

Hantaviruses as emerging zoonotic pathogens: A comprehensive review of their global distribution, disease burden, and public health significance

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ABSTRACT

The family *Hantaviridae* includes the newly discovered zoonotic infections known as hantaviruses, which are mostly found in rodent reservoirs. Inhaling aerosolized particles tainted with rodent urine, feces, or saliva is the primary way that humans become infected. Hemorrhagic fever with renal syndrome (HFRS), which is primarily documented in Asia and Europe, and hantavirus pulmonary syndrome (HPS), which is primarily seen in the Americas, are the two main clinical syndromes caused by hantaviruses. Both disorders are marked by increased arterial permeability, endothelial dysfunction, and considerable morbidity and mortality, despite variations in clinical presentation. Environmental factors, human activity that increases exposure to infected rodents, and reservoir host ecology are all directly related to the epidemiology of hantavirus infection. In many areas, hantavirus-associated diseases have emerged and expanded due to climate variability, land-use changes, urbanization, and agricultural growth. Clinical observations, epidemiological history, serological tests, and molecular methods like reverse transcription-polymerase chain reaction (RT-PCR) are all used to make the diagnosis. While several antiviral medications have demonstrated modest clinical efficacy, treatment is still primarily supportive, concentrating on the management of respiratory, cardiovascular, and renal problems. To lower exposure risk, preventive approaches mainly focus on public education, environmental sanitation, rodent control, and workplace safety procedures. There are still few vaccines that are effective worldwide, despite the fact that a number of vaccine candidates have been created and approved in a few nations. The etiology, epidemiology, transmission, pathogenesis, immune response, pathology, clinical signs, diagnosis, treatment, prevention, and public health significance of hantavirus infections are all summarized in this article. Improving disease surveillance, outbreak planning, and future control measures within a One Health framework requires a thorough understanding of these factors.

Introduction

Emerging zoonotic infections of worldwide public health importance, hantaviruses cause a variety of serious human illnesses (Afzal *et al.*, 2023). Human exposure to infected excreta, such as urine, feces, and saliva, can spread these viruses, which are mostly maintained in rodent reservoirs (Shehata *et al.*, 2025). Due to their extensive geographic distribution, high case-fatality rates in severe infections, and intricate ecological relationships involving wildlife reservoirs and environmental factors, hantaviruses have garnered significant scientific attention since their initial identification as significant human pathogens (Taylor *et al.*, 2025).

Many genetically distinct viral species found throughout Asia, Europe, Africa, and the Americas make up the genus *Orthohantavirus* (Romeo *et al.*, 2025). In the past, hantaviruses were mostly linked to rodent hosts; however, more recent research has shown closely similar viruses in shrews, moles, and bats, broadening our knowledge of their host range and evolutionary history (Souza *et al.*, 2014). Hemorrhagic fever with renal syndrome (HFRS), which is more common in Asia and Europe, and Hantavirus pulmonary syndrome (HPS), which is more common in the Americas, are the two main clinical syndromes linked to human infections (Fawcett *et al.*, 2022). Both disorders are marked by considerable morbidity and have the potential to be lethal, despite differences in their primary target organs and clinical manifestations (Ahmed *et al.*, 2026).

Ecological and environmental factors that impact reservoir host populations and human exposure have a significant impact on the epidemiology of hantavirus infection (Jonsson *et al.*, 2010). The interactions between humans and wildlife have changed due to climate unpredictability, land-use changes, deforestation, agricultural expansion, and urbanization (Ramos-Nino *et al.*, 2026). These changes have created new potential for

zoonotic transmission (Jiang *et al.*, 2017). Variations in rodent population and the onset of epidemics in previously unaffected areas have been linked to increased human intrusion into natural habitats and shifting environmental circumstances (Gorris *et al.*, 2025). As a result, hantavirus infections are becoming more widely acknowledged as illnesses that highlight the interdependence of environmental, animal, and human health (Domingo, 2026).

Even while our knowledge of hantavirus biology has advanced significantly, there are still significant obstacles to illness prevention and control (Dheerasekara *et al.*, 2020). Because early symptoms are nonspecific and resemble those of other febrile disorders, early diagnosis is frequently challenging (Brorstad *et al.*, 2010). Additionally, licensed vaccines are only available in a few nations, and treatment choices are still mainly supportive (Liu *et al.*, 2020). The necessity for continuous surveillance and study is highlighted by the constant appearance of new hantavirus species and the possible impact of environmental change on disease transmission (Guterres and de Lemos, 2018).

A thorough understanding of hantaviruses' etiology, epidemiology, transmission dynamics, pathogenesis, clinical symptoms, diagnosis, prevention, and control is crucial given their increasing significance as emergent zoonotic diseases. Thus, the purpose of this review was to provide an overview of what is currently known about hantavirus infections and to talk about their implications for future research, public health, and disease management within a One Health framework.

Etiology

Hantaviruses are zoonotic, negative-sense, single-stranded RNA viruses that are members of the order *Bunyavirales*, family *Hantaviridae*,

and genus Orthohantavirus (Halwe *et al.*, 2026). These viruses are found all over the world and are sustained in nature by recurring infections in reservoir hosts, mainly rodents, though certain species have also been found in shrews, moles, and bats (de Oliveira *et al.*, 2014). In contrast to unintentional human hosts, reservoir animals typically show no symptoms even after prolonged viral carriage, allowing for ongoing viral transmission within wildlife populations (Berjaoui *et al.*, 2026).

The three RNA segments that make up the hantavirus genome are short (S), medium (M), and large (L) (Meier *et al.*, 2021). The nucleocapsid protein, which is necessary for viral genome encapsidation and replication, is encoded by the S segment (Mir and Panganiban, 2004). Gn and Gc, two envelope glycoproteins that are involved in host cell adhesion and entrance, are encoded by the M segment (Cifuentes-Muñoz *et al.*, 2014). The essential enzyme needed for viral transcription and replication, viral RNA-dependent RNA polymerase, is encoded by the L segment (Muyangwa *et al.*, 2015). In terms of structure, hantaviruses are enveloped viruses with a diameter of about 80 to 120 nm and a spherical to pleomorphic shape (Afzal *et al.*, 2023).

Based on their geographic distribution and related clinical symptoms, hantaviruses are generally divided into Old World and New World categories (Avšič-Županc *et al.*, 2015). The Hantaan virus, Seoul virus, Puumala virus, and Dobrava-Belgrade virus are examples of Old World hantaviruses that are mostly prevalent in Asia and Europe (Chen *et al.*, 2023). Although the severity of the disease differs by species, these viruses are mainly linked to HFRS (Mir and Panganiban, 2004). On the other hand, New World hantaviruses, such as the Andes virus, Laguna Negra virus, Sin Nombre virus, and other similar species, are found all over the Americas (Avšič-Županc *et al.*, 2015). The majority of these viruses are linked to HPS, a serious respiratory condition marked by quick cardiopulmonary decline (Singh *et al.*, 2014). The geographic grouping of hantaviruses and their associated clinical syndromes is illustrated in Figure 1.

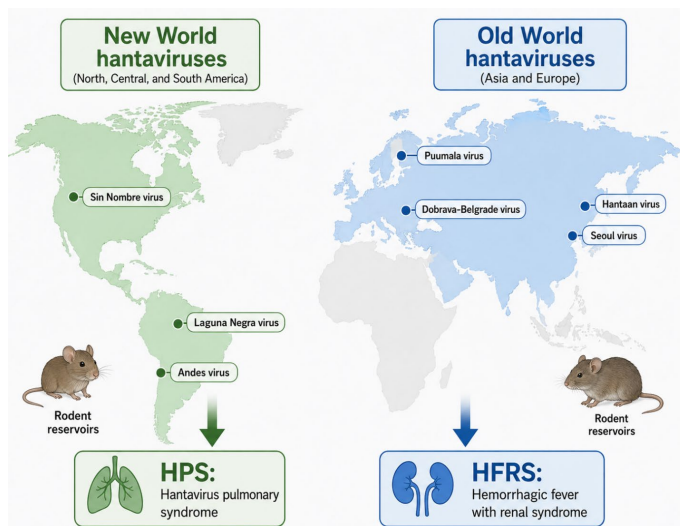


Figure 1. Global distribution, reservoir hosts, and major clinical syndromes of hantaviruses.

The intimate evolutionary link between individual viral species and their reservoir hosts is a characteristic of hantavirus ecology (Pérez-Umphrey *et al.*, 2023). The majority of hantaviruses have a high degree of host specificity; each virus is usually linked to a specific species of rodent or small mammal (Jonsson *et al.*, 2010). Horizontal transmission, especially through contact with saliva, urine, and feces, is how viruses are maintained within reservoir populations (Madières *et al.*, 2019). Humans do not play a major role in the natural maintenance cycle of the majority of hantaviruses; instead, they become infected accidentally through exposure to polluted surroundings (Hussein *et al.*, 2011).

As new species are discovered in wildlife populations across the globe, the genetic diversity of hantaviruses keeps growing (Yanagihara *et al.*, 2014). A wider host range and more evolutionary complexity than

previously thought have been uncovered by developments in molecular monitoring and genomic sequencing (Ramos-Nino *et al.*, 2026). The emergence of diseases, host adaptation, and the creation of diagnostic instruments, treatments, and immunizations are all significantly impacted by this diversity (Hjelle and Torres-Pérez, 2010).

Epidemiology

Hantaviruses are zoonotic infections that are found all over the world and are sustained in a variety of rodent, shrew, mole, and bat reservoirs (Guo *et al.*, 2013). The geographic distribution of reservoir hosts, environmental factors, and human exposure patterns all have a significant impact on their epidemiology (Jonsson *et al.*, 2010). Different hantavirus species are linked to particular clinical symptoms and reservoir populations in Asia, Europe, and the Americas, where human infections are most common (Ramos-Nino *et al.*, 2026).

The most prevalent type of hantavirus disease in the world, HFRS, is mostly reported in Asia and Europe (Manigold and Vial, 2014). Due in significant part to the spread of the Hantaan virus, Seoul virus, and other Old World hantaviruses, the bulk of recorded cases of HFRS occur in nations like China, the Republic of Korea, and Russia (Zhang *et al.*, 2010; Lee *et al.*, 2013; Garanina *et al.*, 2009). Nephropathia epidemica, a normally milder variant of HFRS, is caused by the Puumala virus, which is widespread throughout Europe (Koehler *et al.*, 2022). Human activities that enhance exposure to infected rodents and variations in the amount of reservoir hosts both have an impact on the disease's incidence, which varies significantly between locations (Xiong *et al.*, 2026).

HPS is the most common clinical sign of infection in the Americas (MacNeil *et al.*, 2011a). Numerous instances have been documented in North, Central, and South America since it was originally identified in 1993 (MacNeil *et al.*, 2011b). In North America, the main cause of HPS is the Sin Nombre virus; in South America, the majority of illnesses are caused by the Andes virus and a number of related hantaviruses (Wahl-Jensen *et al.*, 2007). HPS is a significant public health concern since it is associated with a significantly higher case-fatality rate despite having a lower incidence than HFRS (Dheerasekara *et al.*, 2020).

The ecology of reservoir hosts is intimately related to the epidemiology of hantavirus infection (Hart and Bennett, 1999). The majority of hantaviruses show a strong host relationship, with particular rodent populations sustaining particular viral species (Toledo *et al.*, 2022). As a result, variations in rodent behavior, density, and geographic distribution can have a direct impact on the spread of illness (Tian *et al.*, 2024). Temperature, precipitation, and food availability are examples of climate variables that impact reservoir population dynamics and may be a factor in sporadic spikes in human cases (Ferro *et al.*, 2020). Larger rat populations are frequently supported by years with heavy rainfall and increased vegetation growth, increasing the danger of human exposure (Domingo, 2026).

People who are exposed to rodent habitats at work or in their surroundings are more likely to become infected (Gorris *et al.*, 2025). High-risk populations typically include farmers, forestry workers, military personnel, field researchers, and those living in rural areas (Ricco *et al.*, 2021a). Infection is frequently linked to activities like cleaning rat-infested buildings, handling agricultural products that have been kept, or going into enclosed spaces that have been polluted by rodent excrement (de St Maurice *et al.*, 2017). But urban transmission can also happen, especially in places where rodent species like rats have adapted to live near people (Shehata *et al.*, 2025).

The relationships between people, wildlife, and ecosystems have changed as a result of recent environmental changes, such as urbanization, deforestation, agricultural expansion, and climate unpredictability (Moirano *et al.*, 2024). These elements may make it easier for hantavirus infections to spread to previously unaffected areas and raise the possibility of disease outbreaks (Afzal *et al.*, 2023). Furthermore, greater human mobility and globalization may make it easier for infected reservoir ani-

mals to spread to new geographical areas (Zhang *et al.*, 2022a).

Pathogenesis

Endothelial cell infection and the ensuing disturbance of vascular homeostasis are the main drivers of hantavirus infection pathogenesis (Hepojoki *et al.*, 2014). Inhaling aerosolized particles tainted with the urine, feces, or saliva of infected rodent reservoirs is the usual way that humans contract the virus (Afzal *et al.*, 2023). The virus targets endothelial cells that line the microvasculature of different organs after entering the respiratory system and spreading throughout the body (Ermonval *et al.*, 2016).

Viral envelope glycoproteins interact with cellular receptors, especially β -integrins, to allow hantaviruses to enter host cells (Mittler *et al.*, 2019). Hantavirus replication results in very little direct cytopathic damage to infected endothelium cells, in contrast to many viral infections (Spiropoulou and Srikiatkachorn, 2013). Rather, the illness is defined by functional changes in the vascular endothelium that lead to increased plasma leakage and capillary permeability (Gavrilovskaya *et al.*, 2008).

The host inflammatory response is closely linked to the disease's progression (Saavedra *et al.*, 2021). Endothelial activation and vascular dysfunction are caused by the production of cytokines, chemokines, and other inflammatory mediators that are triggered by infection (Connolly-Andersen *et al.*, 2014). Edema, hypotension, and compromised organ function result from these occurrences, which encourage fluid extravasation into surrounding tissues (Coelho *et al.*, 2024). The disease's clinical manifestation is mostly determined by the extent and location of vascular leakage (Schönrich *et al.*, 2015). The proposed sequence from exposure to endothelial dysfunction and organ-specific disease is summarized in Figure 2.

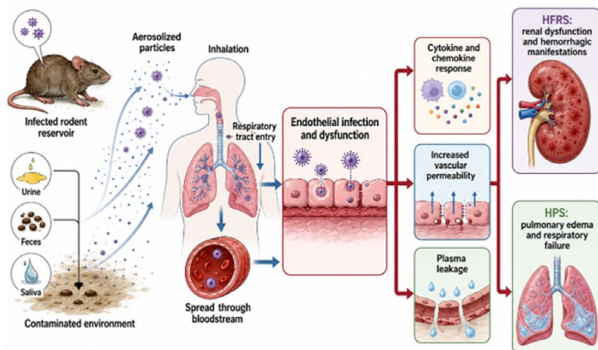


Figure 2. Transmission pathway and pathogenesis of hantavirus infection.

Depending on the type of hantavirus causing the infection, different organs are involved (Krüger *et al.*, 2001). Renal failure and hemorrhagic symptoms are the main outcomes of vascular damage to the kidneys in HFRS (Zou *et al.*, 2016). The main target organs in HPS are the lungs, where significant pulmonary capillary leakage can cause abrupt respiratory failure and non-cardiogenic pulmonary edema (Mackow *et al.*, 2013).

Immune response

Controlling hantavirus infection and determining the course of the disease depend heavily on the human immunological response (Williams *et al.*, 2023). Pattern-recognition receptors (PRRs), such as retinoic acid-inducible gene I (RIG-I) and toll-like receptors (TLRs), recognize viral RNA after viral entry and trigger innate immune responses (Kolli *et al.*, 2013). When these pathways are activated, type I interferons (IFN- α and IFN- β) are produced, which inhibit viral replication and create an antiviral state in infected and nearby cells (Matthys and Mackow, 2012). Furthermore, immune cells are drawn to infection sites by the cytokines and

chemokines secreted by infected cells, which also trigger subsequent adaptive immune responses (Scholz *et al.*, 2017).

The removal of viruses depends on adaptive immunity (Prescott *et al.*, 2013). While CD4+ helper T cells produce cytokines to enhance humoral and cellular immune responses, virus-specific CD8+ cytotoxic T lymphocytes destroy infected cells (Zhang *et al.*, 2022b). By generating particular antibodies against viral antigens, such as neutralizing antibodies against viral glycoproteins, B cells play a role (Engdahl *et al.*, 2021). After recovery, these antibodies may offer long-term protective immunity and restrict the spread of viruses (Shrivastava-Ranjan *et al.*, 2025).

Excessive immune activation can increase the severity of an illness, even while immune responses are essential for preventing infection (Saavedra *et al.*, 2021). Severe clinical symptoms have been linked to elevated levels of pro-inflammatory cytokines, including interleukin-6 (IL-6), interferon-gamma (IFN- γ), and tumor necrosis factor-alpha (TNF- α) (Maleki *et al.*, 2019). Tissue edema and organ damage may ensue from the ensuing inflammatory environment, which may worsen endothelial dysfunction and raise vascular permeability (De Maria *et al.*, 2026).

Pathology

Widespread vascular abnormalities that impact several organ systems, especially the kidneys and lungs, are a hallmark of hantavirus infection pathology (Koehler *et al.*, 2022). Histopathological results show that rather than considerable direct viral cytolysis, tissue damage is mostly linked to increased capillary permeability, edema, bleeding, and inflammatory cell infiltration (Ulrich *et al.*, 2008). As a result, the distribution and severity of lesions differ depending on the clinical state and the type of hantavirus that is causing the infection (Vial *et al.*, 2023).

The kidneys are the main organs impacted by HFRS (Tkachenko *et al.*, 2025). Renal hypertrophy, medullary congestion, and petechial hemorrhages are typical gross pathological features (Jiang *et al.*, 2017). Interstitial edema, vascular congestion, and mononuclear inflammatory infiltrates are commonly seen under a microscope (Saggiaro *et al.*, 2007). In extreme cases, tubular epithelial degeneration and localized tubular necrosis may develop, impairing renal function and causing acute kidney damage (Mir and Panganiban, 2004).

The majority of severe clinical outcomes in HPS are caused by pulmonary lesions (Singh *et al.*, 2014). Usually accompanied by pleural effusion, the lungs seem edematous and congested. Histological analysis shows different degrees of pulmonary bleeding, protein-rich fluid buildup in alveolar spaces, and extensive interstitial and alveolar edema (Saggiaro *et al.*, 2007). Diffuse alveolar destruction and the development of hyaline membranes can occur in advanced illness, which can seriously limit gas exchange and cause respiratory failure (Hamid *et al.*, 2021).

Other organs, including the heart, liver, and spleen, may experience additional pathological alterations (Ma *et al.*, 2021). Lymphoid tissues frequently exhibit reactive hyperplasia, which is indicative of systemic immunological activity (Safronetz *et al.*, 2014). While cardiac abnormalities are typically restricted to interstitial edema and mild inflammatory alterations, modest hepatic congestion and localized inflammatory infiltration may also be observed (Reddy *et al.*, 2023). Petechial hemorrhages and microvascular bleeding in severe infections may be caused by hematological abnormalities such as thrombocytopenia and coagulation disorders (Koskela *et al.*, 2021).

Clinical manifestations

Depending on the viral species and host variables, the clinical signs of a hantavirus infection can range from a minor, self-limiting illness to a serious, perhaps fatal illness (Mir, 2010). The two main clinical syndromes linked to human infections are HPS, which is more common in the Americas, and HFRS, which is more common in Europe and Asia (Fawcett *et al.*, 2022). Both disorders usually start with a vague febrile illness that can

make early identification difficult, despite distinctions in organ involvement (Peters *et al.*, 1999).

Patients typically have acute-onset fever, headache, myalgia, malaise, chills, and exhaustion after an incubation period of between one to six weeks (Ahmed *et al.*, 2026). In the early stages of infection, other symptoms like nausea, vomiting, stomach discomfort, and dizziness are often noted (Mir and Panganiban, 2004). These symptoms frequently resemble those of other viral illnesses, such as leptospirosis, dengue, and influenza (Lukman *et al.*, 2019).

Different levels of renal involvement are indicative of the progression of HFRS (Hong *et al.*, 2012). Acute kidney damage, hematuria, proteinuria, oliguria, and flank pain are possible clinical manifestations (Chand *et al.*, 2020). Petechiae, epistaxis, conjunctival hemorrhage, and gastrointestinal bleeding are examples of hemorrhagic symptoms that can happen, especially in moderate to severe cases (Denecke *et al.*, 2010). Different hantavirus species induce varying degrees of sickness; Puumala virus causes mild nephropathia epidemica, whereas Hantaan and Dobrava-Belgrade viruses cause more severe forms (Krautkrämer *et al.*, 2016).

On the other hand, fast cardiopulmonary impairment is the main characteristic of HPS (Singh *et al.*, 2014). Patients may have coughing, chest pain, increasing dyspnea, and hypoxemia following a brief prodromal phase (Mackow and Koster, 2012). Rapid development of pulmonary edema can result in abrupt respiratory failure, which frequently calls for critical care assistance (MacNeil *et al.*, 2011b). Additionally frequent are tachycardia and hypotension, which in extreme circumstances may lead to circulatory shock (Hepojoki *et al.*, 2014). One characteristic that sets HPS apart and adds to its comparatively high case-fatality rate is the quick development of respiratory impairment (Graziano and Tempest, 2002).

Neurological symptoms such severe headaches, disorientation, and changed mental status have been documented, however they are less fre-

quent, especially in cases of severe infections (Botta and Messina, 2026). Thrombocytopenia, leukocytosis, hemoconcentration, and increased serum creatinine levels are common laboratory findings that indicate the disease's systemic character (Botta and Messina, 2026).

Diagnosis

A combination of laboratory results, clinical presentation, epidemiological history, and confirmatory diagnostic testing are used to diagnose hantavirus infection (Whitmer *et al.*, 2024). Because the initial symptoms are nonspecific and can mimic those of other febrile illnesses, such as influenza, leptospirosis, dengue fever, and other viral hemorrhagic infections, early identification can be difficult (Ekanayake *et al.*, 2025). Therefore, a crucial part of clinical evaluation is a history of possible exposure to rodent-infested areas or contact with rat excrement (de St Maurice *et al.*, 2017).

Hantavirus infection may be supported by routine test results (Plyusnin *et al.*, 2008). Thrombocytopenia, leukocytosis, hemoconcentration, and increased inflammatory markers are common abnormalities (Koebler *et al.*, 2022). Proteinuria, hematuria, and elevated blood creatinine levels are commonly seen in HFRS patients, indicating renal dysfunction (Tariq and Kim, 2022). Laboratory results for HPS frequently show signs of pulmonary dysfunction, thrombocytopenia, and high hematocrit levels (Knust *et al.*, 2012). In endemic areas, these anomalies may cause clinical suspicion even when they are not specific (Vial *et al.*, 2023).

The foundation of laboratory diagnosis is still serological testing (Vilibic-Cavlek *et al.*, 2021). Hantavirus-specific antibodies are frequently found using immunoblot, indirect immunofluorescence assay, and enzyme-linked immunosorbent assay (ELISA) (Chen *et al.*, 2011). Immunoglobulin G (IgG) antibodies may suggest present or prior exposure, while

Table 1. Differential diagnosis of hantavirus infection.

Disease/Condition	Overlapping clinical features with hantavirus infection	Distinguishing characteristics	References
Leptospirosis	Fever, headache, myalgia, thrombocytopenia, renal dysfunction, and hemorrhagic manifestations	Frequently associated with jaundice, conjunctival suffusion, and exposure to contaminated water or infected animals	Kim (2019); Khairullah <i>et al.</i> (2024); Haake and Levett (2015)
Dengue fever	Acute fever, thrombocytopenia, hemorrhagic manifestations, and capillary leakage	Commonly associated with mosquito exposure, rash, leukopenia, and positive dengue serology or molecular tests	Núñez-Samudio <i>et al.</i> (2021); Ekanayake <i>et al.</i> (2025)
Lassa fever	Fever, hemorrhagic manifestations, and multiorgan involvement	Endemic in West Africa and associated with exposure to infected <i>Mastomys</i> rodents	Cleri <i>et al.</i> (2006); Basler (2017)
Crimean-Congo hemorrhagic fever (CCHF)	Fever, thrombocytopenia, bleeding tendencies, and systemic illness	History of tick exposure or contact with infected livestock; often associated with severe hemorrhage	Cleri <i>et al.</i> (2006); Basler (2017)
Community-acquired pneumonia	Fever, cough, and dyspnea	Usually presents with localized pulmonary infiltrates and identifiable bacterial or viral pathogens; lacks characteristic rapid progression to non-cardiogenic pulmonary edema	Jonsson <i>et al.</i> (2010); MacNeil <i>et al.</i> (2011a)
Influenza	Fever, myalgia, malaise, and respiratory symptoms	Typically associated with seasonal outbreaks and lacks severe renal involvement or marked capillary leakage	Jonsson <i>et al.</i> (2010)
Coronavirus disease (COVID-19)	Fever, cough, dyspnea, and respiratory distress	Confirmed by SARS-CoV-2 testing and may present with anosmia, ageusia, and characteristic radiological findings	Jonsson <i>et al.</i> (2010); Lin <i>et al.</i> (2018)
Acute respiratory distress syndrome (ARDS)	Severe respiratory failure, hypoxemia, and diffuse pulmonary infiltrates	Usually develops secondary to sepsis, trauma, or other infectious and noninfectious causes rather than primary hantavirus infection	Lin <i>et al.</i> (2018)
Pneumonic plague	Fever, respiratory symptoms, and systemic illness	Caused by <i>Yersinia pestis</i> ; associated with rodent-flea transmission and characteristic microbiological findings	Widodo <i>et al.</i> (2026)
Tularemia	Fever, pulmonary manifestations, and systemic symptoms	Associated with exposure to rabbits, rodents, or ticks and confirmed by serological or molecular assays	Widodo <i>et al.</i> (2026)
Systemic vasculitis	Renal impairment, pulmonary hemorrhage, and constitutional symptoms	Presence of autoimmune markers and absence of infectious etiology	Ghriss <i>et al.</i> (2026)
Goodpasture syndrome	Pulmonary hemorrhage and renal dysfunction	Characterized by anti-glomerular basement membrane antibodies and autoimmune pathogenesis	Ghriss <i>et al.</i> (2026)
Other viral hemorrhagic fevers (e.g., Ebola and Marburg)	Fever, hemorrhagic manifestations, and multiorgan involvement	Distinguished by geographic distribution, travel history, outbreak setting, and pathogen-specific laboratory testing	Cleri <i>et al.</i> (2006); Basler (2017); Manigold and Vial (2014)

immunoglobulin M (IgM) antibodies indicate recent or acute infection (Toledo *et al.*, 2022). Serological techniques are thought to be extremely sensitive and useful for routine diagnosis because antibody responses usually appear in the early stages of sickness (Tomicic *et al.*, 2006).

Molecular methods are especially useful in the early stages of illness because they offer direct proof of viral infection (Ramos-Nino *et al.*, 2026). Viral RNA can be found in blood or tissue samples using reverse transcription-polymerase chain reaction (RT-PCR) and real-time RT-PCR tests prior to the emergence of discernible antibody responses (Kramski *et al.*, 2007). In addition to providing excellent sensitivity and specificity, these techniques can help with epidemiological studies and viral genotyping (Sui *et al.*, 2019). However, the fleeting nature of viremia and the need for specialist laboratory equipment may restrict their usefulness (Ekanayake *et al.*, 2025).

Immunohistochemistry and molecular investigations of tissue samples may be utilized to confirm infection and detect viral antigens within afflicted organs in severe or lethal instances (Pizarro *et al.*, 2020). These methods are not commonly used in ordinary clinical practice, but rather in research settings or postmortem examinations (Koroknai *et al.*, 2026).

Differential diagnosis

Because the clinical signs of Hantavirus infection can mimic those of a number of infectious disorders that produce severe fever, hemorrhagic symptoms, renal impairment, or respiratory distress, diagnosing the infection can be difficult (Maftai *et al.*, 2012). Differential diagnosis is therefore crucial, especially in endemic areas where several zoonotic and vector-borne illnesses coexist (Bagdi, 2026). Table 1 summarizes major differential diagnoses of hantavirus infection and their distinguishing clinical and epidemiological characteristics.

Leptospirosis is one of the most crucial differential diagnoses for patients with HFRS (Kim, 2019). Fever, headache, myalgia, thrombocytopenia, renal failure, and hemorrhagic consequences are possible symptoms of both conditions (Khairullah *et al.*, 2024). However, jaundice, conjunctival suffusion, and a history of contact with tainted water or diseased animals are frequently linked to leptospirosis (Haake and Levett, 2015). Dengue fever should also be taken into account because it frequently manifests as acute fever, thrombocytopenia, hemorrhagic symptoms, and capillary leakage (Núñez-Samudio *et al.*, 2021). To differentiate between these infections, laboratory confirmation using serological or molecular testing is frequently necessary (Ekanayake *et al.*, 2025).

Hantavirus disease may also be similar to other viral hemorrhagic fevers, such as those brought on by arenaviruses, filoviruses, and nairoviruses (Cleri *et al.*, 2006). Fever, bleeding tendencies, and multiorgan involvement can be symptoms of diseases like Crimean-Congo hemorrhagic fever and Lassa fever (Basler, 2017). To distinguish between various illnesses, epidemiological characteristics, travel history, geographic distribution, and particular test results are crucial (Manigold and Vial, 2014).

Numerous respiratory infections and noninfectious pulmonary conditions are included in the differential diagnosis for patients with HPS (MacNeil *et al.*, 2011a). Similar to HPS, community-acquired pneumonia, influenza, coronavirus illness, and other viral respiratory infections might first manifest as fever, cough, and dyspnea (Jonsson *et al.*, 2010). But what is more typical of HPS is the quick development of acute respiratory failure and non-cardiogenic pulmonary edema (Singh *et al.*, 2014). Additionally, especially in critically ill patients, acute respiratory distress syndrome (ARDS) brought on by bacterial sepsis or other infectious causes should be considered (Lin *et al.*, 2018).

Due to their similar systemic and pulmonary symptoms, a number of bacterial zoonoses, such as tularemia and plague, can occasionally resemble hantavirus infection (Widodo *et al.*, 2026). When infectious causes cannot be verified, autoimmune conditions including systemic vasculitis and Goodpasture syndrome that are linked to pulmonary bleeding or renal involvement should be taken into consideration (Ghriss *et al.*, 2026).

Laboratory testing is crucial for making a definitive distinction between hantavirus infection and other disorders because early clinical signs are nonspecific (Brorstad *et al.*, 2010). Establishing an appropriate diagnosis requires a comprehensive evaluation of epidemiological risk factors, hematological results, molecular diagnostics, and serological testing (Mattar *et al.*, 2015). In order to guarantee prompt patient care and suitable public health initiatives, a thorough differential diagnosis approach is very crucial (Afzal *et al.*, 2023).

Transmission

Humans contract hantaviruses mostly via coming into contact with infected reservoir animals, especially rodents, which carry the virus in the wild without showing signs of illness (Shehata *et al.*, 2025). Because each species of hantavirus is often linked to a particular reservoir host, the virus can persist in rodent populations through horizontal transmission modes such biting, aggressive encounters, and contact with contaminated excreta (Padula *et al.*, 2004).

Inhaling aerosolized particles tainted with the urine, feces, or saliva of infected rats is the most common way for humans to become infected (Afzal *et al.*, 2023). The risk of aerosol production and subsequent infection can be increased by activities that disturb contaminated dust, such as cleaning rodent-infested dwellings, agricultural activity, forestry activities, and occupational exposure in rural areas (de St Maurice *et al.*, 2017). Environmental pollution is important in the epidemiology of hantavirus disease since inhalation is thought to be the primary mode of transmission (Toledo *et al.*, 2022).

Direct contact with infected rodents or their excrement can also spread the infection, though this is less common (Ermonval *et al.*, 2016). This is especially true when contaminated materials come into touch with broken skin or mucous membranes (Mir, 2010). Although rodent bites have been documented as a possible source of infection, they are very uncommon in comparison to aerosol transmission (Jonsson *et al.*, 2010). Eating or drinking food or water tainted by rodent excrement has also been proposed as a potential, albeit rare, method of exposure (Shehata *et al.*, 2025).

Hantaviruses often do not spread from person to person (Toledo *et al.*, 2022). One prominent exception is the Andes virus, which is endemic in some regions of South America (Martinez *et al.*, 2005). Person-to-person transmission through close contact with infected patients has been shown in a number of outbreaks, especially during the prodromal and early symptomatic periods of the disease (Alonso *et al.*, 2020). On the other hand, neither the majority of Old World hantaviruses nor other New World hantavirus species have been shown to exhibit persistent human-to-human transmission (Jacob *et al.*, 2023).

Environmental and ecological factors that impact reservoir host populations and human exposure have an impact on the risk of hantavirus transmission (Guo *et al.*, 2013). The dynamics of rodent populations can be changed by climate variability, land use changes, deforestation, urbanization, and agricultural development, all of which enhance the likelihood of human-rodent interactions (Ramos-Nino *et al.*, 2026). As a result, ecological circumstances that encourage higher reservoir abundance or increased environmental contamination are frequently linked to outbreaks (Tian *et al.*, 2024).

Risk factors

The risk of hantavirus infection is influenced by a mix of environmental, occupational, behavioral, and ecological factors that enhance the possibility of exposure to infected reservoir hosts or contaminated surroundings (Guterres and de Lemos, 2018). Factors that encourage human-rodent contact are crucial in the spread of disease since hantaviruses are mostly maintained in rodent populations (Sadkowska-Todys *et al.*, 2015). Table 2 summarizes major risk factors associated with hantavirus

infection.

One of the biggest risk factors for contracting the hantavirus is occupational exposure (Riccò *et al.*, 2021a). Rodent infestations are more common among those who work in agriculture, forestry, livestock production, wildlife management, the military, and field research (D'Souza and Patel, 2020). Rodents may be drawn to agricultural procedures involving the handling and storage of grain, animal feed, or other food items, increasing the risk of exposure to contaminated excreta (Riccò *et al.*, 2021b). Similarly, workers may be exposed to aerosolized virus particles produced by contaminated dust when cleaning barns, warehouses, sheds, or abandoned structures (Richardson *et al.*, 2013).

Environmental and residential factors also significantly increase the chance of infection (Tian *et al.*, 2024). Human exposure to infected rodents can be increased by inadequate waste management, poor sanitation, and housing situations that encourage rodent infestation (Rodríguez-Morales *et al.*, 2025). In general, people in rural areas who live close to forests, farms, or places with high rodent density are more vulnerable than people in urban areas (Moirano *et al.*, 2024). However, urban outbreaks can happen, especially when rodent species that have adapted to human environments—like rats carrying the Seoul virus—are involved (Clement *et al.*, 2019).

A major factor in determining infection is human activity that increases contact with rodent habitats (Hart and Bennett, 1999). Activities that promote exposure to contaminated soil, vegetation, or enclosed places that harbor rats include camping, trekking, hunting, and leisure trips to endemic areas (de St Maurice *et al.*, 2017). Because it may produce infectious aerosols, cleaning rodent-infested areas without the proper safety precautions is seen as a particularly high-risk operation (Wilken *et al.*, 2015).

Hantavirus epidemiology is significantly influenced by ecological and climatic conditions (Douglas *et al.*, 2022). Rodent population density and distribution can be affected by changes in temperature, precipitation, and food availability (Klempa, 2009). Increased vegetation growth during periods of higher precipitation may provide rodents with more food, which could lead to population growth (Tian *et al.*, 2024). Increased rat populations can worsen environmental contamination and increase human exposure risks (Domingo, 2026). As a result, hantavirus infection epidemics have often been linked to ecological shifts that encourage the growth of reservoir hosts (Hart and Bennett, 1999).

Susceptibility to infection may also be influenced by demographic

factors (Olsson *et al.*, 2002). Due to increased exposure at work and in the environment, adults are typically more impacted than children (Mocanu *et al.*, 2023). Males have higher infection rates in many endemic areas, which is probably due to their greater involvement in outdoor and high-risk jobs (Hjelle and Torres-Pérez, 2010). However, when there is enough exposure, infection can happen to people of all ages and genders (Toledo *et al.*, 2022).

Public health importance

Because of its zoonotic nature, potential for serious clinical consequences, and extensive distribution of reservoir hosts, hantavirus infection poses a serious threat to public health (Jiang *et al.*, 2017). Although the prevalence of human hantavirus disease is generally lower than that of many other infectious diseases, outbreaks continue to occur in various countries of Asia, Europe, and the Americas, creating continuous challenges for healthcare systems and public health agencies (Ahmed *et al.*, 2026). The necessity of ongoing surveillance and preventive measures is further highlighted by the introduction of novel hantavirus species and the growing interface between humans, animals, and the environment (Ramos-Nino *et al.*, 2026).

The comparatively high case-fatality rate of hantaviruses is one of the main public health concerns (Krüger *et al.*, 2001). Despite advancements in supportive medical care, severe forms of illness, especially HPS, can cause significant mortality and fast clinical deterioration (Sindhu, 2026). Furthermore, the generic nature of early symptoms frequently makes prompt diagnosis difficult, which may postpone effective therapeutic therapy and raise the possibility of unfavorable results (Brorstad *et al.*, 2010).

The importance of hantaviruses for public health is greatly increased by the extensive dispersion of rodent reservoirs (Mohiddin, 2026). Many rodent species act as natural hosts and may sustain the virus in a variety of ecological contexts, including as rural, peri-urban, and urban settings (Morand *et al.*, 2015). Urbanization, deforestation, agricultural growth, and changes in land use can all increase human contact with sick rats, which can help spread the disease (Jonsson *et al.*, 2010). Additionally, environmental changes brought on by climate change may modify the dynamics of rodent populations and have an impact on the frequency and geographic dispersion of epidemics (Douglas *et al.*, 2022).

From the standpoint of public health, hantavirus infections empha-

Table 2. Major risk factors associated with hantavirus infection.

Risk factor category	Specific factors	Mechanism increasing infection risk	References
Occupational factors	Farming, forestry, livestock production, wildlife management, military training, and field research	Increased exposure to rodent habitats, reservoir hosts, and environments contaminated with rodent excreta	Riccò <i>et al.</i> (2021a); D'Souza and Patel (2020)
Agricultural activities	Grain storage, animal feed handling, crop harvesting, and storage facility maintenance	Attract rodents and increase the likelihood of contact with contaminated urine, feces, and saliva	Riccò <i>et al.</i> (2021b)
Building maintenance and cleaning	Cleaning barns, warehouses, sheds, cabins, and abandoned buildings	Disturbance of contaminated dust may generate infectious aerosols containing hantaviruses	Richardson <i>et al.</i> (2013)
Residential conditions	Poor sanitation, inadequate waste disposal, and rodent-infested housing	Promote rodent colonization and increase human–rodent contact in domestic environments	Rodríguez-Morales <i>et al.</i> (2025); Tian <i>et al.</i> (2024)
Environmental factors	Living near forests, agricultural fields, rural settlements, or areas with high rodent densities	Greater likelihood of exposure to infected reservoir hosts and contaminated environments	Moirano <i>et al.</i> (2024); Clement <i>et al.</i> (2019)
Recreational activities	Camping, hiking, hunting, and outdoor activities in endemic areas	Increased contact with contaminated soil, vegetation, rodent nests, and enclosed habitats	de St Maurice <i>et al.</i> (2017)
High-risk behaviors	Cleaning rodent-infested areas without protective equipment	Direct exposure to aerosolized viral particles generated from contaminated rodent excreta	Wilken <i>et al.</i> (2015)
Ecological factors	Increased rodent population density and expansion of reservoir host distribution	Enhance environmental contamination and increase opportunities for virus transmission to humans	Klempa (2009); Douglas <i>et al.</i> (2022); Domingo (2026)
Climatic factors	Increased rainfall, favorable temperatures, and abundant food resources	Promote vegetation growth, rodent population expansion, and sustained virus circulation	Klempa (2009); Tian <i>et al.</i> (2024)
Demographic factors	Adult age groups and male sex	Greater participation in occupational, outdoor, and other high-risk activities associated with rodent exposure	Olsson <i>et al.</i> (2002); Mocanu <i>et al.</i> (2023); Hjelle and Torres-Pérez (2010)

size the significance of a One Health strategy that incorporates environmental, animal, and human health (Domingo, 2026). Health care providers, veterinarians, wildlife biologists, epidemiologists, and environmental scientists must work together to prevent disease effectively (Salvarani *et al.*, 2025). Comprehensive disease management strategies must include rodent population surveillance, human case monitoring, and environmental risk factor assessment (Afzal *et al.*, 2023).

It's important to take into account the financial cost of hantavirus outbreaks (D'Souza and Patel, 2020). Severe infections frequently necessitate hospital stays, critical care, and extended recuperation times, which raises healthcare expenses and reduces productivity (Chediack *et al.*, 2026). Recurrent outbreaks may put more pressure on local economies and public health systems in endemic areas (Tian *et al.*, 2018).

Prevention is still the mainstay of hantavirus control due to the lack of readily accessible specialized antiviral treatments and the scarcity of approved vaccinations in the majority of nations (Brocato and Hooper, 2019). Essential tactics for lowering the risk of transmission include environmental sanitation, occupational safety precautions, public education, and rodent control (Shehata *et al.*, 2025). For the early detection and containment of outbreaks, strengthening surveillance systems and enhancing diagnostic capabilities are equally crucial (Ekanayake *et al.*, 2025).

Economic impact

Despite being less common than other infectious diseases, hantavirus infections have a significant financial impact on afflicted communities, healthcare systems, and individuals (D'Souza and Patel, 2020). Both the direct expenses of medical care and the indirect costs of lost production, long-term recuperation, and public health initiatives have an impact on the economy (Smith *et al.*, 2019). These effects are most noticeable during epidemics, when quick mobilization of medical resources and disease prevention strategies is necessary (Afzal *et al.*, 2023).

Hospital stays, diagnostic procedures, and supporting care are the main causes of direct medical expenses (Mir, 2010). In patients with acute kidney injury, severe episodes of HFRS may necessitate extended hospital stays, close observation, and renal replacement treatment (Bergoč *et al.*, 2013). In a similar vein, individuals with HPS frequently need extensive supportive care, mechanical breathing, and admission to intensive care facilities (Jonsson *et al.*, 2010). Healthcare costs are significantly increased when specialized medical management is required, particularly in areas with scarce medical resources (McConnell, 2014).

Reduced worker productivity as a result of illness, disability, or death causes indirect economic costs (Seweryn *et al.*, 2025). After recovering from a severe hantavirus infection, patients may have prolonged weariness, diminished physical capacity, and a delayed return to work, which can result in lost income and lower economic output (Mustonen *et al.*, 2022). The loss of economically engaged people can have long-lasting socioeconomic effects on families and communities in extreme or catastrophic situations (Gorris *et al.*, 2025). In rural communities where manual work and agriculture are the main sources of income, these consequences can be especially noticeable (Garcia *et al.*, 2025).

Additionally, hantavirus epidemics may result in higher expenses for public health response initiatives (Ramos-Nino *et al.*, 2026). Significant financial resources are needed for surveillance programs, laboratory diagnostics, epidemiological studies, rodent control strategies, and community education initiatives (Nguyen *et al.*, 2025). In order to stop the spread of an outbreak, governments and public health organizations may need to set aside more funds for risk assessment, disease surveillance, and emergency response (D'Souza and Patel, 2020).

The healthcare industry may not be the only one affected economically (Smith *et al.*, 2019). Concerns about the spread of diseases can have an impact on outdoor enjoyment, tourism, and agriculture in endemic areas (Dubrulle *et al.*, 2025). Reduced economic activity and municipal income losses may result from temporary access restrictions to affected

areas and public anxiety about the danger of infection (Gorris *et al.*, 2025). In order to reduce future outbreaks, environmental management and rodent control frequently need ongoing funding (Shehata *et al.*, 2025).

As human encroachment into wildlife habitats, urbanization, and environmental changes offer new opportunities for disease onset, the economic burden of hantavirus infection is anticipated to rise (Tian and Stenseth, 2019). Therefore, by lowering the frequency of severe disease and minimizing outbreak-related expenses, investments in surveillance, preventive, and early detection programs may yield significant long-term economic advantages (Ramos-Nino *et al.*, 2026).

Vaccination

One of the most promising methods for preventing and managing hantavirus infections is vaccination, especially in areas where the illness is endemic (Krüger *et al.*, 2001). Nevertheless, despite decades of research, there are still few licensed hantavirus vaccines available, and there isn't currently a vaccine that offers widespread protection against the various hantavirus species that are circulating globally (Liu *et al.*, 2020). The development of vaccines is severely hampered by the genetic variety of hantaviruses, variations in clinical symptoms, and differences in geographic distribution (Widodo *et al.*, 2026).

In some endemic nations, especially those in East Asia, a number of inactivated vaccines have been created and put to use (Yi *et al.*, 2018). In certain high-risk groups, inactivated vaccines that target the Seoul and Hantaan viruses have been used in immunization programs and have shown promise in eliciting protective antibody responses (Park *et al.*, 2004). Concerns about the durability of immunity and the requirement for repeat shots to maintain sufficient protection persist despite the fact that these vaccinations have helped lower the frequency of HFRS in endemic areas (Chai *et al.*, 2025).

The creation of next-generation vaccine platforms has been made easier by developments in immunology and molecular biology (Farsiu *et al.*, 2026). By inducing both humoral and cellular immune responses, DNA vaccines encoding hantavirus glycoproteins have demonstrated encouraging immunogenicity in preclinical research and early clinical trials (Brocato *et al.*, 2024). Similarly, in experimental animal models, vaccines based on viral vectors and recombinant proteins have shown the ability to produce protective immunity and neutralizing antibodies (Safronetz *et al.*, 2009). These methods have benefits in terms of safety, scalability, and flexibility in response to new strains of the hantavirus (Ye *et al.*, 2026).

Research on messenger RNA (mRNA)-based vaccinations has also been spurred by recent interest in new vaccine technologies (Liu *et al.*, 2020). Researchers have investigated the possible use of mRNA platforms for hantavirus prevention, building on their success against other viral diseases (Afzal *et al.*, 2023). According to preliminary research, mRNA vaccines may elicit strong immune responses and offer a versatile approach to combating various hantavirus species (Saavedra *et al.*, 2021). However, further research is needed to assess their effectiveness, safety, and long-term preventive effects in humans (Park *et al.*, 2004).

The creation of broadly protective vaccinations that can target both Old World and New World hantaviruses is one of the main goals of contemporary vaccine research (Kumar and John, 2026). Given the widespread distribution of hantavirus reservoirs and the continuous risk of new infections, such vaccines would be especially beneficial (Jonsson *et al.*, 2010). Progress toward this objective is anticipated to be aided by the discovery of conserved viral antigens and enhanced knowledge of protective immunological correlates (Hussein *et al.*, 2011).

Widespread vaccine adoption is still hampered by a number of issues, despite notable advancements (Chai *et al.*, 2025). These include the necessity for extensive clinical studies to show efficacy, the heterogeneity among circulating hantavirus species, and the limited commercial incentives resulting from the relatively low frequency of sickness (Ahmed *et al.*, 2026). As a result, in addition to ongoing vaccine research projects, pre-

ventative efforts presently mainly focus on rodent control, environmental sanitation, and public health education (Shehata *et al.*, 2025).

Treatment

Since no antiviral medication has been shown to be consistently effective against all hantavirus species, the treatment of hantavirus infection is mostly supportive (Vial *et al.*, 2023). Improving clinical outcomes, especially in patients who experience severe symptoms like HFRS or HPS, requires early diagnosis and timely commencement of supportive therapy (Dheerasekara *et al.*, 2020).

The mainstay of care is still supportive therapy, which aims to manage problems, preserve organ function, and maintain hemodynamic stability (Afzal *et al.*, 2023). Because both dehydration and fluid overload can exacerbate illness outcomes, careful monitoring of fluid balance is crucial (Bi *et al.*, 2008). Correcting electrolyte imbalances, stabilizing blood pressure, and providing renal support are possible therapeutic strategies for patients with HFRS (Hong *et al.*, 2012). Renal replacement therapy, including hemodialysis, may be necessary in severe instances aggravated by acute kidney damage until renal function recovers (Mir and Panganiban, 2004).

Because of the quick development of pulmonary edema and respiratory failure in HPS, substantial breathing support is frequently required (Singh *et al.*, 2014). In severely ill patients, mechanical ventilation and oxygen augmentation are often necessary (Dheerasekara *et al.*, 2020). Extracorporeal membrane oxygenation (ECMO) has been utilized as a life-saving strategy in certain cases of severe cardiopulmonary impairment, especially when traditional respiratory support is inadequate (Yao and McDonald, 2016). For patients with severe HPS, early admission to an intensive care unit is frequently linked to better survival (Tortosa *et al.*, 2026).

For the treatment of hantavirus infection, a number of antiviral medications have been studied (Mayor *et al.*, 2021). When given early in the course of HFRS, ribavirin has demonstrated effectiveness against some Old World hantaviruses (Safronetz *et al.*, 2011). Early ribavirin treatment may lessen illness severity and death in certain patients, according to clinical research (Moreli *et al.*, 2014). However, once advanced disease has progressed, its benefits seem to be limited, and there is still conflicting data to support its usage in HPS (Singh *et al.*, 2014). As a result, ribavirin is not always advised for all hantavirus infections (Severson *et al.*, 2003).

Other therapy strategies, such as favipiravir, monoclonal antibodies, and immunomodulatory medications, have been investigated in recent studies (Chen *et al.*, 2026). Numerous potential drugs have shown antiviral action in experiments, however there is still little clinical data (Vergote *et al.*, 2021). In preclinical models, neutralizing monoclonal antibodies that target hantavirus glycoproteins have demonstrated promise and could potentially provide a post-exposure prophylactic or early therapeutic approach in the future (Mittler *et al.*, 2023).

Immunomodulatory treatments have also been studied because excessive inflammatory reactions aid in the development of the disease (Saavedra *et al.*, 2021). However, there is now little data to support the frequent use of corticosteroids and other anti-inflammatory drugs, and their therapeutic benefits are yet unknown (Jonsson *et al.*, 2010). To fully understand the function of immune-targeted therapies in hantavirus management, more research is required (Xiong *et al.*, 2026).

Control

Preventing human exposure to contaminated surroundings and infected reservoir hosts is the main strategy for controlling hantavirus infection (Krüger *et al.*, 2001). It is not possible to completely eradicate hantaviruses from nature since they are sustained in populations of wildlife, especially rats (de Oliveira *et al.*, 2014). Effective control techniques, therefore, concentrate on lowering the risk of transmission through inte-

grated methods that include public education, rodent control, environmental management, and disease surveillance (Shehata *et al.*, 2025).

Controlling the rodent population is still essential to hantavirus prevention (Afzal *et al.*, 2023). Rodent infestation can be reduced in residential, agricultural, and commercial settings by taking steps including removing food sources, protecting waste disposal systems, and limiting access to shelter locations (Awoniyi *et al.*, 2024). Rodent access and opportunities for human-rodent contact can be effectively reduced by structural changes, such as sealing building openings and enhancing cleaning procedures (Xiong *et al.*, 2026). Targeted trapping and population control initiatives may further reduce the danger of virus transmission in regions with high rodent density (Shehata *et al.*, 2025).

When it comes to avoiding aerosol exposure to rodent excrement, environmental hygiene is very crucial (Gorris *et al.*, 2025). To prevent producing contaminated dust, cleaning operations in rodent-infested areas should be carried out with the proper safeguards (Childs *et al.*, 1993). Before sweeping or handling possibly contaminated objects, wet disinfection techniques are advised (Wilken *et al.*, 2015). People who engage in cleaning, pest control, agriculture, or other high-risk jobs are encouraged to use personal protective equipment, such as gloves and respirators (Dheerasekara *et al.*, 2020).

Health education and public awareness are essential for lowering the risk of infection (Ahmed *et al.*, 2026). Programs for community-based education can increase awareness of risk factors, preventive measures, and hantavirus transmission (McConnell, 2014). Opportunities for exposure can be greatly decreased by educating the public about safe food storage procedures, appropriate waste management, and safety measures while accessing rodent-infested areas (de St Maurice *et al.*, 2017). In endemic areas and among populations with occupational or recreational risk factors, educational efforts are especially beneficial (Gorris *et al.*, 2025).

Monitoring reservoir host populations and early human case identification depend on surveillance technologies (Kim *et al.*, 2021). Programs for integrated surveillance that integrate laboratory, ecological, and epidemiological data can promote prompt public health measures and assist in identifying new dangers (Jonsson *et al.*, 2010). Enhancing epidemic preparedness and response capability can be achieved by keeping an eye on rodent numbers, virus prevalence among reservoir hosts, and environmental changes linked to disease onset (Guterres and de Lemos, 2018).

The One Health strategy has grown in significance in the prevention and management of hantaviruses (Ramos-Nino *et al.*, 2026). Multi-disciplinary cooperation is required to address the complex mechanisms driving hantavirus emergence since interactions between humans, animals, and the environment affect disease transmission (Tian and Stenseth, 2019). Public health officials, veterinarians, wildlife experts, ecologists, and environmental organizations working together can improve surveillance and increase the efficacy of preventative measures (Worsley-Tonks *et al.*, 2022). An integrated One Health framework for surveillance, prevention, and control is presented in Figure 3.

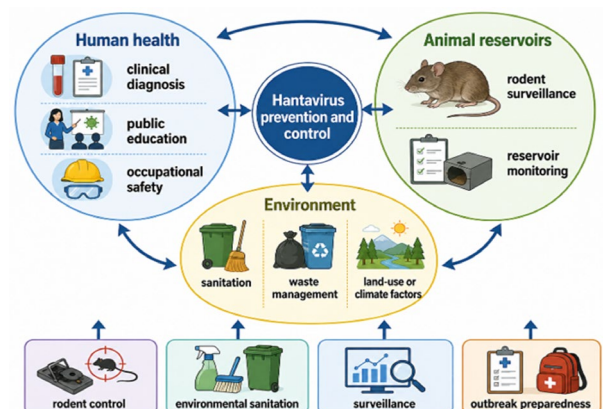


Figure 3. One Health framework for hantavirus surveillance, prevention, and control.

The majority of communities at risk do not now have widespread access to vaccination, despite ongoing advancements in vaccine research (Liu *et al.*, 2020). As a result, the best way to manage hantavirus infection is still through preventive measures that try to limit exposure (Dheerakara *et al.*, 2020). To lessen the effects of hantavirus disease and stop future outbreaks, ongoing funding for surveillance, public education, environmental management, and interdisciplinary cooperation will be crucial (Brocato *et al.*, 2024).

Conclusion

Hantaviruses are widespread zoonotic pathogens that can cause serious illnesses including HFRS and HPS, which make them a serious concern to public health. Exposure to polluted settings and rodent reservoirs is the main cause of transmission. Viral replication, endothelial dysfunction, and host immune responses interact intricately during disease progression, resulting in distinctive pulmonary or renal symptoms. Treatment is still mostly supportive despite advancements in surveillance, diagnostics, and vaccine development. Therefore, lowering the burden of hantavirus infections and enhancing readiness for future outbreaks require bolstering surveillance systems, encouraging preventative actions, and implementing a One Health approach.

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Conflict of interest

The authors declare that there is no conflict of interest.

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