

Environmental Stressors and Viral Hepatitis: Rethinking Disease Ecology in an Era of Climate Change

Dr Deepika Sangtani¹ & Sakshi Chauhan¹

¹HEC Group of Institutions Jagjeetpur, Laksar Road, Haridwar

Corresponding author: sakshichauhan24681@gmail.com

Doi: <https://doi.org/10.5281/zenodo.22686025>

Received: 04 August 2026

Accepted: 19 August 2026

Abstract

Viral hepatitis remains a major global public health challenge, with hepatitis A–E viruses causing substantial morbidity and mortality despite advances in vaccination, antiviral therapy, and surveillance. Increasing evidence suggests that environmental stressors—including climate change, air and water pollution, chemical contaminants, land-use change, urbanization, and biodiversity loss shape the disease ecology of viral hepatitis by influencing transmission, host susceptibility, disease progression, and health outcomes. This review synthesizes current evidence on the ecological determinants of viral hepatitis, the biological mechanisms linking environmental exposures to liver injury, virus-specific environmental interactions, and the potential of One Health, wastewater-based epidemiology, GIS, remote sensing, artificial intelligence, and environmental surveillance to strengthen hepatitis prediction and control. The review also identifies key knowledge gaps and future research priorities, emphasizing the need for interdisciplinary and climate-resilient public health strategies. Integrating environmental management with hepatitis prevention and control will be essential for achieving the WHO goal of eliminating viral hepatitis as a public health threat by 2030, particularly in vulnerable countries such as India.

Keywords: hepatitis; Environmental stressors; Climate change; One Health; Disease ecology; Public health.

Introduction

Viral hepatitis remains a major global public health challenge despite advances in vaccination, antiviral therapy, and disease surveillance (**World Health Organization [WHO], 2024; Sarin *et al.*, 2023; Puri *et al.*, 2023**). The five hepatitis viruses hepatitis A (HAV), hepatitis B (HBV), hepatitis C (HCV), hepatitis D (HDV), and hepatitis E (HEV) continue to cause millions of infections worldwide. Chronic HBV and HCV infections are major causes of liver cirrhosis and hepatocellular carcinoma, whereas HAV and HEV primarily cause acute infections, particularly in regions with poor sanitation and unsafe drinking water (**Acharya *et al.*, 2021; Arora *et al.*, 2022; Chowdhury *et al.*, 2021**). According to the WHO, approximately 304 million people were living with chronic HBV or HCV infection in 2022, resulting in nearly 1.3 million deaths worldwide (**WHO, 2024**).

India carries a substantial burden of viral hepatitis. According to the National Centre for Disease Control (NCDC) and the Indian National Association for the Study of the Liver (INASL), HBV and HCV remain major public health concerns, while HAV and HEV continue to cause outbreaks associated with poor sanitation, contaminated water, and extreme weather events (Sarin *et al.*, 2023; NCDC, 2023).

To achieve the WHO target of eliminating viral hepatitis as a public health threat by 2030, expanded vaccination, early diagnosis, improved treatment, and strengthened surveillance are essential (WHO, 2022). However, environmental changes such as climate change, pollution, rapid urbanization, land-use change, and biodiversity loss are increasingly recognized as important factors influencing hepatitis transmission and disease progression (IPCC, 2023; Satsangi & Chawla, 2016; Kumar *et al.*, 2023). Floods, rising temperatures, and water contamination increase the risk of HAV and HEV outbreaks, whereas air pollution, heavy metals, and chemical contaminants may accelerate liver injury in individuals with chronic HBV and HCV infection. Land-use change and increased human–animal interactions may also contribute to zoonotic transmission of HEV (Arankalle *et al.*, 1994).

These observations highlight that viral hepatitis is shaped not only by the virus itself but also by complex interactions among the host, the environment, and socioeconomic factors. Accordingly, this review examines how environmental stressors—including climate change, air and water pollution, chemical contaminants, urbanization, land-use change, and biodiversity loss—influence the transmission, progression, and control of viral hepatitis. It also discusses the underlying biological mechanisms, emerging surveillance approaches, existing knowledge gaps, and future research priorities to support climate-resilient and One Health–based hepatitis control strategies.

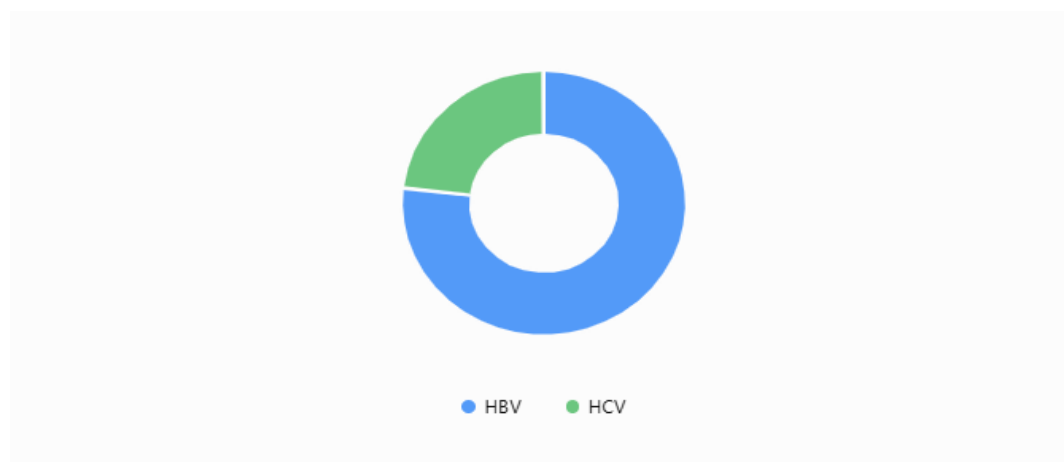


Figure 1: Global distribution of chronic viral hepatitis infections

To understand how environmental stressors influence viral hepatitis, it is first necessary to examine the disease from a disease ecology perspective, where interactions among the virus, host, and environment determine disease dynamics.

1. Viral Hepatitis in the Context of Disease Ecology

Viral hepatitis is made up of five viruses that affect the liver—HAV, HBV, HCV, HDV and HEV—these are still problems for health around the world. Even though they all hurt the liver they are different in how they work how they spread how long they stay in the world who they affect and what happens when someone gets it. From the way diseases work hepatitis is not a sickness but something that happens because of the way the virus, the person and the environment all interact (Ostfeld, 2017).

1.1 Diversity of Hepatitis Viruses (HAV–HEV)

The five hepatitis viruses have ways of working and how they spread. HAV and HEV are mostly passed on through the mouth from the stool so keeping things clean having water and good food is very important to stop it. Outbreaks are often because of water that's not clean not taking care of waste, floods and bad times (Kumar *et al.* 2021).

On the hand HBV, HCV and HDV are spread through blood like from needles, not safe blood, sex and from mom to baby. Having HBV and HCV for a time can make the liver get very bad and HDV needs HBV to work and can make the liver disease worse (EASL, 2024). These differences show that each virus has its place in the natural world shaped by the environment what people do and how society is set up.

Table 1: Comparision of The Five Hepatitis Viruses

Virus	Main Transmission	Chronic Infection	Vaccine	Major Environmental Influence
HAV	Fecal–oral	No	Yes	Poor sanitation, contaminated water, floods
HBV	Blood, sexual, mother-to-child	Yes	Yes	Pollution may worsen liver disease
HCV	Blood	Yes	No	Air pollution and chemicals aggravate liver injury
HDV	With HBV infection	Yes	Indirectly prevented by HBV vaccine	Environmental stress may worsen disease progression
HEV	Contaminated water, zoonotic	Usually No	Limited availability	Climate change, floods, poor sanitation, animal reservoirs

Source: Adapted and synthesized from World Health Organization (2024); European Association for the Study of the Liver (2024); Kumar, N., Izopet, J., & Pavio, N. (2021); Jacobsen, K. H. (2018); Kim, J. H. *et al.* (2022).

1.2 Ecological Determinants of Transmission

The way hepatitis spreads is because of things like the environment what people do, animals that carry it and how rich or poor people're

Environmental Reservoirs

Environmental reservoirs are especially important for HAV and HEV which can live in waste water, rivers, ground water, shellfish and food that's not clean. Looking at waste water is a way to find out if the virus is around (**Ahmed *et al.*, 2020**).

Human Behaviour

Things people do like not washing hands using needles that're not safe not using protection when having sex using drugs and not getting vaccines help spread hepatitis. Cities growing, people moving around and not having health care when there are weather events make it spread even more (**Stanaway *et al.* 2022**).

Animal Reservoirs

Animals that carry diseases are very important in the way HEV works. Pigs, wild boars, deer, rabbits and other animals are places where HEV can live. Making more farms and people meeting animals often makes it easier for the virus to move from animals to people, which shows why we need to look at all parts of the health system (**Velavan & Meyer 2021**).

Socio-economic Factors

Being poor not having clean water not having enough space and not having enough health care are big reasons why hepatitis is a big problem, especially in countries that do not have much money. Changes in the weather make these problems worse by making people move not have enough to eat and be in places that make it easier for diseases to spread (**Whitmee *et al.*, 2015**).

1.3 Current Knowledge and Existing Gaps

Advances in hepatitis research have improved diagnosis, HBV vaccination, HCV treatment, and disease surveillance. However, most studies focus on viral and clinical aspects, with limited attention to environmental and ecological influences on hepatitis transmission and progression.

Climate change, pollution, biodiversity loss, and land-use changes may affect hepatitis ecology, but evidence is mainly based on short-term and single-factor studies, leaving long-term interactions poorly understood (**Semenza & Paz, 2021**). The combined effects of environmental exposures such as air pollutants, heavy metals, chemicals, and microplastics on chronic liver disease remain unclear (**Landrigan *et al.*, 2018**).

Additionally, environmental monitoring tools such as wastewater surveillance, GIS, remote sensing, and predictive models are not widely integrated into hepatitis control programs (**Larsen *et al.*, 2023**). Future research should focus on interdisciplinary approaches, long-term studies, and combined environmental–health monitoring to develop effective climate-resilient hepatitis prevention strategies.

HOST
(Immunity, Genetics,
Nutrition, Vaccination,
Age, Co-morbidities)

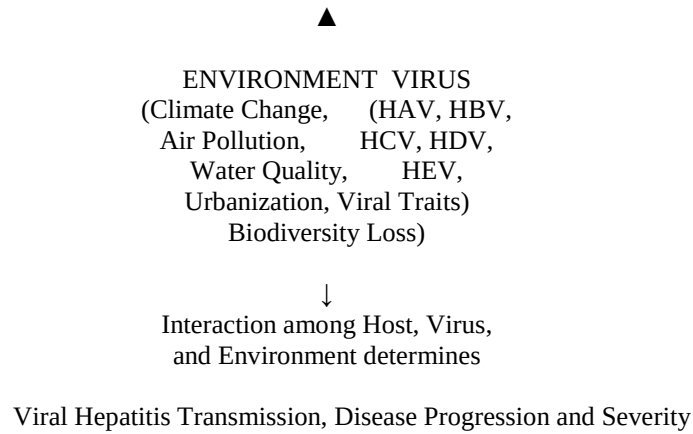


Figure 2: Disease Ecology of Viral Hepatitis

Source: Synthesized from Ostfeld (2017) Whitmee *et al.* (2015) Destoumieux-Garzón *et al.* (2018). Who (2024).

Among the ecological determinants discussed above, environmental stressors have emerged as major drivers influencing hepatitis transmission and progression.

2. Environmental Stressors Relevant to Viral Hepatitis

factors such as climate change, pollution, poor water quality, chemical contaminants, land-use change and biodiversity loss influence viral hepatitis transmission and progression by affecting virus survival, host susceptibility and public health systems (Romanello *et al.*, 2024; Whitmee *et al.*, 2015).

Table 2: Environmental Stressors Relevant to Viral Hepatitis

Environmental Stressor	Effect on Viral Hepatitis	Most Affected Viruses
Climate change	Increases floods, droughts, water contamination	HAV, HEV
Air pollution	Promotes oxidative stress and liver fibrosis	HBV, HCV
Water pollution	Contaminates drinking water and food	HAV, HEV
Chemical contaminants	Accelerate liver inflammation and fibrosis	HBV, HCV
Land-use change & Urbanization	Increases human–animal contact and environmental contamination	HEV
Biodiversity loss	Alters ecosystem balance and zoonotic disease risk	HEV

Sources: Adapted and synthesized from Intergovernmental Panel on Climate Change (IPCC, 2023); World Health Organization (WHO, 2024); Romanello *et al.* (2024); Whitmee *et al.* (2015); Kim *et al.* (2022); Kamar *et al.* (2021); Daszak *et al.* (2020).

2.1 Climate Change

Climate change affects hepatitis ecology through temperature rise, rainfall variability and extreme weather events. Flooding, sanitation and water contamination increase HAV and HEV outbreaks while climate-related disruptions affect vaccination and healthcare access (**IPCC, 2023; WHO, 2024**).

2.2 Air Pollution

Air pollutants such as PM_{2.5}, ozone and nitrogen dioxide promote stress and inflammation which may accelerate liver fibrosis and complications in chronic HBV and HCV infections (**Kim et al. 2022**).

2.3 Water Quality Degradation

Contaminated water, wastewater and inadequate sanitation are major drivers of HAV and HEV transmission. Safe water supply, sanitation and wastewater surveillance are essential for prevention (**WHO, 2024; Ahmed et al., 2020**).

2.4 Chemical Contaminants

Heavy metals, pesticides and industrial chemicals contribute to liver damage through stress and inflammation potentially worsening chronic hepatitis outcomes (**Jaishankar et al., 2014; Kim et al., 2022**).

2.5 Land-Use Change and Urbanization

Deforestation agricultural expansion and rapid urbanization alter ecosystems increase pollution. Promote water contamination and zoonotic transmission particularly of HEV (**IPCC, 2023; Whitmee et al., 2015**).

2.6 Biodiversity Loss and Ecosystem Disruption

Ecosystem degradation reduces protection against pathogens and may increase environmental contamination and zoonotic risks. A One Health approach linking ecosystem conservation and disease surveillance is essential for hepatitis control (**IPBES, 2019; Daszak et al., 2020**).

In India environmental stressors are particularly relevant because rapid urbanization, industrial pollution, poor wastewater management and climate-related disasters such as floods and heatwaves have increased the risk of hepatitis transmission. States including Uttar Pradesh, Bihar, Assam, Kerala and Maharashtra have reported outbreaks of hepatitis A and E following water contamination during monsoon seasons (**NCDC, 2023; ICMR, 2022**).

Although several environmental stressors contribute to viral hepatitis, climate change is increasingly recognized as the overarching driver that intensifies many of these environmental changes.

3. Climate Change and the Changing Ecology of Viral Hepatitis

Climate change is altering hepatitis ecology by affecting temperature, rainfall patterns, extreme weather events, water quality, and sanitation. These changes influence HAV and HEV transmission, while indirectly affecting HBV and HCV through healthcare disruption and increased environmental vulnerabilities (**Romanello et al., 2024; WHO, 2024**).

3.1 Climate-Sensitive Transmission Pathways

Changes in temperature, rainfall, floods, and droughts affect pathogen survival, environmental persistence, human exposure, and healthcare access. Increased water and food contamination mainly promotes HAV and HEV transmission, while climate-related disruptions can reduce vaccination, diagnosis, and treatment services for HBV and HCV (Semenza & Paz, 2021; IPCC, 2023).

3.2 Floods, Storms and Waterborne Hepatitis

Floods and storms can contaminate water sources with sewage, increasing HAV and HEV outbreaks, especially in areas with poor sanitation. They also damage healthcare systems, interrupt surveillance, and displace populations, increasing infection risks (IPCC, 2023; Sridhar *et al.*, 2022).

3.3 Drought, Water Scarcity and Sanitation

Drought-related water scarcity reduces hygiene and sanitation, increasing exposure to contaminated water and promoting HAV and HEV transmission (UNCCD, 2022; UNICEF & WHO, 2023). In India, climate vulnerability due to monsoon dependence, floods, and water shortages may increase hepatitis risks, particularly in densely populated urban and peri-urban areas (IPCC, 2023; IMD, 2023).

These environmental changes influence viral hepatitis through interconnected biological and ecological mechanisms.

4. Biological Mechanisms Linking Environmental Stressors to Viral Hepatitis

Environmental stressors contribute to viral hepatitis progression by promoting oxidative stress, chronic inflammation, immune dysfunction, gut–liver imbalance, epigenetic changes, and fibrosis. These pathways interact with viral infections, increasing the risk of cirrhosis and hepatocellular carcinoma (HCC) (EASL, 2024; Kim *et al.*, 2022).

4.1 Oxidative Stress

Environmental pollutants, heavy metals, and pesticides increase reactive oxygen species (ROS), causing mitochondrial dysfunction, cellular damage, and liver injury (Sies, 2020; Jaishankar *et al.*, 2014). In HBV and HCV infections, increased oxidative stress accelerates fibrosis and may contribute to HCC development (Kim *et al.*, 2022).

4.2 Chronic Inflammation

Pollutants stimulate inflammatory pathways and cytokines such as TNF- α , IL-1 β , and IL-6, promoting hepatocyte damage and fibrosis. These effects can worsen viral-induced inflammation and disease progression (Cave *et al.*, 2010; Medzhitov, 2021).

4.3 Immune Dysregulation

Environmental contaminants can impair immune cells, including macrophages, dendritic cells, NK cells, and T lymphocytes, weakening antiviral responses and supporting chronic HBV and HCV infection (Iwasaki & Medzhitov, 2015; Landrigan *et al.*, 2018). Additional stressors such as heat, malnutrition, and pollution may further contribute to liver injury and fibrosis (Kubes & Jenne, 2018).

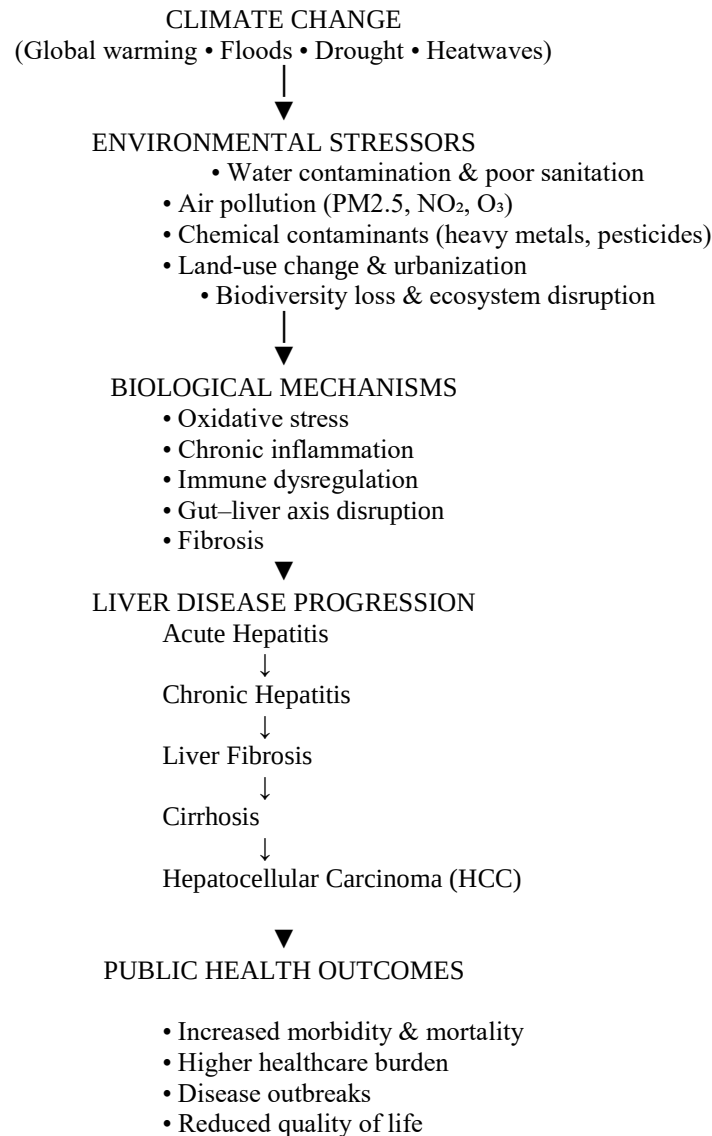


Figure 3: Climate Change–Driven Pathway of Viral Hepatitis Progression

Source: Adapted and synthesized from IPCC (2023); Romanello *et al.* (2024); Whitmee *et al.* (2015); Kim *et al.* (2022); EASL (2024); World Health Organization (2024).

Although these biological mechanisms are broadly applicable, their effects differ among the five hepatitis viruses because of differences in transmission routes and pathogenesis.

5. Virus-Specific Environmental Interactions

Environmental stressors influence hepatitis viruses differently due to their transmission routes and ecological characteristics. HAV and HEV are strongly affected by water quality, sanitation and climate-related factors while HBV, HCV and HDV are mainly influenced through factors that modify disease progression (**WHO, 2024; Jacobsen, 2018**).

5.1 Hepatitis A Virus (HAV)

HAV is transmitted through the oral route and is strongly associated with poor sanitation contaminated water and unsafe food. Flooding, wastewater contamination and inadequate hygiene increase outbreak risk. Improving water quality, sanitation, food safety and wastewater surveillance are prevention strategies (**WHO, 2024; Bosch et al. 2018**).

5.2 Hepatitis E Virus (HEV)

HEV spreads through contaminated water and zoonotic transmission. Livestock, pigs act as reservoirs while habitat changes, poor waste management and climate-related events increase transmission risk. A One Health approach integrating management veterinary surveillance and public health measures is essential for HEV control (**Kumar et al. 2021; Meng, 2022**).

5.3 Hepatitis B Virus (HBV)

HBV is a blood-borne infection. Environmental stressors such, as air pollution, heavy metals and chemical exposure can accelerate liver inflammation, fibrosis and cancer risk. Environmental protection can support disease management (**WHO, 2024**).

5.4 Hepatitis C Virus (HCV)

HCV transmission is not directly influenced by factors; however pollutants and toxic chemicals may worsen liver damage by increasing oxidative stress and inflammation. Reducing exposures may improve long-term disease outcomes (**Kim et al. 2022**).

5.5 Hepatitis D Virus (HDV)

HDV needs HBV to multiply and causes liver disease. Even though environmental factors do not directly cause transmission environmental stress can affect how the disease gets worse and make it harder to treat (**WHO, 2024**). The impact of environmental stressors becomes particularly evident in regions where viral hepatitis is highly endemic.

6. Environmental Influences in HBV-Endemic Regions

In areas where HBV's common air pollution, heavy metals, pesticides and disasters linked to weather increase stress and inflammation making liver damage worse. Climate change can also mess up vaccination, testing, treatment and follow-up. Poverty and weak health systems add problems (**Kim et al., 2022**).

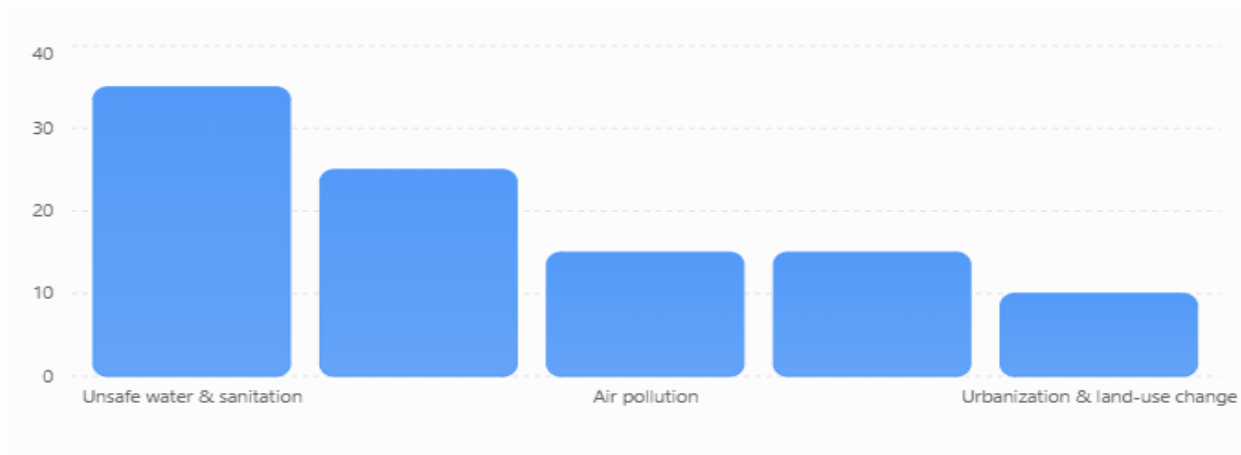


Figure 4 :Major environmental influences in HBV-endemic regions.

Source: Conceptual synthesis based on the reviewed literature (Romanello *et al.*, 2024; Whitmee *et al.*, 2015; World Health Organization, 2024).

6. Emerging Approaches and Future Directions

Environmental stressors such as pollution and climate-related changes may worsen HDV progression by increasing inflammation and liver fibrosis. However, more research is needed to understand these interactions (Wild, 2012). Integrating environmental and public health approaches through the **One Health framework** can improve hepatitis prevention and control.

6.1 One Health Framework

The One Health approach links human, animal, and environmental health. For HEV control, it includes monitoring animal reservoirs, ensuring safe water, and protecting ecosystems to reduce transmission risks (FAO, UNEP, WHO & WOA, 2022).

6.2 Wastewater-Based Epidemiology

Wastewater monitoring helps detect HAV and HEV circulation, identify outbreaks early, and support timely interventions (Ahmed *et al.*, 2020).

6.3 GIS and Remote Sensing

GIS and satellite-based remote sensing combine climate, environmental, and population data to identify high-risk areas and predict disease patterns (Semenza & Paz, 2021; NASA, 2023).

6.4 Artificial Intelligence and Environmental Surveillance

AI-based models analyze environmental and health data to predict outbreaks and improve planning. Integrated surveillance of water, pollution, climate, and animal health strengthens hepatitis prevention strategies (Topol, 2019; WHO, 2024).

Overall using One Health, WBE, GIS remote sensing, AI and environmental checks improves how we predict, track and control hepatitis in a changing world.

Table 3: Emerging Tools for Hepatitis Surveillance and Control

Approach	Purpose	Benefit
One Health	Integrates human, animal, and environmental health	Better prevention and disease control
Wastewater Surveillance	Detects viruses in sewage	Early outbreak detection
GIS	Maps disease distribution	Identifies high-risk areas
Remote Sensing	Monitors climate and land-use changes	Predicts environmental risk
Artificial Intelligence	Analyses environmental and health data	Improves outbreak prediction
Environmental Surveillance	Monitors water, pollution, and wildlife	Supports early warning systems

Source: Synthesized from FAO, UNEP, WHO, & WOA (2022); Ahmed *et al.* (2020); Aslan *et al.* (2021); Paz (2021); NASA (2023); Topol (2019); World Health Organization (2024).

The implementation of these emerging tools has important implications for strengthening public health strategies against viral hepatitis.

7. Public Health Implications

Climate change, pollution, poor water quality and urbanization influence hepatitis transmission and progression. Integrating environmental management with health strategies is essential for achieving WHO hepatitis elimination goals (WHO, 2024).

Climate-resilient health systems, integrated surveillance, vaccination, WASH improvement and pollution control can reduce hepatitis risks (WHO, 2023; Ahmed *et al.*, 2020; UNICEF & WHO, 2023). Community awareness and One Health approaches further strengthen prevention (IPCC, 2023).

In India, programs such as the National Viral Hepatitis Control Program, Universal Immunization Programme, Swachh Bharat Mission and Jal Jeevan Mission provide opportunities for integrated hepatitis control and support WHO 2030 targets (WHO, 2024).

Despite these advances, several scientific and policy challenges remain that require further investigation.

8. Knowledge Gaps and Future Research Priorities

More research is needed to understand how environmental factors influence hepatitis. A One Health approach integrating environmental, health and scientific fields is essential (Whitmee et al., 2015; WHO, 2024).

Future studies should focus on large-scale epidemiological research, long-term exposure studies, multi-omics approaches, improved environmental monitoring and climate-based models for predicting hepatitis risks (Wild, 2012; Hasin et al., 2017; Vrijheid, 2014; IPCC, 2023).

Conclusion

Viral hepatitis is still a problem worldwide. New evidence shows that things like weather, pollution, water problems and cities affect how it spreads and gets worse. So hepatitis should be seen as an environmental health issue where people, germs and the world all connect (Whitmee *et al.*, 2015; WHO, 2024).

Globally linking environment science with hepatitis plans can help stop disease in a changing world. In India better toilets, shots, better checks and using One Health through projects like NVHCP and Swachh Bharat can help lower hepatitis and reach WHO goals by 2030.

References

- 1.Ahmed, W., Angel, N., Edson, J., Bibby, K., Bivins, A., O'Brien, J. W.... Mueller, J. F. (2020). Confirmed detection of SARS-CoV-2 in untreated wastewater in Australia. *Science of the Total Environment* 728, 138764.
- 2.Barua, M., Bhagwat, S. A., & Jadhav, S. (2013). The hidden dimensions of wildlife conflict. *Biological Conservation*, 157 309–316.
- 3.Bosch, A., Gkogka, E., Le Guyader, F. S., Loisy-Hamon, F., Lee, A., Van Lieshout, L.... Phister, T. (2018). Foodborne viruses: Detection, risk assessment and control options. *International Journal of Food Microbiology*, 285, 110–128.
- 4.Cave, M., Falkner, K. C., Ray, M., Joshi-Barve, S., Brock, G., Khan, R., & McClain C. J. (2010). Toxicant-associated steatohepatitis in vinyl chloride workers. *Hepatology*, 51(2) 474–481.
- 5.Cook, N., Bertrand, I., Gantzer, C., Pinto, R. M., & Bosch A. (2019). Persistence of hepatitis A virus in the environment and food. *Food and Environmental Virology*, 11(1) 1–10.
- 6.Destoumieux-Garzón, D., Mavingui, P., Boetsch, G., Boissier, J., Darriet, F., Duboz, P.... Voituren, Y. (2018). The One Health concept: 10 years old and a long road ahead. *Frontiers in Veterinary Science*, 5 14.
- 7.Dickman, A. J. (2010). Complexities of conflict: The importance of considering factors for effectively resolving human–wildlife conflict. *Animal Conservation*, 13(5) 458–466.

8. European Association for the Study of the Liver. (2024). EASL Clinical Practice Guidelines on hepatitis B.
9. European Association for the Study of the Liver. (2024). EASL Clinical Practice Guidelines, on hepatitis C.
10. European Food Safety Authority. (2021). Scientific opinion on viruses and food safety.
11. European Food Safety Authority. (2023). Scientific opinion on hepatitis E virus and food safety.
12. FAO, UNEP, WHO, & WOA. (2022). One Health Joint Plan of Action (2022–2026).
13. Food and Agriculture Organization. (2022). The State of Food and Agriculture 2022.
14. Gupta, S., & Bhatt, D. (2021). Human–wildlife conflict in Uttarakhand: challenges and conservation strategies. *Current Science*, 120(8) 1328–1335.
15. Hasin, Y., Seldin, M., & Lusis, A. (2017). Multi-omics approaches to disease. *Genome Biology*, 18 83.
16. Hellmér, M., Paxéus, N., Magnius, L., Enache, L., Arnholm, B., Johansson, A.... Norder, H. (2014). Detection of viruses in sewage. *Applied and Environmental Microbiology*, 80(21) 6771–6781.
17. Inskip, C., Zimmermann, A. (2009). Human–felid conflict: A review of patterns and priorities. *Oryx*, 43(1) 18–34.
18. Intergovernmental Panel on Climate Change. (2023). Climate Change 2023: Synthesis Report. Geneva: IPCC.
19. Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B., & Beeregowda, K. N. (2014). Toxicity, mechanism and health effects of metals. *Interdisciplinary Toxicology*, 7(2) 60–72.
20. Jacobsen, K. H. (2018). Global epidemiology of hepatitis A virus. *Cold Spring Harbor Perspectives in Medicine* 8(10) a031716.
21. Kamar, N., Izopet, J., & Pavio, N. (2021). Hepatitis E virus infection. *Nature Reviews Disease Primers*, 7 18.
22. Kim, J. H. et al. (2022). Environmental. Chronic liver disease. *Environmental Health Perspectives*.
23. King, L. E., Douglas-Hamilton, I., & Vollrath F. (2011). Beehive fences as a deterrent for elephants. *Conservation Biology*, 25(2) 270–278.

24. Landrigan, P. J., Fuller, R., Acosta, N. J., et al. (2018). The Lancet Commission on Pollution and Health. *The Lancet*, 391(10119) 462–512.
25. Meng, X. J. (2022). Zoonotic and foodborne hepatitis E virus. *Annual Review of Animal Biosciences* 10 387–410.
26. National Aeronautics and Space Administration. (2023). *Earth Observation for Global Environmental Health*.
27. Romanello, M., et al. (2024). The Lancet Countdown on Health and Climate Change 2024. *The Lancet*.
28. Salines, M., et al. (2017). Hepatitis E virus infection in pigs. *Veterinary Research*, 48 31.
29. Semenza, J. C., & Paz, S. (2021). Climate. Infectious disease dynamics. *Environmental Research*, 195, 110839.
30. Shaffer, L. J., et al. (2019). Human–wildlife. Coexistence. *Conservation Biology*.
31. Sukumar, R. (1994). Ecology of the elephant in southern India. *Journal of Tropical Ecology* 10 33–53.
32. Topol, E. J. (2019). High-performance medicine: The convergence of artificial intelligence. *Nature Medicine*, 25 44–56.
33. Treves, A., & Karanth K. U. (2003). Human– conflict and conservation. *Conservation Biology*, 17(6) 1491–1499.
34. UNICEF,. World Health Organization. (2023). *Progress on Household Drinking Water, Sanitation and Hygiene 2000–2022*.
35. Velavan, T. P., & Meyer, C. G. (2021). Hepatitis E virus: Ecology and epidemiology. *Clinical Microbiology Reviews*.
36. Vrijheid, M. (2014). The exposome: A paradigm. *Occupational and Environmental Medicine*, 71(12) 876–878.
37. Whitmee, S., et al. (2015). Safeguarding health in the Anthropocene epoch. *The Lancet*, 386(10007) 1973–2028.
38. Wild C. P. (2012). The exposome: From concept to utility. *International Journal of Epidemiology* 41(1) 24–32.

39. Woodroffe, R., Thirgood, S., & Rabinowitz, A. (2005).. *Wildlife: Conflict or Coexistence?* Cambridge University Press.
40. World Health Organization. (2021). *WHO Global Air Quality Guidelines*.
41. World Health Organization. (2022). *Global Health Sector Strategies on HIV, Viral Hepatitis and Sexually Transmitted Infections 2022–2030*.
42. World Health Organization. (2023). *Operational Framework for Building Climate-Resilient Health Systems*.
43. World Health Organization. (2024). *Global Hepatitis Report 2024*.
44. World Health Organization. (2024). *Hepatitis B Fact Sheet*.
45. World Health Organization. (2024). *Hepatitis C Fact Sheet*.
46. World Health Organization. (2024). *Hepatitis E Fact Sheet*.
47. World Health Organization. (2024). *Hepatitis A Fact Sheet*.
48. World Health Organization. (2024). *Water, Sanitation and Hygiene (WASH) Strategy*.
49. Younossi Z. M., et al. (2018). Global epidemiology of hepatitis C virus infection. *Journal of Hepatology*, 69(1) 20–28.
50. Yin, P., et al. (2023). Long-term exposure to air pollution and chronic liver disease outcomes. *The Lancet Planetary Health*.
51. Aslan, A., Cole, Z. A. Bhattacharya, A., & Oyibo O. O. (2021). The effectiveness of wastewater surveillance for monitoring diseases. *Science of the Total Environment* 785, 147266.
52. Bivins, A., North, D., Ahmad, A., Ahmed, W., Alm, E., Been, F., et al. (2020). Wastewater-based epidemiology: collaborative efforts to monitor infectious diseases. *Environmental. Technology*, 54(13) 7754–7757.
53. Daszak, P., Cunningham, A. A., & Hyatt A. D. (2000). Emerging infectious diseases of wildlife: Threats to biodiversity and human health. *Science*, 287(5452) 443–449.
54. European Centre for Disease Prevention and Control. (2023). *Hepatitis A and E Surveillance Report 2023*. Stockholm: ECDC.

55. GBD 2021 Hepatitis Collaborators. (2024). Global burden of hepatitis 1990–2021: Findings from the Global Burden of Disease Study 2021. *The Lancet. Hepatology*.
56. Haines, A., & Ebi K. L. (2019). The imperative for climate action to protect health. *New England Journal of Medicine* 380(3) 263–273.
57. Hovi, T., Shulman, L. M., Van der Avoort, H., Deshpande, J., Roivainen, M., & De Gourville, E. M. (2012). Role of surveillance in global disease control. *Current Opinion in Virology*, 2(5) 595–601.
58. Levy, B. S., & Patz J. A. (2015). Climate change, human rights and social justice. *Annals of Global Health*, 81(3) 310–322.
59. Li, X., Ning, H., Wang, G., et al. (2023). Air pollution and liver disease: epidemiological evidence. *Environmental Pollution*, 316 120585.
60. Nature Reviews. Hepatology. (2023). Environmental determinants of liver diseases. *Nature Reviews. Hepatology*, 20(8) 465–467.
61. Patz, J. A., Campbell-Lendrum, D., Holloway, T., & Foley J. A. (2005). Impact of climate change on human health. *Nature*, 438(7066) 310–317.
62. Prüss-Ustün, A., Wolf, J., Corvalán, C., Bos, R., & Neira, M. (2016). *Preventing Disease Through Healthy Environments*. Geneva: World Health Organization.
63. Redpath, S. M., Bhatia, S., & Young, J. (2015). Tilting at wildlife: Reconsidering wildlife conflict. *Oryx*, 49(2) 222–225.
64. Rockström, J., Steffen, W., Noone, K. et al. (2009). A safe operating space for humanity. *Nature*, 461(7263) 472–475.
65. Steffen, W., Richardson, K., Rockström, J., et al. (2015). Planetary boundaries: Guiding development on a changing planet. *Science*, 347(6223) 1259855.
66. United Nations Environment Programme. (2022). *Making Peace with Nature: A Scientific Blueprint to Tackle the Climate, Biodiversity and Pollution Emergencies*. Nairobi: UNEP.
67. United Nations. (2015). *Transforming Our World: The 2030 Agenda for Sustainable Development*. New York: United Nations.

68. Venter, O., Sanderson, E. W., Magrath, A., et al. (2016). Sixteen years of change in the terrestrial human footprint. *Nature Communications*, 7 12558.
69. World Meteorological Organization. (2023). *State of the Global Climate 2023*. Geneva: WMO.
70. Zhang, Y., Chen, Y., Wang, S., et al. (2022). Climate. Infectious diseases: Implications, for global public health. *Environmental Research*, 204 112298.