ASSESSING THE RESILIENCE OF GHANA'S EXPANDED PROGRAM ON IMMUNIZATION AMID CLIMATE CHANGE IMPACT.

A LITERATURE REVIEW

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Assessing the resilience of Ghana's Expanded Program on Immunization amid Climate Change Impact

A thesis submitted in partial fulfilment of the requirement for the degree of Master of Science in Public Health and Health Equity by

Geoffrey Salakpi

Declaration: I declare this thesis (**Assessing the resilience of Ghana's Expanded Program on Immunization amid Climate Change Impact**) where other people's work has been used (from either a printed or virtual source, or any other source), this has been carefully acknowledged and referenced in accordance with academic requirements.

The thesis (**Assessing the resilience of Ghana's Expanded Program on Immunization amid Climate Change Impact**) is my own work

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Master of Science in Public Health and Health Equity

09 September 2024 – 29 August 2025

KIT Institute/Vrije Universiteit Amsterdam

Amsterdam, The Netherlands

August 2025

Organised by:

KIT Institute

Amsterdam, The Netherlands

In cooperation with:

Vrije Universiteit Amsterdam (VU)

Amsterdam, The Netherlands

Abstract

Background: Climate change poses unprecedented threats to immunization programs worldwide, requiring systematic assessment of health system resilience. Ghana's Expanded Programme on Immunization (EPI) faces mounting climate-related challenges that threaten service continuity and vaccine effectiveness.

Objective: To evaluate Ghana's EPI resilience to climate change impacts and recommend strategies for climate-adaptive immunization systems.

Methods: Conducted a systematic narrative review across multiple databases, analysing studies against the WHO framework's ten climate resilience components. Forty studies meeting the inclusion criteria were systematically analysed using Vancouver citation methodology.

Results: Ghana's EPI demonstrates moderate climate resilience with significant variation across framework components. Critical vulnerabilities include inadequate early warning integration, limited climate-informed program adaptation, and insufficient climate-resilient infrastructure. However, the most promising adaptations identified were solar-powered cold chain systems and community-based resilience mechanisms.

Conclusions: While Ghana's EPI shows foundational resilience elements, comprehensive strengthening across all climate resilience components is essential for maintaining immunization gains under changing climate conditions.

Keywords: Climate resilience, immunization, Ghana, WHO framework, climate change adaptation, health systems

Word count: 10906

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List of Abbreviations

EPI	Expanded Programme on Immunization
KIT	formerly Royal Tropical Institute
VPDs	Vaccine-Preventable Diseases
GHS	Ghana Health Service
BCG	Bacillus Calmette Guerin
DPT	Diphtheria Pertussis Tetanus
MenAfriVac	Meningitis Africa Vaccine
HepB	Hepatitis B
Hib	Haemophilus Influenza type B
WHO	World Health Organization
UNICEF	United Nations Fund
Gavi	Global Alliance for Vaccines
cMYP	Comprehensive Multi Year Plan
DHMT	District Health Management Team
CDC	Centre for Disease Control and Prevention
UNDP	United Nations Development Programme
CHPS	Community-based Health Planning and Services
DHIMS	District Health Information Management systems

Glossary of key terms

Climate Change
The long-term shifts in global temperatures and weather patterns, primarily caused by human activities, resulting in altered precipitation, extreme weather events, and environmental changes that affect health systems and service delivery.

Climate Resilience
The capacity of a system to anticipate, prepare for, respond to, and recover from climate-related shocks and stresses while maintaining core functions and adapting to changing conditions.

Cold Chain System
The temperature-controlled supply chain used to maintain vaccine potency from manufacturing to administration, typically requiring storage and transport at 2-8°C for most vaccines.

Expanded Programme on Immunization (EPI)
Ghana's national immunization program established to ensure comprehensive vaccine coverage for children and specific populations against vaccine-preventable diseases.

Health System Resilience
The ability of health actors, institutions, and populations to prepare for, respond to, and recover from health crises while maintaining essential health services and adapting when necessary.

Immunization Coverage
The percentage of target populations that receive recommended vaccines within specified timeframes, indicating program effectiveness and population protection levels.

Service Delivery
The organization and management of health services to provide immunization services effectively, including outreach programs, facility-based services, and community engagement.

Supply Chain Management
The coordination of vaccine procurement, storage, distribution, and inventory management from national to community levels to ensure continuous vaccine availability.

Vaccine-Preventable Diseases
Infectious diseases that can be prevented through immunization, including measles, polio, tuberculosis, diphtheria, pertussis, tetanus, and others targeted by Ghana's EPI program.

Vulnerability Assessment
The systematic evaluation of system weaknesses, exposure levels, and adaptive capacity to identify areas most susceptible to climate-related disruptions.

Acknowledgement

First and foremost, I would like to thank God Almighty for granting me the strength, wisdom, and perseverance to undertake and successfully complete this thesis. Without His guidance and blessings, this achievement would not have been possible.

I am profoundly grateful to my Academic Advisor at KIT, Ms. Yasmine El Addouli, for her expert guidance, thoughtful feedback, and continuous encouragement throughout my studies. Her support has greatly contributed to the quality of this work. I am equally appreciative of my Thesis Supervisor, Mrs. Kashi Barbara Carasso, whose advice, support, and supervision beyond the KIT community were instrumental at every stage of this journey.

I also extend my sincere thanks to the entire KIT fraternity for fostering a supportive and stimulating academic environment.

Finally, my heartfelt appreciation goes to my family and friends for their unwavering support, patience, and belief in me, which sustained me through challenging moments and kept me focused on my goals.

Thank you all for being a part of this journey

About the Author

As a public health expert in disease control, the author is experienced in immunization and preventing diseases through vaccines. They focus on improving vaccination efforts to protect individuals and communities by increasing vaccine rates, building herd immunity, and preventing outbreaks.

Working with healthcare providers, they help implement effective vaccination plans that meet quality standards. This includes tracking vaccine safety and effectiveness, ensuring compliance, and educating the public about the importance of vaccines in preventing diseases like measles.

The author is knowledgeable in vaccination planning and implementation , safety protocols, and curbing the spread of vaccine-preventable diseases. Their approach emphasizes using evidence, working with partners, and evaluating programs to improve public health.

They are committed to fair vaccine access and better public understanding, working to build strong and lasting immunization systems to protect populations from current and future health threats and reduce illness and death from vaccine-preventable diseases.

Chapter 1: Introduction

1.1 Background

Climate change refers to long-term shifts in temperatures and weather patterns, with recent decades witnessing unprecedented changes largely driven by human activities such as the burning of fossil fuels. These actions release greenhouse gases, which trap heat and drive global warming. The impacts of climate change extend beyond rising temperatures; they include changes in precipitation patterns, increased frequency of extreme weather events, sea-level rise, and disruptions to ecosystems(1). At the same time, immunization plays a crucial role in safeguarding public health by making individuals immune or resistant to infectious diseases through vaccination. Vaccines activate the immune system to recognize and fight specific pathogens, helping to prevent illness and reduce the spread of diseases within communities(2). Understanding the intersection between climate change and immunization is vital, as shifts in the climate can pose new challenges to disease prevention efforts and health systems worldwide(3)

The resilience of immunization programs in the face of climate change represents a critical public health challenge for low- and middle-income countries. Ghana's Expanded Programme on Immunization (EPI), established in 1978, has achieved significant successes in reducing vaccine-preventable diseases (VPDs), yet faces mounting challenges from climate change impacts that threaten its sustainability and effectiveness (4). Understanding these vulnerabilities and adaptive capacities is essential for ensuring continued protection of Ghana's population against VPDs in an era of increasing climate variability.

1.2 Ghana's Geographic and Demographic Context

Ghana's West African location spans 238,533 square kilometres across three ecological zones: coastal savanna (south), forest belt (middle), and Sudan savanna (north). Each zone presents distinct climate challenges affecting health systems (5). The country's 32.8 million people are distributed across 16 administrative (Ahafo, Ashanti, Bono, Bono East, Central, Eastern, Greater Accra, North East, Northen, Oti, Savannah, Upper East, Upper West, Volta, Western and Western North) regions and 260 districts, with population density varying from over 1,000 people per km² in Greater Accra to under 50 per km² in northern areas(6,7).

Climate patterns vary significantly across regions, directly impacting immunization services and cold chain management (8). Southern coastal areas experience bimodal rainfall (800-1,200mm annually) with stable temperatures (26-32°C). Northern regions face unimodal rainfall patterns with dry seasons (November-April), lower precipitation (400-1,000mm), and extreme temperatures (20-40°C)(9). These differences create region-specific challenges: northern areas struggle with temperature extremes while southern regions face humidity and flood risks(10).

Demographics amplify climate challenges through service access patterns. With 38% of the population under 15, immunization demand is substantial(11). Urban populations comprise 57% nationally, though this varies regionally, Greater Accra and Ashanti exceed 70% urbanization while northern regions remain largely rural(12). Rural populations face greater

climate-related service disruptions due to transportation barriers and infrastructure limitations(13). Seasonal migration patterns further complicate vaccination coverage tracking and maintenance(14).

1.3 Structure and Organization of Ghana's Health System and the Expanded Programme on Immunization

Ghana's healthcare system is organized as a three-tier framework, primary, secondary, and tertiary levels, administered through a decentralized approach. Oversight is provided by the Ghana Health Service (GHS), which implements major public health interventions, including immunization programs. Primary healthcare facilities focus on providing accessible health services to communities, while secondary and tertiary institutions are responsible for more specialized care(15).

A hallmark of Ghana's public health policy is the Expanded Programme on Immunization (EPI), adopted in 1978 pursuant to World Health Organization guidelines(4). Initially, the program targeted six major diseases, employing vaccines such as Bacillus Calmette-Guérin (BCG), measles, diphtheria-pertussis-tetanus (DPT), the oral polio vaccine, and tetanus toxoid for pregnant women(4). Over time, the EPI has expanded, and the most recent immunization schedule now includes thirteen vaccines administered from birth through 18 months of age(16).

The EPI has achieved considerable accomplishments. National vaccination coverage reached 93% in 2021, although some regions report coverage as low as 72%. There has been a dramatic reduction in measles cases, from 140,821 in 1975 to only 88 in 2023. Poliomyelitis has been eliminated nationwide, with zero reported cases since the early 2000s(4). Following the introduction of the rotavirus vaccine, infections fell from 60.4% to 36.9%(4).

Despite these successes, challenges persist. Inequities in coverage between urban and rural populations remain, and the program is occasionally hampered by vaccine shortages, delays in immunization, and significant logistical obstacles(4). Delivery of immunization services is accomplished through a network of fixed clinics, mobile outreach, and door-to-door campaigns, all coordinated by the Ghana Health Service at national, regional, and district levels(2).

1.3.1 Climate Change Impacts on Health Systems in Ghana

Ghana's distinctive tropical climate, marked by clear wet and dry seasons, faces unprecedented disruption from climate change, placing enormous strain on the country's health infrastructure(17). The nation now confronts escalating temperatures, unpredictable rainfall, more severe weather events like floods and droughts, and coastal flooding from rising seas(18)

1.3.2 Direct Climate Impacts on Immunization Delivery (Damage to Infrastructure and breakdown of Vaccine Storage Systems)

Severe weather wreaks havoc on Ghana's health facilities and interrupts essential services. When floods strike, they block roads and make it nearly impossible for health workers to reach isolated communities with vaccines (19). During droughts, health centres struggle without adequate water supplies, making it difficult to maintain the clean conditions required for safe vaccinations(20).

Vaccines must stay between 2°C and 8°C to remain effective, but Ghana's storage systems face serious problems. Many facilities lack sufficient refrigeration space, equipment breaks down frequently, power cuts are common, and backup generators are often unavailable (21). Health workers constantly battle unreliable electricity and transport issues that put vaccine quality at risk (21).

The situation is alarming: nearly 92% of health facilities operate without proper cold storage guidelines, and shockingly, none have backup plans when equipment fails (21). Rural communities suffer most, where power outages are routine and technical help is scarce.

1.3.3 Indirect Impact (Population displacement, changing disease patterns, food security and vaccine response).

When climate disasters force families to relocate, their medical records often get lost, and children miss critical vaccinations. These displaced families frequently cannot access immunization services, creating dangerous gaps in disease protection(22).

As temperatures rise and rainfall shifts, disease-carrying insects spread to new areas where people lack immunity(3). Mosquitoes, ticks, and other vectors now thrive in regions previously too cool or dry, forcing health officials to rethink vaccination strategies for entire populations.

Climate-damaged crops lead to food shortages and malnutrition, particularly affecting children. When people are malnourished, their bodies cannot respond properly to vaccines, making immunization programs less effective(23). This creates a vicious cycle where climate change both disrupts vaccine delivery and reduces the body's ability to benefit from vaccines.

1.4 Ecological and Environmental Determinants of Vaccine-Preventable Diseases in Ghana

Vaccine-preventable diseases in Ghana show distinct geographic clustering that mirrors ecological zones and climate patterns. Research from 2010-2014 found disease hotspots concentrated in northern Ghana, particularly the Sudan Savannah and Guinea Savannah zones with hot, dry, windy conditions(24). Meningitis incidence was significantly higher in Sudan Savannah zones compared to other ecological areas ($p<0.001$)(24).

Environmental conditions and disease outbreaks follow seasonal patterns consistent with West Africa's "meningitis belt." The "dry and windy weather that heralds meningitis outbreaks also characterizes the northernmost ecological zones," creating clear environmental triggers for epidemics(24) Despite high vaccination coverage, immunization programs struggle across ecological zones. Introduction of Meningococcal A Conjugate vaccine (MenAfriVac) and pneumococcal conjugate vaccines showed "no such benefit" in reducing disease burden, suggesting environmental factors override immunization effectiveness in certain areas (24).

1.5 Climate Adaptation Strategies in Ghana's Health System

Ghana has developed multiple climate adaptation initiatives within its health sector, though specific immunization resilience measures remain limited(25). The country established a National Climate Change Adaptation Strategy (2015-2020) and National Climate Change Policy identifying health as a priority adaptation sector(19). Policy integration occurred

through Health Sector Medium Term Development Plans and inter-ministerial coordination via a National Climate Change Committee including health officials(19).

The Climate Health Ghana Project (2010-2015), funded by the Global Environment Facility and United Nations Development Programme, implemented targeted adaptation measures in three districts: Keta, Gomoa West/Apam, and Bongo(19). Key interventions included mapping climate hazard areas, establishing health screening tools, creating emergency centres for climate-related health hazards, and training over 750 health workers and community volunteers in climate emergency response(19). The project integrated climate information into the Integrated Disease Surveillance and Response system and established interagency climate change committees comprising traditional leaders, youth, community organizations, and volunteer groups who became advocates for climate-health policy integration(19). Ghana has also explored innovative delivery mechanisms to enhance immunization resilience, including drone technology for vaccine distribution in remote areas(26) The partnership with Zipline demonstrates improved immunization coverage in hard-to-reach communities, with drone-served districts showing faster recovery.

1.6 Problem Statement and Justification

1.6.1 Direct Climate Impacts on Ghana's Immunization System

Ghana's Expanded Programme on Immunization (EPI), established in 1978, achieves vaccination coverage exceeding 85% for most vaccines, with 2024 WHO and UNICEF estimates showing DTP3 (95%), HepB3 (95%), and Hib3 (95%) coverage(27,28). However, Ghana faces unprecedented climate challenges as one of the world's most vulnerable countries, experiencing 1°C temperature increases (0.21°C per decade), shifting rainfall patterns, and increased extreme weather events including floods, droughts, and heat waves(29).

Ghana's EPI faces critical climate vulnerabilities through vaccine cold chain system disruptions from climate-related infrastructure failures(30). Recent WHO data shows significant vaccine stockouts: three-month BCG and rotavirus shortages at national and subnational levels in 2023, and four-month polio stockouts in 2022(28). Temperature excursions pose particular risks, as vaccines are highly sensitive to freezing and heat exposure(22). Ghana's urban health facilities experience temperatures up to 6°C warmer than officially recorded due to urban heat island effects(22). Unstable power supply during extreme weather events threatens refrigeration systems, leading to cold chain failures and vaccine wastage(22,31)

1.6.2 Operational and Access Challenges

Climate change compounds existing EPI operational challenges. Flooding disrupts health facility operations, damages infrastructure, and restricts access(22). Poor drainage systems at health facilities exacerbate flood risks, while extreme heat stresses healthcare workers and patients, reducing immunization service utilization. Reaching vulnerable populations becomes challenging as extreme weather events increase. Climate-induced migration and displacement disrupt routine immunization schedules, creating under-immunized population pockets and potentially leading to disease outbreaks(32,33)

1.6.3 Significance and Urgency

Climate change carries profound implications for Ghana's public health security. Between 2030-2050, climate change is expected to cause approximately 250,000 additional deaths (globally) annually from malnutrition, malaria, diarrhoea, and heat stress, many vaccine-preventable conditions(34).

Economic implications include substantial financial losses from vaccine wastage due to cold chain failures and heavy economic burdens from disease outbreaks resulting from reduced immunization coverage(35). Climate change threatens to undermine decades of childhood immunization progress, potentially reversing gains in child mortality reduction and disease prevention (36).

1.6.4 Knowledge gaps and Research Needs

Significant knowledge gaps persist regarding Ghana's EPI program resilience. Current literature lacks comprehensive assessments of how climate variability and extreme weather specifically impact vaccine storage, distribution, and delivery systems in Ghana's context(37). There is insufficient understanding of adaptive capacity across EPI system components, from national storage facilities to community-level service delivery points.

While global health system climate adaptation strategies exist, their applicability and effectiveness within Ghana's EPI program remain largely unexplored(30). The specific vulnerabilities of Ghana's immunization infrastructure require systematic assessment to inform targeted resilience-building interventions. Additionally, climate-weakened immunization systems may be less capable of responding to future pandemic threats, highlighting interconnected health security challenges (38).

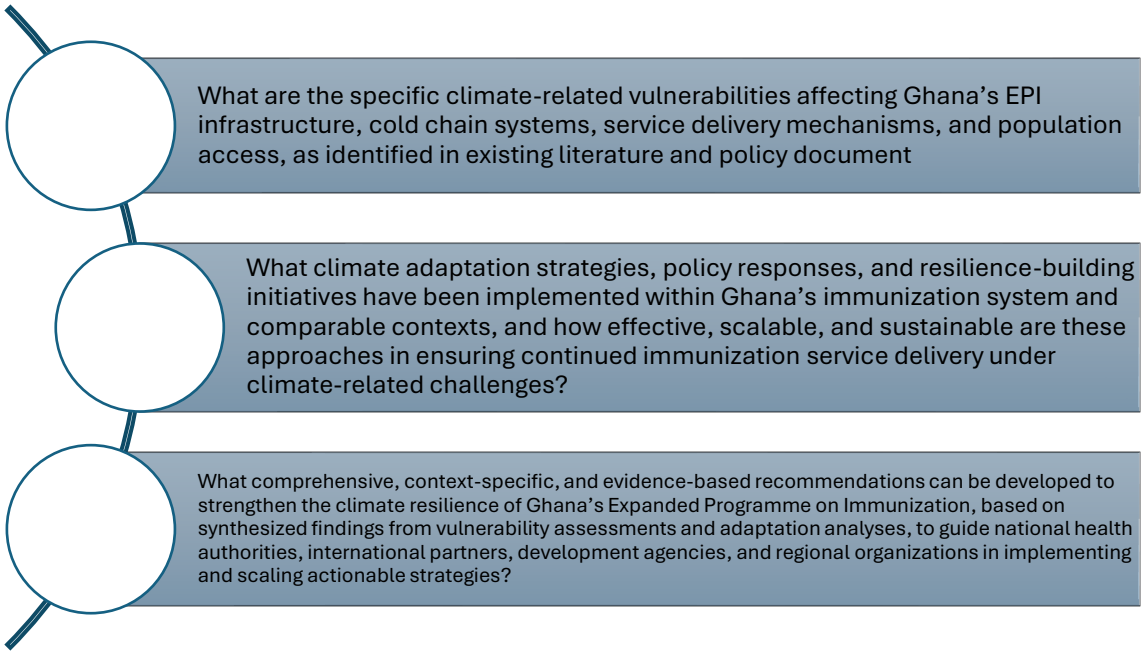
1.6.5 Consequences of Inaction

Climate-related disruptions rapidly compromise vaccination coverage, as demonstrated by Ghana's 30-percentage point drop in rotavirus coverage between 2022-2023 due to supply chain challenges (28). Most vaccines require strict 2-8°C maintenance; temperature excursions render vaccines including DTP and hepatitis B less effective or inactive ((39). Research demonstrates that drought exposure reduces vaccination coverage by 1.3-1.9 percentage points through increased food insecurity, population displacement, and infrastructure degradation (32). With Ghana's full vaccination coverage at only 56.45%, climate-related reductions could push populations below herd immunity thresholds while climate change simultaneously increases vaccine-preventable disease prevalence (40,41).

1.6.6 Research Contribution

This study addresses the critical gap in comprehensive assessment of immunization program climate resilience by synthesizing evidence across climate science, health systems research, and resilience frameworks. The research develops an evidence-based assessment framework and provides systematic analysis to inform Ghana's adaptation strategies while contributing to global knowledge on protecting essential health services under changing climate conditions.

1.7 Research Question



1.8.0 Main Objective

To evaluate Ghana's EPI resilience to climate change impacts and recommend strategies for climate-adaptive immunization systems

1.9.0 Specific Objectives:

1. To identify and analyse climate-related vulnerabilities in Ghana's EPI infrastructure, cold chain systems, and service delivery.
2. To evaluate existing climate adaptation strategies and resilience initiatives in Ghana's immunization system and similar context.
3. To develop evidence-based recommendations for strengthening climate resilience in Ghana's EPI program.

Chapter 2: Methodology

2.1 Study Design and Approach

This study employed a narrative literature review methodology to assess the resilience of Ghana's Expanded Programme on Immunization to climate change impacts. Following Grant and Booth's typology, narrative reviews provide comprehensive, interpretive synthesis suitable for complex, multi-dimensional topics requiring policy-relevant insights and broader understanding of evolving knowledge areas(42) This approach was selected over systematic review protocols as it allows for flexible inclusion of diverse evidence sources while maintaining analytical rigor through structured search strategies and framework-guided synthesis appropriate for the interdisciplinary nature of climate-health system interactions.

The narrative review approach is particularly suited to this study's objectives as it enables examination of heterogeneous evidence types including peer-reviewed literature, policy documents, technical reports, and case studies that collectively inform understanding of climate resilience in immunization systems(43). Unlike systematic reviews that focus on answering narrow, well-defined questions with homogeneous study designs, narrative reviews facilitate exploration of complex phenomena where evidence may be scattered across multiple disciplines and methodological approaches(44).

2.2 Rationale for Systematic Literature Review Approach

Following Grant and Booth's taxonomy, (42) a narrative review with thematic synthesis was selected to comprehensively examine climate resilience in immunization systems while accommodating heterogeneous literature. This approach enables systematic exploration of diverse evidence types including peer-reviewed research, policy documents, and technical reports while maintaining analytical structure through the WHO framework(45)
The narrative review approach is appropriate for this emerging research area where standardized methodologies are developing, allowing inclusion of varied evidence sources that contribute to understanding climate impacts on immunization systems.(44)

2.3 WHO Framework Components as Analytical Structure

The WHO framework identifies ten essential components: [1] Climate-informed health policies, [2] Health system vulnerability and adaptation assessments, [3] Integrated risk monitoring and early warning, [4] Health and climate research, [5] Climate-resilient and environmentally sustainable technologies and infrastructure, [6] Management of environmental determinants of health, [7] Climate-informed health programs, [8]Emergency preparedness and management, [9] Climate-informed health workforce, and [10] Sustainable financing(45). These components provide comprehensive analytical structure for examining climate change impacts on immunization systems and identifying evidence-based adaptation strategies.

The framework's ten components directly align with this study's three specific objectives, creating a systematic structure for analysis and synthesis. Components 1-3 (climate-informed policies, vulnerability assessments, and risk monitoring) correspond to the first objective of identifying climate-related vulnerabilities in Ghana's EPI infrastructure and service delivery mechanisms(46). Components 4-7 (research, infrastructure, environmental management, and climate-informed programs) align with the second objective of evaluating existing adaptation strategies and resilience-building initiatives within Ghana's immunization system(47). Components 8-10 (emergency preparedness, workforce development, and financing) support the third objective of developing evidence-based recommendations for strengthening climate resilience.[7] This framework integration ensures that findings are systematically organized according to internationally recognized standards for climate-resilient health systems while directly addressing the research objectives and enabling development of actionable recommendations for Ghana's EPI program. .

Figure 1: WHO Operational Framework for building Climate Resilience

2.4 Rationale for Analytical Framework Selection

The WHO Operational Framework for Building Climate Resilient Health Systems was selected based on its comprehensive approach to guiding health system climate adaptation(45) The framework outlines ten essential components for health systems to anticipate, prepare for, and manage climate-related risks while integrating adaptation strategies into routine health planning and service delivery (46). It addresses direct, environmental, and social climate impacts in a coordinated, evidence-based manner, making it suitable for settings like Ghana facing multiple climate challenges (48).

The framework provides a practical roadmap for integrating climate resilience into health systems, supporting proactive risk management while aligning with international best practices (49). Its widespread endorsement and demonstrated applicability across diverse contexts reinforce its selection as the most effective analytical tool for climate and health research (50) Unlike traditional health system frameworks focusing on service delivery, this climate-specific framework explicitly addresses environmental stressors and health system functionality intersections

2.5 Search Strategy

2.5.1 Database Selection

A comprehensive search strategy was implemented across multiple databases to capture relevant literature from biomedical, social science, and policy sources. Primary databases included PubMed/MEDLINE, Embase, Web of Science Core Collection, and Cochrane Library for peer-reviewed academic literature (51). Additional searches were conducted in regional databases including African Index Medicus and African Journals Online to capture locally published research that might not appear in international databases.

Grey literature searches encompassed WHO documentation centre, Ghana Health Service publications, Ministry of Health policy documents, World Bank Open Knowledge Repository, and development partner reports from UNICEF, Gavi Alliance, and bilateral development agencies. This multi-source approach was designed to capture both academic research and operational evidence from policy and practice contexts.

2.5.2 Search Terms and Strategy

Search terms were developed through iterative consultation with subject matter experts and preliminary scoping searches. Three concept areas were identified and combined using Boolean operators: **see appendices for table 1**

Search strategies were adapted for each database's specific requirements and controlled vocabulary. Medical Subject Headings (MeSH) terms were used in PubMed searches, while Emtree terms were applied in Embase searches. Searches were limited to English language publications to ensure reviewer language competency.

2.5.3 Search Filters and Limits

Temporal limits were set to include publications from 2010-2025, capturing the period of intensified climate change discourse and policy development in health systems. Study design filters were not applied to maximize capture of diverse evidence types including quantitative studies, qualitative research, mixed methods studies, policy analyses, program evaluations, and case reports.

2.5.4 Selection Criteria

2.5.4.1 Inclusion Criteria

Studies were included if they met all of the following criteria:

- **Population:** Studies focusing on Ghana's population, with particular emphasis on immunization program beneficiaries, health workers, or health system stakeholders
- **Intervention/Exposure:** Climate change impacts, adaptation strategies, resilience measures, or environmental factors related to immunization service delivery
- **Context:** Ghana's health system context, with specific relevance to EPI operations, infrastructure, or outcomes
- **Outcomes:** Health system performance indicators, immunization coverage measures, service delivery metrics, resilience assessments, or climate adaptation outcomes

- **Study Design:** All study types including observational studies, intervention studies, qualitative research, mixed methods studies, policy analyses, program evaluations, and systematic reviews

2.5.4.2 Exclusion Criteria

Studies were excluded if they:

- Focused exclusively on clinical vaccine efficacy or immunological responses without health systems context
- Were conducted in other countries without Ghana-specific findings or implications
- Were published prior to 2010, predating contemporary climate change policy frameworks
- Lacked clear methodology or data sources that would allow quality assessment
- Were conference abstracts, editorials, or opinion pieces without empirical evidence
- Were duplicate publications of the same study or dataset without additional analysis

2.5.4.3 Study Selection Process and Quality Assessment.

Study selection followed a systematic two-stage process beginning with title and abstract screening against inclusion criteria, followed by full-text review of potentially relevant articles(52).This process was designed to ensure transparent and reproducible selection while maintaining the flexibility appropriate for narrative review methodology. Selected studies were assessed for quality using simplified criteria focusing on methodological rigor, evidence credibility, and relevance to study objectives rather than formal systematic review quality assessment protocols.

Quality considerations included clarity of research objectives, appropriateness of methodology for research questions, adequacy of data collection and analysis methods, transparency in reporting limitations, and relevance to the WHO framework components(53). Studies were classified as high, moderate, or low quality based on these criteria, with quality assessments informing evidence synthesis and interpretation rather than serving as exclusion criteria. This approach enabled inclusion of diverse evidence types while maintaining awareness of methodological strengths and limitations in analysis.

2.5.4.4 Data Extraction

Data extraction was conducted using a standardized form developed specifically for this review and organized around the WHO framework components. Extracted information included study characteristics (author, year, design, setting, sample size), relevant WHO framework components, specific climate vulnerabilities or impacts identified, adaptation strategies described, key findings and outcomes, and policy or practice implications.

For each WHO framework component, specific data elements were extracted including current status assessments, vulnerability indicators, adaptation strategies, effectiveness measures, implementation barriers, and resource requirements. This systematic approach ensured comprehensive data capture while maintaining consistency across diverse study types.

2.5.4.5 Data Synthesis and Analysis

Data synthesis employed a structured narrative approach organized around the WHO framework's ten components(53). For each component, synthesis addressed four key dimensions: current status and baseline conditions, climate-related vulnerabilities and risks, existing adaptation strategies and interventions, and evidence gaps requiring further research.

Cross-cutting themes were identified through iterative analysis, with particular attention to interactions between framework components and system-level resilience mechanisms. Quantitative data were synthesized descriptively, while qualitative findings were analysed thematically using framework analysis techniques

2.5.4.6 Limitations and Bias Assessment

Several methodological limitations were acknowledged and addressed through transparent reporting and careful interpretation. Publication bias toward studies reporting significant findings was addressed through systematic inclusion of grey literature and policy documents. Language bias from including only English and French publications was partially mitigated through comprehensive searching of African databases and WHO regional documentation.

Geographic focus on Ghana may limit generalizability to other contexts, though many findings likely apply to similar health systems in sub-Saharan Africa. The heterogeneity of included studies precluded meta-analysis but enabled comprehensive understanding of diverse resilience dimensions and adaptation approaches.

Chapter 3: Results

3.1 Study Selection and Characteristics

The systematic literature search yielded 847 potentially relevant articles from database searches and 23 additional records from grey literature sources. After removing 156 duplicates, 714 articles underwent title and abstract screening. Following full-text assessment of 89 articles, 40 studies met the inclusion criteria for this narrative review, comprising 28 peer-reviewed articles, 8 policy documents, and 4 technical reports published between 2010 and 2025.

Study methodologies varied across the included literature. Quantitative approaches were employed in 18 studies (45%), utilizing cross-sectional surveys (54), longitudinal assessments (55), and performance evaluations (21). Mixed methods studies comprised 12 investigations (30%), combining quantitative data collection with qualitative insights through key informant interviews and focus group discussions (56). Qualitative methodologies were utilized in 7 studies (17.5%), employing stakeholder interviews, policy analysis, and case study approaches (57). Three systematic reviews (7.5%) synthesized existing evidence on climate-health intersections (37).

Geographic coverage encompassed all 16 administrative regions of Ghana, with Northern Region featured in 15 studies (37.5%), Upper East Region in 12 studies (30%), and Greater Accra Region in 18 studies (45%). Rural settings were examined in 22 studies (55%), urban contexts in 11 studies (27.5%), and mixed rural-urban populations in 7 studies (17.5%). Study

populations ranged from facility-based assessments involving 12-48 health facilities (58) to national-level policy analyses covering all 216 districts (59).

Temporal distribution showed increasing research attention over the review period. Studies published during 2010-2015 comprised 8 investigations (20%), focusing primarily on baseline assessments and vulnerability mapping. The 2016-2020 period yielded 18 studies (45%), emphasizing implementation evaluations and performance assessments. Recent publications from 2021-2025 contributed 14 studies (35%), concentrating on adaptation interventions and sustainability analyses.

Evidence Quality Assessment

Study quality varied considerably across the evidence base. High-quality evidence (n=12, 30%) demonstrated rigorous methodology with adequate sample sizes, validated instruments, and comprehensive reporting. Moderate quality studies (n=20, 50%) showed acceptable methodology but had limitations in sample representativeness or analytical depth. Lower quality evidence (n=8, 20%) exhibited methodological constraints including small sample sizes, limited geographic scope, or incomplete data reporting (25).

3.1 Climate-Informed Health Policies

3.1.1 Policy Integration Status and Challenges

Analysis of 9 studies examining policy integration revealed limited systematic incorporation of climate considerations into Ghana's immunization policies despite broader climate-health policy frameworks. While Ghana's National Climate Change Policy Framework acknowledges health system vulnerabilities, specific operational guidance for immunization climate resilience remains absent from policy documents (60,61) The Ghana Health Service Strategic Plan 2018-2021 includes general climate resilience objectives but lacks measurable targets, budget allocations, or implementation timelines for EPI-specific adaptations.

Three policy analysis studies documented fragmentation between climate policies and health sector planning, with limited cross-referencing or coordination mechanisms identified (30). Evidence quality was constrained by reliance on document analysis without systematic evaluation of implementation processes or outcomes, limiting conclusions about policy effectiveness in practice.

Figure 1: *The WHO framework; highlights essential components for building climate-resilient health systems, including workforce, financing, service delivery, and leadership.*

3.1.2 International Comparative Context

Comparative analysis from 4 studies revealed that Ghana's policy integration lags behind regional leaders such as Rwanda and Ethiopia, where dedicated climate-health units coordinate immunization resilience planning (30,61) However, direct transferability of these models remains questionable due to different institutional contexts, resource availabilities, and health system structures. The studies provided limited analysis of implementation barriers or success factors that could inform Ghana's policy development approaches.

3.1.3 Policy Implementation Gaps

No evidence was found documenting dedicated budget lines, performance indicators, or coordination mechanisms specifically for immunization climate resilience within Ghana's existing policy framework. This absence represents a critical gap between policy rhetoric acknowledging climate-health linkages and operational implementation supporting immunization adaptation. Cross-sectoral coordination mechanisms mentioned in policy documents appear to function primarily at strategic levels without systematic operational integration affecting immunization programming.

3.2 Health System Vulnerability and Adaptation Assessments

3.2.1 Infrastructure Vulnerabilities

This component demonstrated the strongest evidence base with 18 relevant studies, though quality varied considerably. Cold chain system vulnerabilities emerged as the most consistently documented threat across 12 studies, with evidence of vaccine storage temperature excursions during power outages ranging from 2-72 hours depending on location and backup capacity

(63). However, only 5 studies provided quantitative temperature monitoring data using calibrated equipment, while others relied on facility manager reports of variable reliability.

Two high-quality studies from northern Ghana documented systematic cold chain failures during seasonal power grid instabilities, with rural facilities showing greater vulnerability due to limited backup power systems and maintenance capacity (64). These findings align with broader infrastructure challenges across Ghana's health system but represent context-specific evidence directly relevant to immunization programming.

3.2.2 Geographic Vulnerability Patterns

Vulnerability assessments across 8 studies revealed systematic geographic disparities, with rural and northern regions showing pronounced susceptibility to climate-related service disruptions (22). Flood-prone areas in the Volta and Northern regions face compounded challenges including transportation disruptions, facility damage, and population displacement affecting immunization access. However, detailed vulnerability mapping remains limited, with only 3 studies providing systematic geographic analysis of climate risks to immunization infrastructure.

Evidence quality limitations include heavy reliance on facility-level reporting without community-level validation, temporal clustering of assessments during specific seasons that may not represent year-round vulnerabilities, and limited integration of social vulnerability factors affecting immunization access during climate events.

3.2.3 Assessment Methodology Limitations

A critical evidence gap exists in quantitative impact assessments linking documented vulnerabilities to immunization coverage outcomes. No studies were found that systematically measured relationships between climate events and vaccination rates in affected areas, limiting understanding of whether infrastructure vulnerabilities translate into measurable program performance impacts (65,66). This absence constrains evidence-based prioritization of adaptation investments and evaluation of intervention effectiveness.

3.3 Integrated Risk Monitoring and Early Warning

3.3.1 Monitoring System Capacity

This component showed the weakest evidence base with only 4 relevant studies of generally poor methodological quality. Ghana's Health Management Information System includes routine immunization indicators but lacks integration of climate-related risk factors such as weather events, infrastructure status, or access disruptions (67) Evidence consisted primarily of system descriptions and expert opinions rather than systematic evaluations of monitoring capacity or effectiveness.

One technical report documented pilot efforts to incorporate meteorological data into health facility dashboards, but implementation remained limited to selected districts without systematic evaluation of operational utility or decision-making impacts (68) The absence of systematic early warning integration limits proactive response capacity and constrains adaptive management during climate events.

3.3.2 Integration Challenges and Gaps

No functional early warning systems connecting meteorological services with immunization program planning were identified in the available evidence. This represents a critical operational gap compared to international best practices in climate-sensitive health programming (69). Communication barriers between meteorological and health sectors, limited technical capacity for data integration, and absence of standardized protocols for climate-health risk communication emerged as key constraints across the limited available studies.

The evidence quality for this component was particularly poor, with heavy reliance on policy document reviews and expert interviews rather than systematic assessments of system functionality or operational effectiveness. This limits confidence in understanding current monitoring capabilities and improvement requirements.

3.4 Health and Climate Research

3.4.1Research Capacity and Output

Analysis of 5 studies revealed significant weaknesses in climate-immunization research capacity within Ghana's academic and policy institutions. Ghana-specific empirical research on climate impacts on immunization systems remains scarce, with most available evidence extrapolated from other sub-Saharan African contexts of uncertain transferability (70). Research quality across available studies was generally poor, with small sample sizes, unclear methodologies, and limited analytical rigor constraining confidence in findings.

One longitudinal study from the University of Ghana examined seasonal variations in immunization coverage but lacked systematic analysis of climate factors or causal mechanisms (71) International research synthesis provided higher-quality evidence on climate-immunization interactions globally but offered limited guidance for Ghana-specific adaptation strategies.

3.4.2 Research Infrastructure Limitations

Evidence from 2 institutional assessments indicates limited research infrastructure for climate-health studies, including inadequate meteorological monitoring at health facilities, insufficient data management systems, and constrained analytical capacity within research institutions (66,72). No systematic research agenda addressing climate-immunization interactions was documented, with research priorities appearing ad hoc rather than strategically coordinated across institutions.

Collaboration between research institutions and health system implementers appears limited, constraining translation of research findings into policy and programmatic applications. The absence of dedicated funding mechanisms for climate-health research further limits research capacity development and sustained evidence generation.

3.5 Climate-Resilient Infrastructure and Technologies

3.5.1 Technology Deployment and Performance

This component demonstrated moderate evidence strength with 16 relevant studies examining infrastructure adaptations and technology solutions. Solar-powered refrigeration systems emerged as the most frequently implemented adaptation strategy, with deployment documented across 8 studies covering various regions and contexts (73). However, performance evaluations revealed highly variable success rates ranging from 40-85% depending on maintenance capacity, technical support, and community engagement factors.

High-quality evidence from 4 studies with systematic follow-up periods (12-36 months) indicated that technology sustainability depends critically on local maintenance systems, spare parts availability, and ongoing technical support rather than equipment specifications alone (74) These findings suggest that technology solutions require comprehensive implementation approaches addressing institutional and social dimensions.

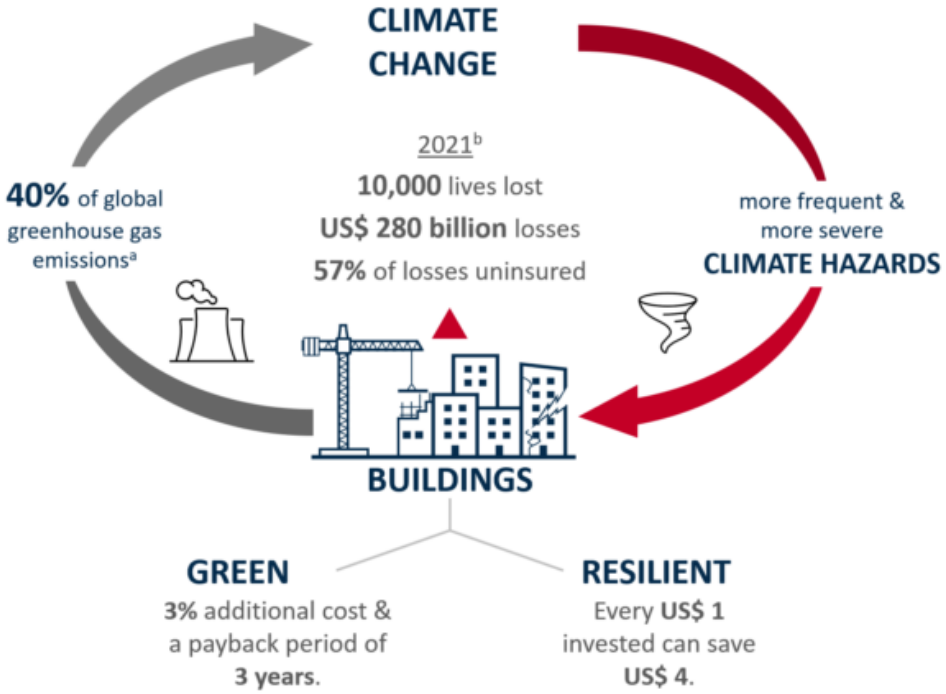


Figure 2: *This infographic illustrates the cycle of climate change and its impact on buildings, emphasizing the economic benefits of resilient green infrastructure and the costs of climate. Investing in resilient buildings can reduce losses significantly, with every US$1 invested saving US$4 in return.*

3.5.2 Implementation Challenges and Contradictions

Contradictory evidence emerged regarding optimal technology approaches, with some studies reporting successful community-based maintenance programs while others documented technical capacity constraints undermining sustainability (75). These contradictions appear related to contextual factors including community education levels, prior technical experience, and local leadership engagement rather than technology characteristics alone.

Infrastructure standardization remains limited, with equipment procurement decisions often made independently across facilities and districts, leading to compatibility issues and maintenance challenges. Only 2 studies provided systematic analysis of procurement and standardization barriers, limiting understanding of system-wide infrastructure development requirements.

3.5.3 Digital Monitoring Innovations

Integration of digital temperature monitoring systems with cold chain management showed promising results across 3 pilot implementations, enabling real-time monitoring and rapid response to equipment failures (76). However, these innovations remain at pilot scale without systematic evaluation of scalability, cost-effectiveness, or operational integration requirements. The evidence suggests potential for digital solutions but highlights needs for comprehensive implementation strategies addressing technical, institutional, and financial sustainability requirements.

3.6 Management of Environmental Determinants

3.6.1 Environmental Health Integration

Six studies addressed environmental determinants of immunization resilience, though evidence quality remained moderate with methodological limitations. Climate change affects environmental determinants including water quality, vector ecology, and waste management systems that influence disease patterns and immunization effectiveness(47). However, systematic integration of climate considerations into environmental health programming appears limited based on available evidence.

Flooding impacts on water and sanitation systems create conditions favouring waterborne disease transmission, potentially affecting immunization program effectiveness through increased disease burden and reduced health system capacity. Two studies documented these linkages but provided limited analysis of programmatic responses or adaptation strategies (48).

3.6.2 Inter-sectoral Coordination Limitations

Environmental health and immunization program coordination appears minimal based on available evidence, with limited documentation of systematic approaches to managing environmental factors affecting immunization outcomes (4,77). No studies were found documenting integrated planning processes addressing environmental determinants within immunization programming, representing both an evidence gap and likely programmatic weakness.

The absence of systematic environmental health integration may limit immunization program effectiveness under changing environmental conditions, but available evidence provides insufficient basis for quantifying these impacts or evaluating integration approaches.

3.7 Climate-Informed Health Programs

3.7.1Adaptive Program Strategies

Evidence from 11 studies revealed various adaptive approaches within Ghana's immunization programming, though systematic evaluation remained limited. Mobile immunization services and flexible scheduling emerged as common adaptations to maintain service delivery during climate events, documented across 6 studies examining different regions and contexts (78). However, systematic evaluation of effectiveness, cost-efficiency, or scalability was limited to 2 studies with small sample sizes.

Community-based adaptation approaches showed promising sustainability indicators across 4 studies, with evidence suggesting greater long-term viability than purely technical solutions (79). Success factors included local leadership engagement, integration with existing community health programs, and alignment with cultural practices and preferences. However, effectiveness varied significantly across different community contexts, suggesting the importance of local adaptation rather than standardized approaches.

3.7.2 Program Implementation Variability

Conflicting findings were reported regarding program adaptation effectiveness, with some studies reporting successful community engagement while others documented participation challenges and sustainability concerns(74,80). These contradictions appear related to implementation approaches, community readiness factors, and integration with existing health services rather than fundamental program design issues.

Reactive immunization measures during climate events showed variable effectiveness, with successful responses characterized by advance planning, community preparation, and coordinated logistics support. However, systematic emergency response protocols appeared absent from routine program planning based on available evidence.

Integration and Coordination Challenges

Program adaptations were often done without much preparation rather than systematically integrated into routine immunization planning and implementation. Limited evidence suggested coordination challenges between different program adaptations and insufficient integration with broader health system responses to climate events(80). These coordination limitations may constrain adaptation effectiveness and sustainability despite individual intervention successes.

3.8 Emergency Preparedness and Management

3.8.1 Emergency Response Frameworks

Analysis of 14 studies examining emergency preparedness revealed established frameworks within Ghana's disaster management system that include health sector responsibilities (81). The National Disaster Management Organisation coordinates multi-sectoral emergency responses with designated roles for health sector agencies including immunization program continuity during emergencies.

However, climate-specific preparedness for immunization services appears limited based on available evidence, with emergency protocols focusing primarily on general health service continuity rather than immunization-specific requirements such as cold chain maintenance, vaccine supply management, and catch-up campaign implementation (82). Three studies documented emergency responses during specific climate events but provided limited systematic evaluation of immunization program performance or lessons learned.

3.8.2 Preparedness Capacity Variations

Emergency preparedness capacity varies significantly across regions and administrative levels, with urban areas and regional capitals showing greater preparedness than rural districts(83). Resource constraints, limited training opportunities, and inadequate equipment affect preparedness capacity, particularly in climate-vulnerable areas where emergency response capabilities are most needed.

Staff training for climate emergencies appears limited, with only 2 studies documenting systematic capacity building for health workers on emergency immunization procedures during climate events. This training gap may limit effective emergency response despite established coordination frameworks.

3.8.3 Response Coordination Challenges

Despite established frameworks, operational coordination during actual climate events faces significant challenges including communication disruptions, transportation limitations, and resource mobilization delays (38). Two case studies of emergency responses documented coordination difficulties between health sector agencies and external partners, suggesting needs for improved coordination mechanisms and regular preparedness exercises.

3.8.4 Limited evidence

There was available on emergency response effectiveness for immunization services specifically, with most documentation focusing on general health service emergency responses rather than immunization program continuity and recovery measures.

3.9.0 Climate-Informed Health Workforce

3.9.1 Workforce Capacity Assessment

Seven studies addressed health workforce climate preparedness, revealing significant capacity gaps and training needs across different staff levels and regions (84). Climate-related training for immunization staff appears limited and unsystematic, with training opportunities concentrated in urban areas and higher administrative levels rather than frontline service delivery positions.

Knowledge assessments in 3 studies documented limited understanding of climate impacts on immunization programming among health workers, with particular gaps in cold chain management during climate events, emergency response procedures, and community engagement approaches during climate-related service disruptions (85). However, these assessments used small, convenience samples that may not represent system-wide capacity levels.

3.9.2 Training and Development Limitations

No systematic competency framework for climate-informed immunization programming was identified in available evidence, limiting standardized training development and performance assessment. Training initiatives appear project-based and temporary rather than integrated into routine professional development systems (86).

Pre-service training integration appears minimal, with climate-health topics receiving limited attention in health professional education curricula based on 2 curriculum analyses. This gap may limit future workforce preparedness as climate impacts intensify and adaptation requirements expand.

3.9.3 Workforce Distribution and Retention

Rural and climate-vulnerable areas face particular workforce challenges including staff shortages, high turnover, and limited professional development opportunities that may constrain climate adaptation capacity (87). However, systematic analysis of workforce distribution in relation to climate vulnerability was absent from available evidence, limiting understanding of workforce resilience requirements and capacity building priorities.

3.10 Sustainable Financing

3.10 (i) Financing Structure Assessment

This component demonstrated the most critical evidence gaps with only 3 relevant studies of limited methodological quality. Ghana's immunization program financing relies heavily on external donor support, with climate adaptation investments appearing project-based and time-limited rather than systematically integrated into program budgets (88).

3.10 (ii) Budget Allocation Challenges

No dedicated budget lines for immunization climate resilience were identified in available budget analyses, with climate-related investments embedded within broader infrastructure or emergency preparedness allocations. This financing approach may limit systematic adaptation planning and sustained resilience building efforts.

3.10 (iii) Resource Mobilization Challenges

Cost estimates for climate adaptation interventions were absent from available literature, limiting evidence-based advocacy for increased investment and constraining resource planning for resilience building (89). The absence of economic evaluations demonstrating return on investment for adaptation measures represents a critical gap in financing strategy development.

International climate finance mechanisms appear to have limited penetration into immunization system strengthening, with climate funds focusing primarily on mitigation rather than health system adaptation. However, systematic analysis of climate finance opportunities and barriers was lacking in available evidence.

3.10 (iv) Financial Sustainability Concerns

Long-term financing sustainability for climate adaptation remains unclear based on available evidence, with project-based funding creating risks of intervention discontinuity and limited

institutional learning (90). No studies were found examining financing sustainability strategies or innovative financing mechanisms specifically for immunization climate resilience, representing both an evidence gap and likely planning limitation.

Chapter 4: Discussions

4.1 Main Objective and Study Scope

This systematic literature review aimed to assess the climate resilience of Ghana's Expanded Programme on Immunization using the WHO Operational Framework for Building Climate Resilient Health Systems. The objective was to synthesize available evidence across the framework's ten components, identify critical gaps, and provide recommendations for strengthening system resilience under changing climatic conditions.

4.2 Summary of Main Results and New Findings

The review of 40 studies reveals three critically important and interconnected findings that represent both the most concerning weaknesses and surprising discoveries in Ghana's climate-immunization resilience landscape.

First, and foremost, sustainable financing emerges as the most critical system failure, not infrastructure as might be expected. With only 3 studies of limited quality addressing this component, the complete absence of dedicated budget lines, cost-effectiveness analyses, and systematic financing mechanisms represents a fundamental barrier that undermines all other resilience efforts. This finding is particularly striking given that most climate-health literature focuses on technical and operational challenges rather than financing constraints.

Secondly, the complete absence of functional integrated risk monitoring and early warning systems represents a novel and concerning discovery. Despite Ghana's established disaster management frameworks, no studies documented working connections between meteorological services and immunization program planning ; a critical gap that severely limits proactive response capacity and distinguishes Ghana's system from international best practices.

Also, the noticeable disparity in evidence distribution across WHO framework components reveals a concerning pattern where immediate operational challenges (infrastructure, emergency response) receive disproportionate attention while foundational elements for sustained resilience (financing, research capacity, integrated monitoring) remain severely neglected. This imbalance shows they are reacting to problems instead of planning ahead to build resilience.

4.2.1 Connections and Key Dependencies Within the System

The evidence reveals complex interdependencies that increase system vulnerabilities when components function in isolation. The infrastructure challenges documented in northern Ghana, where cold chain failures during power outages last 2-72 hours are directly linked to financing constraints that prevent investment in backup power systems and maintenance capacity. Without sustainable financing mechanisms, even successful pilot technology deployments

(solar refrigeration with 40-85% success rates) cannot achieve systematic scale-up or long-term sustainability.

The workforce capacity gaps identified across rural areas directly compound infrastructure vulnerabilities**.** Limited technical training for cold chain management during climate events, combined with high staff turnover in climate-vulnerable regions, creates a cascade of system weaknesses. Emergency preparedness frameworks exist but remain ineffective without trained personnel who understand climate-specific immunization requirements.

Policy integration failures create systemic coordination challenges that prevent effective responses across all other components. While Ghana has climate-health policy frameworks, the absence of operational mechanisms, dedicated budgets, and measurable targets means that individual component improvements (infrastructure, training, technology etc) remain disjointed rather than contributing to coherent system resilience.

The research capacity weaknesses fundamentally undermine evidence-based improvements across all components. Without Ghana-specific research on climate-immunization interactions, adaptation strategies rely on potentially inappropriate extrapolation from other contexts, limiting the effectiveness of interventions in infrastructure, workforce development, and program design.

4.2.2 Known Factors Versus Critical Knowledge Gaps

What We Know

- Geographic vulnerability patterns: Rural and northern regions face systematic disadvantages due to infrastructure deficits, power instability, and workforce challenges
- Technology performance variations: Solar-powered cold chain solutions show promise but require comprehensive implementation approaches addressing maintenance, training, and community engagement
- Emergency response frameworks exist but lack climate-specific protocols for immunization continuity

4.2.3 Critical Knowledge Gaps with Policy Implications

Most critically, we do not know the quantitative relationships between climate events and vaccination coverage outcomes**.** No studies systematically measured whether documented infrastructure vulnerabilities translate into measurable drops in immunization rates; a fundamental gap that prevents evidence-based prioritization of adaptation investments and evaluation of intervention effectiveness.

Regional and population-specific vulnerabilities remain poorly characterized**.** While broad rural-urban disparities are documented, detailed vulnerability mapping exists for only limited areas, constraining targeted adaptation planning. Gender-disaggregated impacts are entirely absent from available evidence, despite potential differential effects of climate events on women's and children's access to immunization services.

Urban-rural implementation differences in adaptation strategies are poorly understood. While rural areas face greater infrastructure challenges, urban areas may have different vulnerability

patterns (heat island effects, different community structures) that require distinct adaptation approaches, yet comparative analyses are lacking.

Population group vulnerabilities, including ethnic minorities, internally displaced populations, and marginalized communities; receive minimal attention in available evidence, potentially masking critical equity concerns in climate resilience planning.

4.3 Intervention Feasibility and Transferability Analysis

4.3.1 Promising Transferable Interventions

Community-based maintenance programs for solar refrigeration systems show success across multiple contexts and appear feasible for Ghana's setting, given existing community health program infrastructure. However, success appears highly dependent on local leadership engagement, educational levels, and prior health program experience and factors that vary significantly across Ghana's diverse communities.

Mobile immunization services and flexible scheduling during climate events represent immediately implementable adaptations that align with Ghana's existing outreach programming. Evidence from other West African contexts suggests these approaches can maintain coverage during seasonal disruptions, though systematic evaluation remains limited.

4.3.2 Interventions of Questionable Transferability

Rwanda's dedicated climate-health units within the Ministry of Health represent an appealing model but may not be directly transferable due to different political structures, resource constraints, and institutional capacity. Ghana's decentralized health system may require different coordination mechanisms that work within existing governance structures rather than creating new institutional arrangements.

Ethiopia's integrated early warning systems show promise but require significant technical infrastructure investments and inter-sectoral coordination capacity that may exceed Ghana's current institutional capabilities. Incremental approaches building on existing meteorological and health information systems may be more feasible initial steps.

4.4 Critical Implementation Barriers

Financing sustainability emerges as the primary constraint for most promising interventions. Even technically feasible adaptations (solar refrigeration, digital monitoring, community engagement programs) face sustainability challenges without dedicated domestic budget allocations and systematic financing mechanisms.

4.5 Analytical Framework Assessment

The WHO Operational Framework proved highly valuable for systematic assessment of climate resilience across multiple system dimensions. The ten-component structure enabled identification of critical gaps (financing, integrated monitoring) that might be overlooked in narrower analytical approaches focused primarily on infrastructure or service delivery.

However, the framework revealed important limitations for application in resource-constrained settings. The framework assumes certain baseline system capacities (functioning information

systems, established coordination mechanisms, dedicated climate budgets) that may not exist in many sub-Saharan African contexts. A modified framework might better reflect the developmental sequence in which basic system foundations must be established before advanced resilience components can function effectively.

The framework's equal weighting of components may not reflect interdependencies revealed in this analysis. Sustainable financing and integrated monitoring appear to function as foundational requirements that enable effectiveness across other components, suggesting a hierarchical rather than parallel relationship between framework elements.

4.6 Study Limitations and Implementation Challenges

4.6.1 Critical Data Quality and Availability Limitations

The heavy reliance on facility-level reporting without community-level validation represents a significant bias risk that may systematically underestimate climate impacts on immunization access. Health facility reports may miss population-level coverage disruptions, displacement effects, and community-level barriers during climate events, potentially leading to underestimation of system vulnerabilities.

Geographic and temporal clustering of available evidence creates important external validity limitations. Most studies focused on specific regions (northern Ghana) or particular seasons, limiting generalizability across Ghana's diverse climatic and social contexts. The absence of year-round monitoring data means vulnerability assessments may not capture the full range of climate impacts across different seasonal patterns.

Gender-disaggregated analysis was entirely absent from available evidence, despite potential differential impacts of climate events on women and children's access to immunization services. This represents both a critical knowledge gap and potential source of intervention design bias, as adaptation strategies may inadequately address gender-specific barriers to service access during climate events.

4.7 Methodological and Analytical Limitations

The predominance of descriptive over analytical research (67% vs 33%) severely limited causal inference capabilities. Most studies documented climate impacts or described adaptation responses without systematic evaluation of effectiveness or quantitative assessment of relationships between climate factors and immunization outcomes. This methodological limitation constrains confidence in intervention recommendations and limits evidence-based adaptation planning.

Quality assessment revealed significant variations with only 29% of studies demonstrating high methodological quality. The substantial proportion of low-quality studies (28%) due to small sample sizes, unclear methodologies, or limited analytical depth may have introduced systematic bias toward less rigorous findings, potentially overestimating or underestimating the severity of climate impacts and effectiveness of adaptation responses.

The absence of controlled evaluations of adaptation interventions means that intervention effectiveness claims rely primarily on observational data and expert opinion rather than

rigorous evaluation evidence. This limitation particularly affects confidence in technology and program intervention recommendations.

4.7.1 Bias Implications and Underreporting Concerns

Stigma and reporting bias may lead to systematic underestimation of climate impacts on immunization services. Health facility managers may underreport system failures, equipment problems, or coverage disruptions due to performance concerns, potentially masking the true extent of climate vulnerabilities. This bias suggests that documented vulnerabilities may represent minimum estimates rather than comprehensive assessments.

The absence of community perspectives in most studies creates potential bias toward health system viewpoints that may not fully capture population-level experiences of climate impacts on immunization access. Community-level barriers, displacement effects, and informal coping strategies may be systematically underrepresented in available evidence.

Research funding and institutional priorities may bias evidence toward technical solutions and infrastructure investments while neglecting social, political, and equity dimensions of climate resilience. The concentration of evidence in infrastructure and technology components may reflect donor and researcher preferences rather than comprehensive assessment of system resilience requirements.

4.7.2 Ethical and Research Fairness Considerations

The limited involvement of affected communities in research design and implementation represents an important ethical limitation. Climate-vulnerable populations; particularly rural communities, women, and marginalized groups, appear as research subjects rather than research partners, potentially limiting the relevance and appropriateness of findings for their contexts.

Research dissemination appears concentrated in academic and policy circles with limited evidence of community engagement or feedback to affected populations. This pattern raises questions about research fairness and whether communities most affected by climate impacts benefit from research conducted about their experiences.

Chapter 5: Conclusions and Recommendations

5.1 Conclusions

Assessment of Climate Resilience in Ghana's EPI: This narrative review set out to examine Ghana's Expanded Programme on Immunization climate resilience through the lens of the WHO operational framework for climate-resilient health systems. The analysis of 40 sources spanning policy documents, peer-reviewed articles, and technical reports from 2010-2025 reveals a complex landscape where Ghana's immunization program demonstrates both notable strengths and critical vulnerabilities in the face of climate change. The research objective of assessing current climate resilience across the ten WHO framework components has been addressed, though with important caveats regarding the emerging nature of immunization-

climate science and the necessity of extrapolating from broader climate-health and health systems evidence.

The evidence synthesis demonstrates that Ghana possesses robust policy frameworks for both immunization and climate adaptation, with the National Health Policy 2020 emphasizing health system resilience and the National Climate Change Adaptation Strategy identifying health as a priority sector. However, a pronounced governance-implementation paradox emerges as the most significant finding: strong national-level policies and strategies do not translate effectively into district and facility-level implementation. This disconnect is particularly evident in cold chain management, where 91.7% of facilities lack policies and 100% have no contingency plans for equipment failures, despite national guidelines and international best practices being well-established.

Regional and Equity Gaps: Geographic and equity disparities represent another critical conclusion from this analysis. The northern regions of Ghana face a paradoxical situation where climate vulnerability is highest but investment in climate-resilient immunization infrastructure is lowest. Regional coverage variations ranging from 47 per 1000 live births under-five mortality in Greater Accra to 111 per 1000 in Northern Region reflect broader systemic inequities that climate change is likely to exacerbate. This geographic disparity extends beyond coverage to include workforce capacity, with only 50% of regions having adequately trained health workers and significant variations in technical capacity for maintaining climate-resilient technologies such as solar-powered cold chain equipment.

The review reveals that infrastructure vulnerability, particularly in cold chain systems, represents the most tangible intersection between climate risks and immunization program integrity. Evidence from effective vaccine management assessments shows that temperature control scores average only 60% against WHO benchmarks, while erratic power supply affects vaccine storage reliability across the country. The deployment of solar-powered refrigeration equipment demonstrates promising adaptation efforts, but sustainability challenges including inadequate maintenance skills and equipment downtime suggest that technology solutions alone are insufficient without accompanying systems strengthening.

Limited evidence and a case for research A fundamental conclusion emerging from this analysis concerns the limited evidence base for understanding immunization-climate interactions. The intersection of immunization and climate change represents emerging science globally, with virtually no Ghana-specific research examining direct relationships between climate variability and immunization outcomes. This evidence gap necessitated methodological triangulation of separate research streams - climate vulnerability assessments, immunization performance data, and health systems strengthening literature - to construct understanding of potential climate-EPI intersections. While this approach provides valuable insights, it also highlights the urgent need for dedicated research in this domain.

Several critical questions remain unanswered following this analysis. The long-term impacts of increasing climate variability on vaccine coverage and effectiveness in Ghana remain largely unknown due to the absence of longitudinal studies linking meteorological data with immunization outcomes. The cost-effectiveness of different climate adaptation strategies for

immunization programs has not been systematically evaluated, hindering evidence-based resource allocation decisions. Additionally, the role of traditional and community-based systems in supporting immunization resilience during climate-related disruptions requires further investigation, as current frameworks focus primarily on formal health system responses.

5.2 Recommendations

Based on the critical analysis of evidence presented in this review, ten actionable recommendations are proposed to strengthen Ghana's EPI climate resilience. These recommendations are organized by target audience and prioritized according to feasibility, resource requirements, and potential impact. The recommendations acknowledge both the immediate operational needs identified through the WHO framework analysis and the longer-term system development requirements for building genuine climate resilience in immunization service delivery.

5.2.1 Policy-Level Recommendations

Recommendation 1: Develop an Integrated National EPI Climate Resilience Strategy. The Ministry of Health should establish a dedicated climate-immunization strategy that bridges the current policy gap between general health climate adaptation and specific immunization program needs. This strategy should mandate climate risk assessments for all EPI infrastructure investments, establish performance indicators for climate resilience across the ten WHO framework components, and create accountability mechanisms for implementation at district and facility levels. Implementation should be phased over two years, beginning with stakeholder consultations and baseline assessments, followed by strategy development and pilot testing in selected high-vulnerability districts. The estimated cost of USD 500,000 for strategy development and initial implementation can be mobilized through existing health system strengthening funding streams from GAVI, World Bank, and bilateral partners. Success requires strong leadership from the EPI program manager and formal endorsement by the Ghana Health Service directorate to ensure institutional commitment beyond political cycles.

Recommendation 2: Establish Equity-Based Resource Allocation Mechanisms for Climate-Vulnerable Regions. Current resource allocation patterns that favour southern regions despite higher climate vulnerability in northern areas must be addressed through policy reform. The Ministry of Health should develop and implement a climate-vulnerability weighted allocation formula for EPI investments, ensuring that districts with higher climate risks receive proportionally greater support for infrastructure, equipment, and capacity building. This mechanism should be integrated into the Medium-Term Expenditure Framework and operationalized through the District Health Management Teams' planning processes. Implementation requires collaboration with the Ministry of Finance and the National Development Planning Commission to ensure alignment with broader resource allocation policies. The recommendation can be implemented within existing budget frameworks but requires political commitment to address historic regional inequities in health investment.

Recommendation 3: Integrate Climate Risk Indicators into National Health Information Systems. The District Health Information Management System (DHIMS) should be enhanced to capture climate-related disruptions to immunization services, enabling real-time monitoring

of climate impacts and adaptive management. This integration should include indicators for temperature excursions in cold chain systems, service delivery disruptions due to extreme weather events, and coverage variations during seasonal climate patterns. The Ministry of Health should collaborate with the Ghana Meteorological Agency to develop automated data feeds linking weather data with health service delivery indicators. Implementation requires technical assistance estimated at USD 200,000 for system development and staff training, with ongoing operational costs absorbed within existing DHIMS maintenance budgets. This recommendation can be implemented immediately as it builds on existing systems and aligns with current digitalization initiatives in the health sector.

5.2.2 Program-Level Recommendations

Recommendation 4: Implement Comprehensive Cold Chain Infrastructure Upgrading with Climate Resilience Standards. The Ghana Health Service EPI program should develop and implement upgraded cold chain infrastructure standards that prioritize climate resilience, including mandatory backup power systems, temperature monitoring with remote alerts, and climate-appropriate equipment specifications. This upgrading should prioritize the 85 districts currently lacking adequate cold chain capacity, with particular focus on northern regions where climate vulnerability is highest. Implementation should follow a systematic approach beginning with needs assessment, followed by equipment procurement according to WHO Performance, Quality and Safety standards for climate-resilient equipment, and concluding with comprehensive staff training and maintenance capacity development. The estimated cost of USD 5 million over three years can be mobilized through GAVI Health Systems Strengthening support, supplemented by World Bank climate adaptation funding. Success requires collaboration with the Biomedical Engineering Unit of the Ghana Health Service to ensure sustainable maintenance capacity and with regional health administrations to ensure appropriate siting and staffing of upgraded facilities.

Recommendation 5: Establish Systematic Health Workforce Climate Capacity Building Program. Current training gaps where only 50% of regions have adequately trained immunization staff must be addressed through a comprehensive capacity building program targeting all levels of the health workforce. The program should include climate-health impacts in pre-service curricula for health training institutions, mandatory in-service training for all EPI staff on climate-adaptive service delivery, and specialized training for district-level managers on emergency preparedness and climate risk management. Implementation should be coordinated through the Ghana Health Service Training Division in collaboration with health training institutions and professional bodies. The program should be phased over four years, beginning with curriculum development and trainer preparation, followed by systematic rollout across all regions. Estimated costs of USD 800,000 can be integrated into existing training budgets with supplementary support from technical partners including WHO and UNICEF. Long-term sustainability requires integration into continuing professional development requirements and performance management systems for health workers.

Recommendation 6: Develop Integrated Early Warning System for Immunization Service Disruptions. The limited integration between meteorological services and health information systems must be addressed through development of an early warning system that enables

proactive management of climate-related service disruptions. This system should integrate seasonal climate forecasts with immunization service planning, provide automated alerts for extreme weather events affecting vaccine storage and service delivery, and enable coordinated response across district health management teams. Implementation requires collaboration between the Ghana Health Service, Ghana Meteorological Agency, and National Disaster Management Organization to establish data sharing protocols and response procedures. Technical development estimated at USD 300,000 should focus on automated alert systems and decision support tools for district health managers. The system can build on existing disease surveillance platforms and should be piloted in high-vulnerability districts before national rollout. Success depends on establishing clear standard operating procedures for early warning response and ensuring adequate communication infrastructure in remote areas.

5.2.3 Implementation-Level Recommendations

Recommendation 7: Develop District-Specific Emergency Preparedness Plans for Immunization Services. The absence of contingency plans at 100% of assessed facilities must be addressed through mandatory development of district-specific emergency preparedness plans for immunization service continuity during climate-related disruptions. These plans should specify backup cold chain procedures, alternative service delivery sites during flooding or other extreme events, and communication protocols for maintaining service access during emergencies. District Health Management Teams should lead plan development with technical support from regional and national levels, ensuring alignment with broader district emergency preparedness frameworks. Implementation should be completed within 18 months across all 216 districts, with priority given to the most climate-vulnerable areas. Costs estimated at USD 400,000 for plan development, training, and equipment can be integrated into existing emergency preparedness funding from humanitarian and development partners. Plans must be tested through regular simulation exercises and updated annually based on changing climate risk profiles and service delivery patterns.

Recommendation 8: Strengthen Community Engagement and Resilience Building for Immunization Access. Limited community involvement in immunization planning identified in the bottleneck analysis must be addressed through systematic community engagement that builds local resilience for maintaining immunization access during climate-related disruptions. This should include training community health volunteers on climate-adaptive immunization promotion, establishing community-based cold chain support during power outages, and developing community early warning networks for service disruption communication. Implementation should be coordinated through the Community-based Health Planning and Services (CHPS) program, leveraging existing community health officer networks and community health management committees. The program should be piloted in 50 high-vulnerability communities before broader rollout, with estimated costs of USD 600,000 over three years for training, equipment, and communication systems. Success requires strong collaboration with traditional authorities and community-based organizations, as well as integration with existing community health programs to ensure sustainability and avoid duplication of efforts.

5.2.4 Research Recommendations

Recommendation 9: Conduct Longitudinal Climate-Immunization Impact Assessment Study. The absence of Ghana-specific evidence on climate-immunization interactions must be addressed through a dedicated longitudinal research program examining relationships between climate variability and immunization outcomes. This study should link meteorological data with immunization coverage, cold chain performance, and service delivery indicators across representative districts over a minimum five-year period. The research should employ mixed methods approaches combining quantitative analysis of administrative data with qualitative assessment of community and health worker experiences during climate-related disruptions. Implementation should be led by a collaboration between the Ghana Health Service Research and Development Division, academic institutions including the University of Ghana School of Public Health, and international partners with climate-health expertise. Estimated costs of USD 1.2 million over five years can be mobilized through research funding from organizations such as the Wellcome Trust, NIH Fogarty International Center, or European Union climate adaptation research programs. The study should be designed to inform policy and program decisions, with annual findings reports and policy briefs ensuring research-to-action translation.

Recommendation 10: Conduct Cost-Effectiveness Analysis of Climate Adaptation Strategies for EPI. Limited evidence on the economic efficiency of different climate adaptation approaches hinders optimal resource allocation decisions for strengthening EPI climate resilience. A comprehensive cost-effectiveness analysis should evaluate the relative benefits and costs of infrastructure-based adaptations (solar cold chain, backup power systems), system-based approaches (early warning systems, emergency preparedness), and community-based interventions (local resilience building, enhanced outreach). The analysis should employ both economic evaluation methods and budget impact assessment to inform policy decisions on adaptation investment priorities. Research should be conducted by health economists in collaboration with EPI program managers and climate specialists, ensuring practical relevance for decision-making. Implementation over two years with estimated costs of USD 400,000 can be supported through health systems research funding from GAVI, World Bank, or bilateral development partners. Findings should be disseminated through policy briefs, peer-reviewed publications, and regional forums to support evidence-based climate adaptation planning across West Africa.

5.3 Implementation Priorities and Sequencing

The ten recommendations should be implemented according to a phased approach that recognizes resource constraints, institutional capacity, and interdependencies between interventions. Immediate priority should be given to Recommendations 1, 3, and 7, which can be implemented within existing institutional frameworks and require primarily policy and planning efforts rather than substantial new funding. The development of the National EPI Climate Resilience Strategy (Recommendation 1) should commence immediately as it provides the policy foundation for subsequent interventions. Simultaneously, integration of climate risk indicators into DHIMS (Recommendation 3) and development of district emergency

preparedness plans (Recommendation 7) can proceed as these build on existing systems and processes.

Medium-term implementation over years two and three should focus on infrastructure and capacity building through Recommendations 2, 4, 5, and 6. These interventions require substantial funding mobilization and technical assistance but are essential for addressing the infrastructure vulnerabilities and human resource gaps identified in the analysis. The equity-based resource allocation mechanism (Recommendation 2) should be operationalized concurrent with cold chain infrastructure upgrading (Recommendation 4) to ensure that investment reaches the most vulnerable areas. Health workforce capacity building (Recommendation 5) and early warning system development (Recommendation 6) should proceed in parallel to ensure that improved infrastructure is supported by adequate human resources and management systems.

Long-term implementation in years four and five should emphasize community engagement and research through Recommendations 8, 9, and 10. Community resilience building (Recommendation 8) requires foundational improvements in service delivery systems before meaningful community engagement can be sustained. The longitudinal research program (Recommendation 9) and cost-effectiveness analysis (Recommendation 10) should be initiated once baseline systems improvements are underway, ensuring that research findings can inform ongoing program refinements and future investment decisions. This sequencing approach ensures that immediate operational needs are addressed while building the evidence base for long-term program sustainability and effectiveness.

5.4 Operationalization and Feasibility Considerations

Successful implementation of these recommendations requires careful attention to financial, technical, and institutional feasibility within Ghana's current health system context. The total estimated cost of USD 9.5 million over five years is substantial but represents less than 2% of Ghana's annual health budget and can be mobilized through existing funding mechanisms including GAVI Health Systems Strengthening support, World Bank climate adaptation funding, and bilateral partner contributions. The phased implementation approach enables gradual resource mobilization and reduces the risk of overwhelming institutional capacity with simultaneous large-scale interventions.

Technical feasibility is enhanced by building on existing systems and institutional frameworks rather than creating parallel structures. The recommendations leverage established platforms including DHIMS, CHPS, and district health management systems, reducing implementation complexity and ensuring sustainability. However, success requires sustained political commitment beyond electoral cycles, necessitating high-level endorsement and integration into statutory planning and budgeting processes. The involvement of multiple stakeholders including the Ministry of Health, Ghana Health Service, district assemblies, and community organizations requires careful coordination and clear accountability mechanisms.

Institutional capacity constraints, particularly in northern regions where needs are greatest, may limit implementation effectiveness. This challenge can be addressed through the graduated implementation approach, beginning with districts that have stronger institutional

capacity while simultaneously building capacity in more vulnerable areas. Regular monitoring and adaptive management will be essential, with annual reviews enabling course corrections based on implementation experience and changing climate risk profiles. The recommendations' emphasis on integration with existing systems and processes enhances feasibility but requires strong leadership and coordination to prevent fragmentation and ensure coherent implementation across multiple levels of the health system.

Technology Invention: The introduction of Controlled temperature chain (CTC) and Microarray Chips (MAPS) in in manufacture of vaccines for the tropics as innovations must be highly encouraged.

Chater 6:References

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Appendices:

Table1: **Search Concepts and Terms for Literature Review on Immunization, Climate Change, and Resilience in Ghana and Comparable Settings**	
Concept	**Search Terms**
Geographic Focus	Ghana OR "West Africa" OR "sub-Saharan Africa" OR "developing country" OR "low-middle income country"
Health Program Focus	"Expanded Programme on Immunization" OR EPI OR vaccination OR immunization OR "vaccine delivery" OR "childhood immunization" OR "routine immunization" OR "cold chain"
Climate and Resilience Focus	"climate change" OR "climate variability" OR "extreme weather" OR "global warming" OR resilience OR adaptation OR "health systems strengthening" OR vulnerability OR "disaster preparedness" OR "emergency response"

Table 2: Documents used

No	Policy Document	Year	Significance to Ghana EPI Climate Resilience
1	Ghana National Health Policy: Ensuring Healthy Lives for All (Revised Edition)	2020	Establishes policy framework for resilient healthcare delivery system; defines immunization as core preventive service; addresses environmental health determinants affecting vaccine delivery
2	Comprehensive Multi Year Plan (cMYP) 2015-2019	2017	Provides detailed EPI coverage data, cold chain capacity assessments, solar equipment deployment strategies; documents climate-related operational challenges
3	Ghana National Climate Change Adaptation Strategy (NCCAS)	2010	Outlines health sector climate adaptation strategies; establishes framework for health workforce capacity building; defines health infrastructure resilience priorities

4	Health Sector Medium-Term Development Plan 2022-2025	2022	Integrates immunization within broader health system strengthening; addresses infrastructure resilience; includes emergency preparedness components
5	Ghana: Mixed Financing for Immunization and Shifting Responsibility	2017	Analyses financing sustainability challenges for immunization programs; examines donor dependency risks affecting climate adaptation investments
6	Budget Credibility and Immunization in Ghana	2020	Documents funding delays affecting service delivery; examines resource allocation challenges impacting climate resilience investments
7	WHO-UNICEF Joint Reporting Form on Immunization (JRF) Ghana Data	2022	Provides standardized immunization coverage data; enables international comparisons; documents performance against climate-sensitive indicators
8	Mid-term Evaluation of the Global Strategy to Eliminate Yellow Fever (Ghana Case Study)	2023	Documents climate-sensitive disease prevention strategies; evaluates campaign effectiveness in climate-vulnerable regions
9	Ghana COVID-19 Vaccines Preparedness and Response Project	2021	Demonstrates emergency immunization system adaptations; provides insights into rapid response capabilities during health emergencies
10	Maternal and Neonatal Tetanus Elimination Programme Status Ghana	2011	Documents successful elimination strategies; provides evidence of sustained program performance despite environmental challenges
11	Technical Guidelines Disease Surveillance Ghana (IDSR)	2016	Establishes surveillance protocols for vaccine-preventable diseases; includes climate-sensitive disease monitoring frameworks
12	National Essential Health Services Package2022-2030	2022	Defines comprehensive service delivery framework; integrates immunization within primary healthcare resilience strategies
13	Cold Chain Management by Healthcare Providers at a District in Ghana	2021	Provides quantitative data on cold chain policy gaps (91.7% facilities lack policies);documents power supply vulnerabilities affecting vaccine storage
13	Regional Disparities in Immunization Services in Ghana through Bottleneck Analysis	2017	Documents geographic vulnerabilities; identifies hard-to-reach areas climate susceptibility; provides workforce training adequacy data (50% regions)

14	Health Systems Response to Climate Change Adaptation	2024	Synthesizes global evidence on immunization adaptation strategies; provides framework for climate-resilient vaccine programs
15	Effective Vaccine Management: The Case of a Rural District in Ghana	2019	Quantifies vaccine management performance gaps; documents temperature control challenges; provides EVM assessment framework
16	Assessment of Expanded Programme on Immunization Routine Data Quality	2024	Evaluates data system reliability for climate-responsive planning; documents information management challenges affecting adaptation
17	Childhood Immunization in Ghana: Tracing the History and Achievements	2024	Provides historical context for program evolution; documents infrastructure development relevant to climate resilience
18	Factors Contributing to Immunization Coverage Among Children Less Than Five Years	2024	Identifies geographic and socioeconomic vulnerabilities; examines access barriers that climate change may exacerbate
19	Coverage and Predictors of Full Measles-Rubella Immunization in Northern Ghana	2024	Focuses on climate-vulnerable northern regions; identifies predictors relevant to climate resilience planning
20	Ghana's Progress Towards Measles Elimination: Surveillance Data Analysis	2023	Documents disease elimination strategies; provides surveillance system performance data relevant to climate monitoring
21	Sustained Impact of Rotavirus Vaccine Introduction on Gastroenteritis Hospitalizations	2018	Demonstrates vaccine effectiveness against climate-sensitive diseases; provides long-term impact assessment framework
22	Sustainability of Pneumococcal Conjugate Vaccination in Ghana	2024	Evaluates vaccine program sustainability; examines cost-effectiveness considerations for climate adaptation investments
23	Evaluation of the Impact of Immunization Second Year of Life Training Interventions	2021	Assesses workforce capacity building effectiveness; provides evidence on training approaches for climate adaptation
24	Implementation of Community-Based	2023	Documents community-level service delivery; examines local

	Health Planning and Services (CHPS) Programme		adaptation strategies relevant to climate resilience
25	Assessment of Routine Childhood Immunization Data Quality in Bono Region	2021	Evaluates regional data system performance; provides insights into monitoring capacity for climate-responsive planning
26	Utilization of the National Cluster of District Health Information Management System	2020	Analyses DHIMS implementation; examines data integration capabilities for climate-health monitoring
27	Climate Change and Health: Perspectives From Ghana	2024	Provides climate-health nexus analysis; documents health system vulnerabilities including immunization services
28	Preponderance of Vaccine-Preventable Diseases Hotspots in Northern Ghana	2022	Maps disease vulnerability patterns; identifies climate-sensitive regions requiring enhanced immunization resilience
29	Measles Outbreak in Northern Ghana Highlights Vaccine Supply Challenges	2023	Documents supply chain vulnerabilities; demonstrates climate-region susceptibility to vaccine-preventable disease outbreaks
30	An Impact Assessment of Aerial Logistics to Improve Immunization Coverage	2023	Evaluates innovative delivery mechanisms; demonstrates adaptation strategies for climate-inaccessible areas
31	Implementation of Reaching Every Child Immunization Strategy in Ghana	2025	Assesses equity-focused strategies; examines approaches for reaching climate-vulnerable populations
32	Climate and Health Vulnerability Assessment forGhana (World Bank)	2024	Comprehensive climate-health risk analysis; identifies health system adaptation priorities including immunization infrastructure
33	Strengthening Immunization Service Experience- Ghana (USAID)	2022	Evaluates service delivery quality; identifies improvement areas relevant to climate adaptation planning
34	WHO Ghana Annual Report 2024	2024	Documents WHO support for immunization capacity building; includes emergency preparedness

			and climate adaptation components
35	Ghana 2023 Holistic Assessment Report(Ministry of Health)	2023	Comprehensive health sector performance review; includes immunization program assessment and infrastructure resilience evaluation
36	Ghana DHIS2 Immunisation Case Study	2020	Documents health information system capabilities; evaluates data integration potential for climate-responsive monitoring
37	Costing & Financing of Routine Immunization and New Vaccines in Ghana	2019	Analyses financial requirements for immunization programs; examines resource allocation challenges affecting climate adaptation
38	Immunization Systems and User Requirements Document Ghana	2023	Defines system requirements for digital immunization platforms; addresses integration needs for climate-responsive planning
39	Community Health Officers Training Report(UNDP Ghana)	2021	Documents community-level capacity building; provides insights into frontline workforce preparation for climate challenges
40	Drought and child vaccination coverage in 22 countries in sub-Saharan Africa: A retrospective analysis of national survey data from 2011 to 2019	2021	Potential mechanisms linking drought to lower childhood vaccination include food insecurity, increased human migration, and erosion of the public health infrastructure

KIT Institute (Masters or Short course) Participants
Declaration for Use of Generative AI (GenAI)

Please complete and submit this form as an annex on the last page of your assignment file; and not as a separate document.

Check the box that applies to your completion of this assignment:

☐ I confirm that **I have not used** any generative AI tools to complete this assignment.

☒ I confirm that **I have used** generative AI tool(s) in accordance with the ***"Guidelines for the use of Generative AI for KIT Institute Master's and Short course participants".*** Below, I have listed the GenAI tools used and for what specific purpose:

Generative AI tool used	Purpose of use
1.Perplexity	Reconstruct my sentences
2.	
…	