Review article

Nipah Virus Outbreaks: A CBRNE Framework for Global Biocontainment

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Abstract

Nipah virus (NiV), a deadly zoonotic pathogen with a fatality rate of 40-75%, continues to pose a significant pandemic threat, as evidenced by recent outbreaks in Kerala, India (2023 and 2024). These events highlight NiV's potential for human-to-human transmission, particularly in healthcare settings, and its ability to cause severe respiratory and neurological disease. Given the absence of approved vaccines or therapeutics, this review explores the implementation of CBRNE (Chemical, Biological, Radiological, Nuclear, and Explosive) strategies for outbreak containment through military-developed protocols including high-level biocontainment units, aerosolized disinfectant systems, and controlled movement zones. The proposed framework addresses NiV's unique challenges by combining rapid deployment of mobile isolation pods, strict corpse management procedures, and specialized healthcare worker protection with broader public health preparedness. Recent responses to epidemics in India demonstrate how the potential integration of CBRNE approaches can reduce transmission risks while preserving essential social functions through preventive training, interagency coordination, and strategic resource allocation. This review provides policymakers with actionable recommendations for mitigating NiV's biological threat through unified military-civilian response architectures.

Key words: Nipah Virus; CBRNE; Health Emergency Management; Global Security.

Introduction

NiV is a recently described paramyxovirus that causes an acute febrile encephalitic, stands as one of the most lethal zoonotic pathogens known to humanity due to its high lethality rate [1]. First identified during the 1998-1999 outbreak in Malaysia and Singapore, where it caused severe encephalitis and respiratory disease among pig farmers, NiV has since emerged periodically in South and Southeast Asia, with Bangladesh and India reporting recurrent cases [2,3]. The virus's natural reservoir is fruit bats of the *Pteropus* genus, which shed the virus through urine, saliva, and other excretions, enabling spillover events to intermediate hosts (e.g., pigs) or directly to humans [2,3,4,5]. Recent outbreaks in Kerala, India (2023-2024), with case fatality rates exceeding 70%, have underscored NiV's potential for nosocomial amplification and limited human-to-human transmission—traits that elevate its pandemic risk; however, it should be noted that despite the high case fatality rate, the number of deaths remained low [5,6,7,8] (Table 1).

Current public health strategies for NiV containment remain reactive, relying heavily on outbreak surveillance, contact tracing, and isolation protocols. However, the virus's high mortality rate, environmental stability, and potential for airborne transmission demand a more robust, preemptive approach [5,9]. This review argues for the integration of CBRNE (Chemical, Biological, Radiological, Nuclear, and Explosive) protocols, traditionally reserved for biowarfare scenarios, into NiV pandemic preparedness plans. By adapting military-grade strategies—such as mobile high-containment units, large-scale decontamination systems, and AI-assisted outbreak modeling—civilian health systems could bridge critical gaps in biocontainment, resource allocation, and crisis communication.

The objective of this review is threefold: (1) to synthesize the virological, epidemiological, and clinical features of NiV that necessitate a CBRNE framework; (2) to model a hypothetical pandemic

scenario where NiV acquires enhanced transmissibility; and (3) to propose actionable CBRNE interventions, from lockdown enforcement to corpse management, that could mitigate catastrophic outcomes. Climate change amplifies these risks by forcing bat populations to migrate into human-dominated landscapes due to habitat fragmentation and altered fruiting cycles, thereby increasing spillover opportunities—a pattern documented in South Asian NiV hotspots. As deforestation and anthropogenic pressures further intensify human-bat interfaces, the lessons from NiV preparedness may extend to other high-consequence zoonoses, positioning CBRNE strategies as a cornerstone of 21st-century global health security [10].

Table 1. Chronology of Major Nipah Virus Outbreaks (1998-2024)

Year(s)	Location	Cases (Deaths)	Case Fatality Rate	Transmission Pattern	Key Findings	References
1998-1999	Malaysia/Singapore	265 (105)	40%	Pig-to-human, limited human-to-human	First identified outbreak; farming nexus	[2,8]
2001-2023	Bangladesh (Annual)	~300 (~210)	70-90%	Bat-to-human (date palm sap), human-to-human	High CFR; nosocomial superspreading events	
2018, 2021, 2023-2024	Kerala, India	23 (17), 1 (1), 6 (4)	74-100%	Bat-to-human, hospital-acquired	Healthcare worker vulnerability	
2007	West Bengal, India	5 (5)	100%	Unknown index case, human-to-human suspected	Small cluster with extreme lethality	

CFR = Case Fatality Rate.

NiV: Virology, Epidemiology, and Clinical Features

NiV belong to the genus Henipavirus in the family *Paramyxoviridae* and is relatively large (120–150 nm diameter), enveloped, single-stranded RNA virus [4,10]. Its genome encodes six structural proteins: nucleocapsid (N), phosphoprotein (P), matrix (M), fusion protein (F), glycoprotein (G), and RNA polymerase (L). The F and M proteins play a crucial role in the entry of the virus inside the host cell. In addition, these proteins facilitate viral penetration into endothelial and neuronal cells, explaining NiV's propensity for causing both severe respiratory distress and encephalitis [11].

Molecular studies have identified two primary strains—NiV-Malaysia (NiV-M) and NiV-Bangladesh (NiV-B)—with the latter demonstrating higher mortality and more frequent human-to-human transmission. Viral shedding occurs via respiratory secretions, urine, and saliva, creating multiple routes of exposure in outbreak settings [12,13,14] (Table 2).

Epidemiologically, NiV outbreaks have been largely confined to South and Southeast Asia, where human activities encroach upon the habitats of Pteropus fruit bats, the virus's natural reservoir [13]. Spillover events typically occur through direct contact with infected bats or consumption of contaminated raw date palm sap, followed by secondary transmission among humans via close contact [11,12,13]. The 1998-1999 Malaysian outbreak, linked to pig farming, resulted in 265 cases and 105 deaths, while subsequent outbreaks in Bangladesh and India have shown mortality rates exceeding 70%. Notably, the 2023 Kerala outbreak revealed alarming patterns of nosocomial spread, with healthcare workers accounting for 40% of cases, underscoring the virus's potential to exploit gaps in infection control protocols [14,15].

Clinically, NiV infection manifests in two primary forms: acute encephalitis and severe respiratory syndrome [8,16,17]. Early symptoms—fever, headache, and myalgia—are

nonspecific, often leading to misdiagnosis as influenza or dengue. Within days, neurological signs (disorientation, seizures, coma) or acute respiratory distress emerge, depending on the viral strain and host factors [18]. Magnetic resonance imaging (MRI) of encephalitic cases typically reveals diffuse cortical and brainstem lesions, while pulmonary involvement presents as bilateral infiltrates resembling acute respiratory distress syndrome (ARDS) [15,16,17,18]. The absence of licensed vaccines or antivirals forces reliance on supportive care, with ribavirin and monoclonal antibodies remaining experimental [19]. Survivors frequently exhibit long-term neurological sequelae, including personality changes and residual paralysis, further straining healthcare systems [20].

This triad of virological adaptability, epidemiological volatility, and clinical severity positions NiV as a uniquely challenging pathogen—one that demands innovative containment strategies beyond conventional public health measures [14,21].

Table 2. Comparative Features of Nipah Virus Strains

Characteristic	NiV-Malaysia (NiV-M)	NiV-Bangladesh (NiV-B)	Emerging Variants (Kerala)	References
Primary Reservoir	*Pteropus hypomelanus*	*Pteropus medius*	*Pteropus giganteus*	[13,14]
Transmission	Swine intermediate host	Direct bat-to-human	Bat/human-to-human	
Human CFR	35-40%	70-90%	70-100%	
Clinical Focus	Encephalitis dominant	Respiratory + neurological	Rapid multi-organ failure	
Human-to-Human	Rare	Frequent	Emerging evidence	
Molecular Marker	G protein (E447K mutation)	F protein cleavage efficiency	Enhanced fusion activity	

Containing a Nipah Virus Pandemic: A CBRNE Approach and Global Coordination Framework

The persistent recurrence of NiV outbreaks across South and Southeast Asia necessitates a tiered approach to epidemic preparedness, one that marries conventional public health measures with targeted military-derived containment strategies [14,22,23,24,25]. While community-level interventions addressing zoonotic spillover remain foundational, the unique characteristics of NiV – its staggering case fatality rate, propensity for nosocomial amplification, and environmental tenacity – create scenarios where civilian infrastructure becomes rapidly overwhelmed [11,14]. Historical precedents from Ebola and Middle East Respiratory Syndrome (MERS) outbreaks demonstrate that precisely calibrated CBRNE protocols can function as force multipliers when deployed judiciously alongside existing public health frameworks [26,27,28].

The operational superiority of CBRNE strategies manifests most clearly in three critical domains of outbreak response [29]. First, in rapid case identification and containment, where mobile diagnostic units adapted from biodefense systems achieve laboratory-grade accuracy in field conditions, enabling real-time perimeter control without disrupting ongoing community education initiatives [30,31]. Second, in healthcare facility protection, where modular isolation units derived from NATO CBRN standards prevent the hospital-based transmission clusters that accounted for nearly half of cases during recent NiV outbreaks [29,32]. Third, as a bridge to long-term solutions, with military-grade containment buying vital time for vaccine deployment – particularly relevant as several NiV vaccine candidates now progress through clinical trial phases [33].

Economic considerations, while often cited against such high-intensity approaches, must account for both direct costs and catastrophic risk mitigation [28]. Permanent high-containment facilities require capital expenditures orders of

magnitude greater than deployable CBRNE solutions, while the opportunity costs of uncontrolled outbreaks – in lives lost, healthcare systems paralyzed, and economies destabilized – dwarf prevention investments [28,29,32]. This calculus becomes particularly compelling when considering NiV's pandemic potential, a lesson seared into global consciousness by SARS-CoV-2's emergence from another ostensibly "low-mortality" zoonosis [29,32,34].

The ethical implementation of such measures demands rigorous safeguards. Singapore's pandemic response blueprint offers an instructive model, combining military-grade outbreak analytics with robust civilian oversight – using anonymized heat mapping rather than individual surveillance, and collocating advanced containment units with community treatment centers to maintain accessibility and public trust. This balanced approach acknowledges that the extraordinary powers invoked during biological crises must be both proportional and transparent [35].

Ultimately, the justification for CBRNE integration lies not in replacing traditional public health, but in providing specialized tools for scenarios where conventional measures falter against particularly virulent pathogens [36,37]. As climate change intensifies human-wildlife interfaces and global connectivity accelerates outbreak potential, such multidimensional preparedness frameworks may well determine whether localized zoonotic events escalate into civilizational threats [10,28].

Conclusion

NiV represents a paradigm-shifting challenge in pandemic preparedness, where conventional public health measures reach their limits against a pathogen combining high mortality, environmental persistence, and nosocomial transmission risks. This review establishes that selectively adapted CBRNE protocols—particularly mobile high-containment units and precision decontamination systems—can bridge this preparedness gap when integrated with civilian health infrastructure. The success of such hybrid approaches in recent Ebola and MERS outbreaks demonstrates their viability, though full implementation demands three pillars: (1) World Health Organization (WHO)-coordinated military-civilian task forces for cross-border response, (2) regional training hubs for CBRNE-adapted biocontainment, and (3) parallel investment in both vaccine development and outbreak-ready deployment systems.

While ethical governance remains essential—particularly regarding movement restrictions and resource triage—the accelerating frequency of zoonotic spillovers under climate change leaves little margin for delay. The strategies outlined here provide not merely a response framework for NiV, but a scalable prototype for future high-consequence pathogens. Their proactive adoption could redefine global health security from reactive containment to preventable crisis.

Ethics Approval and Consent to Participate

The informed consent was waived because of the retrospective nature of this study.

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Conflict of Interest

The authors have no conflicts of interest to declare.

Authors' Contributions

Conceptualization: GML, PAT; Data curation: GML, AM; Formal analysis: PAT; Investigation: GML, PAT; Methodology: RQ; Project administration: AI, CR, AM; Resources: GG, SR; Supervision: AM; Validation: AI, CR, AM; Visualization: AM, GG, SR; Writing–original draft: GML; Writing–review & editing: all authors.

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