.6%). A majority (72.8%) acknowledged that healthcare systems contribute to climate change. Fatalistic beliefs were uncommon—only 17.2% agreed that climate-related disasters are unavoidable “acts of God.”

3.4 Practices regarding climate change mitigation

Overall engagement in climate change mitigation practices was moderate, with 62.4% ($n=156$) classified as having “Good” climate change mitigation practices (Supplementary

Table S3). Individual-level practices were more commonly adopted than institutional ones. Nearly 80% (79.6%) met the threshold for “Good” individual practices. Routine behaviors included switching off lights and appliances (92.0%), adopting low-energy devices (82.0%), and using energy-efficient bulbs (85.2%). Fewer respondents reported harvesting rainwater (50.0%), practicing waste sorting (45.6%), or using low-carbon transport (59.2%).

Only 11.2% (n = 28) achieved “Good” institutional practice scores. While most reported turning off unused digital (64.4%) and clinical equipment (61.6%), a minority reported minimizing single-use plastics (15.2%) or integrating climate mitigation into staff meetings or training (4.4%).

3.5 Factors associated with climate-change knowledge, attitudes, and practices

Most FHWs demonstrated good knowledge and positive attitudes toward climate change and health across sociodemographic, professional, and training categories. In descriptive analyses, slight variations were observed by age, facility type, and prior infectious-disease training, but overall awareness and attitudes remained consistently high across all groups (Table 2).

In the adjusted multivariate logistic regression, knowledge, professional role, and training source were the only significant covariates (Table 3). Compared with nurses, other clinical staff had higher odds of good knowledge. We observed that receipt of monkeypox training was associated with lower odds of good knowledge than among those who did not receive it. Accessing climate change information via conventional media was associated with higher odds of positive attitudes than no conventional media access.

For practices, institutional settings, and training providers emerged as key covariates. Relative to Community-based Health Planning and Services compounds, FHWs based at district or regional hospitals were associated with lower odds of good practices. Compared with no training, participation in international non-governmental organization-led training was associated with higher odds of good practices, whereas Ministry of Health-led training was associated with lower. In the adjusted model, receipt of monkeypox training was also associated with lower odds of good practices versus no monkeypox training. There were no significant associations in crude logistic regression (Supplementary Table S4).

3.6 Characteristics of participant in qualitative study

The focus group discussion involved seven women and two men ranging in age from 28 to 56 years old. While all nine attended the focus group discussion, only eight actively conversed during the discussion (Table S1). Educational backgrounds varied: two participants held upper-secondary diplomas, six held Bachelor of Science degrees, and one held a master’s degree. Participants also represented a range of occupational cadres, included Senior Medical Officer, Head of Pharmacy, Senior Nursing Officer, Neonatal Intensive Care Unit nurse, inpatient department nurse, maternity ward midwife, two Senior Staff Midwives, and Senior Medical Laboratory Technician, respectively. Time employed at their health facility ranged from nine months to eighteen years.

Table 2 Proportions of good climate change and health knowledge among frontline healthcare workers (N = 250)

Predictor	Level	Knowledge (n, %)		Attitudes (n, %)		Attitudes (n, %)	
		Poor	Good	Poor	Good	Negative	Positive
Sociodemographic Characteristics							
Age (in years)	20–29	11 (13.1)	73 (86.9)	11 (13.1)	73 (86.9)	35 (41.7)	49 (58.3)
	30–34	15 (18.1)	68 (81.9)	11 (13.1)	72 (86.7)	32 (38.6)	51 (61.4)
	35–57	16 (19.3)	67 (80.7)	11 (13.1)	72 (86.7)	27 (32.5)	56 (67.5)
Sex	Man	12 (17.9)	55 (82.1)	6 (9.0)	61 (91.0)	24 (35.8)	43 (64.2)
	Woman	30 (16.4)	153 (83.6)	27 (14.8)	156 (85.2)	70 (38.3)	113 (61.7)
Professional Characteristics							
Healthcare Facility Type	CHPS Compound	2 (9.1)	20 (90.9)	2 (9.1)	20 (90.9)	5 (22.7)	17 (77.3)
	District/Regional Hospital	21 (18.1)	95 (81.9)	18 (15.5)	98 (84.5)	56 (48.3)	60 (51.7)
	Health Center	19 (17.0)	93 (83.0)	13 (11.6)	99 (88.4)	33 (29.5)	79 (70.5)
Occupational Category	Nurse	29 (18.3)	125 (81.7)	19 (12.4)	134 (87.6)	56 (36.6)	97 (63.4)
	Midwives	9 (20.0)	36 (80.0)	8 (17.8)	37 (82.2)	19 (42.2)	26 (57.8)
	Other Clinical Staff	4 (9.8)	37 (90.2)	4 (9.8)	37 (90.2)	15 (36.6)	26 (63.4)
Experience in Current Role	> 5 years	20 (21.3)	74 (78.7)	11 (11.7)	83 (88.3)	34 (36.2)	60 (63.8)
	≤ 5 years	22 (14.1)	134 (85.9)	22 (14.1)	134 (85.9)	60 (38.5)	96 (61.5)
Diagnoses/Treats Patients w/IDs	Yes	26 (16.7)	130 (83.3)	19 (12.2)	137 (87.8)	55 (35.3)	101 (64.7)
	No	15 (16.7)	75 (83.3)	14 (15.6)	76 (84.4)	35 (38.9)	55 (61.1)
Training Characteristics							
Received ID Training	Yes	31 (17.7)	144 (82.3)	21 (12.0)	154 (88.0)	64 (36.6)	111 (63.4)
	No	11 (14.9)	63 (85.1)	12 (16.2)	62 (83.8)	29 (39.2)	45 (60.8)
Experts Who Delivered ID Training	No—Respondents' Health Facility	14 (10.9)	115 (89.1)	12 (9.3)	117 (90.7)	44 (34.2)	85 (65.9)
	Yes—Respondents' Health Facility	28 (23.1)	93 (76.9)	21 (17.4)	100 (82.6)	50 (41.3)	71 (58.7)
	No—Ministry/ Government Health Authorities	28 (19.2)	118 (80.8)	26 (17.8)	120 (82.2)	54 (37.0)	92 (63.0)
	Yes—Ministry/ Government Health Authorities	14 (13.5)	90 (86.5)	7 (6.7)	97 (93.3)	40 (38.5)	64 (61.5)
	No—International NGOs	38 (17.0)	185 (83.0)	31 (13.9)	192 (86.1)	88 (39.5)	135 (60.5)
	Yes—International NGOs	4 (14.8)	23 (85.2)	2 (7.4)	25 (92.6)	6 (22.2)	21 (77.8)
	What ID Training Was Delivered	No—COVID-19	11 (10.9)	90 (89.1)	12 (11.9)	89 (88.1)	42 (41.6)
Yes—COVID-19	31 (20.8)	118 (79.2)	21 (14.1)	128 (85.9)	52 (34.9)	97 (65.1)	
No—Ebola virus disease	26 (14.0)	160 (86.0)	23 (12.4)	163 (87.6)	74 (39.8)	112 (60.2)	
Yes—Ebola virus disease	16 (25.0)	48 (75.0)	10 (15.6)	54 (84.4)	20 (31.2)	44 (68.8)	
No—Human monkeypox virus	20 (11.4)	156 (88.6)	20 (11.4)	156 (88.6)	62 (35.2)	114 (64.8)	
Yes—Human monkeypox virus	22 (29.7)	52 (70.3)	13 (17.6)	61 (82.4)	32 (43.2)	42 (56.8)	
No—Rabies	23 (12.9)	155 (87.1)	22 (12.4)	156 (87.6)	64 (36.0)	114 (64.0)	
Yes—Rabies	19 (26.4)	53 (73.6)	11 (15.3)	61 (84.7)	30 (41.7)	42 (58.3)	
Information Access Characteristics							

Table 2 (continued)

Predictor	Level	Knowledge (n, %)		Attitudes (n, %)		Attitudes (n, %)	
		Poor	Good	Poor	Good	Negative	Positive
Current Source of Zoonotic Disease Information	No—Conventional media	24 (25.3)	71 (74.7)	15 (15.8)	80 (84.2)	41 (43.2)	54 (56.8)
	Yes—Conventional media	18 (11.6)	137 (88.4)	18 (11.6)	137 (88.4)	53 (34.2)	102 (65.8)
	No—Public media	32 (20.5)	124 (79.5)	22 (14.1)	134 (85.9)	64 (41.0)	92 (59.0)
	Yes—Public Media	10 (10.6)	84 (89.4)	11 (11.7)	83 (88.3)	30 (31.9)	64 (68.1)
Current Source of Climate Change Information	No—Conventional media	25 (28.7)	62 (71.3)	19 (21.8)	68 (78.2)	39 (44.8)	48 (55.2)
	Yes—Conventional media	17 (10.4)	146 (89.6)	14 (8.6)	149 (91.4)	55 (33.7)	108 (66.3)
	No—Public media	35 (21.0)	132 (79.0)	24 (14.4)	143 (85.6)	67 (40.1)	100 (59.9)
	Yes—Public Media	7 (8.4)	76 (91.6)	9 (10.8)	74 (89.2)	27 (32.5)	56 (67.5)
Frequency of Climate Change Information	Always or Often	3 (11.5)	23 (88.5)	2 (7.7)	24 (92.3)	7 (26.9)	19 (73.1)
	Sometimes, Rarely, or Never	39 (17.4)	185 (82.6)	31 (13.8)	193 (86.2)	87 (38.8)	137 (61.2)

CHPS Community-based Health Planning and Services; ID infectious diseases

3.7 FHWs' understanding of climate change and how it impact on health

Primary themes from the focus group discussion reflected how FHWs interpret and understand climate change and its link to zoonotic disease (Supplementary Table S5). FHWs described climate change as an observable shift in environmental conditions, particularly weather patterns. In defining climate change, most participants referred to their lived experiences with rising temperatures, unpredictable rainfall, and deviations from expected seasonal norms. One respondent noted:

“Climate change might be either excessive or complete change in what is expected. For example, I'm expecting a Harmattan to start somewhere in December, ending in January. I'm now feeling some funny things in my nose, like we are facing harmattan.” (Participant #1, Male, 56 years, Pharmacist).

Meanwhile, others highlighted the rising heat as one of the most tangible indicators of climate change, with the same respondent stating, *“Change in weather. Yes. Like currently as we are fanning ourselves, the weather is very hot, so there is a change in the weather”* (Participant #1, Male, 56 years, Pharmacist). In addition to temperature and seasonal shifts, participants also emphasized changes in rainfall patterns as an indicator of climate change: *“Maybe they are expecting this month to be rainy season, but because of climate change, they will see the sun”* (Participant #5, Female, 51 years, Midwife). For one participant, climate change was understood as a broader national or even regional phenomenon that manifests differently depending on location. They thoughtfully remarked:

“I was expecting to hear a question like, is the climate in Ada different from maybe Accra, or maybe Tema, or Ahafo, or somewhere else? ... There are times where it could be raining heavily in Accra, but here in Ada, we are still in the heat. So, ... currently our climate has changed to the extent that one state... can be experiencing a cool weather, the other can be experiencing a very hot weather.” (Participant #7, Female, 28 years, Midwife).

Furthermore, several respondents linked changing temperatures, heavy rains, and the Harmattan season with increases in specific health conditions: *“[Patients] with sickle*

Table 3 Predictors of good climate change attitudes among frontline healthcare workers (N= 250)

Predictor	Level	Knowledge		Attitudes		Practices	
		adjOR	95% CI	adjOR	95% CI	adjOR	95% CI
Sociodemographic Characteristics							
Age (in years)	20–29	1.00		1.00		1.00	
	30–34	0.66	0.24–1.82	0.76	0.26–2.16	1.11	0.51–2.44
	35–57	0.80	0.22–3.04	0.66	0.16–2.73	1.41	0.53–3.88
Sex	Man	1.00		1.00		1.00	
	Woman	1.65	0.56–4.70	0.40	0.08–1.50	0.57	0.24–1.30
Professional Characteristics							
Healthcare Facility Type	CHPS Compound	1.00		1.00		1.00	
	District/Regional Hospital	0.70	0.09–3.83	0.69	0.08–3.62	0.18	0.05–0.61
	Health Center	0.43	0.06–1.96	0.98	0.13–4.63	0.89	0.25–2.81
Occupational Category	Nurse	1.00		1.00		1.00	
	Midwives	1.00	0.34–3.14	0.87	0.29–2.84	1.39	0.58–3.44
	Other Clinical Staff	4.52	1.12–22.76	0.87	0.21–4.24	1.11	0.42–3.00
Experience in Current Role	> 5 years	1.00		1.00		1.00	
	≤ 5 years	0.98	0.32–2.93	0.40	0.10–1.47	1.22	0.52–2.87
Diagnoses/Treats Patients w/IDs	Yes	1.00		1.00		1.00	
	No	0.70	0.27–1.79	0.76	0.29–2.03	0.63	0.31–1.26
Training Characteristics							
Received ID Training	Yes	1.00		1.00		1.00	
	No	0.58	0.19–1.72	0.69	0.23–2.04	0.70	0.31–1.57
Experts Who Delivered ID Training	No—Respondents’ Health Facility	1.00		1.00		1.00	
	Yes—Respondents’ Health Facility	0.55	0.19–1.53	0.65	0.23–1.91	0.83	0.39–1.74
	No—Ministry/Government Health Authorities	1.00		1.00		1.00	
	Yes—Ministry/Government Health Authorities	1.44	0.58–3.72	2.27	0.79–7.34	0.44	0.21–0.91
	No—International NGOs	1.00		1.00		1.00	
	Yes—International NGOs	1.33	0.38–5.76	2.16	0.46–16.71	4.61	1.44–18.47
What ID Training Was Delivered	No—COVID-19	1.00		1.00		1.00	
	Yes—COVID-19	0.62	0.22–1.72	0.63	0.21–1.84	2.10	0.97–4.65
	No—Ebola virus disease	1.00		1.00		1.00	
	Yes—Ebola virus disease	0.91	0.30–2.83	0.80	0.23–2.79	2.44	0.95–6.58
	No—Human monkeypox virus	1.00		1.00		1.00	
	Yes—Human monkeypox virus	0.24	0.08–0.64	0.39	0.12–1.22	0.39	0.17–0.90
No—Rabies	1.00		1.00		1.00		
	Yes—Rabies	0.70	0.24–2.03	1.25	0.37–4.50	0.50	0.20–1.25
Information Access Characteristics							
Current Source of Zoonotic Disease Information	No—Conventional media	1.00		1.00		1.00	
	Yes—Conventional media	1.68	0.53–5.31	0.35	0.08–1.36	1.58	0.64–3.86
	No—Public media	1.00		1.00		1.00	
	Yes—Public Media	1.28	0.35–5.06	1.29	0.28–6.87	1.63	0.52–5.39
Current Source of Climate Change Information	No—Conventional media	1.00		1.00		1.00	
	Yes—Conventional media	2.04	0.67–6.57	7.86	1.94–37.37	1.10	0.45–2.73
	No—Public media	1.00		1.00		1.00	
	Yes—Public Media	2.41	0.55–11.14	0.58	0.09–3.18	0.73	0.21–2.50

Table 3 (continued)

Predictor	Level	Knowledge		Attitudes		Practices	
		adjOR	95% CI	adjOR	95% CI	adjOR	95% CI
Frequency of Climate Change Information	Always or often	1.00		1.00		1.00	
	Sometimes, Rarely, or Never	1.16	0.22–4.52	0.72	0.10–3.19	0.62	0.19–1.76

*Multivariable logistic regression results are presented as adjusted odds ratios (adjORs) with 95% confidence intervals (CIs). Models were adjusted for the covariates shown in the table, including sex, age group, facility type, occupational category, years of experience, infectious disease training and exposure, climate information access (source type and frequency), and training characteristics (provider type and topics)

NGO non-governmental organization; ID Infectious Diseases; Adjusted models were estimated using complete cases (N=245) because missing covariate data were limited to two variables (Received Infectious Diseases Training, n=1; Diagnoses and Treats Patients with Infectious Diseases, n=4).

cell crisis, because of the coldness of the weather... Meanwhile, they're supposed to warm themselves up. But because of that, they also face that [pain] crisis during the rainy season." (Participant #6, Female, 36 years, Midwife). Another participant elaborated on how the prevalence of asthma cases seemed to increase with the onset of the Harmattan season:

"The asthma clients visit us more, because most of them get the attacks during this weather [Harmattan season]. So, when it becomes warm, they come a lot. They get triggered." (Participant #7, Female, 28 years, Midwife).

A similar correlation between climate variability and health was observed among children, with participants noting increased upper respiratory and skin-related reactions during periods of rapid weather change: *"Most of them [children], they come with cold, catarrh, headache, running nose, and cough. They normally come with such conditions when the weather changes... And then heat rash as well"* (Participant #9, Female, 43 years, Nurse). Malaria was also commonly mentioned, with more than half of participants highlighting the role of rainfall and stagnant water in creating mosquito breeding environments, with one participant commenting,

"During the rainy season and when there are floods and stagnant water, it breeds mosquitoes" (Participant #3, Female, 32 years, Laboratory Technician). Together, these narratives frame climate change and its impacts on health as a daily reality for FHWs.

3.8 Perceived link between climate change and zoonotic disease transmission

When asked directly about the relationship between climate change and zoonotic disease transmission, some participants pointed to biological and environmental mechanisms they believed could heighten outbreak risk. For instance, one participant explained,

"Increasing temperature ... aids viruses, bacteria, and the likes to also multiply faster and are more active. There's a possibility of increased variance of those microorganisms. We expect Ebola diseases to be very serious because of climate change... and transmission very fast because of climate change." (Participant #1, Male, 56 years, Pharmacist)

This participant later goes on to emphasize habitat destruction, particularly deforestation and seasonal bushfires, as factors that lead to more frequent interactions between local native populations and animals:

“Deforestation and dehabitation, we [humans] tend to deprive these animals from their natural habitat. So, they rather get closer to humans for shelter and for protection. And by that, they end up getting closer to us and causing zoonotic diseases to spread... I know snakes. Normally in the hot seasons, they ... come to hide in our rooms and near human settlement, where they can take shelter, because there’s a lot of bush fires... their cover is naturally exposed, so they have nowhere to hide, and they find themselves living amongst us.” (Participant #1, Male, 56 years, Pharmacist)

This sentiment was followed by a few participants discussing the practices of the local Fulanese population, particularly regarding the hunting and consumption of wild animals such as monkeys. One participant remarked that wild animals “won’t dare” come near town because the Fulanese locals “will kill them before they even come.” (Participant #6, Female, 36 years, Midwife). Another participant added, “They [Fulanese natives] take them [wild animals] around to eat. So they [bushmeat] are all around,” reflecting perceptions of increased human–animal interaction driven by both cultural practices and habitat changes.

Lastly, one participant suggested that extreme heat combined with overcrowded public spaces, could facilitate the transmission of infectious diseases like Ebola—especially in transport settings where bodily contact is common:

“So in a hot season like this, when you sweat a lot and you sit close... especially in the trotros and the taxi, before you can move your body, somebody has already pasted their whole sweat on you. So it will increase the spread of Ebola in particular.” (Participant #7, Female, 28 years, Midwife).

FHWs account converge on three perceived mechanisms linking climate change and zoonotic diseases: human-induced environmental change, cultural practices, and dense urban living.

3.9 Observations of drivers of delayed Zoonotic disease care

Participants described a range of culturally embedded beliefs and practices that shape how community members respond to illnesses, like zoonotic diseases. These beliefs were seen to contribute too often to delayed care-seeking behavior, with implications for both individual and public health. First, many FHWs described spiritual or religious interpretations of zoonotic disease-related illness among community members. One participant explained,

“Some also believe that besides sicknesses, you have to consult the oracles. So, they go and consult the oracle to find out whether it is the cause of you having offended somebody or it is a curse that has been put on you” (Participant #1, Male, 56 years, Pharmacist).

Another adds,

“In our setting, they believe much in this. So, everything, they will go to the prayer camp first before they’ll come to the hospital. And most of the time, before they’ll come to the hospital, their condition has gotten worse... when the prophetess or the prophet, they realize the person is about to die, they will push you to the hospital

because when you die in their premises, it will spoil their business.” (Participant #4, Female, 39 years, Nurse)

Others explained that when community members did eventually arrive at healthcare facilities, they sometimes imposed restrictions on the type of healthcare, as dictated by religious leaders: *“They do come with their terms and conditions. The spiritual man says, you shouldn’t inject me or I should come for IV fluids and come back to the camp.” (Participant #9, Female, 43 years, Nurse).*

In addition, participants described widespread use of herbal remedies and over-the-counter medications as initial ‘treatments’ for zoonotic diseases before seeking formal care, with one participant noting, *“Sometimes they try with the herbal medicines. If it doesn’t work, then they will come” (Participant #6, Female, 36 years, Midwife).* Another notes, *“Some also choose to medicate themselves. They go to the pharmacies, the chemical shops, and then they buy medications they feel would solve their problem for them. So, it worsens, and then they come to the hospital” (Participant #7, Female, 28 years, Midwife).*

FHWs further emphasized that these behaviors often contributed to delayed care, with implications for zoonotic disease spread:

“They will go to the prayer camp, and before the person will be rushed here, she has already infected those at the prayer camp... It will spread to the community.” (Participant # 4). One participant responds, “It will spread like wildfire... we are in trouble” (Participant #7, Female, 28 years, Midwife).

Respondents also noted that family expectations and media messaging—particularly radio broadcasts—influenced care-seeking pathways. One participant explained the hierarchical order that community members follow when they suspect a zoonotic disease: *“So, prophets number one, family members number two, maybe the radio number three, and then health workers would be the last.” (Participant #7, Female, 28 years, Midwife).* FGD Participant #9 expands on this sentiment and states: *“We have a local radio station, Radio Ada. They have specific days that they do programs where they speak their local dialect, and then they educate them.”*

In discussing zoonotic disease detection and response within their practice, participants further described how community members often hesitated to report sick livestock due to economic concerns and limited awareness. As focus group discussion Participant #7 explained, *“They will lose revenue, and maybe they lack the knowledge about the fact that they have to report such things to the hospital. Because if my animal is sick, why should I come and tell the healthcare worker that my animal is sick?”* Another participant added, *“I think those who are learned will rather go to the veterinary.” (Participant #4, Female, 39 years, Nurse).* Participant #1 further noted,

“The moment they report a sick animal to the facilities, you might tell them to quarantine it or kill them. Most of the meat we buy in the market is not certified. They buy the cattle from the Fulanese and take them straight to the market. Such practices we see in the big cities and some area, but not in the country globally.” (Participant #1, Male, 56 years, Pharmacist)

These insights reflect a broader perception among FHWs that low awareness and economic concerns among community members impacted their reporting of zoonotic diseases, particularly in areas where livestock trade occurs without veterinary oversight.

3.10 Institutional gaps in preparedness for climate-driven zoonotic threats

FHWs emphasized that preparedness measures—such as PPE usage and isolation protocols—were rarely implemented until an outbreak had already been declared. One participant explained:

"We wear PPEs only when we hear of an outbreak, and we dress like we are living on the moon. Yeah, that is when the alert comes. If we don't get any alert from anywhere, it might be very difficult. Because now we know Mpox. We know COVID-19, the signs and symptoms we must expect. But if some of these zoonotic diseases, whose alert has not been communicated from higher centers, most of our hospitals will miss the diagnosis." (FGD Participant #1, Male, 56 years, Pharmacist)

FHWs stressed that in emergency cases, a lack of early warning systems or accessible protective equipment often placed them at personal risk:

"The person is rushed in, so before you even get to know that this is what is happening to the person, you've already gotten infected... Yeah, because there's no PPEs around ... Because when the person comes in, it's an emergency. The only thing you know is putting on your gloves for you to examine the person, and before later, they will do this test... When the result comes out positive, and by then, most of the health professionals that come in contact with the person are already gotten infected." (Participant #3, Female, 32 years, Laboratory Technician)

All participants also described a general lack of institutional guidelines for managing zoonotic disease cases. One participant noted, *"I think it's when there is an outbreak, that is when we follow the guidelines. But as of now, that we are all sitting here, there is actually no guidelines for anyone."* (Participant #7, Female, 28 years, Midwife). Even for more locally recognized zoonotic threats like rabies, Marburg, or Ebola, participants reported limited awareness of existing protocols, with one participant stating, *"When it comes to rabies, we don't have protocols that we follow but we a [have] treatment. So, I don't know of any of them. No, I'm not aware of that [protocols for Marburg or Ebola]."* (Participant #6, Female, 36 years, Midwife).

Furthermore, respondents described minimal access to ongoing training. One participant mentioned that the only recent opportunity to refer their knowledge had been through informal clinical meetings, which had not occurred in a long time. This point was elaborated on by another participant,

"I don't remember the last time there was any workshop in this country to that effect, even in Ada. You can attest that most of us haven't even entered our books in a very long time, let alone open them to look at what is going on. So, some of these things help. It freshens your memory. You might have forgotten about something, but with this, it [protocols would] freshen your memory." (Participant #9, Female, 43 years, Nurse)

In the absence of formal systems, participants relied heavily on informal communication networks to stay informed about zoonotic outbreaks and climate-related updates. These included personal Google searches, professional WhatsApp groups, and information shared by family members.

Another respondent added, *“Sometimes, they post this [information] on our [WhatsApp] page, there is an update... Our family members keep calling, so they will update us.”* (FGD Participant #6, Female, 36 years, Midwife). One respondent stated, *“Ask AI”* (Participant #7, Female, 28 years, Midwife).

FHWs expressed a strong desire for more structured, formal training workshops, ideally organized by the Ministry of Health (MOH) or other government bodies. These workshops were viewed as more trustworthy and effective than piecemeal updates: *“[We prefer] Workshop, because the researcher or the person who is presenting has done his research. He has done his findings. And the person also is an expert in what he or she is talking about.”* (Participant #2, Female, 32 years, Nurse).

In terms of their own practices, participants described small-scale institutional actions to mitigate environmental risks driving zoonotic outbreaks, such as conserving electricity, turning off unused appliances, or switching to energy-saving bulbs: *“When we come, let’s say the lights. The lights, when they are not in use, we put them off to preserve energy.”* (Participant #4, Female, 39 years, Nurse). Another respondent notes, *“We try and light the energy-saving bulbs. Fridges and other things, we buy the energy-saving ones so that we can save energy”* (Participant #5, Female, 51 years, Midwife).

They also shared their vision for broader community education on the link between climate change and zoonoses:

“Bats, yes. They should desist from killing such animals or even any sick animals around them. They should desist from killing and bringing them to the market to sell them. Secondly, we will talk about the fact that if there is any sick person in the community, they shouldn’t treat themselves. They should come to the facility for health care. The third thing would be the mode of transmission. Body fluids, they should wash their hands often, keep their environment clean, and all these things. And then lastly, if there is even a death in the community, they should bring their body to the health facility because they do not know exactly what killed that particular person.” (Participant #7, Female, 28 years, Midwife)

These comments reflect FHWs’ emphasis on the importance of discouraging bushmeat consumption, promoting proper hygiene, and encouraging timely reporting of unexplained illnesses or deaths within the community.

3.11 Perceived stakeholder roles and call for action on the climate-zoonosis nexus

Participants widely agreed that addressing the dual impact of climate change and zoonotic disease requires multisectoral collaboration, particularly between meteorological agencies, the Ministry of Environment, Science and Technology, and health authorities. One participant suggested:

“Inter-sectoral collaboration, where governments would coordinate between the Ministry of Environment, Science and Technology, so that we can be informed that instead of expecting rain, we should expect very dry seasonal conditions... So that at least, they say to be forewarned.” (Participant #1, Male, 56 years, Pharmacist)

This same participant, echoing the views of others, further described FHWs as implementers of policies handed down from district or regional health directorates, noting

that district directors—many of whom are public health specialists—play a strong coordinating role:

“Almost all our district directors are public health specialists. When there is any outbreak, direction and guidance will certainly come from them. We will still fall on the district that will also fall on the regional health directorate for guidance and direction. We here are basically more or less like policy implementers who will implement whatever policy comes from higher centers. In question, with this cholera outbreak, I realized that it was when I had more contact with the district director than anything else. He would call me, do you have this, we are expecting this medicine to come. They will bring it today; come and receive it.” (Participant #1, Male, 56 years, Pharmacist)

Governmental actors were also perceived as critical in building resilient infrastructure and protecting environmental resources to reduce future risks: *“I think that the government should build a new facility for us here, a well-equipped one that, regardless of whether it’s a zoonotic disease or a normal illness, you know that the people are receiving good care.” (Participant #1, Male, 56 years, Pharmacist)*. The role of the government was further noted on by another participant who stated, *“The government should see to it that our forests are being preserved. By preventing this deforestation and waste that force the wild animals to lose their habitats.” (Participant #4, Female, 39 years, Nurse)*. In addition to these comments, one FHW adds, *“I think the previous governments wanted us to have this planting of trees. I don’t know how far that thing went, but I think it’s a good idea. The planting of trees will help ease the scorching sun on our heads.” (FGD Participant #7, Female, 28 years, Midwife)*.

All FHWs in the discussion called for more infectious disease centers, quicker diagnostic access, and adequate supplies like PPE and medications—needs described as basic yet unmet:

“We don’t even have an isolation place. If we are able to identify an infectious disease at the district hospital, we straight away refer to a specialized center where they can be handled professionally, rather than trying to manage them with the general knowledge that we have. As the pharmacist sitting here, if you ask me what are the medicines we used to mitigate the spread of Ebola, I may have to refer. Resources to manage such patients must come from the headquarters. PPE has to come from Central Medical Store... Per our facilities, those things were finished when we last heard of COVID.” (FGD Participant #1, Male, 56 years, Pharmacist)

Others stressed the need for rapid testing, with one participant stating, *“With something like Ebola, for us to diagnose it, they will say take a sample, bring it to a place. We cannot do it in our facility. If we could have the places close by, it won’t take 3 days or 1 week for us to know because we are at risk here.” (Participant #7, Female, 28 years, Midwife)*. One participant captured these sentiments, voicing the concern shared by many frontline staff: *“With this not prepared, not having an isolation bay, and then the way the people in the community, their attitude towards certain conditions, we are in trouble.” (Participant #9, Female, 43 years, Nurse)*.

Respondents also emphasized that FHWs themselves deserved greater recognition, protection, and compensation, particularly during zoonotic outbreaks potentially

exacerbated by climate change: *“We are the frontline health workers. There should be some kind of assurances that we would have, that even though you are the frontline, taking care of people, if you get infected, your medications are free, maybe you will be given this amount of money. COVID, we heard about those things, but truthfully, it didn’t work. I never received any of that money.”* (Participant #7, Female, 28 years, Midwife).

Enthusiasm for continued engagement in research on zoonotic disease and climate change was palpable, with participants seeing research as a means to both document on-the-ground realities and inform policy. However, they also voiced a strong desire that their participation be followed by meaningful implementation. *“I hope that this wouldn’t be the only research that will be done, because there are a lot of diseases that are coming up. And we would like you people to know how best we know the diseases and how best we handle them, and what the government should do about it because it’s these researchers that inform them of our knowledge on the grounds and what is being done. So, my hope is that in the future, there’ll be more researchers, and then most important, there’ll be implementation of them.”* (Participant #7, Female, 28 years, Midwife).

4 Discussion

This mixed-methods study offers a critical district-level examination of Ghanaian FHWs’ knowledge, attitudes, and practices (KAP) regarding the climate-zoonosis nexus. Additionally, our analysis of how frontline health workers in Ghana perceive and respond to the interconnected challenges of climate change and zoonotic diseases illustrates how climate change is understood and addressed within a health system that faces both resource constraints and increasing environmental pressures. These findings indicate strong baseline awareness among FHWs along with critical gaps in system preparedness. Addressing these challenges will require multisectoral collaboration, investments in infrastructure and diagnostics, and concrete steps to translate policy commitments into frontline practice.

4.1 High experiential knowledge as an early warning resource for climate-health risks

Our findings suggest that FHWs in Ada East, Ghana, are well-informed of climate change’s impacts on health, especially regarding zoonotic diseases. This high awareness positions them as “climate-health sentinels” who can provide early warnings of climate-driven zoonotic threats. Quantitatively, 95.6% of respondents correctly identified how changing climate patterns can drive infectious disease outbreaks. Many also reported climate-linked shifts in patient cases—particularly air-quality-related illnesses, heat-related conditions, and allergic reactions. This experiential, place-based knowledge is valuable as a first signal for emerging zoonotic risks.

Qualitative insights reinforced these patterns and illustrated how providers mechanistically linked climate phenomena to everyday health outcomes. For example, participants described erratic rainfall leading to more stagnant water and mosquito breeding, coinciding with spikes in malaria; dry, dusty Harmattan winds aggravating respiratory illnesses like asthma; prolonged cool and wet periods triggering increases in sickle cell crises; and heat waves bringing surges in heat rashes and dehydration. Some also observed that during very hot, dry periods, wildlife encroach closer to homes (e.g., bats or snakes seeking water), increasing human-animal contact and the risk of zoonotic disease spillover. These frontline observations align with broader evidence that climate

variability is amplifying health burdens and could accelerate zoonotic spillover under future warming [14, 19–25, 33, 85, 86].

Ghana's frontline providers are already detecting signals that may foreshadow larger public health threats, as evidenced in our findings, underscoring the value of their experiential knowledge as a complement to formal surveillance data systems [66, 67, 70–73, 87]. Their on-the-ground observations mirror trends documented in climate-health literature and echo global calls to empower healthcare professionals as sentinels and educators at the climate-zoonosis nexus [66, 67, 70–73].

To leverage this local knowledge, health systems should establish formal channels for frontline staff to share climate-linked clinical observations [69, 72, 73]. For instance, routine debriefings or monthly meetings could be instituted for frontline staff to report any unusual case patterns following heat waves, floods, or other weather extremes. Systematically capturing these insights would strengthen surveillance and shorten the lag between the onset of zoonotic outbreaks and a public health response [67, 71]. In essence, incorporating FHWs' experiential reports into early warning systems can enrich One Health monitoring at the grassroots level [67]. Such community-based reporting is a cornerstone of proposed One Health early warning frameworks, which emphasize that empowering local actors is essential for timely, coordinated outbreak preparedness [67, 80]. We recommend that Ghana's health authorities pilot mechanisms to integrate frontline climate-health intelligence into district surveillance—a low-cost step that could enhance national outbreak alert systems [68, 70, 80, 88].

4.2 Assessment of knowledge gaps through a one health lens

While Ada East FHWs readily recognized direct clinical impacts of climate change, we also found significant knowledge gaps regarding broader climate-health pathways. In particular, the understanding of the One Health dimensions was limited. Few respondents were aware of how agricultural and livestock practices contribute to climate change, despite agriculture being a primary anthropogenic driver of land-use change and greenhouse gas emissions in Ghana [39–43, 46, 52, 89]. Fewer than one-third connected climate change to psychosocial health outcomes, such as stress, anxiety, or social conflict, and recognition of especially vulnerable groups like children, older adults, or women was low despite evidence that these groups face heightened climate-related health risks [90–92]. Notably, we found that attending highly vertical, disease-focused workshops—namely, trainings on monkeypox—was associated with lower overall climate-health knowledge scores. This counterintuitive finding may suggest that siloed training programs might isolate diseases from their environmental context, leaving providers less attuned to how climate and ecological changes influence disease emergence and connect to broader One Health dimensions [75]. The unexpected link between monkeypox training and lower knowledge or practice may be due to confounding or reverse causation, as training might have been given to lower-capacity facilities or specific cadres. Although breakdowns by facility type or cadre could be helpful, available data lacked reliable disaggregation, and details on training timing, content, quality, source, and whether it was mandatory were not captured. This limits interpretation, and the association should be viewed cautiously and not considered definitive causal.

Addressing these identified gaps will require retooling health education toward a more holistic, One Health perspective—an integrated approach that recognizes

the interconnected health of people, animals, and the environment and emphasizes cross-sector collaboration [80, 93]. Educators could expand pre-service curricula and in-service training to include underrepresented climate-health topics such as agriculture-driven greenhouse gas emissions, the dynamics of wildlife-livestock-human interfaces, and the mental health implications of climate change [75, 80]. We also suggest using locally relevant, case-based teaching that explicitly links recent climatic events to changes in disease patterns; for example, analyzing how a recent flood coincided with leptospirosis clusters, a drought with anthrax events, or a heatwave with bat-human contact and Marburg risk in the district. This approach would ensure that even specialized zoonotic disease training is contextualized within the broader climatic and environmental landscape [24]. By integrating One Health concepts into training and continuous professional development, as urged by international frameworks, Ghana's health workforce may better anticipate indirect and multi-sectoral drivers of climate-driven zoonotic outbreaks [67, 74, 80, 93–95]. Finally, in Supplementary Table S6, we summarize the Actionable One Health Recommendations.

4.3 From individual initiative to institutional preparedness

Despite strong knowledge and positive attitudes, a clear gap remains between frontline workers' personal climate-friendly behaviors and their institutions' climate-zoonotic preparedness. Most respondents reported engaging in low-cost individual-level actions—such as conserving water, turning off unused equipment, or using cleaner cookstoves—yet fewer than 12% reported “Good” climate mitigation practices at the facility level. Focus group narratives further noted that frontline staff often take a reactive stance to climate-driven zoonotic threats. Essential resources—including PPE, emergency protocols, or climate-focused guidelines—typically arrive after a crisis begins rather than as preventative measures. Smaller community-based clinics (e.g., CHPS compounds) were positively associated with better climate mitigation practices, whereas larger district hospitals were less engaged in these measures. This pattern of strong individual engagement in climate mitigation but weak institutional climate-zoonotic preparedness might indicate that structural barriers are limiting the translation of frontline commitment into system-wide resilience.

Closing this practice gap will require deliberate support from health authorities to climate-proof health facilities as an indirect means to reduce the risk of zoonotic disease and empower staff-led initiatives [38, 69, 73]. Investments are needed to upgrade infrastructure and operations for a climate-resilient approach to zoonotic preparedness [25, 96]. Ensuring essential medicines, vaccines, and supplies are pre-positioned in anticipation of climate-related events, rather than delivered only in emergency response, is another crucial step for zoonotic preparedness [97, 98].

Our data also underscore the importance of training and information flow in driving climate-informed zoonotic preparedness. Both quantitative and qualitative results identified training exposure as a key predictor of good climate-friendly practices. Notably, FHWs who had participated in NGO-led training workshops reported better climate-health practices than those trained through government programs. Participants explained that most official training on emerging zoonotic diseases in the backdrop of climate change is infrequent, prompting them to rely on ad-hoc sources like WhatsApp groups or personal internet searches to fill knowledge gaps. This indicates an

opportunity to improve not just the content, but also the delivery of training. Instituting regular, hands-on drills and learning modules focused on climate-related health emergencies may prove beneficial. Developing these trainings in collaboration with frontline staff would ensure they are relevant to local realities, and embedding such exercises and discussions into routine continuing education would keep climate preparedness at the forefront of FHWs' minds [25, 38, 53, 67, 70, 72, 75, 91, 98]. It would also address the anxiety FHWs voiced about being “in trouble” during a major zoonotic outbreak if left unprepared.

Respondents expressed frustration that national climate-health policies and plans often do not translate into tangible support for the local staff. To remedy this, participatory governance mechanisms should be strengthened, for example, via the creation of local climate-health focal points or committees within each district where frontline workers can both receive updates on policies and feed their experiences upward [67, 68, 70, 73, 75, 98]. Regular forums for FHWs to voice needs—such as reporting PPE shortages or flagging upticks in certain illnesses that could signal zoonotic emergence—would help decision-makers allocate resources more responsively [72, 97, 98].

4.4 Socio-cultural and economic barriers to rapid outbreak response

Community-level factors identified by FHWs, including economic pressures, health-seeking behaviors, and long-standing livelihood practices, seem to strongly shape how quickly climate-sensitive zoonotic threats are detected and addressed. This study highlighted that effective preparedness must therefore extend beyond health facilities into the community, since even well-trained staff and better-equipped clinics cannot overcome delays rooted in the community context. FHWs in Ada East observed that patients' economic vulnerabilities heavily influenced their care-seeking practices. Similarly, FHWs reported that farmers also rarely report strange illnesses or deaths in their livestock, often out of fear of losing income or because there are no clear mechanisms to do so. These identified gaps signal that animal warning signs, which serve as potential precursors to human outbreaks, are frequently missed. Future research should explore how economic and food insecurity may impact both climate mitigation practices and zoonotic disease reporting.

Cultural beliefs and trust in traditional medicine seem to further shape health-seeking behaviors within the community. Participants explained that sudden illness is frequently attributed to spiritual causes, prompting families to seek help first from prayer camps, faith healers, or herbalists. While these practices remain central to community life, FHWs stressed that they delay engagement with the formal health system. They warned that a fast-spreading zoonosis like Ebola could “*spread like wildfire*” if patients remain at home or in spiritual centers without timely diagnosis and isolation. Even when families choose biomedical care, further delays arise when individuals first try self-medication or over-the-counter drugs, often arriving at clinics only when the illness has advanced.

Addressing these socio-cultural challenges will require proactive engagement and multi-sector collaboration [39–41, 44, 69, 70, 72]. Public health authorities should work with trusted local leaders to improve understanding of climate-driven zoonotic risks and foster trust in early reporting [70, 72]. Outreach campaigns can respect cultural traditions while stressing that specific symptoms or unusual illness clusters require

immediate medical attention [40, 91]. Leveraging local media, such as Radio Ada, offers promising channels for tailored communication.

4.5 Strengths and limitations

This study's concurrent mixed-methods design provided a more nuanced understanding of FHWs' KAP regarding climate change and its link to zoonotic disease. This Ghana district, the Ada East District of Ghana's Greater Accra Region, where the study was conducted, has demographic and geographic diversity—encompassing urban, peri-urban, and rural areas—and its high concentration of healthcare facilities staffed by a range of clinical personnel, including nurses, midwives, pharmacists, community health officers, and physicians. The district's dual role as a hotspot for climate-sensitive diseases and a frontline hub for outbreak response made it a highly relevant setting for this study. The survey quantified levels of knowledge, attitudes, and practice, while the focus group offered a platform for FHWs to expand on existing barriers to climate-linked zoonoses preparedness and how providers interpret the challenges they face. The qualitative data added depth and context to the survey findings, strengthening credibility through triangulation. We used validated questions where possible and applied rigorous thematic analysis, grounding findings in participants' own statements and experiences. The relatively large and diverse sample spanned multiple facility types and professional roles, enhancing the transferability of findings to similar coastal districts in Ghana and increasing their relevance for district-level health planning.

However, several limitations should be acknowledged. The cross-sectional design prevents causal inference. Because the number of eligible staff approached and reasons for non-participation were not systematically documented, formal calculation of response rates was not possible, which may limit assessment of potential participation bias. Participants were clustered within healthcare facilities; however, facility-level clustering was not accounted for in the regression analyses, which may have led to underestimation of standard errors and overprecision of confidence intervals. Recruitment happened during specific on-site times, and staff availability differences across shifts (day vs. night) may have affected participation, possibly causing selection bias.

Because no prior district-specific data were available, the sample size calculation relied on an assumed prevalence of poor KAP (6%); although this assumption was informed by previous studies among healthcare workers, it may have resulted in imprecision in the initial sample size estimation. Also, sampling in a single district limits generalizability, as climate–health awareness may differ in other regions with distinct exposures, health systems, or socio-cultural contexts. That said, Ada East includes urban, peri-urban, and rural facilities, offering a reasonable cross-section for a climate-vulnerable coastal zone. All data were self-reported, raising the possibility of social desirability and recall bias. We attempted to reduce this risk by assuring anonymity and clarifying that the survey was not an evaluation of job performance. We encouraged the frontline staff to describe system gaps they perceive openly. Furthermore, thresholds for “Good” practice or attitude ($\geq 60\%$) were based on Bloom's taxonomy, a common approach in KAP studies but inherently arbitrary. Some adjusted estimates were associated with wide confidence intervals, reflecting limited precision and the possibility of overfitting in multivariable models; these findings should therefore be interpreted with caution. Formal regression diagnostics, including goodness-of-fit testing, variance inflation factors, and sensitivity

analyses, were not performed; therefore, model fit and robustness could not be formally assessed.

Finally, the qualitative component involved only one focus group ($n = 9$). Those participants were volunteers and may have been more engaged or motivated than the broader survey population, which may limit the transferability of qualitative findings. Although we sampled diverse roles within the discussion, some perspectives, particularly from those who did not volunteer for the focus group discussion, may not have been captured. Also, the participants received the most honorarium that may have influenced their willingness to participate. Although we did not perform any statistical comparison, the consistency we observed between quantitative trends and qualitative narratives lends confidence to the robustness and credibility of our findings. Together, they provide a valuable baseline for future longitudinal or multi-site research on climate–health preparedness among frontline health workers.

5 Conclusion

Ghana's frontline healthcare workers are a critical yet underutilized resource in the national response to climate-sensitive zoonotic threats. They offer valuable experiential knowledge, practical observational skills, and community trust, coupled with a willingness to act. However, conceptual gaps, structural limitations, and social, cultural, and economic barriers hinder the translation of these strengths into sustained institutional preparedness. Bridging this gap requires targeted training, empowerment structures at the facility level, cross-sectoral early-warning systems, and climate-resilient infrastructure. Building on the strengths already present, such as practical observational capacity, media engagement, and community trust, may accelerate climate mitigation efforts and reduce the risk of climate-driven zoonotic outbreaks. Investment in these frontline actors is also an investment in both national health security and global pandemic prevention.

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s12982-026-01622-w>.

Additional file 1.

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Author contributions

A.N.Y. conceived and designed the project, developed the data collection instrument, coordinated data collection, performed data analysis, and drafted and finalized the manuscript. K.P.W. contributed to data management, analysis, manuscript preparation. H.E.S. participated in the review of the survey instrument and qualitative data analysis. K.K.S. assisted in the study design, reviewed the manuscript for scientific content, and provided critical revisions. G.H., L.B., E.K., and C.L.N. contributed to data collection, review of study instruments, and manuscript review. K.T.R. and A.T.G. reviewed and provided input on the manuscript. M.A.K. supervised the final analysis, contributed to the interpretation of results, and finalized the results and discussion sections. All authors read and approved the final version of the manuscript.

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Data availability

The datasets used and analyzed during the current study are not publicly available due to confidentiality restrictions but can be made available upon reasonable request and collaboration with the corresponding authors (A.N.Y. and M.A.K.).

Declarations

Ethics approval and consent to participate

This study was approved by the Ghana Health Service Ethical Review Committee (GHS-ERC 024/08/24) and the Pennsylvania State University Institutional Review Board (STUDY00025492). Written informed consent was obtained from all survey participants prior to enrollment. Participants in the focus group discussion provided separate written consent for participation and audio recording. All procedures were conducted in accordance with relevant ethical guidelines and regulations.

Consent for publication

Not applicable. No individual-level identifiable data are included in this manuscript.

Competing interests

The authors declare no competing interests.

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References

1. What Is Climate Change? - NASA Science. 2022. <https://science.nasa.gov/climate-change/what-is-climate-change/>. Accessed 12 Aug 2025.
2. Zell R. Global climate change and the emergence/re-emergence of infectious diseases. *Int J Med Microbiol Suppl.* 2004;293:16–26. [https://doi.org/10.1016/S1433-1128\(04\)80005-6](https://doi.org/10.1016/S1433-1128(04)80005-6).
3. Heffernan C. Climate change and multiple emerging infectious diseases. *Vet J.* 2018;234:43–7. <https://doi.org/10.1016/j.tvjl.2017.12.021>.
4. Daszak P, Cunningham AA, Hyatt AD. Anthropogenic environmental change and the emergence of infectious diseases in wildlife. *Acta Trop.* 2001;78:103–16. [https://doi.org/10.1016/S0001-706X\(00\)00179-0](https://doi.org/10.1016/S0001-706X(00)00179-0).
5. Bartlow AW, Manore C, Xu C, Kaufeld KA, Del Valle S, Ziemann A, et al. Forecasting zoonotic infectious disease response to climate change: mosquito vectors and a changing environment. *Vet Sci.* 2019;6:40. <https://doi.org/10.3390/vetsci6020040>.
6. Caminade C, McIntyre KM, Jones AE. Impact of recent and future climate change on vector-borne diseases. *Ann NY Acad Sci.* 2019;1436:157–73. <https://doi.org/10.1111/nyas.13950>.
7. Fouque F, Reeder JC. Impact of past and on-going changes on climate and weather on vector-borne diseases transmission: a look at the evidence. *Infect Dis Poverty.* 2019. <https://doi.org/10.1186/s40249-019-0565-1>.
8. Treskova M, Semenza JC, Arnés-Sanz C, Al-Ahdal T, Markotter W, Sikkema RS, et al. Climate change and pandemics: a call for action. *Lancet Planetary Health.* 2025;9:101302. <https://doi.org/10.1016/j.lanplh.2025.101302>.
9. Zoonoses JFEC on, Organization WH, Nations F and AO of the U. Joint WHO/FAO Expert Committee on Zoonoses [meeting held in Stockholm from 11 to 16 August 1958]: second report. World Health Organization; 1959.
10. Jones KE, Patel NG, Levy MA, Storeygard A, Balk D, Gittleman JL, et al. Global trends in emerging infectious diseases. *Nature.* 2008;451:990–3. <https://doi.org/10.1038/nature06536>.
11. García-Rubio VG, Ojeda-Carrasco JJ, Espinosa-Ayala E, Hernández-García PA, Rueda-Quiroz LD. Climate change and its role in the emergence and re-emergence of zoonotic diseases that increase the risk of future pandemics. *IJAB.* 2023;1:1–7. <https://doi.org/10.47278/book.oht/2023.01>.
12. Usmani MW, Rizvi F, Shakir MZ, Mahmood N, Numan M, Abdullah RM, et al. Factors Influencing the Emergence and Re-emergence of Zoonotic Infectious Diseases in Livestock and Human Populations. *IJAB.* 2023;Zoonosis Volume 1:316–26. <https://doi.org/10.47278/book.zoon/2023.023>.
13. Yeni D, Nazir M, Ijaz M, Rafique A, Ali T, Ashraf A. Effects of climate change on emerging and reemerging zoonotic diseases. *IJAB.* 2023;1:211–25. <https://doi.org/10.47278/book.zoon/2023.015>.
14. Wilson ME. Spillover: from climate change to pandemics. *Field Act Sci Reports J Field Act.* 2025; Special Issue 27:58–64.
15. Lecka M, Omyła M, Pietryszak E, Paruzel M. Impact of climate change on the spread of infectious diseases - review. *J Educ Health Sport.* 2025;82:60532. <https://doi.org/10.12775/JEHS.2025.82.60532>.
16. Smith KF, Goldberg M, Rosenthal S, Carlson L, Chen J, Chen C, et al. Global rise in human infectious disease outbreaks. *J R Soc Interface.* 2014;11:20140950. <https://doi.org/10.1098/rsif.2014.0950>.
17. Pfenning-Butterworth A, Buckley LB, Drake JM, Farner JE, Farrell MJ, Gehman A-LM, et al. Interconnecting global threats: climate change, biodiversity loss, and infectious diseases. *Lancet Planet Health.* 2024;8:e270–83. [https://doi.org/10.1016/S2542-5196\(24\)00021-4](https://doi.org/10.1016/S2542-5196(24)00021-4).

18. Mora C, McKenzie T, Gaw IM, Dean JM, von Hammerstein H, Knudson TA, et al. Over half of known human pathogenic diseases can be aggravated by climate change. *Nat Clim Chang*. 2022;12:869–75. <https://doi.org/10.1038/s41558-022-01426-1>.
19. Umar F. Climate change, urbanization, and zoonotic diseases: a narrative review for public health resilience. *Jurnal Riset Kualitatif dan Promosi Kesehatan*. 2024;3:1–12. <https://doi.org/10.61194/jrpk.v3i1.671>.
20. Liao H, Lyon CJ, Ying B, Hu T. Climate change, its impact on emerging infectious diseases and new technologies to combat the challenge. *Emerg Microbiol Infect*. 2024;13:2356143. <https://doi.org/10.1080/22221751.2024.2356143>.
21. Wang Z, Pei S, Cui H, Zhang J, Jia Z. Zoonotic spillover and extreme weather events drive the global outbreaks of airborne viral emerging infectious diseases. *J Med Virol*. 2024;96:e29737. <https://doi.org/10.1002/jmv.29737>.
22. Elder BD, Reilly JR. Warmer temperatures increase disease transmission and outbreak intensity in a host–pathogen system. *J Anim Ecol*. 2014;83:838–49. <https://doi.org/10.1111/1365-2656.12180>.
23. Leal Filho W, Nagy GJ, Gbaguidi GJ, Paz S, Dinis MAP, Luetz JM, et al. The role of climatic changes in the emergence and re-emergence of infectious diseases: bibliometric analysis and literature-supported studies on zoonoses. *One Health Outlook*. 2025;7:12. <https://doi.org/10.1186/s42522-024-00127-3>.
24. Rupasinghe R, Chomel BB, Martínez-López B. Climate change and zoonoses: a review of the current status, knowledge gaps, and future trends. *Acta Trop*. 2022;226:106225. <https://doi.org/10.1016/j.actatropica.2021.106225>.
25. Phillips MC, LaRocque RC, Thompson GR III. Infectious diseases in a changing climate. *JAMA*. 2024;331:1318–9. <https://doi.org/10.1001/jama.2023.27724>.
26. Cimaroli A. Climate Change and Nipah virus: exploring the links between climate variability, extremes, and zoonotic spillover in Bangladesh. *laurea. Politecnico di Torino*; 2024.
27. Abbasi E. Climate change and vector-borne disease transmission: the role of insect behavioral and physiological adaptations. *Integr Org Biol*. 2025. <https://doi.org/10.1093/iob/obaf011>.
28. CDC. Vector-Borne Diseases. Climate and Health. 2025. <https://www.cdc.gov/climate-health/php/effects/vectors.html>. Accessed 13 Aug 2025.
29. Ma J, Guo Y, Gao J, Tang H, Xu K, Liu Q, et al. Climate change drives the transmission and spread of vector-borne diseases: an ecological perspective. *Biology*. 2022;11:1628. <https://doi.org/10.3390/biology11111628>.
30. Williams JE, Blois JL. Range shifts in response to past and future climate change: can climate velocities and species' dispersal capabilities explain variation in mammalian range shifts? *J Biogeogr*. 2018;45:2175–89. <https://doi.org/10.1111/jbi.13395>.
31. Wrenford KC, Angert AL, Gaynor KM. Linking individual animal behavior to species range shifts under climate change. *Trends Ecol Evol*. 2025;40:805–17. <https://doi.org/10.1016/j.tree.2025.06.002>.
32. Shifting habitats. *Nat Clim Chang*. 2020;10:377–377. <https://doi.org/10.1038/s41558-020-0789-x>.
33. Carlson CJ, Albery GF, Merow C, Trisos CH, Zipfel CM, Eskew EA, et al. Climate change increases cross-species viral transmission risk. *Nature*. 2022;607:555–62. <https://doi.org/10.1038/s41586-022-04788-w>.
34. Parrish CR, Holmes EC, Morens DM, Park E-C, Burke DS, Calisher CH, et al. Cross-species virus transmission and the emergence of new epidemic diseases. *Microbiol Mol Biol Rev*. 2008;72:457–70. <https://doi.org/10.1128/mmr.00004-08>.
35. Interactive Country Fiches. Ghana Biodiversity. 2022. <https://dicf.unepgrid.ch/ghana/biodiversity>. Accessed 13 Aug 2025.
36. Kondra M. Current state of biodiversity in Ghana A literature review. water power working paper no governance and sustainability lab Trier University, Trier. 2019.
37. Ministry of Environment, Science, Technology, and Innovation. National Biodiversity Strategy and Action Plan. 2016.
38. Cardona O, van Aalst M, Birkmann J, Fordham M, McGregor G, Perez R, et al. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change. Cambridge University Press; 2012.
39. Gibb R, Franklins LHV, Redding DW, Jones KE. Ecosystem perspectives are needed to manage zoonotic risks in a changing climate. *BMJ*. 2020. <https://doi.org/10.1136/bmj.m3389>.
40. Weiss RA, McMichael A. Social and environmental risk factors in the emergence of infectious diseases. 2004.
41. Ghana at a glance | FAO in Ghana | Food and Agriculture Organization of the United Nations. <https://www.fao.org/ghana/ao-in-ghana/ghana-at-a-glance/en/>. Accessed 7 June 2025.
42. Ntiamao-Baidu Y, Nations F and AO of the U. Wildlife and Food Security in Africa. Food & Agriculture Org.; 1997.
43. Pearce F. The Protein Gap. *Conservation in Practice*. 2005;6:117–23. <https://doi.org/10.1111/j.1526-4629.2005.tb00178.x>.
44. Nasi R, Brown D, Wilkie D, Bennett E, Tutin C, Tol G van, et al. Conservation and use of wildlife-based resources: the bushmeat crisis. 2008.
45. Amoah L a. O. Potential Transmission Of Zoonoses Between The Human-Domestic-Wildlife Interface And Its Implication For Sustainable Health. University of Ghana; 2021.
46. Studies the AC for S. African Biodiversity Loss Raises Risk to Human Security. Africa Center. <https://africacenter.org/spotlight/african-biodiversity-loss-risk-human-security/>. Accessed 13 Aug 2025.
47. Gibb R, Redding DW, Chin KQ, Donnelly CA, Blackburn TM, Newbold T, et al. Zoonotic host diversity increases in human-dominated ecosystems. *Nature*. 2020;584:398–402. <https://doi.org/10.1038/s41586-020-2562-8>.
48. Danso GK, Takyi SA, Amponsah O, Yeboah AS, Owusu RO. Exploring the effects of rapid urbanization on wetlands: insights from the Greater Accra Metropolitan Area, Ghana. *SN Soc Sci*. 2021;1:212. <https://doi.org/10.1007/s43545-021-00218-2>.
49. Mendoza H, Rubio AV, García-Peña GE, Suzán G, Simonetti JA. Does land-use change increase the abundance of zoonotic reservoirs? Rodents say yes. *Eur J Wildl Res*. 2019;66:6. <https://doi.org/10.1007/s10344-019-1344-9>.
50. Ostfeld RS, Keesing F. Species that can make us ill thrive in human habitats. *Nature*. 2020;584:346–7. <https://doi.org/10.1038/d41586-020-02189-5>.
51. Amisshah-Reynolds PK. Zoonotic risks from domestic animals in Ghana. *Int J Path Res*. 2020;4:17–31. <https://doi.org/10.9734/ijpr/2020/v4i330113>.
52. Jones BA, Grace D, Kock R, Alonso S, Rushton J, Said MY, et al. Zoonosis emergence linked to agricultural intensification and environmental change. *Proc Natl Acad Sci*. 2013;110:8399–404. <https://doi.org/10.1073/pnas.1208059110>.
53. Dobson AP, Pimm SL, Hannah L, Kaufman L, Ahumada JA, Ando AW, et al. Ecology and economics for pandemic prevention. *Science*. 2020;369:379–81. <https://doi.org/10.1126/science.abc3189>.
54. Olivero J, Fa JE, Real R, Márquez AL, Farfán MA, Vargas JM, et al. Recent loss of closed forests is associated with Ebola virus disease outbreaks. *Sci Rep*. 2017;7:14291. <https://doi.org/10.1038/s41598-017-14727-9>.

55. In Africa, 63% jump in diseases spread from animals to people seen in last decade | WHO | Regional Office for Africa. 2025. <https://www.afro.who.int/news/africa-63-jump-diseases-spread-animals-people-seen-last-decade>. Accessed 7 June 2025.
56. Ayala AJ, Yabsley MJ, Hernandez SM. A review of pathogen transmission at the backyard chicken–wild bird interface. *Front Vet Sci*. 2020. <https://doi.org/10.3389/fvets.2020.539925>.
57. Gamble A, Olarte-Castillo XA, Whittaker GR. Backyard zoonoses: the roles of companion animals and peri-domestic wildlife. *Sci Transl Med*. 2023;15:eadj0037. <https://doi.org/10.1126/scitranslmed.adj0037>.
58. Suu-Ire R, Obodai E, Bel-Nono SO, Ampofo WK, Mazet JAK, Goldstein T, et al. Surveillance for potentially zoonotic viruses in rodent and bat populations and behavioral risk in an agricultural settlement in Ghana. *One Health Outlook*. 2022;4:6. <https://doi.org/10.1186/s42522-022-00061-2>.
59. Fahr J, Abedi-Lartey M, Esch T, Machwitz M, Suu-Ire R, Wikelski M, et al. Pronounced seasonal changes in the movement ecology of a highly gregarious central-place forager, the African straw-coloured fruit bat (*Eidolon helvum*). *PLoS ONE*. 2015;10:e0138985. <https://doi.org/10.1371/journal.pone.0138985>.
60. Kamins AO, Restif O, Ntiamao-Baidu Y, Suu-Ire R, Hayman DTS, Cunningham AA, et al. Uncovering the fruit bat bushmeat commodity chain and the true extent of fruit bat hunting in Ghana, West Africa. *Biol Conserv*. 2011;144:3000–8. <https://doi.org/10.1016/j.biocon.2011.09.003>.
61. Boakye MK, Kotzé A, Dalton DL, Jansen R. Unravelling the Pangolin bushmeat commodity chain and the extent of trade in Ghana. *Hum Ecol*. 2016;44:257–64. <https://doi.org/10.1007/s10745-016-9813-1>.
62. Petrozzi F, Amori G, Franco D, Gaubert P, Pacini N, Eniang EA, et al. Ecology of the bushmeat trade in west and central Africa. *Trop Ecol*. 2016;57:545.
63. Sackey HNK, McNamara J, Milner-Gulland EJ, Ntiamao-Baidu Y. The bushmeat trade in northern Ghana: market dynamics, drivers of trade and implications for conservation. *Oryx*. 2023;57:216–27. <https://doi.org/10.1017/S0030605322000096>.
64. Brashares JS, Arcese P, Sam MK, Coppolillo PB, Sinclair ARE, Balmford A. Bushmeat hunting, wildlife declines, and fish supply in West Africa. *Science*. 2004;306:1180–3. <https://doi.org/10.1126/science.1102425>.
65. Africa's growing risk of diseases that spread from animals to people. IFPRI. 2020. <https://www.ifpri.org/blog/africas-growing-risk-diseases-spread-animals-people/>. Accessed 13 Aug 2025.
66. Health Workers | Frontline Health Workers Coalition. <https://www.frontlinehealthworkers.org/frontline-health-workers>. Accessed 13 Aug 2025.
67. Hassan OA, de Balogh K, Winkler AS. One Health early warning and response system for zoonotic diseases outbreaks: emphasis on the involvement of grassroots actors. *Vet Med Sci*. 2023;9:1881–9. <https://doi.org/10.1002/vms3.1135>.
68. Baatiema L, Sumah AM, Tang PN, Ganle JK. Community health workers in Ghana: the need for greater policy attention. *BMJ Glob Health*. 2016;1:e000141. <https://doi.org/10.1136/bmjgh-2016-000141>.
69. Codjoe SNA, Gough KV, Wilby RL, Kasei R, Yankson PWK, Amankwa EF, et al. Impact of extreme weather conditions on healthcare provision in urban Ghana. *Soc Sci Med*. 2020;258:113072. <https://doi.org/10.1016/j.socscimed.2020.113072>.
70. Idriss-Wheeler D, Ormel I, Assefa M, Rab F, Angelakis C, Yaya S, et al. Engaging community health workers (CHWs) in Africa: lessons from the Canadian Red Cross supported programs. *PLoS Glob Public Health*. 2024;4:e0002799. <https://doi.org/10.1371/journal.pgph.0002799>.
71. Newsroom AG-A, Africa WRO for. Strengthening Epidemic Preparedness and Response: Building Resilience After Ghana's 2023 Floods. 2024. <https://who-africa.africa-newsroom.com/press/strengthening-epidemic-preparedness-and-response-building-resilience-after-ghanas-2023-floods>. Accessed 13 Aug 2025.
72. Climate change and health – the health workers' eyewitness perspective. <https://www.gavi.org/vaccineswork/climate-change-and-health-health-workers-eyewitness-perspective>. Accessed 13 Aug 2025.
73. Sorensen CJ, Fried LP. Defining roles and responsibilities of the health workforce to respond to the climate crisis. *JAMA Netw Open*. 2024;7:e241435. <https://doi.org/10.1001/jamanetworkopen.2024.1435>.
74. Pörtner H-O, Roberts DC, Tignor MMB, Poloczanska ES, Mintenbeck K, Alegría A, et al., editors. Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. 2022.
75. Mazumder H, Hossain MM. Climate change education for health-care professionals: crucial gaps in low-income and middle-income countries. *Lancet Planet Health*. 2024;8:e216. [https://doi.org/10.1016/S2542-5196\(24\)00010-X](https://doi.org/10.1016/S2542-5196(24)00010-X).
76. West KP, Sznajder KK, Sauve HE, Hwang G, Roba KT, Baatiema L, et al. Zoonotic disease preparedness among frontline healthcare workers in Ghana: assessing literacy and behaviors in a One Health context. 2025;2025.07.08.25331119. <https://doi.org/10.1101/2025.07.08.25331119>.
77. Armel KC, Yan K, Todd A, Robinson TN. The Stanford Climate Change Behavior Survey (SCCBS): assessing greenhouse gas emissions-related behaviors in individuals and populations. *Clim Change*. 2011;109:671–94. <https://doi.org/10.1007/s10584-011-0031-y>.
78. Collecting Data. *One Health Behaviors*. <https://onehealthbehaviors.org/research/>. Accessed 29 June 2025.
79. CDC. Completed OHZDP Workshops. *One Health*. 2025. <https://www.cdc.gov/one-health/php/prioritization/complete-d-workshops.html>. Accessed 7 June 2025.
80. Zinsstag J, Crump L, Schelling E, Hattendorf J, Maidane YO, Ali KO, et al. Climate change and one health. *FEMS Microbiol Lett*. 2018;365:fny085. <https://doi.org/10.1093/femsle/fny085>.
81. CDC. About Zoonotic Diseases. *One Health*. 2024. <https://www.cdc.gov/one-health/about/about-zoonotic-diseases.html>. Accessed 7 June 2025.
82. Mohamud AK, Ali IA, Ali AI, Dirie NI, Inchon P, Ahmed OA, et al. Assessment of healthcare workers' knowledge and attitude on Ebola virus disease in Somalia: a multicenter nationwide survey. *BMC Public Health*. 2023;23:1650. <https://doi.org/10.1186/s12889-023-16562-2>.
83. Wang L, Abualfoul M, Oduor H, Acharya P, Cui M, Murray A, et al. A cross-sectional study of knowledge, attitude, and practice toward COVID-19 in solid organ transplant recipients at a transplant center in the United States. *Front Public Health*. 2022. <https://doi.org/10.3389/fpubh.2022.880774>.
84. Kaliyaperumal K. Guideline for Conducting a Knowledge, Attitude and Practice (KAP) Study. *AECS Illumination*, 4, 7–9. References-Scientific Research Publishing. 2004. <https://www.scirp.org/reference/referencespapers?referenceid=3737065>. Accessed 25 Jan 2026.
85. Willoughby AR, Phelps KL, PREDICT Consortium, Olival KJ. A Comparative Analysis of Viral Richness and Viral Sharing in Cave-Roosting Bats. *Diversity*. 2017;9:35. <https://doi.org/10.3390/d9030035>.

86. Otoh OP, Hedima EW, Sawyerr HO. Nationwide evaluation of health workers knowledge and awareness of climate change health related hazards. *Discov Public Health*. 2025;22:548. <https://doi.org/10.1186/s12982-025-00909-8>.
87. Mabena MM, Mooa RS, Masenge A, Sepeng NV. Knowledge and attitude of nurses in primary health care regarding climate change in Mpumalanga. *Health SA*. 2025;30:3105. <https://doi.org/10.4102/hsag.v30i0.3105>.
88. Tesfaye AH, Prior J, McIntyre E. Impact of climate change on health workers: a scoping review. *J Public Health (Berl)*. 2025. <https://doi.org/10.1007/s10389-025-02418-z>.
89. Acheampong EO, Macgregor CJ, Sloan S, Sayer J. Deforestation is driven by agricultural expansion in Ghana's forest reserves. *Sci Afr*. 2019;5:e00146. <https://doi.org/10.1016/j.sciaf.2019.e00146>.
90. Experts warn of serious health impacts from climate change for pregnant women, children, and older people. *Saudi Med J*. 2024;45:754–5.
91. Sorensen C, Murray V, Lemery J, Balbus J. Climate change and women's health: impacts and policy directions. *PLoS Med*. 2018;15:e1002603. <https://doi.org/10.1371/journal.pmed.1002603>.
92. US EPA O. Climate Change and the Health of Older Adults. 2022. <https://www.epa.gov/climateimpacts/climate-change-and-health-older-adults>. Accessed 23 Aug 2025.
93. CDC. About One Health. *One Health*. 2025. <https://www.cdc.gov/one-health/about/index.html>. Accessed 7 June 2025.
94. Ahmed MM, Okesanya OJ, Othman ZK, Ibrahim AM, Adigun OA, Ukoaka BM, et al. Holistic approaches to zoonoses: integrating public health, policy, and one health in a dynamic global context. *Zoonotic Dis*. 2025;5:5. <https://doi.org/10.3390/zoonoticdis5010005>.
95. Amuguni H, Bikaako W, Naigaga I, Bazeyo W. Building a framework for the design and implementation of one health curricula in East and Central Africa: OHCEAs one health training modules development process. *One Health*. 2019;7:002–002. <https://doi.org/10.1016/j.onehlt.2018.08.002>.
96. Codjoe SNA, Owusu G. Climate change/variability and food systems: evidence from the Afram Plains, Ghana. *Reg Environ Change*. 2011;11:753–65. <https://doi.org/10.1007/s10113-011-0211-3>.
97. EcoHealth Alliance. Strengthening Pandemic Preparedness in Ghana. 2021.
98. World Health Organization. 2024 Annual Report WHO Ghana. 2024.

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