

Emergency and Mass Casualty Response in Resource-Limited and Geographically Isolated Environments: Systems, Training, and Technology

Stephen Vure Gbaraba^{1*}, Florence Eribenne², Helen Ekwi Osinem³, Sylviastella Favour Peteranaba⁴

¹Independent Researcher, Greater Manchester, UK, stephenstrangebaraba@gmail.com

²Bay Cove Human Services, Boston, MA, USA, feribenne1980@gmail.com

³Jos University Teaching Hospital (JUTH), Nursing Services Department, Jos, Nigeria, helenosinem@gmail.com

⁴Independent Researcher, MASSACHUSETTS, USA, Favourpeteranaba@gmail.com

*Corresponding Author: Stephen Vure Gbaraba, stephenstrangebaraba@gmail.com

Abstract: Emergency and mass-casualty events place disproportionate pressure on health systems operating under resource scarcity, weak infrastructure, and geographic isolation. This review examined the organizational, clinical, technological, and community-level determinants of effective response in such environments, with emphasis on system coordination, workforce preparedness, logistics, essential services, and emerging digital capabilities. A thematic review approach was used to synthesize evidence across command structures, triage and referral pathways, transport and communication, simulation and competency development, telemedicine, drones, mobile platforms, remote diagnostics, trauma stabilization, infection control, community preparedness, cross-sector partnerships, and implementation priorities. The findings indicate that response effectiveness depends principally on the alignment between casualty demand and locally available surge capacity rather than on casualty numbers alone. Persistent weaknesses include fragmented governance, workforce shortages, limited specialist access, unreliable transport, communication failures, fragile supply chains, and inadequate infrastructure. Recurrent simulation, interprofessional training, community responder development, and decentralized preparedness were identified as critical for strengthening operational readiness. Digital tools can extend specialist reach, improve situational awareness, accelerate logistics, and support decision-making, but their benefits remain conditional on interoperability, cybersecurity, connectivity, workforce readiness, and sustainable financing. The review further demonstrates that resilient emergency systems require coordinated participation from health services, governments, humanitarian actors, military structures, private organizations, and local communities. It concludes that locally adapted, integrated, and scalable response architectures offer the most credible pathway to reducing preventable mortality and service disruption. Policy priorities should include sustained investment in emergency care, resilient communications and energy systems, standardized data platforms, recurrent training, stronger referral networks, and context-specific implementation research across remote, underserved, disaster-vulnerable populations in all regions.

Keywords: Mass-casualty response; Emergency preparedness; Resource-limited settings; Geographic isolation; Digital health technologies; Community resilience.

1. Introduction

1.1 Global Burden of Mass Casualty Emergencies

Mass casualty emergencies constitute a distinctive component of the global emergency-care burden because their significance is determined not solely by the absolute number of casualties, but by the relationship between sudden demand and locally available response capacity. An incident involving dozens of patients may remain manageable in a densely resourced metropolitan trauma network yet overwhelm a small district hospital, island facility, conflict-affected service, or remote rural emergency unit. Consequently, the burden of mass casualty incidents (MCIs) is best understood as a dynamic interaction among hazard severity, casualty volume, injury complexity, health-system resilience, transport accessibility, workforce availability, and surge capacity. International evidence also remains difficult to compare because documentation practices differ substantially between incidents and jurisdictions; a scoping review spanning 154 manuscripts from 42 countries across all World Health Organization regions found marked inconsistency in the recording of deaths, injuries, treatments, prehospital care and longer-term outcomes (Pallot et al., 2025).

The global burden is generated by heterogeneous hazards, including earthquakes, floods, transportation crashes, industrial explosions, structural collapse, armed violence and deliberate attacks. These events produce compressed waves of need for triage, haemorrhage control, surgery, blood products, imaging, critical care and evacuation, while simultaneously disrupting the

infrastructure required to deliver those services. Contemporary evidence-based guidance therefore conceptualises MCI management as a system-wide problem extending across prehospital triage, transport, hospital logistics, diagnosis, treatment and resource allocation rather than as an isolated emergency-department function (Suda et al., 2025). This distinction is particularly important in resource-limited environments, where ordinary service capacity may already operate close to saturation. Reviews of disaster and mass-casualty management consistently identify communication failure, insufficient coordination, inadequate resources, leadership difficulties and responder preparedness as recurrent determinants of operational strain (Hugelius, Becker & Adolfsson, 2020).

Africa illustrates how routine injury burdens can generate recurrent mass-casualty pressure even outside headline disasters. In Lagos, Nigeria, a three-year review identified 5,629 road-traffic-injury cases among trauma presentations, yet only 2.3% of injured patients received formal prehospital care through the state ambulance service; many were transported by relatives or bystanders, demonstrating how a high trauma burden intersects with limited organized prehospital capacity (Ibrahim et al., 2017). The implication for mass casualty response is substantial: when multiple severely injured patients arrive simultaneously, deficits that are tolerable during routine operations can rapidly become system-limiting constraints.

Comparable vulnerabilities are evident elsewhere on the continent. Assessment of 17 hospitals in northwest Ethiopia found that most facilities did not reach an acceptable level of preparedness for potential MCIs, with 12 hospitals classified as insufficiently prepared, underscoring the gap between exposure to emergencies and institutional surge readiness (Getu et al., 2023). More recent Rwandan evidence provides unusually direct epidemiological insight: analysis of national emergency medical service records identified 173 MCIs involving 770 injured people, with road traffic crashes accounting for 96% of incidents and an estimated 6.7 MCIs occurring monthly across healthcare levels (Velin et al., 2026). These findings demonstrate that mass casualty burden in lower-resource settings may be recurrent and dispersed rather than restricted to rare catastrophic disasters.

The same relationship between recurrent hazards and constrained response capacity is visible beyond Africa. In central Haiti, frequent road-traffic-related MCIs required a 300-bed teaching hospital to iteratively refine low-cost protocols for communication, triage, patient identification, supply deployment and emergency-department reorganization, illustrating how chronic resource scarcity shapes the practical meaning of casualty surge (Rouhani et al., 2022). In Nepal, district-hospital experience similarly revealed that MCI response depends heavily on whole-hospital mobilisation, communication channels, pre-identified triage areas and available disaster stores, while staff knowledge gaps and difficulties implementing triage can compromise response effectiveness (Singh et al., 2023).

Geographic isolation compounds these pressures because distance increases the interval between injury, stabilization and definitive care while narrowing opportunities for interfacility redistribution. Lessons from China's Wenchuan earthquake and Hangzhou bus fire show that MCI burden cannot be interpreted through casualty counts alone; vulnerability and real-time system capacity are central to understanding whether an event becomes medically overwhelming (Shen et al., 2014). Such disparities complicate global surveillance because under-resourced and remote systems are often least able to produce complete, comparable MCI datasets. Taken together, the international evidence portrays mass casualty emergencies as an unequal global health burden: the same numerical casualty load can have profoundly different consequences depending on geography, infrastructure, emergency medical services, hospital readiness and access to reserve capacity. This inequity is central to understanding emergency response in resource-limited and geographically isolated environments, where preventable mortality and disability may arise not only from the initiating hazard, but also from delayed access, constrained surge capability and fragmented systems of care.

1.2 Resource Scarcity and Geographic Isolation References

Resource scarcity and geographic isolation convert otherwise manageable emergencies into system-level crises by constraining the speed, scale and quality of response. In resource-limited settings, shortages of ambulances, trained personnel, blood products, surgical capacity, diagnostics, medicines and reliable communications frequently coexist with long travel distances and weak referral networks. These constraints are particularly acute in rural Nigeria, where delayed response, poor road infrastructure, limited ambulance coverage, high out-of-pocket costs and communication deficiencies create compounded barriers to emergency access, especially for communities distant from urban centres (Oreh et al., 2026).

During mass-casualty events, such limitations become more consequential because multiple critically injured patients compete simultaneously for scarce staff, beds, operating theatres and essential supplies. Evidence from Kamuzu Central Hospital in Malawi demonstrates that sudden increases in trauma arrivals can exceed institutional capacity and are associated with increased mortality, illustrating that an MCI threshold is inherently relative to the resources available at a particular facility rather than determined by casualty numbers alone (Hester et al., 2026).

Prehospital weakness further magnifies geographic disadvantage. Across low- and middle-income countries, emergency care systems frequently remain fragmented, with shortages of trained responders, basic equipment, coordinated transport and dependable information exchange. Such deficiencies lengthen the interval between injury and definitive treatment and reduce opportunities for early stabilization, particularly where referral hospitals are separated from communities by substantial distances or difficult terrain (Bhattarai et al., 2023).

Transport itself is a critical determinant of survivability. A systematic review of low- and lower-middle-income settings identified transport limitations, infrastructure deficits, communication failures, equipment shortages and inadequate skilled personnel as recurrent barriers to out-of-hospital emergency care. These constraints are especially damaging during casualty surges because informal transport may neither support triage nor permit safe clinical intervention while patients are being transferred (Kironji et al., 2018).

Geographic isolation is not exclusively a low-income-country problem. A review of small rural emergency departments in Australia, Canada and the United States showed that such facilities routinely manage substantial proportions of injuries and other acute presentations despite limited local resources and variable staffing models. Their operational role therefore extends beyond simple stabilization, yet remoteness may restrict immediate access to specialist intervention and complicate transfer during periods of exceptional demand (Baker & Dawson, 2013).

Distance consequently functions as both a spatial and operational risk multiplier. Geospatial analysis in New York State shows that isolated emergency facilities can carry exceptionally large catchment responsibilities, with some populations remaining beyond timely ground access because of distance, transport infrastructure and terrain. In geographically isolated mass-casualty environments, these realities can delay evacuation, concentrate demand on small hospitals and reduce the feasibility of rapid interfacility redistribution, making locally adaptable surge capacity, resilient communications, trained multidisciplinary teams and context-sensitive transport planning fundamental components of effective emergency response (Bedenbender, 2026).

1.3 Rationale for Integrated Emergency Response Systems

Integrated emergency response systems are essential because mass-casualty events generate interdependent clinical, logistical, operational and infrastructural demands that cannot be managed effectively through fragmented institutional arrangements. In resource-limited and geographically isolated environments, fragmentation is especially hazardous: disconnected ambulance services, hospitals, referral facilities, communication centres and public agencies can produce duplicated effort, delayed triage, inappropriate patient distribution and inefficient use of already scarce resources. Nigeria illustrates this imperative particularly clearly. Early implementation of its national emergency medical response architecture has revealed substantial stakeholder support alongside uneven resource availability, variable knowledge of emergency-care frameworks and weaknesses in communication and feedback mechanisms, demonstrating that effective response depends upon coordinated governance rather than the isolated performance of individual institutions (Elechi et al., 2026).

Integration should extend from the community and prehospital environment through definitive hospital care. Experience from South Africa demonstrates the value of formally connecting community-based Emergency First Aid Responders with established emergency medical services, particularly where conventional ambulance response may be delayed in remote areas. Defined activation pathways, standardized preparation, communication links and institutional recognition enable community responders to complement rather than operate separately from professional emergency services (Abdullah et al., 2026).

At hospital level, integration requires an explicit command architecture capable of converting multiple departments into a coordinated response organization. Incident-command models provide defined leadership, functional responsibilities and communication pathways, enabling emergency departments to align operational decisions with hospital-wide resource allocation during rapidly evolving crises (Farcas et al., 2021). Evidence from Taiwan similarly demonstrates how a structured Hospital Emergency Incident Command System can organize leadership functions and operational units during a major health emergency, reinforcing the importance of predetermined command relationships rather than improvised coordination after demand has escalated (Tsai et al., 2005).

Technological integration further strengthens this system's logic. Although derived from industrial rather than clinical environments, SCADA-based research demonstrates how interconnected monitoring, automation and real-time information architectures can improve situational visibility and coordinated operational control, principles transferable cautiously to emergency operations centres and critical-support infrastructure (Omoegun et al., 2024). Similarly, automated energy-management research emphasizes real-time monitoring, adaptive control and system resilience, supporting the broader requirement that emergency facilities maintain dependable power and information infrastructure during casualty surges (Shittu, Adaramola & Shittu, 2025). Integrated emergency response therefore represents not merely administrative coordination, but the deliberate coupling of command, clinical care, transport, communications, community capacity, technology and essential infrastructure into a coherent and adaptable response system.

1.4 Review Scope, Objectives, and Approach

This review examines emergency and mass casualty response in resource-limited and geographically isolated environments, with particular attention to the interaction between system organization, workforce preparedness, operational constraints, and enabling technologies. Its scope encompasses prehospital care, hospital surge capacity, triage, referral pathways, interfacility transfer, communication systems, essential infrastructure, community participation, and cross-sector coordination. Emphasis is placed on

settings where limited personnel, equipment, transport capacity, specialist services, and geographic accessibility can intensify the consequences of sudden casualty surges.

The principal objective is to synthesize current knowledge on how emergency response systems can be designed, strengthened, and adapted to function effectively under conditions of scarcity and isolation. The review further seeks to identify the operational determinants of successful mass casualty management, assess the contribution of training and simulation to workforce readiness, and evaluate the potential of digital technologies, telemedicine, remote diagnostics, decision-support tools, resilient energy systems, and communication platforms to extend emergency capability. Particular consideration is given to the practical requirements for integrating community responders, emergency medical services, hospitals, public agencies, humanitarian actors, and critical infrastructure providers into coherent response networks.

The review adopts a thematic and systems-oriented approach, organizing the evidence around preparedness, coordination, resource limitations, clinical priorities, training, technology, resilience, and implementation gaps. Rather than treating mass casualty management as a discrete clinical activity, it is examined as a multi-layered emergency system whose performance depends on the continuity and interoperability of human, institutional, technological, and logistical components. The analysis also considers differences between high-resource and constrained settings to clarify which practices are transferable and which require contextual adaptation. This approach is intended to support evidence-informed policy, operational planning, capacity development, and future research directed toward resilient, scalable, and locally appropriate emergency response architectures across diverse vulnerable populations and emergency care contexts.

2. Emergency Response Systems and Operational Readiness

2.1 Command, Coordination, and Incident Management Structures

Command, coordination, and incident management structures determine whether a mass-casualty response functions as a coherent system or as a collection of disconnected agencies. In resource-limited and geographically isolated environments, this distinction is critical because scarce ambulances, personnel, blood products, transport assets, communications capacity, and referral beds must be allocated rapidly across competing priorities. Effective incident management therefore requires a predefined authority structure that clarifies who leads, how information is validated, where resources are deployed, and when operational priorities should change. Experience from public health emergency operations centres in Ethiopia, Nigeria, and Senegal demonstrates that formal incident management systems can consolidate surveillance, case management, laboratory services, logistics, risk communication, and other response functions under a coordinated architecture, although financing and hazard-specific planning remain important limitations (Fekadu et al., 2026).

At the facility level, incident command provides a scalable mechanism for translating strategic direction into operational action. Evidence from Iranian hospitals showed that structured Hospital Incident Command System roles can be used to assess decision-making performance across command, operations, planning, logistics, and finance functions, while also exposing weaknesses before a real disaster overwhelms routine arrangements (Djalali et al., 2012). Similarly, implementation experience in an integrated United States hospital system indicates that formal emergency incident command reduces dependence on particular individuals and creates an organizational structure capable of coordinating personnel and institutional resources during abnormal demand (Zane & Prestipino, 2004).

Coordination is equally important beyond individual hospitals. Uganda's Public Health Emergency Operations Center illustrates how a permanent coordination platform can link national authorities, technical partners, subnational structures, information systems, simulation exercises, and emergency meetings. Its experience across numerous public-health events emphasizes the value of legal authority, trained personnel, leadership engagement, emergency plans, and decentralized coordination capacity (Kayiwa et al., 2022). Such arrangements are particularly relevant to geographically dispersed mass-casualty networks, where command must connect scene operations, transport providers, receiving hospitals, referral centres, and governmental agencies without creating parallel chains of authority.

Governance principles from adjacent operational fields can further illuminate this requirement when applied cautiously. A supply-chain governance model developed in Nigeria emphasizes accountability, compliance, information integration, and coordinated quality control across geographically dispersed networks; these principles can support the design of transparent emergency logistics arrangements but should not be interpreted as direct disaster-medicine evidence (Akin-Oluyomi & Akhigbe, 2022). Likewise, strategic alignment between leadership and logistics decision-making can strengthen the synchronization of resource deployment with overarching operational objectives, particularly when circumstances change rapidly (Akin-Oluyomi & Akhigbe, 2023). For austere emergency systems, command structures must therefore combine clear authority with interoperability, decentralized adaptability, reliable information flows, and predefined mechanisms for escalating resources across institutional and geographic

boundaries. This architecture also supports continuity when communications fail, personnel rotate, transport is delayed, or neighboring facilities become saturated, preventing local disruption from cascading across the wider emergency network.

2.2 Triage, Referral, and Patient Flow Systems

Triage, referral, and patient-flow systems are interdependent components of mass-casualty management because the effectiveness of initial prioritisation is ultimately determined by whether patients can be moved efficiently toward appropriate levels of care. In resource-limited environments, triage must reconcile clinical urgency with finite personnel, treatment spaces, transport assets, blood products, and surgical capacity. Yet existing disaster-triage algorithms are not uniformly accurate; comparative evidence demonstrates substantial variation in sensitivity, specificity, under-triage, and over-triage across commonly used systems. This reinforces the need for protocols that are standardized but sufficiently adaptable to casualty profiles and available resources (Bazyar et al., 2022).

Effective triage should also accelerate access rather than simply classify patients. Experience from a resource-constrained South African emergency department showed that introducing structured nurse-led triage improved the organization of waiting patients and facilitated earlier attention according to clinical urgency. Such findings are especially pertinent during casualty surges, when unstructured queues can allow deteriorating patients to remain unidentified while scarce clinical capacity is consumed inefficiently (Bruijns, Wallis & Burch, 2008).

Patient flow subsequently depends upon coordinated referral beyond the point of initial assessment. Recent Nigerian evidence from public primary healthcare facilities in Benin City identified absent written referral protocols, inadequate emergency transportation, poor two-way communication, staffing shortages, and logistical constraints as barriers to effective emergency referral. These weaknesses demonstrate that referral is not merely a transfer decision but an interconnected process involving communication, transport readiness, receiving-facility acceptance, documentation, and continuity of care (Odjesa et al., 2026).

Within receiving facilities, multidisciplinary coordination is equally important because emergency patients frequently require simultaneous medical, nursing, diagnostic, surgical, and logistical inputs. Collaborative practice can strengthen information exchange, reduce fragmented decision-making, and improve continuity across successive stages of emergency care, thereby supporting safer and more responsive patient movement through congested departments (Ohunyon, Ayinde & Ojukwu, 2023).

Operational principles from workforce-centred line balancing provide an indirect but useful perspective on surge flow. Matching workload with workforce capability, identifying shifting bottlenecks, and dynamically reallocating personnel can inform emergency-department strategies for managing abrupt fluctuations in demand, although such manufacturing-derived principles require cautious clinical adaptation (Akanbi, Ganiu & Sunday, 2022).

Diagnostic pathways must likewise be integrated into patient-flow design. Delays or errors in specimen handling, testing, and result transmission can prolong disposition decisions and consume scarce emergency capacity. Process optimisation, digital traceability, automation, and coordinated laboratory workflows can therefore support faster clinical decision-making and more reliable movement from assessment to admission, transfer, intervention, or discharge (Ayinde, Ohunyon & Ojukwu, 2026). In geographically isolated environments, these functions must operate as a continuous pathway in which triage decisions, referral communication, transport, diagnostics, multidisciplinary care, and capacity monitoring remain synchronized despite constrained resources.

3. Resource Constraints and Geographic Barriers

3.1 Workforce, Infrastructure, and Supply Chain Limitations

Workforce, infrastructure, and supply-chain limitations are mutually reinforcing constraints in mass-casualty response, particularly where health systems already operate near routine capacity. A sudden influx of critically injured patients increases demand for clinicians, beds, operating theatres, oxygen, blood products, diagnostics, medicines, transport, and communications at precisely the moment when normal procurement and staffing mechanisms may be disrupted. Geographic isolation further restricts timely mutual aid between neighboring facilities. Across low- and middle-income countries, emergency medical services remain constrained by workforce shortages, weak financing, fragmented governance, limited equipment, and inadequate physical infrastructure, making surge response highly sensitive to pre-existing system fragility (Pant et al., 2026).

The African context illustrates how such limitations extend beyond simple headcounts. Emergency-care systems frequently confront shortages of appropriately trained personnel alongside inconsistent facility organization, inadequate equipment, weak referral infrastructure, and uneven governmental support. These deficiencies reduce the capacity to maintain quality when emergency volumes rise because available staff must simultaneously manage triage, resuscitation, diagnostics, patient transfer, and routine caseloads. System strengthening therefore requires investment not only in personnel numbers but also in training, supervision, equipment availability, communications, and facility-level organization (Kannan et al., 2020).

Nigeria provides a particularly relevant example of supply vulnerability. Evidence from Lagos during the COVID-19 emergency showed disruptions in essential-commodity distribution, transport difficulties, medicine-price increases, and limited preparedness among pharmaceutical and health-service delivery points. Such vulnerabilities are directly relevant to mass-casualty settings, where interruptions in last-mile delivery can rapidly translate into shortages of consumables, medications, protective equipment, and other life-sustaining resources (Adonye & Adonye, 2023).

Workforce resilience is equally dependent on the ability to anticipate fluctuations in demand. Although developed for commercial supply chains rather than emergency medicine, workforce-optimization models emphasize forecasting, flexible deployment, skills diversification, and continuous monitoring as mechanisms for matching labour capacity to rapidly changing operational requirements. Applied cautiously, these principles support emergency planners in designing reserve staffing, cross-training personnel, and redeploying teams during casualty surges without relying exclusively on static rosters (Falemi, Akhigbe & Akin-Oluyomi, 2023b).

Retention also matters because chronically unstable staffing erodes institutional memory and limits the pool of experienced personnel available during crises. Integrating workforce-retention indicators with productivity and workload data can help organizations identify attrition risks, workload imbalance, and capability gaps before they undermine operational continuity. In emergency systems, the transferable value lies in linking human-resource intelligence with surge planning, rather than treating staffing as a separate administrative function (Falemi, Akhigbe & Akin-Oluyomi, 2023a).

Supply-chain resilience requires comparable visibility. Demand-driven inventory approaches can improve anticipation of changing stock requirements by combining consumption information with forward-looking demand signals. Although the retail orientation of this framework limits direct clinical inference, its emphasis on reducing stockouts, improving replenishment responsiveness, and continuously reassessing inventory profiles is relevant to emergency stockpiles, where inappropriate quantities or poorly matched commodities can be as problematic as absolute scarcity (Akanbi, Ganiyu & Sunday, 2025).

Material flow across the wider response network is another critical constraint. End-to-end logistics frameworks emphasize synchronization between sourcing, storage, internal movement, and downstream distribution, offering a useful operational analogy for emergency supply chains that must move critical commodities from central stores to peripheral or isolated facilities. In austere environments, such coordination should account for damaged roads, uncertain delivery times, limited storage capacity, and dependence on a small number of external suppliers (Akanbi, Sunday & Ganiyu, 2026).

These vulnerabilities become most visible during major disasters. Evidence from northwest Syria following the 2023 Türkiye-Syria earthquakes demonstrated weaknesses in procurement, forecasting, information systems, staffing, and cross-border supply, with delayed and incomplete shipments compounding pressure on already fragile health facilities. For geographically isolated or resource-constrained services, resilience therefore depends on pre-positioned stocks, diversified supply routes, trained logistics personnel, real-time inventory visibility, flexible workforce arrangements, and infrastructure capable of sustaining clinical operations when conventional systems are disrupted (Almidani et al., 2026).

3.2 Transport, Communication, and Evacuation Challenges

Transport, communication, and evacuation constitute critical determinants of survival during mass-casualty incidents because clinical capability has limited value when casualties cannot be reached, identified, transferred, or distributed appropriately. In resource-constrained settings, ambulance shortages, congestion, poor road conditions, adverse weather, long travel distances, and limited dispatch coordination can extend response intervals and intensify preventable deterioration. Evidence from Lagos shows that ambulance performance is substantially affected by non-response and operational delays, with traffic congestion representing a major recorded cause of delayed attendance, demonstrating how urban infrastructure can constrain emergency mobility even where formal services exist (Venkatraman et al., 2021).

Comparable challenges occur elsewhere in Africa. Analysis of Ghana's National Ambulance Service found response times that exceeded the national target, highlighting the dependence of timely prehospital care on ambulance availability, station distribution, dispatch efficiency, and road accessibility (Mahama et al., 2018). These constraints become more severe in geographically isolated communities, where transfer distances narrow the margin for definitive intervention and may require prolonged stabilization before evacuation.

Mass-casualty transport should therefore be conceived as a dynamic allocation problem rather than simple movement to the nearest hospital. Recent modelling demonstrates that casualty routing can be improved by integrating triage priority, ambulance availability, hospital capacity, travel time, and evolving field conditions into real-time transport decisions, thereby reducing inefficient concentration of casualties at already saturated facilities (Kilanitis et al., 2026). Hospital evacuation presents a parallel coordination challenge: safe movement requires predetermined evacuation routes, receiving destinations, patient documentation, command authority, and continuous communication with external agencies and field facilities (Tekin et al., 2017).

Supporting logistics research further indicates that transportation networks benefit from coordinated routing, resource allocation, and infrastructure-efficiency planning, principles that can inform emergency evacuation design when adapted cautiously to clinical priorities (Opara et al., 2024). Communication resilience is equally essential because transport decisions depend on accurate information regarding casualty location, vehicle status, road accessibility, and receiving-facility capacity. Secure distributed-data architectures developed for SCADA environments illustrate how integrity, availability, and controlled information exchange can strengthen coordination across decentralized systems (Shittu et al., 2022).

Similarly, blockchain-enabled supply-chain systems demonstrate the value of secure stakeholder access and real-time tracking across distributed operational networks, concepts potentially transferable to emergency logistics and ambulance coordination (Shittu & Nabil, 2023). RFID research also illustrates the technical capacity of tagged identification systems to automate tracking and reduce manual identification errors, although its library setting means direct clinical inference is inappropriate (Yusuf et al., 2023). For isolated emergency environments, effective evacuation therefore depends on redundant communications, interoperable information platforms, adaptive routing, reliable patient identification, and transport strategies explicitly matched to geography and available receiving capacity.

4. Mass Casualty Training and Workforce Preparedness

4.1 Simulation, Drills, and Competency Development

Simulation, drills, and competency development are central to mass-casualty preparedness because emergency performance depends on the ability to translate theoretical protocols into coordinated action under time pressure, uncertainty, and resource scarcity. In Nigeria, a full-scale yellow-fever simulation involving health facilities, laboratories, points of entry, and emergency operations centres demonstrated that structured exercises can expose weaknesses in inter-agency coordination, clarify roles, and reveal capability gaps that routine planning may overlook (Okunromade et al., 2019).

For resource-limited settings, training must be practical, repeatable, and adaptable to local constraints. Evaluation of the WHO Mass Casualty Management course in Somalia showed substantial gains in knowledge and self-reported confidence after a programme combining lectures with interactive tabletop exercises, particularly in triage planning, documentation, emergency-unit clearance, and activation of mass-casualty plans (Ali et al., 2026). Such findings support competency-based programmes that assess what responders can actually perform rather than relying solely on attendance or knowledge acquisition.

Technology can broaden access to realistic practice where large field exercises are expensive or logistically difficult. A randomized trial in China found that virtual-reality mass-casualty training improved practical performance relative to lecture-based instruction, highlighting the value of immersive scenarios for scene assessment, triage, and emergency decision-making (Li et al., 2026). Successful technology adoption, however, also depends on workforce readiness, adaptability, capability development, and sustained reinforcement, making implementation a socio-technical rather than purely technical process (Akhigbe, Falemi & Akin-Oluyomi, 2024).

Competency assessment should additionally consider cognitive performance. Multimodal workload frameworks show that physiological, behavioural, and performance indicators can help characterize operator strain in complex human-machine environments, offering a cautious basis for evaluating cognitive overload during high-fidelity emergency simulations (Adamolekun et al., 2025). Finally, structured root-cause analysis can strengthen post-exercise learning by systematically identifying why failures occurred and translating observations into corrective actions. Although developed for industrial restoration, its emphasis on causal diagnosis and iterative improvement is transferable to after-action review when applied cautiously (Akanbi, Ganiu & Sunday, 2023).

4.2 Interprofessional Teams and Community Responder Training

Interprofessional teams are indispensable in mass-casualty response because casualty management requires coordinated contributions from emergency clinicians, nurses, paramedics, pharmacists, laboratory personnel, logisticians, public-health practitioners, and non-clinical responders. In austere settings, teamwork must compensate for limited specialist availability through role clarity, shared situational awareness, flexible task allocation, and disciplined communication. Canadian disaster-response experience indicates that effective practice depends on technical expertise alongside interpersonal, cognitive, and austere-environment competencies that sustain collaboration under uncertainty (Peller, Schwartz & Kitto, 2013).

Training should extend beyond professionals to community members likely to reach casualties before formal services. In Lagos, a hybrid training-of-trainers programme for lay first responders improved first-aid knowledge and confidence while enabling trained transportation providers to deliver emergency interventions, demonstrating a scalable approach for Nigerian settings with constrained prehospital coverage (Eisner et al., 2024).

Evidence from Sierra Leone similarly shows that context-adapted lay-responder programmes can expand access to basic trauma care, particularly haemorrhage control, before hospital arrival. Declining knowledge during follow-up, however, underscores the

need for refresher training, supervision, and sustainable local instructor networks rather than one-off courses (Eisner et al., 2020). Community-response models can incorporate occupational groups already positioned near emergency scenes. Training traffic police in Arusha, Tanzania, improved trauma-care knowledge, self-efficacy, and intended emergency practices, illustrating how public-safety personnel can bridge incident occurrence and professional medical response where formal EMS coverage remains limited (Koranda et al., 2023).

Interprofessional preparedness should begin before deployment. Indonesian tabletop disaster exercises involving health students improved readiness and knowledge for interprofessional learning, supporting simulation as a practical method for teaching role recognition, coordinated decision-making, and communication without resource-intensive field exercises (Maryana et al., 2024).

Leadership is necessary to sustain these competencies. Although focused on residential care rather than disaster medicine, nursing-leadership evidence emphasizes multidisciplinary coordination, clinical governance, workforce development, and safety culture. In isolated environments, these transferable principles support connecting community responders and professional teams through escalation pathways, recurrent practice, supervision, and leadership structures capable of maintaining coordinated performance during casualty surges (Ohunyon, Ojukwu & Ayinde, 2025).

5. Technology-Enabled Emergency Response Solutions

5.1 Telemedicine, Drones, and Digital Decision Support

Digital technologies can substantially extend emergency capability where distance, workforce scarcity, and infrastructure limitations restrict conventional mass-casualty response. Telemedicine is particularly valuable for connecting isolated facilities with specialist expertise, supporting remote consultation, clinical escalation, and transfer decisions. In rural Nigeria, however, inadequate connectivity, technological access, digital literacy, training, and organizational support continue to constrain telemedicine adoption, indicating that digital access must accompany technological deployment (Adewojo & Olalere, 2026).

Drones provide a complementary solution where damaged roads, difficult terrain, or prolonged ground transport impede urgent logistics. Rwanda's national drone programme significantly shortened blood-product delivery times to health facilities while supporting more responsive management of time-sensitive supplies, illustrating the potential of unmanned aerial systems for geographically isolated emergency networks (Nisingizwe et al., 2022).

Digital decision support can simultaneously strengthen casualty prioritisation. Artificial-intelligence systems can process rapidly changing clinical information, support triage classification, enhance situational awareness, and assist resource allocation under cognitive pressure, although professional judgment and transparent oversight must remain central to high-stakes decisions (Mohamed & Rizek, 2026).

Related digital-twin research demonstrates how continuously synchronized physical and virtual systems can support real-time monitoring, predictive fault identification, and operational visibility, principles cautiously transferable to emergency infrastructure and command environments (Shittu et al., 2023). AI-enhanced digital twins further illustrate how sensor data, predictive analytics, and low-latency processing can anticipate system degradation before service disruption, potentially strengthening the resilience of critical support infrastructure for emergency facilities (Shittu & Shittu, 2024).

Similarly, multi-agent AI architectures demonstrate decentralized coordination among autonomous mobile systems, offering conceptual relevance to future drone fleets, automated logistics, and distributed emergency resource deployment, where centralized control may become congested or unavailable (Akanbi, Ganiu & Sunday, 2025).

5.2 Mobile Platforms, Sensors, and Remote Diagnostics

Mobile platforms, distributed sensors, and portable diagnostic technologies can reduce the informational and diagnostic disadvantages that characterize emergency care in resource-limited and geographically isolated environments. During mass-casualty incidents, paper documentation can delay transmission of triage status, injury patterns, and patient location. Evaluation of an app-based mass-casualty triage system showed that digital documentation incorporating GPS and automatic data transfer can improve casualty-classification speed and accuracy while providing incident commanders with a clearer operational picture (Schmollinger et al., 2024). In rural Nigeria, an offline-capable mHealth platform using patient-held smartcards showed that clinically important information can remain accessible through mobile devices when reliable internet connectivity is unavailable, an important design principle for disrupted emergency networks (Gbadamosi et al., 2018).

Remote diagnostics can similarly shift critical assessment closer to the patient. In an Ethiopian emergency centre with constrained imaging resources, point-of-care ultrasound generated clinically useful information in most examinations and altered diagnosis, treatment, consultation, or disposition decisions for many patients, illustrating its value where conventional imaging is limited (Stachura et al., 2017). Low-cost smartphone-enabled biosensing extends this approach: field testing in rural India demonstrated

that a paper-based haemoglobin sensor coupled with a smartphone application could provide rapid quantitative measurements with minimal infrastructure, supporting portable diagnostics in austere settings (Biswas et al., 2021).

Automated image interpretation offers another pathway for reducing dependence on continuously available specialists. Computer-aided mammographic analysis using template matching demonstrated how algorithmic image processing can flag suspicious regions for professional review; although unrelated to emergency trauma, it provides a technical precedent for machine-assisted diagnostic screening (Ejofodomi et al., 2014). Likewise, sensor-based fault-detection research shows how continuous monitoring can identify deviations from expected system performance, a principle cautiously transferable to monitoring medical devices and critical facility systems during emergencies (Sunday & Omoegun, 2020).

Reliable connectivity remains essential for transmitting these data across isolated response networks. RF MEMS research for 5G front-end systems illustrates advances in low-loss, high-reliability wireless components that may underpin future resilient communications, although it is not clinical evidence (Gideon, 2025). Machine-learning anomaly detection using continuous sensor streams further demonstrates how interpretable algorithms can distinguish normal from abnormal conditions in real time, supporting automated alerts and remote situational surveillance when human monitoring capacity is limited (Adamolekun et al., 2026).

Clinical Priorities in Austere Environments

6.1 Trauma Stabilization and Time-Critical Care

Trauma stabilization in mass-casualty settings is governed by the need to identify and treat reversible threats immediately while preserving personnel, blood products, operating capacity, and transport resources for patients likely to benefit. In Nigeria, trauma surgeons have described deficiencies in trauma systems, specialist availability, prehospital coordination, equipment, and training, illustrating how delays in early assessment and definitive intervention can magnify mortality when multiple patients arrive simultaneously (Akinlade et al., 2024).

Time-critical care requires an integrated continuum from scene stabilization to definitive treatment rather than isolated excellence at a receiving hospital. Evidence from Ghana demonstrates that preventable trauma deaths remain associated with deficiencies in resuscitation and delays in hospital treatment, even where improvements in prehospital transport have occurred. Such findings are relevant to geographically isolated environments, where prolonged transfer times increase dependence on early recognition, stabilization, and prioritized referral (Konadu-Yeboah et al., 2020).

Haemorrhage control remains a central determinant of early trauma survival. The multinational CRASH-2 analysis showed that the effectiveness of tranexamic acid in bleeding trauma patients was strongly time-dependent, reinforcing the wider principle that life-saving interventions lose value when treatment is delayed. Resource-limited mass-casualty protocols must therefore minimize delays between recognition of critical bleeding and appropriate treatment (CRASH-2 Collaborators, 2011).

Damage-control resuscitation provides a complementary framework for severely injured patients by prioritizing rapid haemorrhage control, physiologically appropriate resuscitation, prevention of worsening coagulopathy, and early transition toward definitive intervention. Contemporary clinical guidance emphasizes coordinated resuscitation rather than sequential care, an approach especially important when casualty surges place simultaneous pressure on emergency, surgical, laboratory, and transfusion services (LaGrone et al., 2024).

Resource scarcity can nevertheless make technically appropriate care inaccessible. A recent synthesis from Pakistan identified long travel times, weak prehospital coverage, shortages of trained personnel and essential supplies, limited specialist support, and delayed in-hospital treatment as recurrent barriers across the trauma pathway. These constraints demonstrate why stabilization protocols in isolated settings must be designed around what can reliably be delivered before transfer rather than assumptions of immediate tertiary access (Atiq et al., 2025).

Following initial resuscitation, wound assessment and management remain important for limiting complications, supporting tissue preservation, and maintaining continuity of acute care. Evidence-based wound-care literature emphasizes structured assessment, infection prevention, appropriate dressing selection, and multidisciplinary management, principles relevant after immediate life threats have been addressed but which should not substitute for primary trauma-resuscitation evidence (Ohunyon et al., 2024).

6.2 Infection Control and Essential Emergency Services

Infection control and continuity of essential emergency services are inseparable priorities during mass-casualty events because overcrowding, invasive procedures, disrupted sanitation, and rapid staff turnover can amplify transmission risks while simultaneously increasing demand for care. In Nigeria, national infection-prevention programming has shown the importance of coordinated governance, standardized facility assessment, workforce development, and implementation across heterogeneous health settings, providing a relevant foundation for maintaining safe emergency services during periods of extraordinary demand (Okwor et al., 2026).

Across sub-Saharan Africa, infection-prevention capacity remains constrained by underfunding, weak water, sanitation and hygiene infrastructure, limited laboratory capability, inconsistent supplies, and shortages of trained personnel. During casualty surges, these deficits can compromise isolation, hand hygiene, environmental cleaning, waste management, and antimicrobial stewardship precisely when exposure intensity is greatest (Okomo et al., 2026).

Prehospital services also require explicit infection-control architecture. Evidence from emergency medical services emphasizes personal protective equipment, hand hygiene, equipment decontamination, respiratory protection, sharps safety, and exposure-management protocols as core protections for responders who repeatedly move between field, ambulance, and hospital environments (Jenkins et al., 2022).

Rapid pathogen identification can further strengthen containment. AI-assisted biosensor approaches demonstrate how accelerated detection of antimicrobial-resistant organisms may support earlier risk recognition where conventional laboratory turnaround is slow, although this evidence derives from foodborne-pathogen surveillance rather than emergency care (Olorunkosebi et al., 2023).

Advanced antimicrobial nanomaterials likewise illustrate emerging mechanisms for reducing microbial contamination, but their current evidentiary value is primarily technological and should not substitute for established clinical infection-prevention measures (Mensah et al., 2024). One Health research additionally underscores that environmental pathways can influence viral persistence and transmission, reinforcing the need to integrate environmental hygiene, safe waste handling, and surveillance into emergency-service continuity planning (Ayinde et al., 2024).

7. Community Resilience and Cross-Sector Coordination

7.1 Local Preparedness and Community-Based Response Networks

Local preparedness is the first operational layer of mass-casualty resilience because communities are often required to act before formal emergency assets arrive. In resource-limited and geographically isolated settings, preparedness therefore extends beyond household awareness to locally organized warning, evacuation, first response, communication, sheltering, and continuity arrangements. A recent systematic review of flood-prone communities across sub-Saharan Africa found preparedness levels to be consistently low and shaped by income, education, home ownership, social resources, and participation in local risk-reduction measures, underscoring the need to convert risk awareness into practical community capability (Inyang-Ogim et al., 2026).

The effectiveness of such capability depends heavily on social capital. Evidence from Old Fadama, Ghana, shows that both personal and collective social capital significantly influence flood preparedness and community resilience, with collective networks offering particularly important pathways for mobilizing information, mutual assistance, and locally available resources when formal response capacity is weak (Abunyewah et al., 2023). Volunteer-based models provide a related mechanism. Community Emergency Response Teams in the United States demonstrate how trained residents can support preparedness education, basic emergency functions, and community capacity, with rural programmes placing greater emphasis on self-sufficiency where formal infrastructure is less accessible (Flint & Stevenson, 2010).

Preparedness is strengthened further when routine community institutions are deliberately connected to disaster functions. Following the 2024 Noto Peninsula earthquake in Japan, community learning centres with established preparedness activities supported rescue, evacuation-shelter management, local coordination, and social cohesion, illustrating the value of trusted places, local leadership, and pre-existing relationships in geographically disrupted environments (Ishiwatari et al., 2026).

Local response networks also require resilient infrastructure. Hybrid solar-load optimisation research from developing economies demonstrates the value of decentralised generation, storage, and adaptive load management for sustaining services where centralized grids are unreliable, although its relevance to emergency preparedness is infrastructural rather than clinical (Sunday & Omoegun, 2019). Similarly, peer-to-peer renewable microgrid research indicates that distributed energy systems can support local autonomy, transparency, and resilience, principles pertinent to maintaining communications, lighting, refrigeration, and charging capability during disruptions (Shittu et al., 2021). More recent IoT-enabled microgrid and battery-storage architectures further demonstrate how real-time monitoring, distributed energy resources, and adaptive control can strengthen climate-resilient local power continuity (Shittu et al., 2025). For isolated communities, preparedness is therefore most robust when trained residents, trusted local institutions, social networks, communication channels, and decentralized essential infrastructure are deliberately integrated before emergencies occur. This integration reduces dependence on delayed external assistance during casualty surges.

7.2 Government, Military, Humanitarian, and Private Partnerships

Government, military, humanitarian, and private-sector partnerships are indispensable in mass-casualty response because no single institution can independently supply the personnel, logistics, transport, communications, specialist expertise, security, and financing required during emergencies. In resource-limited environments, partnership effectiveness depends on predetermined mandates, interoperable command arrangements, information-sharing protocols, and mechanisms for pooling assets. Evidence from

humanitarian organisations in Uganda shows that interagency collaboration strengthens preparedness, resource allocation, and response agility, while fragmented institutional arrangements weaken timely intervention (Ntale et al., 2026).

Government–humanitarian relationships are particularly important where displacement, conflict, or disaster overwhelms public capacity. Research from Borno State, Nigeria, demonstrates both the importance of local non-governmental organisations in humanitarian delivery and the governance risks created when accountability, oversight, and donor-resource controls are weak, reinforcing the need for transparent partnership structures (Ajiboye, 2025). Comparable lessons from South Africa indicate that public–private partnerships can supplement under-resourced municipal disaster-management capacity, provided responsibilities and accountability are defined (Van der Berg, 2015).

Military capabilities can add strategic lift, engineering, medical, logistics, communications, and rapid-deployment capacity when civilian systems are saturated. International field evidence nevertheless shows that effective civil–military cooperation requires joint exercises, mutual understanding, compatible procedures, and respect for distinct civilian and military mandates rather than improvised coordination during crises (Casartelli et al., 2026). Private-sector participation is similarly most effective when incentives, investment responsibilities, and risk-sharing arrangements are established before disaster onset, allowing governments to mobilise additional infrastructure and preparedness capacity without sacrificing accountability (Guan et al., 2018).

Supporting organizational research suggests that integrating workforce planning with operational analytics can strengthen resilience by connecting human capability, risk information, and real-time decision-making across organizational boundaries (Falemi, Akhigbe & Akin-Oluyomi, 2024). Likewise, real-time operational-data models emphasize visibility, responsiveness, and identification of service bottlenecks; cautiously transferred to emergency partnerships, these principles can support situational awareness across participating agencies (Akhigbe, Falemi & Akin-Oluyomi, 2023). Effective partnerships in isolated environments therefore require formal agreements, shared procedures, interoperable communications, accountability safeguards, joint training, and decentralized authority sufficient to sustain coordination when assistance is delayed.

8. Evidence Gaps and Future Priorities

8.1 Implementation Barriers and Research Methodological Gaps

Implementation barriers in emergency and mass-casualty response arise not only from shortages of finance, personnel, infrastructure, and technology, but also from weak institutional readiness, fragmented governance, limited interoperability, and insufficient evidence for context-sensitive implementation. In Africa, priority-setting research shows that emergency preparedness requires stronger evidence on programme implementation, workforce capacity, surveillance, coordination, financing, and community engagement, indicating that policy ambition can exceed operational evidence (Onwujekwe et al., 2023).

The methodological evidence base remains uneven for mass-casualty systems. A broad scoping review found substantial variation in how essential response components are defined and reported, with literature disproportionately originating from high-income countries and limited evidence from low- and middle-income settings. This restricts external validity for geographically isolated environments where staffing, transport, infrastructure, and referral conditions differ markedly (Usoro et al., 2023). Similar problems emerge in South Africa, where consensus work identified unanswered questions concerning dispatch, interfacility transfer, health-seeking behaviour, workforce wellbeing, and system performance, demonstrating the need for locally prioritized research rather than transfer from better-resourced systems (Holliman, Wallis & Saunders, 2024).

Technology introduces additional implementation uncertainty. Evidence on information and communication technologies in mass-casualty management remains limited, with few experimental studies and reliance on simulation rather than evaluation during real incidents. Consequently, effectiveness, usability, interoperability, and decision-quality outcomes remain incompletely established (Režek & Žvanut, 2024). Comparative healthcare research likewise suggests that generative-AI adoption depends on organizational readiness, governance, workforce capability, digital infrastructure, and managerial maturity, with disparities between high-income and lower-resource environments (Ayinde, Ojukwu & Ohunyon, 2025).

Operational research can help address these gaps, although transferability must be tested. Supply-chain analytics frameworks emphasize forecasting, bottleneck detection, and real-time data integration, offering tools for studying emergency resource demand and distribution (Akin-Oluyomi & Akhigbe, 2023b). Multi-site performance frameworks support standardized indicators, comparative benchmarking, and data architectures across dispersed facilities, but emergency validation is required before such approaches guide systems confidently (Akin-Oluyomi & Akhigbe, 2023a). Future research requires multicentre LMIC studies, common outcome definitions, prospective registries, implementation-effectiveness designs, economic evaluation, and transparent reporting capable of distinguishing technological feasibility from measurable improvements in emergency-system performance.

8.2 Policy, Innovation, and System Strengthening Priorities

Policy strengthening for emergency and mass-casualty response must move beyond episodic disaster planning toward institutionalized systems capable of maintaining readiness, financing, coordination, workforce competence, and essential services under routine and surge conditions. Nigerian policy analysis has long identified fragmented intersectoral coordination, inadequate emergency-response structures, weak surveillance, and insufficient planning as barriers requiring an integrated national policy architecture with explicit responsibilities, implementation benchmarks, and sustainable programmes (Aliyu, 2002).

Across Africa, system strengthening should prioritize regulated emergency medical services, sustainable financing, trained personnel, interoperable dispatch, standardized clinical governance, and stronger prehospital-to-hospital integration. Continental evidence indicates considerable heterogeneity in EMS availability, organization, financing, regulation, and resources, demonstrating why reforms must combine national standards with context-sensitive implementation rather than importing uniform models from high-resource settings (Mould-Millman et al., 2017).

At the global level, policy direction increasingly recognizes emergency, critical, and operative care as a core health-system platform rather than an optional specialist service. The contemporary international agenda therefore supports integration into universal health coverage, preparedness for health emergencies, workforce development, quality improvement, and resilient referral networks capable of delivering time-sensitive care across geographic and socioeconomic boundaries (Global Acute Care Advocacy Authors, 2023).

Governance innovation is equally important. Transparent reporting pathways, defined accountability, performance monitoring, and adaptive feedback can strengthen strategic execution across multi-agency response systems, particularly where government, humanitarian, private, and community actors share operational responsibilities (Akhigbe, Falemi & Akin-Oluoyomi, 2025).

System resilience also depends upon infrastructure that continues functioning during disruption. Research on Nigeria's Owerri-Urban distribution network illustrates the importance of identifying and mitigating power-quality disturbances, offering supporting evidence for policies that protect reliable electricity supply to critical facilities rather than direct evidence on emergency medicine itself (Okwe et al., 2025).

Digital infrastructure should likewise incorporate cyber-physical protection, real-time sensing, interoperability, and adaptive fault response so that increased technological dependence does not create new failure points during emergencies (Shittu, Shittu & Olagunju, 2024). Future innovation can extend this principle through digital twins, predictive analytics, and autonomous control architectures capable of supporting resilient infrastructure management, although their deployment requires validation, cybersecurity safeguards, regulatory oversight, and trained personnel before translation into high-stakes emergency environments (Shittu et al., 2026).

Conclusion

This review examined the systems, training requirements, technologies, and institutional conditions that shape emergency and mass-casualty response in resource-limited and geographically isolated environments. Its objectives were met by integrating evidence on command structures, triage and referral systems, workforce and infrastructure constraints, responder training, digital technologies, clinical priorities, community resilience, cross-sector partnerships, and future implementation needs. The analysis demonstrates that effective response is determined less by the absolute scale of an incident than by the relationship between casualty demand and the capacity, connectivity, and resilience of the local health system.

Several findings are especially significant. Fragmented command arrangements, weak referral pathways, workforce shortages, unreliable transport, communication failures, and fragile supply chains consistently magnify avoidable delays and reduce surge capability. Training, simulation, and community responder development strengthen preparedness when they are recurrent, competency-based, and adapted to local realities. Telemedicine, drones, mobile platforms, sensors, digital twins, and decision-support tools offer important opportunities to extend specialist reach, improve situational awareness, and support logistics, but their value depends on reliable infrastructure, interoperability, cybersecurity, workforce readiness, and appropriate governance. Equally, trauma stabilization, infection control, and continuity of essential services require context-sensitive protocols that match available resources and transfer realities.

The review further shows that resilience is strongest when communities, emergency medical services, hospitals, governments, humanitarian actors, military assets, and private organizations operate through predefined and accountable coordination mechanisms. Policy should therefore prioritize integrated emergency-care architectures, sustainable financing, decentralized surge capacity, resilient communications and energy systems, standardized data collection, and continuous multidisciplinary training. Future research should expand multicentre studies in low- and middle-income settings, improve common outcome measures, and evaluate technologies under real operational conditions. Ultimately, strengthening local capability before crises occur remains the most credible pathway to reducing preventable mortality, protecting continuity of care, and improving equitable emergency outcomes across remote and systematically underserved populations worldwide sustainably.

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