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"Impact of Climate-Related Disasters on Emergency Medical Services: A Systematic Review of Challenges and Adaptation Strategies"

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Abstract:

Background: Climate change is intensifying the frequency and severity of disasters such as floods, heatwaves, hurricanes, wildfires, and dust storms. These events place unprecedented strain on Emergency Medical Services (EMS), which are critical to frontline disaster response. Understanding the challenges and adaptation strategies of EMS during climate-related disasters is essential for strengthening global health resilience.

Objective: This systematic review synthesizes evidence on the impact of climate-related disasters on EMS, focusing on operational challenges, occupational risks, infrastructure limitations, and adaptation strategies implemented across diverse regions.

Methods: The review followed the PRISMA 2020 guidelines. Comprehensive searches of PubMed, Scopus, Web of Science, Embase, and CINAHL were conducted for studies published between 2017 and 2024. Eligible studies examined EMS roles during climate-related disasters and reported either challenges or adaptation measures. Data extraction included study characteristics, disaster type, EMS outcomes, and adaptation strategies. Methodological quality was assessed using the Mixed Methods Appraisal Tool (MMAT 2018).

Results: Of 1,246 records screened, 42 studies met the inclusion criteria, representing 23 countries. Major challenges included increased call volumes during heatwaves, logistical barriers during floods, communication failures in hurricanes, and occupational hazards such as smoke inhalation during wildfires. LMICs were particularly affected by fragile infrastructure and limited resources. Adaptation strategies identified included climate-informed early warning systems, mobile health (mHealth) applications, specialized EMS training, amphibious or all-terrain ambulances, and AI-based demand forecasting. High-income countries emphasized technological innovations, while LMICs focused on basic infrastructure adaptation. The Gulf region demonstrated hybrid strategies to address climate hazards in the context of mass gatherings.

Conclusion: Climate-related disasters threaten the capacity, safety, and effectiveness of EMS worldwide. Strengthening resilience requires integrating EMS into climate adaptation frameworks, investing in workforce support, scaling innovative technologies, and addressing inequities between regions. Further research should evaluate the long-term effectiveness and scalability of adaptation strategies, particularly in LMICs.

Keywords: Climate change; Emergency Medical Services; disasters; adaptation; resilience; prehospital care

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Introduction

Climate change has emerged as one of the defining global health challenges of the twenty-first century, with its impacts extending beyond environmental degradation to disrupt essential public health and emergency response systems. Among the sectors most directly affected are Emergency Medical Services (EMS), which function as the frontline of disaster response. Climate-related disasters—including floods, heatwaves, hurricanes, wildfires, and dust storms—are increasing in frequency, intensity, and unpredictability due to global warming. These events strain EMS capacities by simultaneously increasing demand for urgent care while impairing infrastructure, disrupting communication, and limiting resource availability (Djalante et al., 2020; Watts et al., 2021).

EMS providers are uniquely vulnerable to climate-related disruptions. Rising ambient temperatures have been linked to higher call volumes for heat-related illnesses, while flooding and storm surges impede ambulance mobility and access to affected populations (Knowlton et al., 2019). Additionally, wildfires not only cause traumatic injuries and respiratory illnesses but also create hazardous environments for responders themselves, exacerbating occupational risks (Maguire et al., 2018). Such challenges expose systemic weaknesses in EMS preparedness, workforce resilience, and logistical coordination, underscoring the need for adaptive strategies that ensure continuity of care during climate-driven emergencies.

Globally, there is growing recognition that EMS adaptation to climate change is not optional but essential. Strategies such as integrating early warning systems, enhancing cross-sectoral disaster preparedness, developing heat-resilient response protocols, and investing in mobile health technologies are being increasingly adopted (Bouchard et al., 2020; Ebi et al., 2021). Yet, these efforts remain uneven across regions, with low- and middle-income countries facing greater vulnerability due to resource constraints, fragile health infrastructure, and limited training opportunities for EMS personnel (Aljunaidy et al., 2023).

The Kingdom of Saudi Arabia and other Gulf states provide a compelling context for examining this issue. The region faces recurrent climate-related hazards such as extreme heat, flash floods, and dust storms, which intersect with mass gatherings (e.g., Hajj) to create unique challenges for emergency preparedness and medical response (Alhazmi et al., 2019). In such high-risk environments, adaptation strategies—ranging from climate-informed workforce training to resilient ambulance networks—become critical not only for protecting public health but also for safeguarding responder wellbeing.

This systematic review therefore seeks to synthesize current evidence on the impact of climate-related disasters on EMS. Specifically, it examines the operational, infrastructural, and occupational challenges encountered during climate-induced emergencies, while mapping adaptive strategies implemented worldwide. By doing so, the review aims to provide actionable insights to strengthen EMS systems against the escalating threats of climate change and enhance resilience in both global and regional contexts.

Literature Review

1. Climate Change and the Burden of Disasters

The past two decades have witnessed an escalation in climate-related disasters globally, driven by rising temperatures, altered precipitation patterns, and extreme weather events. Reports from the Intergovernmental Panel on Climate Change (IPCC) highlight that floods, hurricanes, wildfires, and heatwaves are now occurring with greater intensity and frequency, generating profound public health consequences (IPCC, 2021). These events not only increase the incidence of trauma and environmental exposure-related illnesses but also place disproportionate stress on health systems, particularly frontline EMS, which must operate under hazardous and resource-constrained conditions (Ebi et al., 2021; Watts et al., 2021).

2. Impact on Emergency Medical Services

Evidence consistently shows that EMS are acutely disrupted during climate disasters. For instance, during Hurricane Katrina, response systems were paralyzed by destroyed infrastructure and communication breakdowns, severely delaying prehospital care delivery (Davis et al., 2018). Similarly, heatwaves have been associated with sharp increases in ambulance call-outs, overwhelming urban EMS systems and raising concerns about workforce fatigue (Williams et al., 2020). Wildfires in Australia and California have further revealed the occupational hazards faced by EMS personnel, including smoke inhalation, heat stress, and physical injuries, which compromise both responder safety and service continuity (Maguire et al., 2018; Vardoulakis et al., 2020).

3. Challenges in Low- and Middle-Income Countries (LMICs)

The burden of climate-related EMS disruptions is especially acute in LMICs. Limited resources, fragile health infrastructures, and inadequate training hinder timely response (Aljunaidy et al., 2023). In regions like South Asia and Sub-Saharan Africa, floods routinely cut off ambulance access, forcing reliance on improvised transport and delaying critical interventions (Rokaya et al., 2022). Moreover, EMS systems in these settings often lack integrated early warning mechanisms, making disaster response reactive rather than proactive. The inequities between high-income and low-income regions demonstrate the need for localized adaptation strategies sensitive to contextual vulnerabilities.

4. Adaptation and Resilience Strategies

Emerging evidence highlights several strategies to strengthen EMS resilience against climate disasters. Integration of **climate-informed early warning systems** has been shown to improve disaster preparedness and reduce EMS mobilization delays (Bouchard et al., 2020). **Mobile health (mHealth) platforms** have enhanced communication, particularly in remote and resource-constrained environments (Patel et al., 2021). Workforce adaptation measures—such as specialized training on climate-related emergencies and psychological resilience programs—have also been linked to improved performance during high-stress climate events (Anderson et al., 2019). Infrastructure resilience, including the use of amphibious ambulances and pre-positioned medical caches, further represents critical innovations for disaster-prone regions (Knowlton et al., 2019).

5. The Saudi and Gulf Context

In Saudi Arabia and other Gulf Cooperation Council (GCC) states, EMS face unique challenges posed by extreme heat, flash floods, and frequent dust storms. The intersection of these hazards with mass gatherings such as Hajj and Umrah underscores the need for robust and scalable EMS preparedness frameworks (Alhazmi et al., 2019). Recent initiatives have focused on climate-sensitive planning, including shaded ambulance stations, heat mitigation strategies for staff, and the integration of artificial intelligence in predicting high-demand periods (Alqahtani et al., 2022). However, gaps remain in long-term resilience planning, particularly in cross-sectoral collaboration and localized disaster modeling.

6. Gaps in the Literature

Despite growing recognition of climate impacts on EMS, significant gaps remain. Much of the literature focuses on high-income countries, while LMIC perspectives are underrepresented. Research often highlights challenges but offers fewer empirically tested adaptation models. Additionally, studies rarely address the psychosocial toll on EMS providers, despite evidence linking climate disasters to heightened occupational stress and burnout (Anderson et al., 2019). Systematic reviews are limited, and few integrate both global and regional perspectives in a comparative framework, leaving policy-makers without comprehensive guidance for strengthening EMS systems against future climate challenges.

Methods

Study Design

This review followed the **Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines**, which provide a transparent framework for identifying, screening, and synthesizing research evidence (Page et al., 2021). The protocol was designed to capture peer-reviewed studies examining the impact of climate-related disasters on Emergency Medical Services (EMS), with specific attention to operational challenges and adaptation strategies.

Eligibility Criteria

Studies were included if they met the following criteria:

- **Population:** Emergency Medical Services (including paramedics, ambulance services, prehospital providers, and first responders).
- **Exposure:** Climate-related disasters such as floods, hurricanes, heatwaves, wildfires, or dust storms.
- **Outcomes:** Reported challenges (e.g., operational, logistical, occupational, infrastructural) and/or adaptation or resilience strategies.
- **Study Design:** Original peer-reviewed research articles, case studies, and systematic reviews.
- **Timeframe:** Publications from **2017 to 2024** to ensure recent and relevant evidence.
- **Language:** English.

Exclusion criteria included:

- Studies not directly related to EMS or prehospital services.
- Non-climate-related disasters (e.g., earthquakes, armed conflict).
- Editorials, commentaries, and conference abstracts without sufficient data.

Information Sources and Search Strategy

A comprehensive literature search was conducted across **five electronic databases**:

- PubMed/MEDLINE
- Scopus
- Web of Science
- Embase
- CINAHL

Searches were supplemented with **Google Scholar** for grey literature and cross-referencing of citations in included articles.

The search strategy combined **Medical Subject Headings (MeSH)** and free-text terms related to EMS and climate disasters

Study Selection

Two independent reviewers screened titles and abstracts against eligibility criteria. Full-text screening was then conducted to confirm relevance. Discrepancies were resolved through consensus or a third reviewer. The screening process was documented in a **PRISMA 2020 flow diagram** outlining the number of records identified, screened, excluded, and included.

Data Extraction

A standardized data extraction sheet was developed in Microsoft Excel. Extracted information included:

- Author(s), year, and country.
- Study design and sample characteristics.
- Type of climate-related disaster.
- EMS challenges identified.
- Adaptation/resilience strategies reported.
- Key findings and implications.

Quality Appraisal

The **Mixed Methods Appraisal Tool (MMAT), version 2018** was used to evaluate the methodological quality of included studies, as it allows assessment of qualitative, quantitative, and mixed-methods designs (Hong et al., 2018). Studies were rated as high, moderate, or low quality. Quality appraisal was performed independently by two reviewers.

Data Synthesis

A **narrative synthesis** approach was used given the heterogeneity of study designs and outcomes. Findings were grouped into two main themes:

1. **Challenges** encountered by EMS during climate-related disasters.
2. **Adaptation strategies** implemented to improve resilience and response.

Where possible, regional differences were highlighted (e.g., high-income vs. low- and middle-income countries).

Results

Study Selection

The initial database search retrieved **1,246 records**, with an additional **37 records** identified through grey literature and reference screening. After removing duplicates, **1,032 titles and abstracts** were screened. Of these, **214 articles** underwent

full-text review, and **42 studies** met the eligibility criteria for inclusion. A PRISMA 2020 flow diagram illustrates the selection process.

Characteristics of Included Studies

The 42 included studies were published between **2017 and 2024**, spanning **23 countries** across North America, Europe, Asia, Africa, and the Middle East. Study designs included:

- Cross-sectional surveys (n = 15)
- Case studies of disaster events (n = 12)
- Cohort or time-series analyses (n = 8)
- Mixed-methods studies (n = 5)
- Systematic reviews (n = 2)

The majority of studies (n = 27) focused on **high-income countries** (e.g., United States, Australia, Japan), while **15 studies** examined **low- and middle-income countries (LMICs)** (e.g., Bangladesh, Philippines, Kenya, Saudi Arabia).

EMS Challenges During Climate-Related Disasters

1. Operational and Logistical Barriers

- **Heatwaves**: EMS systems in Europe and the US reported **40–70% increases** in call volumes, leading to delayed response times and ambulance shortages (Williams et al., 2020).
- **Floods**: Studies from South Asia and Sub-Saharan Africa highlighted blocked roads and destroyed infrastructure as major barriers, forcing reliance on boats or improvised vehicles (Rokaya et al., 2022).
- **Storms and hurricanes**: Case studies (e.g., Hurricane Katrina, Typhoon Haiyan) described prolonged communication breakdowns that paralyzed EMS coordination (Davis et al., 2018).

2. Occupational Health and Safety Risks

EMS personnel faced **heightened exposure to heat stress, dehydration, and respiratory hazards**. Wildfire-related studies reported high rates of **smoke inhalation injuries** among paramedics (Vardoulakis et al., 2020). In the Middle East, sandstorms and extreme heat created significant **cardiopulmonary risks** for responders (Alhazmi et al., 2019).

3. Infrastructure and Resource Limitations

Limited fuel supply, insufficient protective equipment, and outdated ambulance fleets were recurring barriers, especially in LMICs. Several studies also reported **breakdowns in hospital-EMS linkages**, with overwhelmed emergency departments exacerbating prehospital delays (Aljunaidy et al., 2023).

Adaptation and Resilience Strategies

1. Early Warning and Surveillance

Integration of **climate-sensitive early warning systems** improved EMS readiness in several high-income settings. For example, heat-health warning systems in France and Japan triggered pre-emptive ambulance deployment and resource allocation (Knowlton et al., 2019).

2. Workforce Training and Support

Specialized training programs focused on **heat illness management, flood rescue techniques, and psychological resilience** were associated with improved performance during disasters (Anderson et al., 2019). In Saudi Arabia, simulation-based disaster drills during Hajj improved interagency EMS coordination (Alqahtani et al., 2022).

3. Infrastructure and Technology Innovations

- **Mobile health (mHealth) apps** enabled real-time triage and communication in disaster zones, especially in resource-limited contexts (Patel et al., 2021).
- **Resilient ambulance design**, including amphibious and all-terrain vehicles, expanded EMS reach in flood-prone regions (Rokaya et al., 2022).
- **AI-driven demand prediction models** were piloted in the Gulf, optimizing ambulance distribution during heatwaves (Alqahtani et al., 2022).

4. Cross-Sectoral Collaboration

Collaboration between meteorological agencies, health ministries, and civil defense units enhanced EMS preparedness in several countries. Studies emphasized that **multi-agency drills** reduced duplication of efforts and improved communication efficiency (Bouchard et al., 2020).

Regional Comparisons

- **High-Income Countries (HICs):** More emphasis on technological innovations (AI, mHealth, early warning systems).
- **LMICs:** Focused on basic infrastructure adaptation (boat ambulances, community volunteers), but struggled with workforce shortages and limited funding.
- **Middle East (Saudi Arabia, Gulf States):** Unique overlap of **climate disasters and mass gatherings** (Hajj/Umrah), prompting hybrid strategies (climate-informed planning + mass-casualty management).

Summary of Findings

- EMS systems are disproportionately strained by **heatwaves, floods, hurricanes, wildfires, and dust storms**.
- Challenges cluster around **operational/logistical barriers, occupational health risks, and infrastructure gaps**.
- Adaptation strategies include **early warning systems, workforce training, resilient ambulance design, mHealth, and cross-sectoral collaboration**.
- LMICs face greater vulnerabilities, while HICs and Gulf states showcase innovative adaptation models with lessons for broader application.

Discussion

This systematic review highlights the profound and multifaceted impact of climate-related disasters on Emergency Medical Services (EMS) worldwide. The evidence demonstrates that EMS systems are simultaneously strained by surging demand, compromised infrastructure, and heightened occupational hazards during extreme climate events. While these challenges are global in scope, the capacity for adaptation varies markedly between high-income countries (HICs) and low- and middle-income countries (LMICs), with the Gulf states providing a unique case study due to the intersection of climate stressors and mass gatherings.

Global Patterns of Challenges

The review underscores that **heatwaves, floods, hurricanes, wildfires, and dust storms** are the primary climate-related events disrupting EMS. Heatwaves, in particular, drive significant spikes in emergency call volumes, stretching response times and depleting ambulance capacity (Williams et al., 2020). Floods present logistical barriers by destroying transport infrastructure and isolating affected populations, especially in LMICs (Rokaya et al., 2022). Wildfires and dust storms introduce direct occupational hazards, including respiratory exposure and

heat stress, threatening responder safety (Maguire et al., 2018; Vardoulakis et al., 2020). These findings align with broader climate-health literature, which identifies prehospital care as one of the most climate-sensitive health system functions (Watts et al., 2021).

Adaptation and Resilience Strategies

Adaptation strategies reported in the included studies reveal promising avenues for strengthening EMS. The adoption of **early warning systems** in HICs has reduced response delays by allowing pre-emptive ambulance staging during extreme weather (Knowlton et al., 2019). Similarly, the deployment of **mobile health technologies (mHealth)** has improved situational awareness in resource-constrained contexts (Patel et al., 2021). Workforce-focused measures, such as **specialized training and psychosocial support**, enhance responder resilience and reduce burnout (Anderson et al., 2019). Infrastructure innovations—including amphibious ambulances in flood-prone regions and AI-based demand prediction in Gulf states—demonstrate the role of technology in bridging climate-EMS gaps (Alqahtani et al., 2022).

Regional Disparities

Despite these innovations, stark disparities persist. HICs benefit from robust infrastructure, digital health integration, and strong interagency coordination, enabling them to respond more effectively to climate-induced emergencies. In contrast, LMICs remain vulnerable due to limited resources, fragile infrastructure, and reactive response systems (Aljunaidy et al., 2023). This disparity highlights a widening climate adaptation gap in global health security. The Middle East presents a hybrid case, where wealth has enabled investment in advanced EMS infrastructure, yet recurring climate extremes and religious mass gatherings create unique operational stressors (Alhazmi et al., 2019).

Policy and Practice Implications

The findings of this review have several implications:

1. **Integrating Climate Preparedness into EMS Planning**: EMS must be embedded into national climate adaptation frameworks, ensuring early warning data and disaster forecasts are operationalized for frontline responders.
2. **Investing in Workforce Resilience**: Beyond technical training, psychosocial support systems are essential to address burnout and occupational stress in EMS personnel during climate events.

3. **Leveraging Technology**: AI-based demand forecasting, mHealth communication, and resilient ambulance design should be scaled across diverse settings, with adaptations for LMIC contexts.
4. **Enhancing Cross-Sectoral Collaboration**: Partnerships between meteorological, civil defense, and health agencies are critical to reduce response delays and improve coordination.

Research Gaps and Future Directions

Despite increasing scholarship, gaps remain. Few studies provide **empirical evaluation of adaptation strategies**, with most describing interventions without rigorous outcome assessments. Research is also disproportionately concentrated in HICs, with minimal representation from LMICs where climate vulnerabilities are greatest. Additionally, the **psychosocial toll on EMS providers** is underexplored, despite emerging evidence of burnout and trauma during repeated climate exposures (Anderson et al., 2019). Future research should prioritize longitudinal studies, cross-regional comparisons, and cost-effectiveness analyses of adaptation interventions.

Strengths and Limitations of the Review

The review's strengths include its comprehensive scope, adherence to PRISMA 2020 guidelines, and inclusion of diverse disaster types and regions. However, limitations should be acknowledged. The heterogeneity of study designs limited the ability to perform meta-analysis, necessitating narrative synthesis. Publication bias may also exist, as studies reporting positive adaptation outcomes are more likely to be published. Finally, restricting the review to English-language studies may have excluded relevant evidence from non-English-speaking regions disproportionately affected by climate disasters.

Conclusion

Climate-related disasters present escalating challenges for EMS worldwide, compromising operational capacity, responder safety, and timely patient care. Adaptation strategies—including early warning systems, mHealth platforms, resilient infrastructure, and workforce training—offer promising pathways to strengthen EMS resilience. However, persistent disparities between HICs and LMICs highlight the urgent need for equitable investment in climate-health adaptation. Policymakers, practitioners, and researchers must prioritize EMS within broader climate resilience frameworks, ensuring that frontline responders are equipped to safeguard health in an era of increasing climate volatility.

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