In-Depth Review Article

Viral Zoonotic Diseases in India:
A One Health Saga of Human, Animal, and Environmental Confluence

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Abstract: Zoonotic viral infections represent an important public health problem. These diseases pose serious risks to both animal and human health with an ultimate impact on livelihoods and economies. The recent upsurge in COVID-19 infections which caused a global pandemic has exposed our vulnerabilities and was a wakeup call to build resilient healthcare ecosystems globally. We have not only highlighted the global drivers of the emergence & re-emergence of zoonotic diseases but have also elucidated the Indian saga of management of viral zoonotic diseases at human-animal-environment interface through One Health approaches. To combat zoonotic diseases, a One Health approach dovetailed with public health measures that optimally thwarts ongoing or potential health threats at human-animal and environmental interface is the need of the hour.

Key Words: Zoonotic Diseases, One Health Approach, COVID-19, Viral Diseases, Reverse Zoonoses

Introduction: The world has seen that zoonotic diseases can cause pandemics. The World Health Organization (WHO) estimates that 25% of the 57 million annual deaths that occur globally are caused by microbes with a major proportion in the developing world (1). It has been identified that 1,415 species of infectious organisms are pathogenic to humans. These include 217 viruses and prions, 538 bacteria and rickettsia, 307 fungi, 66 protozoa and 287 helminths. Zoonoses constitute 868 (61%) of all known infectious diseases, with humans serving as the primary reservoir for only 33%. Of the 175 diseases considered emerging, 132 (75%) are zoonotic (2). The zoonotic diseases include viral (rabies, yellow fever, influenza, Kyasanur forest disease, etc.), bacterial (anthrax, brucellosis, plague, leptospirosis, salmonellosis, etc.), Rickettsial (tick typhus, scrub typhus, murine typhus, etc.), protozoal (toxoplasmosis, leishmaniasis, trypanosomiasis, etc.), helminths (hydatid disease, taeniasis, schistosomiasis, leishmaniasis, etc.), fungal (histoplasmosis, cryptococcus, etc.) and ectoparasites (scabies, myiasis, etc.) (3). Emerging zoonotic diseases pose potentially serious impacts on human health and economies of nations. Their upwards trend is likely to continue.

AES	Acute Encephalitis Syndrome
CCHF	Crimean-Congo Hemorrhagic Fevers
CMV	Cytomegalovirus
COVID-19	Corona Virus Disease 2019
IDSP	Integrated Disease Surveillance Programme
JEV	Japanese Encephalitis Virus
KFD	Kyasanur Forest Disease
LCMV	Lymphocytic Choriomeningitis Virus
MERS	Middle East Respiratory Syndrome
NCDC	National Centre for Disease Control
PHEIC	Public Health Emergency of International Concern
RSV	Respiratory Syncytial Virus
SARS	Severe Acute Respiratory Syndrome
SARS CoV-2	Severe Acute Respiratory Syndrome Coronavirus 2
SFTS	Severe Fever Thrombocytopenia Syndrome
VRDLN	Viral Research and Diagnostic Laboratory Network
VZV	Varicella-Zoster virus
WHO	World Health Organization

Human activities carve the path to pandemics due to the unsustainable destruction of the environment and biodiversity that leads to an intermingling of humans, wildlife, livestock, and pathogens. Zoophytic diseases can happen due to the spill over of pathogenic organisms or the transmission of infections from animals to humans (zoonoses), from humans to animals (reverse zoonoses), or even from abiotic environmental reservoirs into vertebrates (Sapronoses) (4). Zoophytic disease emergence often occurs in stages, with an initial series of spill-over events, followed by repeated small outbreaks in people, and then pathogen adaptation for human-to-human transmission. Each stage might have a different driver, and therefore a different control measure is required (5).

The recent upsurge in zoonotic diseases shows that diseases can spill over into urban communities too. This is contrary to our prior beliefs about exotic pathogens' confinement to densely populated forests in developing countries with teeming population densities living in proximity with their livestock-pigs, chickens and ducks.

At least 37 pathogens emerged or re-emerged in India between 1992 and 2020 and the majority were of animal origin. Agriculture, animal husbandry workers such as farmers, livestock owners, animal handlers, veterinary extension workers and veterinarians have been found to commonly get infected with zoonotic diseases. Similarly, people engaged in the production and processing of livestock products such as personnel working in an abattoir, dairy, poultry enterprises and piggery suffer frequently from zoonotic diseases. Since zoonosis involves animals and humans, a "One Health" approach is essential to address both animal and human health in an integrated manner for global health security. In India, the National Centre for Disease Control (NCDC) is the key player to address zoonotic diseases through multi-sectoral and intersectoral approaches to strengthen surveillance and effective containment. Epidemic potential diseases are under surveillance by the Ministry of Health & Family Welfare, the Government of India's IT-enabled, laboratory-based, Integrated Disease Surveillance Programme (IDSP) (6). The network of laboratories designated as Virus Research and Diagnostic Laboratory (VRDLN) has infrastructure and diagnostic capabilities to identify viruses of public health importance with epidemic potential in India (7).

SARS-CoV-2 pandemic has revealed there were many significant weaknesses in global health security. Leaders around the world marshalled the resources and commitment to look beyond the COVID-19 pandemic and build much stronger global health security for the future based on the principle of One Health. In this publication, we have put together global drivers of emerging and re-emerging zoonotic diseases along with a lucid narrative on preponderant viral zoonotic diseases in India that mandate strategic interventions to prevent potential infectious disease spillover at animal-human interface. Thus, progress towards global health security requires a greater focus on the interface between humans and animals and a strong collaboration between the human health and the animal health sectors. This paper provides mapping of zoonotic diseases as per Indian context which pools around human - animal and environment interface.

Global Drivers of Emergence & Re-emergence of Zoonotic Diseases: Many factors lead to the emergence of zoonotic diseases (Figure 1). The environment associated with pathogens and their reservoir hosts are constantly changing (8). The key factors driving the emergence and re-emergence of zoonotic diseases are explained below:

a) **Human Factors:** Population growth has been unevenly distributed around the globe and is expected to become even more so in the next few decades. With the current global population at 8 billion (9), skyrocketing population expansion with dense growth pockets creates a conducive environment for zoonotic diseases to thrive and spill over to humans. The spread of zoonotic diseases is likely to happen when there is increased population mobility. Human travel associated with tourism, business, and other moves has significant implications for human and animal health and are at risk of contracting communicable diseases. When visiting other countries, humans can act as vectors for delivering infectious diseases to a different region or potentially around the world, as in the case of SARS and COVID-19. Manmade modifications in an environment such as dams for hydroelectric power or canal building for transportation have multiplied breeding sites for disease vectors, the classical example being, *Aedes aegypti*, the mosquito which transmits dengue fever. Globalization has provided raw food from different cultures and regions to other cultures that contain raw meat or fish, and this can facilitate several parasitic zoonoses (10). Transplantation has resulted in several cases of zoonotic diseases infecting transplant recipients. Perhaps most widely cited instance was an organ donor infected with rabies and transplanted organs subsequently infected & killed four transplant recipients (11).

b) **Animal Factors:** Pet ownership increases the chances of zoonotic infection from several types of diseases (e.g., Salmonellosis, Giardia, Cryptosporidium, Toxoplasmosis and Rabies). The transnational trade of exotic animals from birds to non-traditional companion animals is growing and creating new challenges for both human and animal health professionals and demands their closer collaboration (12). The trade in wildlife has helped to introduce pathogens that threaten human and animal health, agricultural production, and biodiversity. The human-mediated introduction of infectious disease and vectors, termed "pathogen pollution" (13) is expected to continue to rise via future expansion of global travel and trade (14, 15). Handling animal by-products and waste are also known to spill over diseases to humans e.g., anthrax and tularemia.

c) **Deforestation and Agriculture:** Deforestation led to several ecosystem consequences. Deforestation decreases the overall habitat for wildlife species and has implications for the distribution of many microorganisms and the health of human, domestic animal, and wildlife populations. Agriculture occupies most of the world's arable land and uses over two-thirds of the world's fresh water (16). The subsequent increase in irrigation reduces water availability for other uses and increases breeding sites for disease vectors. Major changes such as new agricultural practices, modernization and intensification of farming systems and habitat clearing for cropping and grazing have fueled spillover of zoonotic diseases e.g., spread of Nipah Virus as a classic example of connecting the dots between emerging diseases and biodiversity loss (17). Increasing trade in bushmeat can heighten the risk of transmission if live animals are transported to centralized markets where diverse species are forced into close contact (18, 19).

d) **Environmental Factors:** Climate models for greenhouse warming predict that geographic changes will foster several water-borne (e.g., cholera) and vector-borne (e.g., malaria, yellow fever, dengue, leishmaniasis) diseases (20).

e) **Research and Innovation:** As research in animals continue, there is always a possibility of zoonotic disease among scientific staff responsible for the care of the animals, or in laboratory workers engaged in microbiological aspects of the disease. Examples include glanders, tularemia, Q fever, Venezuelan equine encephalitis and Herpes B (12). Many of the Centers for Disease Control, USA Category A, B, and C bioterrorism agents such as anthrax, plague, tularemia, brucellosis, and cryptosporidium are zoonoses (22).

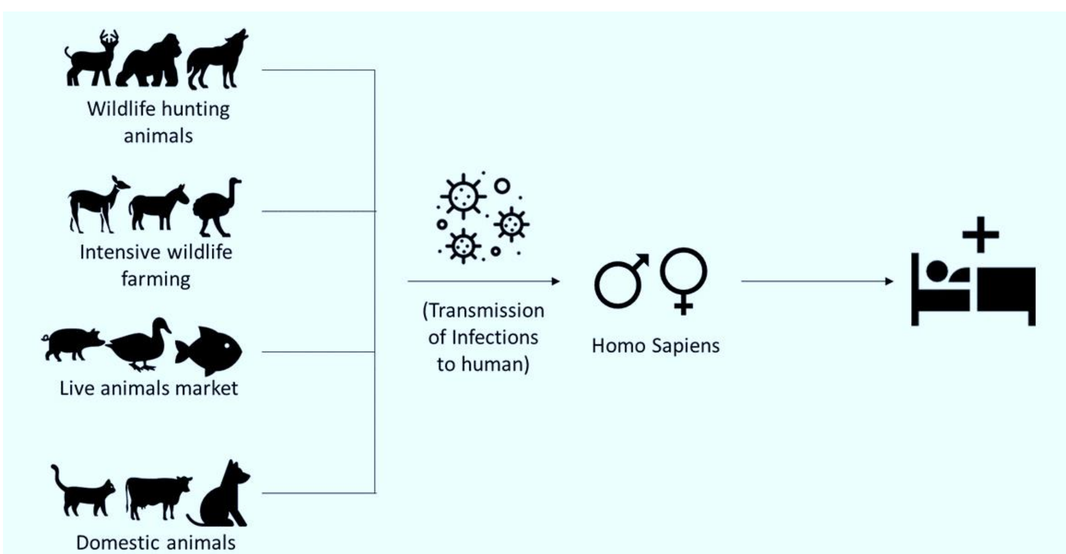

Figure 1: Zoophytic diseases have (re-) emerged due to intermingling at the animal-human interface. Transmission pathways include direct contact through handling of living animals (wildlife trade, domestic animals), preparation of slaughtered animals for consumption of meat or traditional medicinal uses.

Viral zoonotic diseases in India: A consistent theme in the infectious disease landscape of the country has been the periods of quiescence of several pathogens following their initial discovery, only to be followed by their reappearance in virulent forms. IDSP is a laboratory-based, IT-enabled system in the country which facilitates outbreak reporting and data analysis of disease surveillance through regional and national level from sub centers, primary health centers, community health centers, hospital including government and private sector hospital and medical colleges (23). IDSP monitors disease trends to detect and respond to outbreaks in early rising through trained Rapid Response Team. Their concreted efforts, increases the functionality of referral laboratory network across the nation in timely detection of epidemic prone diseases during outbreaks and fosters public health action through disease specific public health programs for timely action and management of index cases and contact tracing to curb transmission.

Recent IDSP data showed that 71% of outbreaks were caused by viral pathogens, while 29% were due to non-viral pathogens (23). Nearly 72,000 individuals were affected by these outbreaks, and amongst them, 60 percent had a viral etiology. The emerging/re-emerging viral zoonotic infections reported in India are described in Table 1 with some being critical for their potential in jumping the species barrier. For an effective One Health strategy in India, Ministries/ Departments of Health and Family Welfare, Drinking Water and Sanitation, Social Justice and Empowerment, Women and Child Development, Urban Development (Housing and Urban Poverty Alleviation) and Human Resource Development (Department of School Education and Literacy) actively engage.

Table 1: Emerging/re-emerging Viral Infections in India and New Viruses

Family	Viruses	Mode of Transmission	Outbreak Potential	Biosafety-risk Group
Bunyaviridae	Ganjam virus	Tick-borne	Yes*	2
	Bhanja virus	Tick-borne	Yes*	2
	Severe Fever Thrombocytopenia Syndrome (SFTS) virus	Tick-borne	Yes	4
	Chobar Gorge virus	Tick-borne	No	2
	Cat Que virus	Arthropod-borne	Yes*	2
	Kaisodi virus	Tick-borne	Yes*	2
	Umbre virus	Arthropod-borne	Yes*	2
	Oya virus and Ingwavuma virus	Arthropod-borne	No	2
	Chittoor virus	Tick-borne	Yes*	2
	Thottapalayam virus	Rodent-borne	No	2
Nairoviridae	Crimean-Congo Hemorrhagic Fevers (CCHF) virus	Tick-borne, human to human	Yes	4
Flaviviridae	Yellow fever	Arthropod-borne	Yes	4
	Zika virus	Arthropod-borne, mother-to-child, sexual route	Yes	2
	Kyasanur Forest Disease (KFD)	Tick-borne	Yes	4
	Japanese Encephalitis (JE)	Arthropod-borne	Yes	2
	Dengue	Arthropod-borne	Yes	2
	Bagaza virus	Arthropod-borne	Yes*	2
Paramyxoviridae	Influenza - H3N2	Airborne	Yes	3
	Influenza -Avian H5N1	Airborne	Yes	4

Table 1: Emerging/re-emerging Viral Infections in India and New Viruses				
Family	**Viruses**	**Mode of Transmission**	**Outbreak Potential**	**Biosafety-risk Group**
	Respiratory Syncytial Virus (RSV)	Airborne	Yes	2
	Quaranfil virus	Tick-borne	Yes*	2
	Parainfluenza 1-4	Airborne	Yes*	2
	Enterovirus-D68	Airborne	Yes	2
Paramyxoviridae	Nipah virus	Human to human direct contact/consumption of infected bat/fruit infected with bat	Yes	4
Picornaviridae	Human rhinovirus A, B and C	Airborne	Yes	2
	Hand, foot and mouth disease	Direct contact, faecal-oral route	Yes	2
	Coxsackie-A21 virus	Faeco-oral route	Yes	2
	Coxsackie-A10 virus	Faeco-oral route	Yes	2
	Sapovirus	Faeco-oral route	Yes	2
	Rotavirus	Faeco-oral route	Yes	2
	Polio and nonpolio flaccid paralysis	Faeco-oral route	Yes	3
Caliciviridae	Noroviruses	Faeco-oral route	Yes	2
Hepadnaviridae	Hepatitis virus new and vaccine escape mutants of HBV	Blood-borne	Yes	2
Togaviridae	Rubella virus	Airborne	Yes	2
	Chikungunya virus	Arthropod-borne	Yes	2
Poxviridae	Buffalopox virus (Orthopoxvirus)	Direct contact	Yes	2
Parvoviridae	Human parvovirus 4	Parenteral transmission	Yes	2
Arenaviridae	Lymphocytic Choriomeningitis Virus (LCMV)	Rodent-borne	Yes*	3
Herpesviridae	Cytomegalovirus (CMV)	Direct contact	Yes	2
	Chickenpox (varicella), Varicella-Zoster virus (VZV)	Airborne, direct contact	Yes	2
Rhabdoviridae	Chandipura virus	Arthropod-borne	Yes	3
Reoviridae	Kammavanpettai virus (Orbiviruses)	Tick-borne	No	Unknown#
* May cause an epidemic; however, no epidemic has been reported. # Unknown: No clear information on the risk assessment is available.				

If any infections of public health importance are notified, it needs to be assessed whether it is fulfilling the criteria of Public Health Emergency of International Concern (PHEIC) as per International Health Regulations (2005) guidelines (Figure 2).

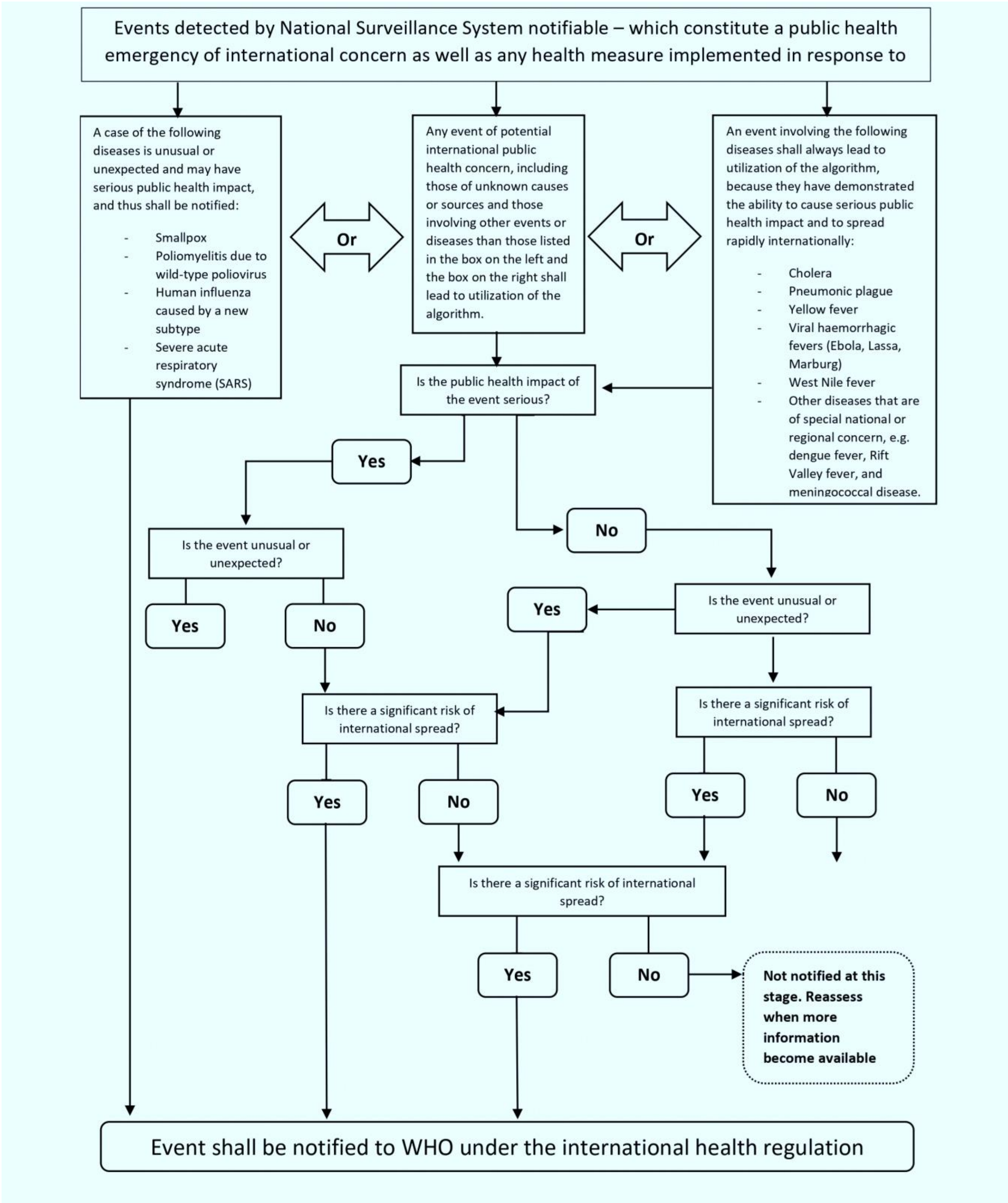

Figure 2: Decision making approach to public health emergencies.
https://www.who.int/health-topics/international-health-regulations#tab=tab_1

The animals, humans, and environment are interlinked, resulting in several benefits as well as a spread of zoonosis and multifactorial chronic diseases. For successfully implementing the One Health model, integration, and collaboration between multiple sectors of agriculture, animal health, and human health is required. Here, we showcase successful implementation of One Health approaches to thwart public health menace of viral zoonotic infections in India:

1. Corona Virus Disease (COVID-19): An epidemic of COVID-19, triggered by SARS-CoV-2, caused great suffering to China in November 2019 (24). Commencing from the epicentre in Wuhan, Hubei province the infection rapidly became a pandemic that has affected all continents (25). In severe cases, cytokine storm causes acute respiratory distress syndrome, multiorgan failure and sepsis (26). The positive-sense single-stranded RNA virus spreads from person to person through aerosol and contact transmission (27). Respiratory infections caused by the Middle East Respiratory Syndrome (MERS) coronavirus and Severe Acute Respiratory Syndrome (SARS) corona-virus have higher mortality rates. However, SARS-CoV-2 spreads much more rapidly than the other two Coronaviridae members, probably because it is also transmitted through asymptomatic carriers, which renders containment a challenge (28). India reported its first case of COVID-19 in late January in the southern state of Kerala. As of May 3, 2023, India has tested 927, 239, 236 samples for COVID-19 (29). The fact that more animals are reported infected with the COVID-19 virus, warrants One Health approach is crucial to address the threats posed by new diseases to the health of people and animals. One lesson learned from COVID-19 is that emerging zoonotic infectious diseases are here to stay and fighting new disease including development of drugs, vaccines and therapeutics require multisector collaborations across organizations working in human, animal, and environmental health sectors.

2. ***Monkeypox Virus Disease:*** The 2022 monkeypox outbreak in India is a part of the ongoing outbreak of human monkeypox caused by the West African clade of the monkeypox virus. The outbreak was first reported in India on July 14, 2022. India was the first country in South Asia and the tenth globally to report a monkeypox case. India has reported twenty-two confirmed cases of monkeypox, as of 20 January 2023 (30). The disease is caused by the monkeypox virus, a zoonotic virus in the genus Orthopoxvirus. The requirements for a One Health approach, should include consideration of land-use change and the bushmeat and exotic pet trades, to prevent opportunities for the emergence of monkeypox and diseases caused by other Orthopoxviruses. This also enables a rapid and effective response to any outbreaks to limit their spread.

3. Avian Influenza (Bird Flu): Avian influenza is an acute respiratory infection characterized by fever, cough and dyspnea. Pandemic flu viruses have some avian flu virus genes and usually some human flu virus genes. Both the H2N2 and H3N2 pandemic strains contained genes from avian influenza viruses. The first avian flu was detected in Italy in the early 1900. In India, the first cases were reported in Maharashtra in 2006. The poultry outbreaks have been reported from the north-eastern part of the country, near the border with Bangladesh: between January and April 2008 from West Bengal, in April 2008 and January 2012 from Tripura, in November and December 2008 from Assam, and again from West Bengal between December 2008 and May 2009. Recently, India reported its first case of human infection and death from Bird Flu (31). The H5N1 was labelled 'avian' influenza because it was first found in birds. It affects both wild and domesticated birds. According to the World Health Organization, between 2003 and 2014, the virus claimed 407 human lives globally. India saw outbreaks in 15 states between 2006 and 2015. The first confirmed case of human infection of influenza A (H5N1) virus was identified from Haryana state (31). As it is evident from the reported case there is transmission of avian influenza to humans in India, but there is a low likelihood of human-to-human transmission, sporadic cases of human infection with avian influenza viruses may be reported because these viruses have been occasionally detected in poultry populations in India (31). For the prevention and control of the Avian flu epidemic, strategy involves the One Health approach brainstorming and coming together of public health experts, medical consultants, veterinary doctors, bureaucrats, and environmentalists.

4. Nipah Virus Disease: Nipah virus infection is an emerging infectious disease of public health importance in the South-East Asia Region. Mingling between bats and human habitats, either due to urbanization or deforestation is the key driver of this spill over zoonotic disease. There were focal outbreaks of the Nipah virus in Bangladesh and India during winter in 2001. Drinking fresh date palm sap, possibly contaminated by fruit bats' excreta (*P. giganteus*) during the winter season, may have been responsible for indirect transmission of the Nipah virus to humans (32). In September 2021, the Kerala State Health Department reported an isolated case of Nipah virus disease in India (33). This was the fifth outbreak of the disease in India. To control this outbreak, the state government applied the principle of One Health. A multi-disciplinary central team from the NCDC was sent to Kerala state to provide technical support. State authorities issued an alert to Mysuru, Mangalore, Chamarajanagar and Kodagu districts in Karnataka state, which border Kerala state to curtail spread of the viral disease.

5. Zika Fever: Zika virus was first discovered in 1947 in the rhesus monkey of the tropical Zika Forest in Uganda. The first human Zika Fever spillover was reported from Nigeria in 1954. On 1st February 2016, WHO declared Zika Virus Disease as a Public Health Emergency of International Concern (34). Zika virus is an arthropod borne flavivirus that shares the *Aedes* mosquito. India reported its first case in 2017 followed by 159 cases of Zika virus infection in Rajasthan (35, 36) and 127 in Madhya Pradesh (37) in 2018 with no neurological complication. The re-emergence of Zika Virus disease has highlighted spread of infectious diseases beyond geographical barriers due to growing globalization, increased travel and the universal presence of the *Aedes* mosquito. In July 2021, a Zika virus infection was laboratory-confirmed in India (38). In India, control of the Zika virus outbreak succeeded as the One Health approach was applied involving synergies between public health experts, clinicians, veterinary doctors, communication experts and other stakeholders.

6. Chikungunya Virus Infection: Chikungunya is a mosquito-borne viral infection characterized by severe, sometimes persistent joint pain (arthritis) with fever and rashes. Monkeys, and other wild animals, serve as reservoirs of the virus. It is mainly caused by the bite of infected *Aedes aegypti* and *Aedes albopictus* mosquitoes. The incubation period can be 2-12 days but is usually 3-7 days followed by clinical signs of fever, debilitating arthralgia (joint pain), swelling of joints, stiffness of joints, myalgia (muscular pain), headache, fatigue (weakness), nausea, vomiting and rash. It is rarely life-threatening. Chikungunya fever has interesting epidemiology, it shows a cyclical pattern of appearance and disappearance, of which major epidemics occur at an interval of 7-8 years and sometimes as long as 20 years between two episodes. During the 2005-2007 explosive epidemics in the Indian Ocean islands and India, anecdotal cases of Chikungunya-associated deaths, encephalitis and neonatal infections were reported (39). In 2020, India has reported 5,159 confirmed and 32,287 suspected cases of Chikungunya with the disease being endemic in 32 provinces/union territories and dominant presence in Andhra Pradesh, Karnataka, Maharashtra, Madhya Pradesh, Tamil Nadu, Gujarat, and Kerala (40). There is neither a chikungunya virus vaccine nor drugs available to cure the infection. Prevention, therefore, hinges on avoiding mosquito bites, involving the One Health approach, source reduction method, use of larvicides and biological control of mosquitoes.

7. ***Japanese Encephalitis:*** Japanese Encephalitis (JE) is a mosquito-borne viral zoonotic disease of public health importance with epidemic potential and a high mortality rate. Japanese encephalitis virus (JEV) (Family-Flaviviridae) is the most common cause of childhood viral encephalitis in the world with about 50,000 cases and 10,000 deaths annually (41). JE was clinically diagnosed for the first time in India in 1955 at Vellore, Tamil Nadu. The longest and most severe epidemic of JE in 3 decades occurred from July to November 2005 in Gorakhpur, Uttar Pradesh, India. Overall, 5,737 persons were affected in 7 districts of eastern Uttar Pradesh, and 1,344 persons died (WHO 2005). The disease has been reported in 2007 in Assam (368 patients), Goa (44 patients), Tamil Nadu (17 patients), Manipur (11 patients), Karnataka (6 patients), Haryana (6 patients) and Kerala (1 patient) (42). Human cases were reported from all states except Dadra, Daman, Diu, Gujarat, Himachal, Jammu & Kashmir, Lakshadweep, Meghalaya, Nagar Haveli, Punjab, Rajasthan, and Sikkim. From Ardeid birds (pond herons and cattle egrets), JE infection is transmitted by mosquitoes to pigs/ducklings. Humans or cattle get infected either by birds or pigs/ducklings through a mosquito bite. Despite the best laboratory facilities and practices, the JE virus cannot be isolated easily from clinical specimens, apparently because of low levels of viremia and the rapid development of neutralizing antibodies. Hence, the diagnosis is usually based on the presence of antibodies, using techniques such as IgM capture ELISA for serum and CSF. These have become the accepted standard for diagnosing JE (43). The Ministry of Health & Family Welfare, India has been taking various prevention and control measures against Acute Encephalitis Syndrome (AES). The problem resolution entailed a synergistic association amongst stakeholders to overcome broader development and rehabilitation challenges rather than merely a medical problem, embedded in One Health strategy.

In the world of global health challenges today, One Health approach has emerged one of the ideal ways to create regional and national animal surveillance systems which are well coordinated with strong public health systems. This approach is paramount in the formulation and implementation of animal health policies and programs to control animal diseases and possible human spillover. To enable this, early detection and diagnosis of zoonotic diseases is needed, which can be done with the support of necessary scientific and technological expertise as per international standards and guidelines. Veterinarians, Entomologists, Surveillance Staff, Epidemiologists, Microbiologists, Clinicians, Pharmacists, Environmental Health Staff, Emergency Preparedness Staff and health care workers-Public Health Nurse, Infectious Disease Program Staff, Medical and Laboratory Staff act as first line of defense against the zoonotic diseases. State and District Surveillance Units are involved in regular and timely data collection, analysis and making actionable recommendations. As part of disease surveillance, a syndromic diagnosis is made by paramedics and community health workers. The Medical Officer of community health centers/district hospital/urban hospitals/medical colleges and physicians in private health facilities make a presumptive diagnosis based on patient history and clinical symptoms. They trigger requests for confirmed diagnosis based on positive laboratory identification and are responsible for patient management and emergency response based on outbreak investigations and surveillance reports.

Conclusions: The factors which influence the emergence and re-emergence of zoonotic diseases are multifaceted and need to be handled through a collective and comprehensive strategy. The One Health approach is increasingly gaining attention as the standard approach globally to combat emerging infectious diseases and zoonotic threats. The increasing trend of zoonotic virus emergence in recent years brings in the need to implement an integrated One Health approach which would enable proper outbreak investigation, control, and prevention. Governments, health workers and scientists need to collaborate at every level, work in tandem and nurture and maximize One Health practices so we can be more effective in our future fight against emerging and re-emerging zoonotic diseases. A comprehensive strategy and policy on infectious disease containment and prevention needs to be developed at the national level that would involve all relevant sectors both governmental and nongovernmental. Apart from strengthening surveillance systems, building rapid response mechanism, ensuring compliance with International Health Regulations, building capacity in epidemiology, strengthening laboratory network, working on basic, translational, and applied research, and fostering information sharing between all the stakeholders is needed to meet the threat of emerging and re-emerging infections.

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References:

1. Chugh TD. Emerging and re-emerging bacterial diseases in India. *J Biosci* 33:549–555, 2008
2. Taylor LH, Latham SM, Woolhouse ME. Risk factors for human disease emergence. *Philos Trans R Soc Lond B Biol Sci* 356:983-989, 2001
3. World Health Organization. Regional Meeting on Zoophytic Diseases. Jakarta, Indonesia: Report of the Meeting; 2007. https://apps.who.int/iris/handle/10665/205812
4. Borremans B, Faust C, Manlove KR, et al. Cross-species pathogen spill over across ecosystem boundaries: Mechanisms and theory. Philosph Trans B 374:20180344, 2019
5. Drivers of Zoophytic Diseases - Sustaining Global Surveillance and Response to Emerging Zoophytic Diseases - NCBI Bookshelf. https://www.ncbi.nlm.nih.gov/books/NBK215318/
6. Integrated Disease Surveillance Project, Ministry of Health and Family Welfare, www.idsp.nic.in,
7. DHR/ICMR virus research and diagnostic laboratory network, http://112.133.207.124:82/vdln/vdls.php
8. Dubal ZB et al Important Zoophytic diseases: Prevention and Control, *Technical Bulletin*: 39, Indian Council of Agricultural Research, Goa, 2019. https://ccari.res.in/Technical%20Bulletin%20No.%2039.pdf
9. Worldometer. https://www.worldometers.info/world-population
10. Macpherson CN. Human behaviour and the epidemiology of parasitic zoonoses. *Int J Parasit* 35:1319–1331, 2005
11. Srinivasan A, Burton EC, Kuehnert MJ et al. Rabies in transplant recipients investigation team. Transmission

of rabies virus from an organ donor to four transplant recipients. *New Eng J Med* 352:1103–1111, 2005

12. Bezerra-Santos MA, Mendoza-Roldan JA, Thompson RCA, et al. Illegal wildlife trade: A gateway to zoonotic infectious diseases. *Trends Parasit* 37:181–184, 2021

13. Infectious disease and amphibian population declines, Open access on Diversity and Distribution, Daszak and Cunningham, 2003, https://onlinelibrary.wiley.com/doi/full/10.1046/j.1472-4642.2003.00016.x

14. Daszak P, Cunningham AA, Hyatt AD. Emerging infectious diseases of wildlife--threats to biodiversity and human health. *Science* 287:443–449, 2000

15. Cunningham AA. A walk on the wild side--emerging wildlife diseases. *BMJ* 331:1214-1215, 2005

16. Horrigan L, Lawrence RS, Walker P. How sustainable agriculture can address the environmental and human health harms of industrial agriculture. *Environ Health Persp* 110:5 CID, 2002

17. Tollefson J. Why deforestation and extinctions make pandemics more likely. *Nature* 584:175–176, 2020

18. Wang LF, Eaton BT. Bats, civets, and the emergence of SARS. *Curr Top Microbiol and Immunol* 315:325–344, 2007

19. Wang LF, Shi Z, Zhang S, et al. Review of bats and SARS. *Emerg Infect Dis* 12:1834–1840, 2006

20. Caminade C, McIntyre KM, Jones AE. Impact of recent and future climate change on vector-borne diseases. *Ann New York Acad Sci* 1436:157–173, 2019

21. Coelho AC and García Díez J. Biological risks and laboratory-acquired infections: a reality that cannot be ignored in health biotechnology. *Front Bioeng Biotechnol* 3:56, 2015

22. Emergency preparedness and response, Bioterrorism agents, Centers for Disease Control and Prevention April 2018 https://emergency.cdc.gov/agent/agentlist-category.asp

23. Integrated Disease Surveillance Programme, Ministry of Health & Family Welfare, Government of India. http://idsp.nic.in/index4.php?lang=1&level=0&linkid=406&lid=3689

24. Sharma A, Tiwari S, Deb MK, Marty JL. Severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2): A global pandemic and treatment strategies. *Int J Antimicrob Agents* 56(2):106054, 2020

25. Zhu H, Wei L, Niu P. The novel coronavirus outbreak in Wuhan, China. *Glob Health Res Policy* 5:6, 2020

26. Huang C et al. Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. *Lancet* 395:497-506, 2020

27. Chan JF, Yuan S, Kok KH et al. A familial cluster of pneumonia associated with the 2019 novel coronavirus indicating person-to-person transmission: A study of a family cluster. *Lancet* 395:514–523, 2020

28. Vincent JL, Taccone FS. Understanding pathways to death in patients with COVID-19. *Lancet Resp Med* 8:430–432, 2020

29. SARS-CoV-2 (COVID-19) Testing Status: India Council of Medical Research. https://www.icmr.gov.in/indexcovid.html

30. 2022-2023, Mpox (Monkey Pox) outbreak: Global trends, WHO https://worldhealthorg.shinyapps.io/mpx_global

31. Human infection with avian influenza A (H5N1) - India, Disease Outbreak News, WHO https://www.who.int/emergencies/disease-outbreak-news/item/human-infection-with-avian-influenza-a(h5n1)-%EF%BD%B0-india

32. Rahman MA, Hossain MJ, Sultana S. Date palm sap linked to Nipah virus outbreak in Bangladesh, 2008. *Vector Borne Zoon Dis* 12:65–72, 2012

33. Nipah virus disease-India, Disease Outbreak News, WHO https://www.who.int/emergencies/disease-outbreak-news/item/nipah-virus-disease---india

34. Rackimuthu S, Hunain R, Islam Z, Natoli V. Zika virus amid COVID-19 in India: A rising concern. *Int J Health Plan Manag* 37:556–560, 2022

35. Yadav PD, Malhotra B, Sapkal G et al. Zika virus outbreak in Rajasthan, India in 2018 was caused by a virus endemic to Asia. Infection, genetics and evolution. *J Mol Epidemiol Evol Genet Infect Dis* 69, 199–202, 2019

36. Malhotra B, Gupta V, Sharma P et al. Clinico-epidemiological and genomic profile of first Zika Virus

outbreak in India at Jaipur city of Rajasthan state. *J Infect Public Health* 13:1920–1926, 2020

37. Saxena SK, Kumar S, Sharma R et al. Zika virus disease in India - Update October 2018. *Travel Med Infect Dis* 27:121–122, 2019
38. Zika Virus, Fact sheets, WHO https://www.who.int/news-room/fact-sheets/detail/zika-virus
39. Powers AM, Logue CH. Changing patterns of chikungunya virus: re-emergence of a zoonotic arbovirus. *J Gen Virol* 88:2363–2377, 2007
40. Guidelines on Mosquito and other Vector Control Response, National Vector Borne Disease Control Programme, Ministry of Health and Family Welfare, Government of India https://nvbdcp.gov.in/Doc/Guidelines-Mosquito-and-other-vector-control-response-2020.pdf

34

41. Solomon T, Ni H, Beasley DW et al. Origin and evolution of Japanese encephalitis virus in southeast Asia. *J Virol* 77:3091–3098, 2003
42. Saxena V, Dhole TN. Preventive strategies for frequent outbreaks of Japanese encephalitis in Northern India. Journal of Biosciences, 33:505–514, 2008
43. Swami R, Ratho RK, Mishra B, Singh MP. Usefulness of RT-PCR for the diagnosis of Japanese encephalitis in clinical samples. Scand J Infect Dis 40:815–820, 2008