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Review

Human health implications of emerging diseases and the current situation in India's vaccine industry

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ABSTRACT

Emerging diseases are infectious diseases that pose significant threat to human health, causing millions of deaths and disabilities in the upcoming days. Periodic epidemics of new infections and old reinfections increase the global burden of disease prevalence. They can be caused by new pathogens or evolving ones, which change human behavior and environmental factors. Researchers have studied the dynamic connections between microbes, hosts, and the environment, but new infectious diseases like coronavirus disease 2019 (COVID-19), re-emerging diseases, and deliberately disseminated diseases persist despite earlier hopes of elimination. With heavy privatesector investments, Indian pharmacology now provides core Expanded Programme on Immunization vaccines to United Nations International Children's Emergency Fund, producing previously unattainable vaccines for diseases like meningitis, hepatitis B, pneumococcal conjugate, rotavirus, influenza A (H1N1), and COVID-19. India's vaccine sector has emerged, among the oriented leaders of the Bharat Biotech, Serum Institute of India, Panacea Biotech and Biological E. Specifically, the technology transferred from Western countries has benefited the sector, which produces 1.3 billion doses annually. The Serum Institute is the world's largest manufacturer of vaccines, providing measles and diphtheria-tetanus-pertussis vaccines to United Nations. The Serum Institute has developed several vaccines, including Nasovac, MenAfriVac, Pentavac, and an inactivated polio vaccine. India's success in vaccinations can be attributed to attractive investment conditions, government assistance, international alliances, and rising domestic technical talent. Despite its booming economy and technical advances, India's disproportionate share of the world's child mortality rate remains unchanged. However, the growing production and distribution of vaccinations in developing nations has initiated a new era, leading to a worldwide decline in childhood death and disease.

1. Introduction

Emerging infectious diseases (EIDs) in the 21st century have posed a notable threat to society with worldwide health security [1]. Emerging global disease outbreaks, like the COVID-19, Ebola and Zika virus epidemics, underscore the need for global collaboration and preparedness due to their potential for rapid spread and devastating consequences if not promptly addressed. EIDs are either newly discovered in a community or have been present in the past but are now spreading across the globe. Some infectious diseases that had been under control in the past but have since reemerged as a significant risk to public health are referred to as re-emerging infectious diseases (RIDs) [2]. The origins of nearly three quarters (75%) of newly found diseases can be traced back to animals [3,4]. Many of these diseases lack a cure, and healthcare providers are often victims. Global warming, host behavior, population displacement, pathogen adaptation, overseas travel, unemployment, and industrial and economic growth all represent considerable dangers for disease propagation (Fig. 1) [5]. The monkeypox outbreak in 2003 served as a small novelty, yet it highlighted the potential for diseases to transcend borders and reach distant shores [6]. Similarly, the devastating impact of acquired immunodeficiency syndrome (AIDS) has reverberated worldwide in 1981, reminding us of the urgent need for effective prevention and treatment strategies [7]. The significance of a cohesive strategy in addressing infectious diseases has been emphasized by the

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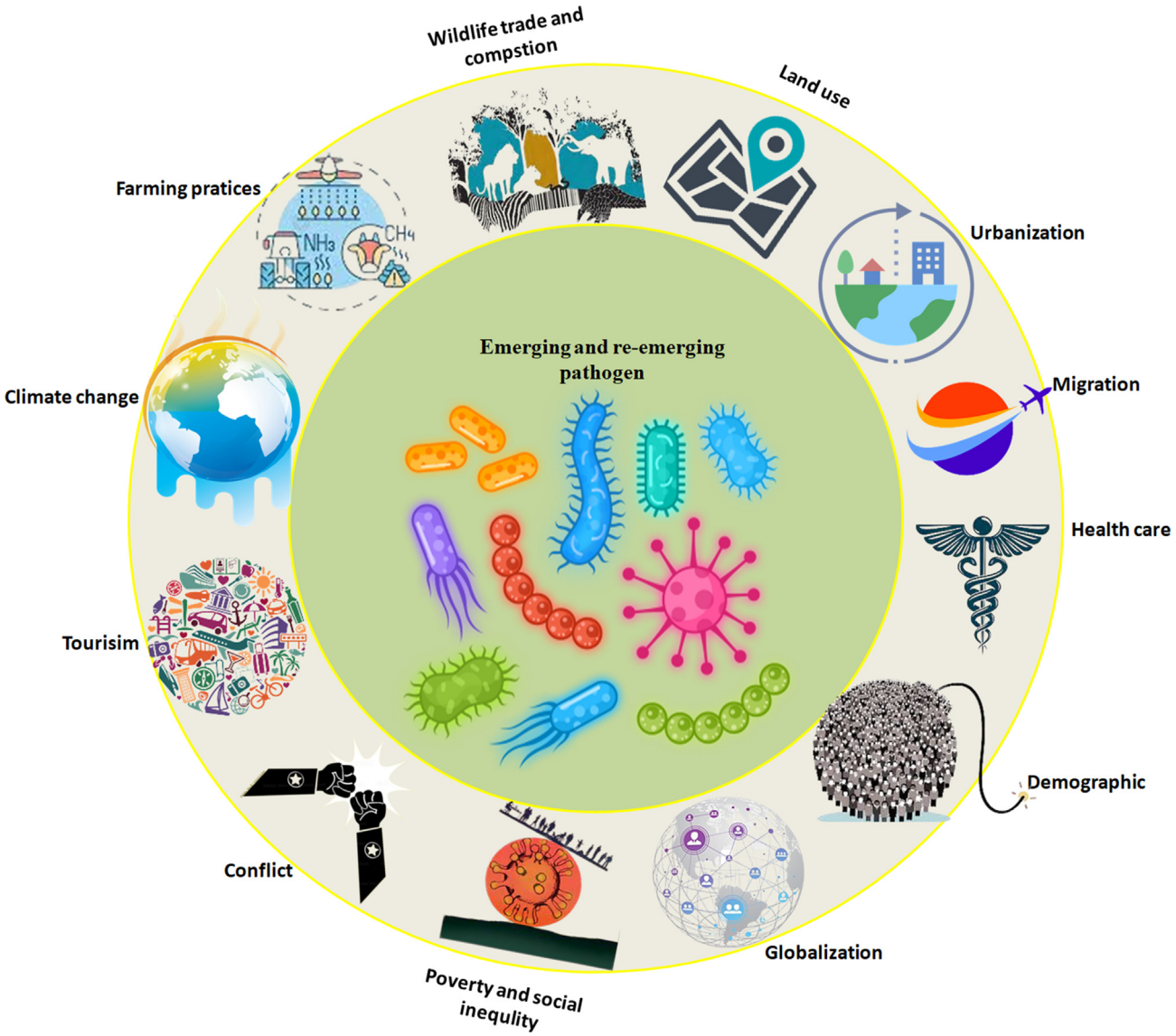

Fig. 1. The contributors to the development and spread of emerging infectious diseases and re-emerging infectious diseases are referred to as the precipitating factors.

appearance of various outbreaks such as severe acute respiratory syndrome (SARS), H5N1 (avian influenza), H1N1 (swine flu), and most recent one is COVID-19 pandemic (Fig. 2). As we navigate through these challenges, it becomes increasingly clear that a communal strategy is not only essential for our survival but also for safeguarding the health and well-being of future generations.

Over 30 new infectious diseases have developed in the past three decades, with Asia leading the way [8,9]. Most newly identified infectious diseases in humans have animal origins, accounting for 60% of all known diseases (Fig. 3) [10]. Novel diseases are accelerated by factors like climate change, environmental shifts, and microbial genetic mutations. To prevent the spread of infectious diseases, a well-functioning public health system is crucial. Clinical experience is alarming in Southeast Asian countries, including India, where antibiotic resistance is a growing concern [11]. Vaccines have been developed for at least 27 infectious agents, with many more being developed. Most countries include vaccinations against diphtheria, pertussis, tetanus, poliomyelitis, measles, and hepatitis B.

By the turn of the 20th century, India had commercially accessible vaccines of smallpox, cholera, plague, and typhoid. In 1798, the first vaccination was found. In 1948, the King Institute established a bacille Calmette-Guérin (BCG) Vaccine Laboratory in Chennai. The β-propiolactone (BPL)-inactivated rabies vaccine was created in 1970, while the influenza vaccine was created in 1957. In 1970, the facility created India's first locally made trivalent oral polio vaccine (OPV) (Fig. 4). Until 1973, Americans could only obtain an approved cholera vaccination by injection. In 2010, India introduced a second dose of the measles vaccine as part of its national vaccination program. By 2012, the measles immunization drives had vaccinated 127 million children in 367 districts in 14 states [12]. India's pharmaceutical sector is the world's largest supplier of generic pharmaceuticals, with vaccines and treatments renowned for their low cost and third-largest pharmaceutical market by volume and 14th-largest by value. Pharmaceutical industry has grown at a compound annual growth rate (CAGR) of 9.43% in the past nine years, making it the third largest pharmaceutical output by volume. India's subsectors include generic pharmaceuticals, over the counter (OTC) medications, bulk drugs, vaccines, contract research and manufacture, biosimilars, and biologics. With 500 active pharmaceutical ingredients (API) manufacturers and the most Food and Drug Administration (FDA)-approved pharmaceutical production facilities, India supplies 25% of all pharmaceuticals in the UK and 40% of the demand for generics in the United States [13]. The industry accounts for 1.72% of the country's gross domestic product and is expected to reach a value of USD130 billion by 2030. The industry is highly attractive for foreign investment and is sold in over 200 countries, including Australia, Japan, the United States and Western European

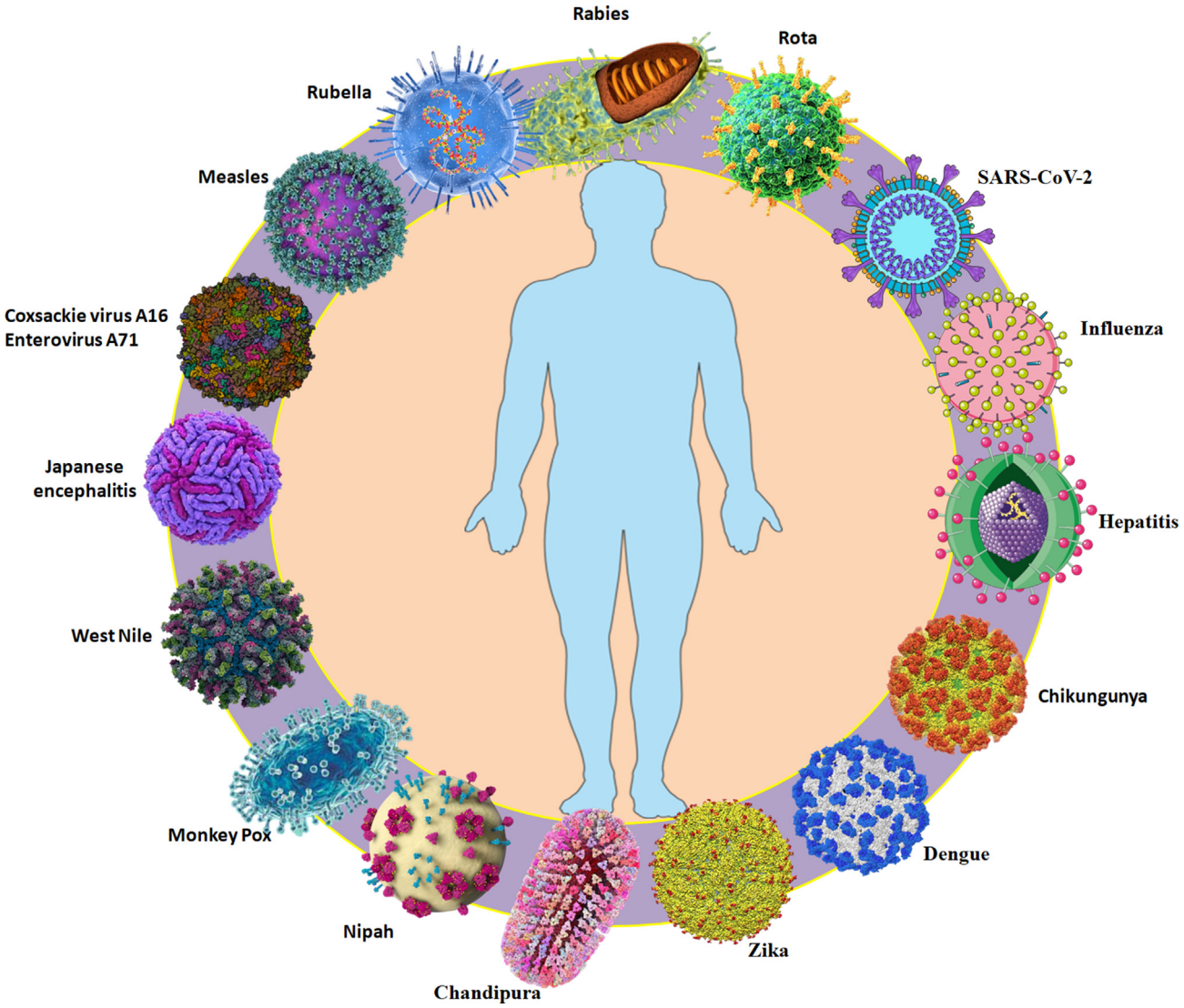

Fig. 2. The schematic plot represents various viruses that have been associated with human diseases.

countries. About 114 countries received supplies of hydroxychloroquine from India, amounting to 45 metric tons and 400 million tablets. The Indian government has launched Mission COVID Suraksha to accelerate research and manufacture of indigenous COVID vaccines under "Atmanirbhar Bharat 3.0". Brazil stopped purchasing 20 million doses of Bharat Biotech's Covaxin after receiving information about the COVID-19 pandemic. The Ministry of Health and Family Welfare is leading a national effort to vaccinate priority of the populations. Gavi's COVAX Advance Market Commitment aided the Serum Institute of India in producing a low-cost vaccine for India and other low- and middle-income countries. The COVAX initiative aims to expand access to the vaccine worldwide, with about 20% of people in the 92 Advance Market Commitment (AMC) nations expected to be vaccinated. India's Vaccine Maitri Program offers vaccine assistance to several nations [14]. India is a significant player in the international vaccination market, with at least 21 large vaccine producers operating in the United States and expected to grow. India is a significant buyer and seller of vaccinations worldwide, with its vaccine development program including 25 research-based institutions, organizations, and laboratories (Table 1). Despite the COVID-19 pandemic, India has been expanding its vaccine production, becoming a leading producer of vaccinations against diseases like measles, tuberculosis, and DPT. The thriving vaccine production ecosystem and the central hindu principle of "Vasudhaiva Kutumbakam" have united the world during the epidemic, providing immunizations to 1.4 billion people at home and 242 million vaccines to 101 countries worldwide at affordable and high-quality prices [15]. The Indian major public sector vaccine-developing institutes include Central Research Institute (Kasauli), Bharat Immunological & Biological, Pasteur Institute of India, Indian Immunologicals, BCG vaccine laboratory and Haffkine Bio-Pharmaceutical. Similarly, Shantha Biotech, Serum Institute of India, Panacea Biotech and Bharat Biotech International are private sector pharmaceutical companies that develop vaccines (Table 1). Indian pharmaceutical companies should invest in manufacturing viral vectors to reach a USD130 billion market by 2030. By utilizing the 740 FDA-approved plants, India can capitalize on the existing infrastructure and maintain its position in the market [16]. India plans to provide rotavirus vaccinations throughout the country by 2022, with ROTAVAC already distributed in 25 states. Cadila Healthcare developed the first DNA vaccine against COVID-19 (ZyCoV-D) in August 2021, which was granted the Emergency Use Authorization (EUA) in August 2021. Biological E's CorbevaxTM, a protein subunit vaccine, was granted EUA for use in children and adolescents aged 12–18 in February 2022. Bharat Biotech's intranasal vaccine and Gennova Biopharmaceuticals' first mRNA vaccine are currently undergoing Phase III clinical studies. As of September 21, 2023, the total number of adults in India who may have benefited from vaccination was 2,206,770,644. This article examines emerging health dangers in India and its potential

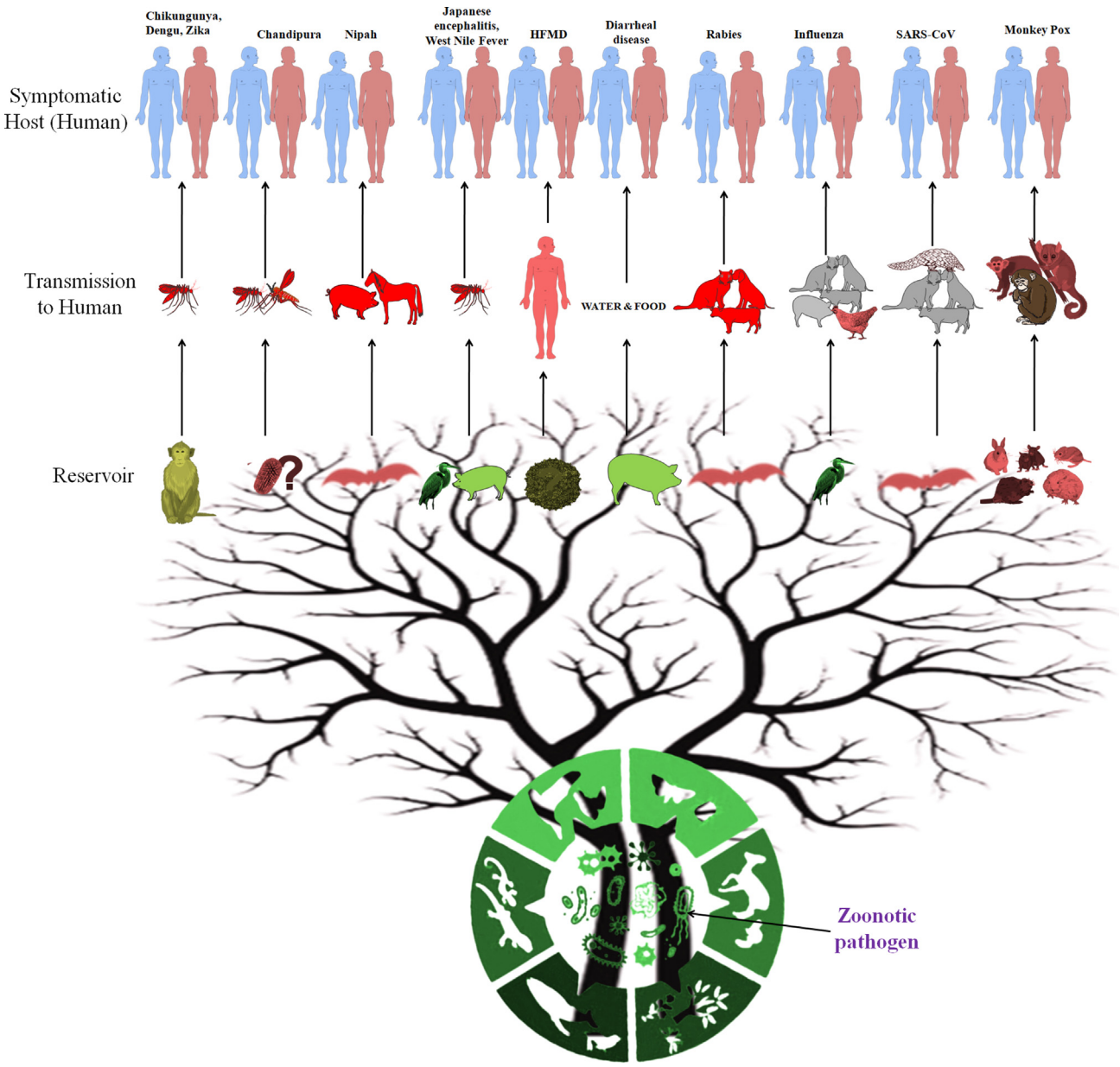

Fig. 3. Emerging infectious diseases are transferred to symptomatic humans from natural reservoir through suitable transmuted pathogens.

contribution to vaccination through the Indian pharmaceutical sector. The content of this paper emphasizes the prevailing diseases in India for which vaccines are presently being utilized or are undergoing clinical or preliminary studies prosperity. This article presents an overall views of the achievements, potential and challenges faced by the Indian vaccine industry during the preceding decades. The review also briefly discusses the Indian vaccine and its pharmacological aspects throughout the previous decade to address new infectious disease risks and outcomes. The analysis evaluates India's current standing in the bio-similar domain, investment plans, development, and innovation, as well as the need for a more trained labor force, increased industrial cooperation, and new business models. This would facilitate the exportation of India's distinctive to the realization of a self-reliant India. The compilation's shortcomings are highlighted towards the conclusion.

2. Emerging disease and its vaccine

Arthropod-borne viruses play a significant role in the transmission of novel and recurring diseases within the Indian subcontinent, frequently involving RNA viruses. More than 130 arboviruses, namely flaviviruses, alphaviruses, and bunyaviruses, have been associated with human diseases (Fig. 2) and possess noteworthy implication for public health, with certain ones being particularly common in India. Arboviral diseases have been responsible for severe outbreaks, encompassing Crimean Congo hemorrhagic fever, Dengue fever, Kyasanur Forest disease, Japanese encephalitis and Chikungunya fever (Table 2) [17,18].

2.1. *Chikungunya fever*

Since 2005, the Chikungunya disease has caused resurgence in India which is transmitted by mosquito (Fig. 3), causing bone pain and morbidity, but with rare mortality. Chikungunya virus (CHIKV) was first reported at Kolkata in 1963 (Table 2) and Maharashtra in 1973 with Asian strain [19]. In 2023, 853 cases were believed to be related to CHIKV by the Indian government (Fig. 5). In 1986, the Thai AF15561 isolate was used to create the first live attenuated vaccine (LAV), using human lung cells from Thailand. Chikungunya lacks a vaccine or

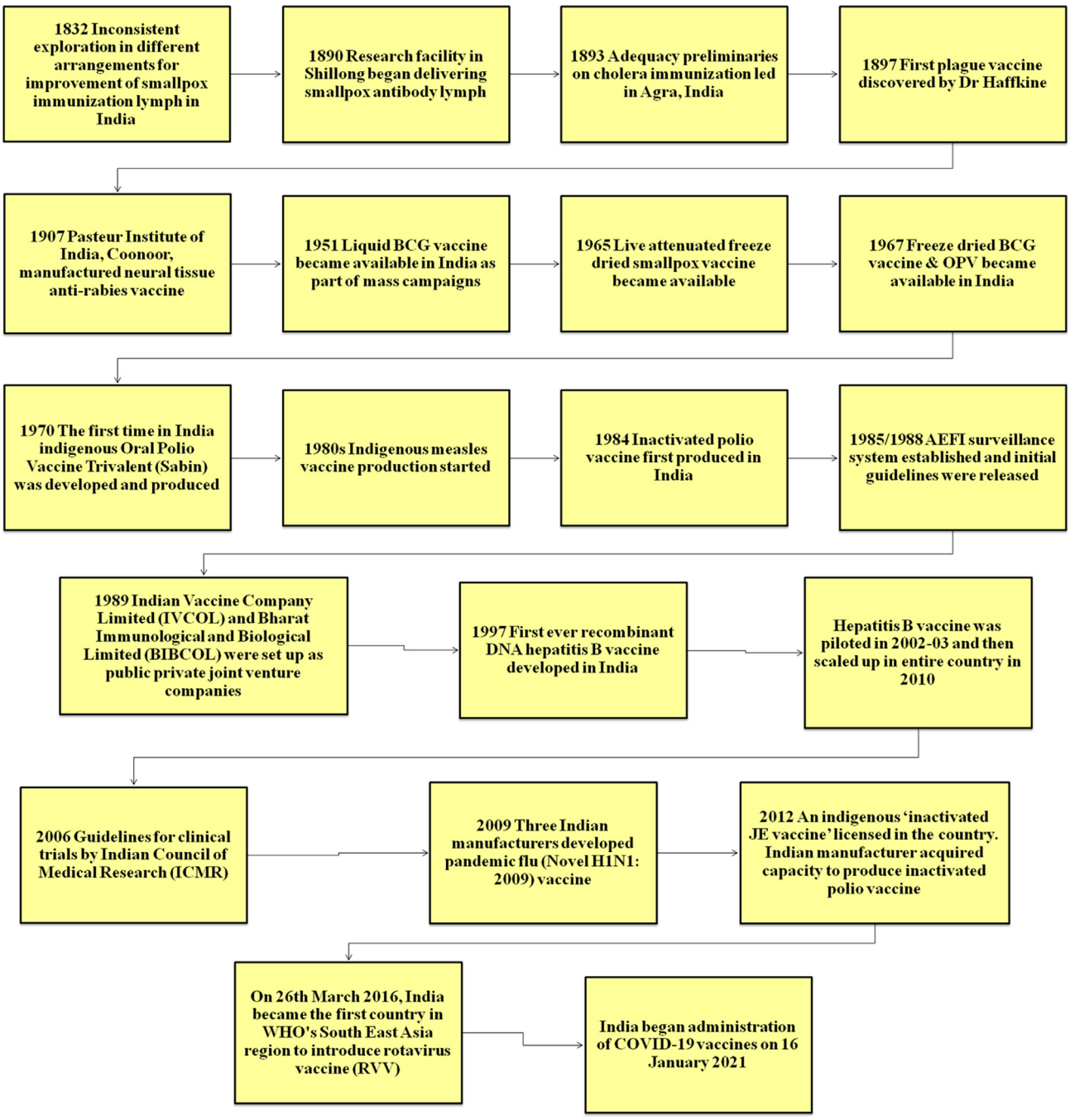

Fig. 4. A condensed account of the evolution of immunization practices over the course of various companies in India.

treatment, but rest, fluids, and pain medications, like Tylenol® (acetaminophen or paracetamol), can alleviate symptoms in the Indian pharmaceutical market [20]. Arbidol, suramin, and micafungin have been shown to stop CHIKV from spreading early. PCA binds to the capsid protein, preventing it from interacting with the E2 glycoprotein (cdE2). The MADTP series has found nsP1 to be a possible target, and carbocyclic adenosine analogues like 6′-β-fluoro-homoaristeromycin and 6′-fluoro-homoneplanocin A can stop the MTase activity of nsP1. Chloroquine, an antimalarial medication, has been used in human clinical studies since 1934 [21]. Valneva (VLA1553), a potential vaccine for Chikungunya, is undergoing regulatory assessment for lasting immunity after a single vaccination. The FDA aims to complete its assessment by November 2023. Valneva is lobbying for its Chikungunya vaccine study in adults, with 96% of vaccinated individuals showing protective antibody levels [22]. Bavarian Nordic A/S prepares for a Phase 3 clinical study on its CHIKV VLP vaccine (PXVX0317) candidate, which has shown 98% neutralization in vaccinated individuals up to 22 days post-vaccination [23]. Bharat Biotech has developed an inactivated and highly purified CHIKV immunogenic formulation (BBV87) for use as a vaccine. Phase 1 clinical trials successfully elicited an immunological response against CHIKV [24].

2.2. *Dengue fever*

The dengue virus is the causative agent of dengue fever and causes a significant global challenge to the human population, as it is transmitted by the *Aedes aegypti* (Fig. 3). The disease exhibits endemicity in more than 100 countries spanning the World Health Organizations' regions include

Table 1
The following list comprises vaccine manufacturers in India, encompassing entities from the public sector, private sector, and government sector organization.

Manufacturer	Licensed vaccine	Target disease
Serum Institute of India	DTP, TT, DT, Hib (Vaccine & bulk), BCG, IPV, DTP+Hep B+Hib (Liquid +lyophilized), Vaccine seasonal, Diphtheria Vaccine (bulk),TT bulk, Pertussis bulk, Measles bulk, Mumps bulk, Rubella bulk & DT bulk & OPV vaccine, CRM 197 Bulk, DTP+ Hep B+ Hib Bulk, COVOVAX (Novavax formulation)	Hepatitis B, measles, rubella, rabies, DTP, H1N1, meningococcal A conjugate (freeze dried), mumps, MR, H1N1(whole virion inactivated), mumps, influenza, COVID-19
Bharat biotech International Ltd,	bOPV, mOPV, DTP+Hib+HepB, Vi polysaccharide Typhoid, DTP, DTP+HepB, Rotavirus vaccine, Inactivated JE vaccine, Typhoid+TT Conjugate Vaccine & DTP+Hep- B+Hib (Liquid), DTP+Hib	Hib, rabies, rotavirus , typhoid, H1N1, diphtheria, pertussis, tetanus
Cadila healthcare	Rabies vaccine, bulk rabies vaccine, pandemic influenza H1N1 2009 monovalent vaccine, typhoid vaccine, tetravalent influenza (split virion)	Rabies, influenza H1N1, typhoid, influenza (split virion)
Biomed Pvt. Ltd,	Hib, Meningococcal Polysaccharide (A,C, Y,W 135), bOPV, Vi Polysaccharide Typhoid Vaccine & Meningococcal polysaccharide (A & C), Rabies	*Haemophilus influenzae* type B, prevent infection by certain groups of meningococcal bacteria , typhoid, rabies
Green signal Bio Pharma Ltd	BCG Vaccine, DTP, HepB, DTP+Hep-B, DPT+Hep-B+Hib, IPV, Hib & H1N1, bOPV, DTP-Hib, DPT+Hep-B+Hib+IPV, Bulk DS of Hep-B, Diphtheria, TT, wP, H1N1 & Hib (Only bulk mfg facility)	Tuberculosis, DTP, hepatitis B, H1N1, Wp, bOPV, diphtheria
Dano Vaccine & Biological Pvt. Ltd.	TT	Tetanus
Ranbaxy Lab	Typhoid polysaccharide & Hib Conjugate vaccine	Typhoid polysaccharide & Hib
Shantha Biotechnics Ltd.	DTP, DTP+HepB+Hib (Liquid), DTP+Hib, DPT+Hep B, TT, Hib, Hep-B, DT bulk, TT Bulk, Hib Bulk, Hep B Bulk, DTP bulk, DTP+HepB+Hib bulk, DTP+HepB+Hib RTF bulk, Oral cholera vaccine, IPV RTF Bulk, IPV, Inact. B. pertussis bulk, Oral cholera vaccine, DTP+HepB+Hib	Hepatitis B, DTP, poliomyelitis, pertussis, cholera
GSK Asia Pvt. Ltd.	Pneumococcal Polysaccharide and Non-Typeable Haemophilus influenza vaccine (packing and labeling)	Pneumoniae, non-typeable haemophilus influenza
Sanofi Pasteur India Pvt Ltd	Hib, DTP-Hib, typhoid, Hep A, Pneumococcal, Yellow fever, Seasonal influenza, Rabies, Meningococcal, IPV, DTaP-IPV-Hib, Varicella, DTaP	Typhoid, yellow fever, seasonal influenza, rabies, prevent infection by certain groups of meningococcal bacteria, varicella
BCG Vaccine Laboratory	Freeze dried BCG vaccine	Tuberculosis
Central Research Institute	Yellow fever vaccine, JE vaccine, DTP vaccine, DT vaccine, TT	Japanese encephalitis, pertussis, tetanus, diphtheria and tetanus
Haffkine, Parle	bOPVand Mopv	Poliomyelitis
HLL Biotech Ltd.	DTwP- HepB-Hib, Hep B	Diphtheria, tetanus, pertussis, hepatitis B, and haemophilus influenzae type b
BIBCOL	bOPV	Poliomyelitis

the Western Pacific, Africa, South Asia, Eastern Mediterranean and America (Table 2) [25]. Approximately 100–400 million individuals residing in tropical and subtropical urban regions face the potential threat of contracting dengue fever [26]. The rapid spread of dengue fever in India is concerning, with the first case of virological confirmation in 1780 in Chennai (Table 2) [27]. In 2022, around 1821 people in India contracted the virus, with a mortality rate of 25% (Fig. 5). Dengvaxia® (CYD-TDV), developed by Sanofi Pasteur, is the first live attenuated tetravalent vaccine to receive regulatory approval on December, 2015 in approximately 20 countries all over the world [28]. The US National Institutes of Health are conducting phase III efficacy trials on both TetraVax-DV and TDV dengue vaccines. India is working on two different dengue vaccine candidates at the same time: DSV4 and TetraVax-DV (Tables 2 and 3). TetraVax-DV is a live attenuated vaccine (LAV) licensed by the US National Institutes of Health to Indian pharmaceutical companies, whereas DSV4 is a protein-based vaccine [29]. Biological E, Serum Institute, and Panacea Biotec have all been awarded non-exclusive rights to use the technology.

2.3. Zika fever

The Zika disease spread by mosquito-borne pathogen (Fig. 3), has exhibited a close relationship with dengue and flavivirus. Since 2015, it has experienced a rapid dissemination throughout the Caribbean, Mexico and South and Central America. It was initially discovered in 1947 through the isolation of a rehesus monkey in the Zika forest of Uganda [30]. The National Institute of Virology in Pune, India, reported the first laboratory-confirmed case of Zika virus infection on July 8, 2021 in Kerala (Table 2). This case was identified through a reverse transcription-polymerase chain reaction study conducted in the state of Uttar Pradesh and Maharashtra. Several vaccine candidates have been formulated and evaluated through preclinical and clinical trials, encompassing nucleic acid-based approaches (DNA; VRC5283, VRC5288, GLS-5700, VRC 705 and RNA; mRNA-1325 and mRNA-1893 vaccines), inactivated whole virus [ZPIV, PZIV (TAK-246), BBV121, VLA1601], live attenuated (ChAdOx1 Zika, rZIKV/D4Δ30-713, MV-ZIKV-RSP, MV-ZIKV), viral vectored vaccine, protein antigen vaccines, and virus-like particles [31–33]. VRC5283, a DNA vaccine developed by vaccine research center at Institute of Allergy and Infectious Diseases (NIAID), was tested in Phase I of the VRC 320 trials, which were conducted at a single site. The VRC 319 Phase I trials were conducted in three locations to evaluate plasmid VRC5288. Inovio Pharmaceuticals and GeneOne Life Sciences are working on a synthetic vaccine called GLS-5700 to combat Zika virus infections. The phase I human studies for GLS-5700 began on July 26 after gaining FDA (US Food and Drug Administration) permission. The CDC prioritizes creating an effective and safe Zika vaccine. The Walter Reed Army Institute of Research Clinical Studies Center in Maryland completed four clinical studies on the purified formalin-inactivated ZIKA vaccine, ZIKV, with participants aged 18–49. The vaccine was found to be 92% effective and seroconverted at day 43, surpassing protective thresholds [31]. The mRNA-1893 trial involved a placebo group from the United States and Puerto Rico. The mRNA-1325 study, which lasted until August 2018, involved 90 participants, with high tolerance to all three doses. However, the vaccine only produced weak responses in terms of Zika virus-specific neutralizing antibodies. Moderna Therapeutics is conducting phase I clinical studies on its mRNA vaccine candidates [34]. The Indian Institute of Medicine (ICMR) and Bharat Biotech of Hyderabad plan to conduct a phase II study on the BBV121 inactivated viral vaccine, which is effective against both Asian and African Zika virus strains. The vaccine will undergo clinical trials, which will evaluate two Zika and Chikungunya vaccines in people. The trials, which take around two years and involve 200–300 people, are required before a vaccine can be commercialized [31].

Table 2
This discourse elucidates a significant novel disease, encompassing its geographical extent and transmission dynamics, the specific species acting as a reservoir for the disease, the ongoing epidemic in India, existing treatment alternatives presently accessible within the country, and causative agents.

	Mode of transmission	Outbreak in India	Vaccine company	Drugs available company	Distribution	Reservoir	Reference
Chikungunya (Chikungunya virus)	*Aedes aegypti* and *Aedes albopictus*	1963, West Bengal		Tylenol® (Mallinckrodt Pharmaceuticals, Sri Krishna Pharmaceuticals Ltd.)	Africa, Asia, and the Americas	Humans	[20]
Dengue (Dengue viruses)	*Aedes aegypti* or *Aedes albopictus*	1780, Chennai	Dengvaxia (Sanofi India Private Ltd. & Sanofi Pasteur Inc.), TetraVax-DV (Panacea Biotec Ltd), DSV4		Tropical and sub-tropical climates worldwide	Humans and mosquitoes	[29]
Zika (Zika virus)	*Aedes aegypti*	July 8, 2021, Kerala			Mexico, Central America, the Caribbean and South Americas, India	Humans	
Chandipura (Chandipura virus)	Mosquitoes, ticks and sand flies	1965, Maharashtra		Ribavirin (PENDOPHARM, Pharmascience Inc.)	Africa, Bhutan, India, Nepal and Sri Lanka	Humans	[37]
Nipah (Nipah virus)	Bats or Pigs	May 19 2018, Kerala		Acyclovir and Ribavirin (No specific drugs)	Malaysia, Singapore, India, and Bangladesh	Fruit bats	[40]
Japanese encephalitis (Japanese encephalitis virus)	*Culex tritaeniorhynchus*	1955, Karnataka	IMOJEV® (Sanofi Pasteur's), IXI-ARO® (Biological E), JENVAC (Bharat Biotech), JEEV (Biological E Ltd)		South- East Asia and Western Pacific region	Herons and egrets	[44,45]
Hand, Foot, Mouth Disease (Coxsackie virus A16/ Entero virus A71)	Contact with droplets that contain the virus made when a person sick with HFMD coughs, sneezes, or talks	2007, West Bengal	No vaccine available	Acetaminophen (Pharm-RX Chemical Corporation)	Asia, the Middle East, South America and parts of Africa.	Humans	[47]
Diarrheal disease (Rota virus)	Person-to-person	1985, Manipur	ROTAVAC (Bharat Biotech), ROTASIIL (Serum Institute of India), and Rotavin-M1 (Polyvac)	Loperamide, Lomotil and Bismuth subsalicylate	All over the world	Humans	[51,53, 54]
Rabies (Lyssa virus)	Bite of a rabid animal		IndiRab (Bharat Biotech.) Abhayrab & AbhayRIG (Indian Immunologicals Limited, India), Rabipur® (Sanofi Aventis), Verorab (Zydus Cadila Health Care Ltd), Equirab & Berirab P (Bharat Serums & Vaccines Ltd.)	Tegretol, Sprycel, Purinethol, Chlormethine, Yondelis, Gemzar, Leukeran (GSK, novartis pharmaceutical company, Bristol-myers squibb company, Janssen biotech, inc)	Asia and Africa	Raccoons, skunks, bats, and foxes.	[57,58]
Hepatitis (Hepatitis virus)	Sharing needles, syringes, or other drug-injection equipment; or from mother to baby at birth		Engerix-B, Heplisav-B, and Recombivax HB, Revac-B mcf, Hepabig – VHB (Bharat Biotech, Dynavax, Serum Institute of India). Elovac-B & Vaxtar-5™ (Indian Immunologicals Limited, India)	Entecavir (Schwitz Biotech), Tenofovir (Gilead Sciences, Inc.), Lamivudine (Anant Pharmaceuticals Pvt. Ltd.), Adefovir and Telbivudine (Novartis India Ltd)	Worldwide	Humans	[61–64]
Influenza (Influenza virus)	Respiratory droplets	May 16, 2009 from Telengana (Hyderabad)	Quadrivalent (Lupin Laboratories Ltd., CSL Seqirus, Sanofi Pasteur Inc) Vaxigrip (Chiron Panacea Vaccines Pvt.Ltd.), Vaxigrip (Sanofi Pasteur), Fiuarix (Glaxo Smith Kline Pharmaceuticals Ltd), Influgen (Lupin Laboratories Ltd.), and Influvac (Abbott)	Oseltamivir (Hetero Drugs Ltd. and Ranbaxy Laboratories), Zanamivir (GlaxoSmithKline), Peramivir (Biocryst Pharmaceuticals)	North and South America, Europe, and parts of Asia, Africa	Pigs, wild birds	[70,71]
Acute Respiratory Illness (MERS-CoV, SARS-CoV)	Respiratory droplets or hand-to-hand contact	Kerala, on January 27, 2020	COVAXIN® (Bharat Biotech) COVOVAX®, Covishield® (Serum Institute of India Pvt. Ltd.) ZyCoV-D (M/s Cadila Healthcare Ltd), Sputnik-V (Dr. Reddy's Laboratories, M/s Gamaleya Institute & M/s Panacea Biotec Ltd Russia) CORBEVAXTM, GEMCOVACTM-19,		Worldwide	Humans	[75]

(*continued on next page*)

Table 2 (*continued*)

	Mode of transmission	Outbreak in India	Vaccine company	Drugs available company	Distribution	Reservoir	Reference
			iNCOVACC (M/s Bharat Biotech), Moderna (Cipla Ltd.), Janssen (Johnson & Johnson and Biological E limited), GEMCOVAC-OM (Gennova Biopharmaceuticals), HGCO-19 (Genova, DBT), CORBEVAX (Biological E Limited)				
West Nile Fever (West Nile virus)	Mosquitoes (*Culex)*	Maharashtra (Mumbai) in the year 1952	Innovator™ & Prestige®, Recombitek™	Ribavirin	East Africa and Indian subcontinent	Domestic dogs (*Canis familiaris*)	[77,78]
Measles (Morbilli virus)	Direct contact with infectious droplets or by airborne spread		MR-VAC (Serum Institute of India)	Acetaminophen, ibuprofen or Naproxen sodium (Mcneil Laboratories, Inc.)	World wide	Humans	[79]
Rubella (RuV virus)	when an infected person breathes, coughs, or sneezes		Tresivac (Serum Institute of India), Priorix (GlaxoSmithKline Biologicals), MMR vaccine (Serum Institute of India, Merck & Co, Inc.)		Europe, Asia, and North America	Humans	[82,83]
Monkey Pox (Monkeypox virus**)**	Through contact with lesions or scabs of a person with mpox	July 14, 2022, Kerala	JYNNEOS and ACAM 2000 (Bavarian Nordic A/S)	Tecovirimat (Siga technologies)	Central and West Africa, Nigeria, Congo, and Morocco	Rope and sun squirrels, giantpouched rats, African dormice	[84,86]

2.4. Chandipura fever

The epidemics that occurred in central India during the period of 2003–2004 involving the Chandipura virus (CHPV), which belongs to the Rhabdoviride family with *Vesiculovirus* genus, garnered global recognition due to its capacity to induce encephalitis (Fig. 3) [35]. The presence of the virus has been documented in various regions, including Africa, Bhutan, India, Nepal and Sri Lanka. That virus was first recognized in 1965, Maharashtra, subsequently extended its reach to Andhra Pradesh in 2003 with a fatality rate ranging from 56% to 75%, 2004 in Gujarat and Odisha in 2015 [36]. Some researchers used ribavirin, which has antiviral properties, to combat CHPV. Ribavirin is effective in preventing virus replication in human cells (Table 2) [37]. The National Institute of Virology is the sole organization in India working on a potential CHPV vaccine based on the glycoprotein gene. The vaccine study was completed in 2008, but no clinical trials have been conducted in humans [38]. A BPL-inactivated vaccine against the dead virus has been created but has not yet undergone human clinical testing [35].

2.5. Nipah disease

Nipah virus is a food-borne disease transmitted through infected bats' urine or saliva, with the *Henipavirus* genus including NiV (Fig. 3) [39]. The Indian state of Kerala experienced an epidemic in September, 2021 (Table 2). There are no recognized therapies for NiV infection, so supportive care is the only option for affected individuals. In previous instances of outbreaks, the administration of acyclovir and ribavirin has been observed (Table 2) [40]. Moderna, Inc. and NIAID vaccine research center developed an mRNA vaccine against NiV (Phase 1 clinical study) [41], while Auro Vaccines LLC (AurobindoPharma Ltd.) developed a recombinant subunit vaccine HeV-Sg-V, 2020. Similarly, in February

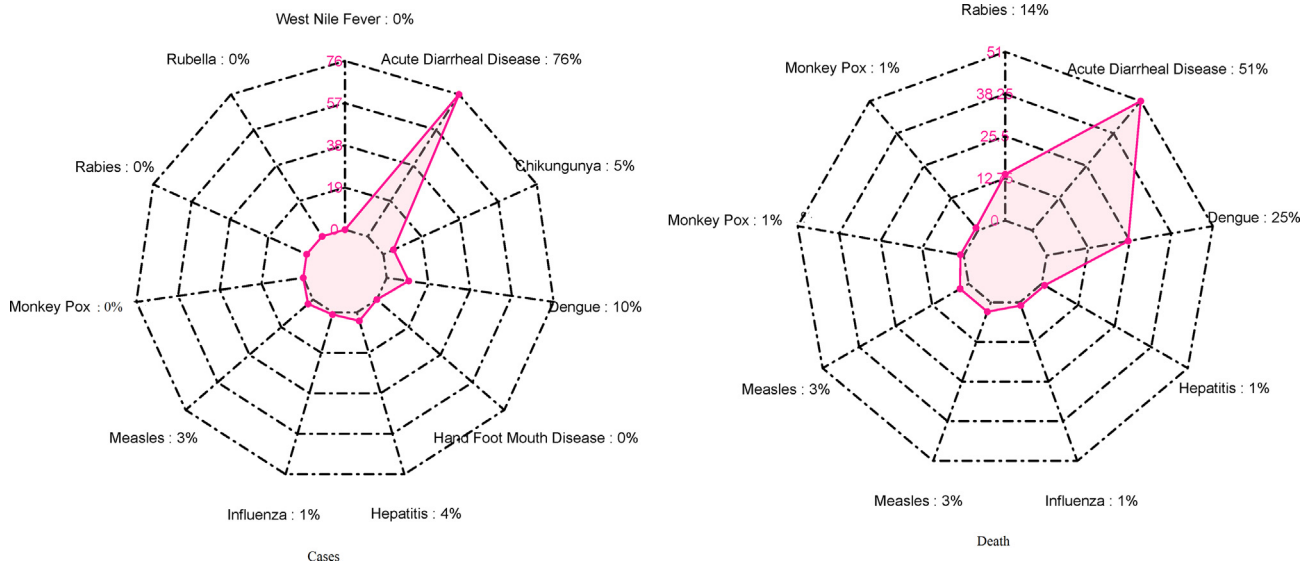

Fig. 5. The graphical representation depicts the incidence of recently reported diseases in India during the year 2022.

Table 3
Multiple biopharmaceutical companies in India are currently directing their efforts towards the research, advancement, and manufacturing of vaccines targeting the COVID-19 virus (https://covid19.trackvaccines.org/country/india/), December 9, 2022.

Vaccines	Manufactures	Collaborator	Approved (in countries)	Max. no. of trials	Type of vaccine
COVOVAX (Novavax formulation)	Serum Institute of India		6	7	Protein subunit
Corbevax	Biological E Limited		2	7	Protein subunit
ZyCoV-D	Cadila Healthcare Ltd., Ahmedabad, India	Department of Biotechnology, India	1	7	DNA
GEMCOVAC-19	Gennova Biopharmaceuticals Limited		1	2	RNA
Spikevax	Moderna		88	74	RNA
Incovacc	Bharat Biotech		1	4	Non-replicating viral vector
BBV121	Bharat Biotech			1	Whole virion
HNVAC	Bharat Biotech			1	Inactivated
ROTAVAC	Bharat Biotech		6	13	Live attenuated
ROTAVAC 5D	Bharat Biotech		3	4	Monovalent vaccine
ROTASIIL	Serum Institute of India		Multiple		Live attenuated
JENVAC	Bharat Biotech	National Insitute of Virology, India	2	4	Inactivated
JEEV	Biological E Ltd		Multiple	2	Inactivated
Sputnik Light	Gamaleya		26	7	Non-replicating viral vector
Sputnik V	Dr. Reddy's lab, Hyderabad, India	Gamaleya National Centre, Russia	74	25	Non-replicating viral vector
Jcovden	Janssen (Johnson & Johnson)		113	26	Non-replicating viral vector
Vaxzevria	Oxford/AstraZeneca		149	73	Non-replicating viral vector
Covishield (Oxford/ AstraZeneca formulation)	Serum Institute of India	Oxford-AstraZeneca	49	6	Non-replicating viral vector
Covaxin	Bharat Biotech	Indian Council of Medical Research, National Institute of Virology, India	14	16	Inactivated
Nuvaxovid	Serum Institute of India		40	22	Protein subunit
Corbevax	Biological E Limited	Baylor College, US	2	7	Protein subunit
COVOVAX (Novavax formulation)	Serum Institute of India		6	7	Protein subunit
AKS-452	University Medical Center Groningen		Pre-clinical	4	Protein subunit
ZyCoV-D	Zydus Cadila		1	7	DNA
GEMCOVAC-19	Gennova Biopharmaceuticals Limited		1	2	RNA
Incovacc	Bharat Biotech		1	4	Non-replicating viral vector
Sputnik Light	Gamaleya		26	7	Non-replicating viral vector
Sputnik V	Gamaleya		74	25	Non-replicating viral vector
Vaxzevria	Oxford/AstraZeneca		149	73	Non-replicating viral vector
Covishield (Oxford/ AstraZeneca formulation)	Serum Institute of India		49	6	Non-replicating viral vector
Covaxin	Bharat Biotech		14	16	Inactivated
BECOV2B	Biological E Limited		Pre-clinical	2	Protein subunit
BECOV2C	Biological E Limited		Pre-clinical	2	Protein subunit
BECOV2D	Biological E Limited		Pre-clinical	2	Protein subunit
HGCO19	Gennova Biopharmaceuticals Limited	Department of Biotechnology, India	Pre-clinical	2	RNA
Codon-deoptimised COVID-19 Vaccine	Indian Immunologicals Limited, India	Grifith University, Australia	Pre-clinical		Live attenuated
IndiRab	Bharat Biotech		1	1	Inactivated
Abhayrab	Indian Immunologicals Limited, India		1	1	Inactivated
Heppacine –B &Revace-B	Bharat Serum Vaccines Ltd.		1	1	Recombinant vaccine
Genevac-B	Serum Institute of India		1	1	rDNA vaccine
Elovac-B&Vaxtar-5™	Indian Immunologicals Ltd		1	1	Recombinant DNA & inactivated
CERVAVAC	Serum Institute of India	Bill & Melinda Gates Foundation, US	1	1	Recombinant vaccine
NASOVAC-S	Serum Institute of India		1	1	Live attenuated
MR-VAC	Serum Institute of India		1	1	Live attenuated
Tresivac/Tresivac-PFS	Serum Institute of India		1	1	Live attenuated
TetraVax-DV	Panacea Biotec Ltd	US National Institutes of Health	Clinical	Phase I/II	Live attenuated

2022, Public Health Vaccines, LLC (PVH) of Cambridge began producing the NiV vaccine [42].

2.6. Japanese encephalitis

The identification of the Japanese encephalitis (JE) virus can be traced back to its initial discovery in India in 1955, specifically in the region of Karnatak which is transmitted by mosquitoes (Fig. 3). Subsequently, in 2022 about 76 cases reported by IDSP and 11 deaths due to JE (Fig. 5). The leading candidates for the JE vaccine by Intercell's (Austria) purified inactivated vaccine (PIV) IXI-ARO® (IC51) and Sanofi Pasteur's chimeric vaccine IMOJEV®, both using ChimeriVax Technology platforms based on Yellow fever virus 17D (YFV17D). Biological E, Intercell's partner in India, will produce and sell IXIARO® there (Table 2). The financial implications associated with the JE vaccine are expected to play a crucial role in the decision-making process, given its anticipated higher cost compared to the Chinese live attenuated vaccine is SA14-14-2 [43]. The Japanese encephalitis vaccine (JENVAC) is an inactivated, single-dose vaccine, produced using the Indian strain of the JE virus (Kolar-821564XY). This vaccine has developed by the collaboration of NIV with Bharat Biotech in September 2013 (Fig. 4; Tables 2 and 3) [44]. Biological E Ltd, a pharmaceutical company based in Hyderabad, has trademarked their first locally developed inactivated vaccine, JEEV (Tables 2 and 3) [45].

2.7. Hand, foot, and mouth disease (HFMD)

The *Enterovirus* genus is the most prevalent cause of HFMD, also known as tomato fever. The virus is primarily caused by CV-A16 (Coxsackievirus A16) and EV-71 (Enterovirus A71) [46]. The disease has rapidly spread in India and Southeast Asia, with first reports in West Bengal in 2007, and later in Kerala, Maharashtra, and Tamil Nadu and Odisha during 2022. Currently, no antiviral therapies or proven clinical care techniques have been developed for HFMD. Antiviral therapy with interferon, ribavirin, ibuprofen, acetaminophen, and IFN-α has been proven effective in managing HFMD (Table 2) [47]. Three companies Chinese Academy of Medical Science, Sinovac and Vigo are developed of highly efficacious EV71 inactivated whole virus vaccine with an effectiveness rate of 97.4% (Phase 3 trial) [48].

2.8. Diarrheal disease

Diarrhea constitutes a prominent contributor to the burden of disability adjusted life years on a global scale. Diarrheal disease in newborns and young children is almost often caused by rotaviruses (Fig. 2). The *Reoviridae* family includes the genus *Rotavirus*, which is composed of viruses with double-stranded RNA. In India, an estimated annual mortality rate of approximately 47 per 1 lakhs infants and children under the age of 5 is attributed to diarrheal diseases [49]. Approximately 92 thousand cases of diarrhea were identified in three districts during the first outbreak of diarrhea in Manipur in 1985[50]. In the year 2022, a total of 13,580 cases were officially documented, resulting in 49 reported fatalities (Fig. 5). Currently, there are two RV vaccines that have been approved by the US Food & Drug Administration (FDA) and are available globally. These vaccines include a pentavalent vaccine called RotaTeq® manufactured by Merck Sharp & Dohme, and a monovalent vaccine known as Rotarix® produced by GlaxoSmithKline [51]. A recent completion of a phase III study on a vaccine targeting RV in infants was conducted at the All India Institute of Medical Science. The Indian manufactured vaccines, namely ROTAVAC developed by Bharat Biotech, ROTASIIL produced by Serum Institute of India (Tables 2 and 3), and Rotavin-M1 manufactured by Polyvac, have obtained official authorization at the national level (Table 2) [51]. The Rotavirus Vaccine (Live Attenuated, Oral), a single-dose liquid-frozen vaccine manufactured by Bharat Biotech, is used to protect against rotavirus gastroenteritis. India introduced the rotavirus vaccine (RVV) in Southeast Asia on March 26, 2016, as part of the World Health Organization's Southeast Asia region (Fig. 4). India's first and largest vaccine efficacy clinical study tested the vaccine's effectiveness and safety, finding that it prevented 56.4% of severe non-vaccine rotavirus gastroenteritis in the first year and 49.0% in the second year [52]. The new rotavirus vaccine, ROTAVAC 5D®, is a liquid that may be administered at room temperature and does not need a buffer. The low dose makes it convenient for distribution, cold chain management, and the disposal of biological waste. Clinical safety and immunogenicity characteristics for ROTAVAC 5D® are similar to those of the WHO-prequalified ROTAVAC®. The vaccine is available in a variety of dosage sizes and containers, including pre-filled syringes, single-use vials, and multi-dose vials [53]. The OTC medications loperamide, lomotil, and bismuth subsalicylate are typically what people turn to in order to treat acute cases of diarrhea (Table 2) [54].

2.9. Rabies

Rabies is a zoonotic virus that has been spreading to humans in India, with dogs being the most important reservoirs (Fig. 3). Annually 59,000 people death worldwide due to rabies, but 35% in India [55]. Specifically, in the year 2022, approximately 13 cases were recorded resulting in fatalities (Fig. 5) [56]. Encephalitic and paralytic are two clinical syndromes are recognized in human. Rabipur® vaccine produced by Sanofi Aventis in India, as well as the Verorab® vaccine manufactured by Sanofi Pasteur and Ranbaxy® marketed in India, have received approval from the WHO (Table 2). Similarly, vero cell based vaccines are Abhayrab™ (Indian Immunologicals Ltd., Hyderabad) and Indirab™ (Bharat Biotech International Ltd., Hyderabad) have shown safety and immunogenicity in humans (Tables 2 and 3). Moreover Sanofi Pasteur manufactured inactivated rabies vaccine is Merieux. Indian-manufactured vaccines such as Rabipur® developed by the Serum Institute of India, and HDC® marketed by Pitman–Moore were created in 1999 using of human diploid cells from the RABV strain [57]. Verorab®, AbhayRIG, and Equirab are three vaccines used for rabies prevention. Verorab® is a purified duck embryo vaccine produced by Zydus Cadila Health Care Ltd. in Ahmedabad. Similarly, AbhayRIG is manufactured by Indian Immunologicals Ltd. in Hyderabad, while Equirab is produced by Bharat Serums & Vaccines Ltd. in Thane (Table 2) [58]. Other Indian-made vaccines include Favirab-Ranbaxy and Imogam (Ranbaxy), Worab (Wockhardt) Carig, Erig, Hrig, and Pars (Cadila) are presented in Indian pharma market. Further various drugs such as Tegretol, Sprycel, Purinethol, Chlormethine, Yondelis, Gemzar, Leukeran are used for treatment of rabies (Table 2).

2.10. Hepatitis

Hepatitis B is a significant global public health concern, impacting a staggering 257 million individuals across the globe. Tragically, this viral infection leads to approximately 8 lakh deaths each year [59,60]. India has a 2%–4% prevalence of HBsAg, with around 40 million carriers [60]. The pilot program for protecting children from hepatitis B-related diseases began in 2002–2003 and was implemented nationwide in 2010 (Fig. 4). Monovalent formulations or fixed-dose combinations of hepatitis B vaccinations are currently accessible for HBsAG through recombinant process. Production of recombinant Hepatitis B vaccine is carried out domestically by prominent Indian companies, include Bharat Serum Vaccines Ltd (Heppacine –B & Revace-B), Serum Institute of India (Genevac-B) (Tables 2 and 3), Alkem Laboratories Ltd (Hepaccine B), Shantha Biotech (Shanvac-B), Genbiotech VHB Life (Hepabig&Hepagen Plus), Indian Immunologicals Ltd (Elovac-B&Vaxtar-5™) (Tables 2 and 3), Panacea Biotech (Enivac-HB &Enivac-HB SAFSY), and GlaxoSmithKline Biologicals (Engerix-B &Twinrix) (Table 2) [61,62]. Some drugs are manufactured by Indian pharmacy industry, including Entecavir (Schwitz Biotech), Tenofovir (Gilead Sciences, Inc.), Lamivudine (Anant Pharmaceuticals Pvt. Ltd.), Adefovir and Telbivudine (Novartis India Ltd.) [63,64].

2.11. Sexual and cervical cancer diseases

Human papillomavirus (HPV) is a type of virus that primarily affects epithelial tissues, leading to the development of proliferative lesions in the layer of skin or mucosal epithelia [65]. Cervical cancer ranks as the second most prevalent ailment in India, wherein approximately 5% of women are found to carry the HPV-16/18 infection at any given point of time [66]. The only two recombinant DNA technology vaccines with worldwide licenses available in India are Gardasil® (Quadrivalent vaccine; Merck Sharp & Dohme) and Cervarix® (Bivalent vaccine; Glaxo Smith Kline). The retail prices of Gardasil® and Cervarix® in the general Indian public are INR 6,900 & INR 7,800, respectively [67]. Prominent Indian companies, namely Indian Immunologicals, Serum Institute of India, Shantha Biotech, and Bharat Biotec are currently engaged in the development of vaccines targeting the HPV. The Department of Biotechnology (DBT) is funding the development of HPV vaccines by these firms and two additional businesses via the Biotechnology Industry Partnership Programme (BIPP). The development of CERVAVAC, a quadrivalent vaccine was facilitate through financial support from the Bill & Melinda Gates Foundation and collaboration with Serum Institute of India (Table 3) [68].

2.12. Influenza

According to the WHO, approximately 1.9 million children under the age of 15 succumb to acute respiratory infections on annually. The influenza virus is classified within the Orthomyxoviridae family (Fig. 2) and exhibits genetic similarities with the influenza A virus responsible for the 2009 swine flu outbreak [69]. As of March 9, 2023, 3038 cases of H3N2 and 955 cases of H1N1 were reported in India according to the latest data available on IDSP-IHIP (Fig. 5). Indian pharmaceutical companies worked on three versions of the pandemic flu (Novel H1N1: 2009) vaccine in 2009 (Fig. 4). The Serum Institute of India is currently engaged in the production of a live-attenuated vaccine, called NASOVAC-S (Table 3), which was funded by the Department of Biotechnology through the Biotechnology Industry Partnership Programme. Additionally, Bharat Biotech and Panacea Biotech are actively involved in the development of alternative immunogens and monoclonal antibodies targeting the pandemic H1N1 strain (Table 1) [70]. Vaxigrip (Chiron Panacea Vaccines Pvt. Ltd.), Vaxigrip (Sanofi Pasteur), Fiuarix (GlaxoSmithKline Pharmaceuticals Ltd.), Influgen (Lupin Laboratories Ltd.), and Influvac (Abbott) are all available in Indian pharmacies (Table 2). Several drugs are available in India for treatment of Influenza, including Oseltamivir (Hetero Drugs Ltd. and Ranbaxy Laboratories), Zanamivir (GlaxoSmithKline), Peramivir (Biocryst Pharmaceuticals) (Table 2) [71].

2.13. Respiratory diseases

The initial instance of severe acute respiratory syndrome (SARS) was officially recorded in China in 2003, while the inaugural case of Middle East respiratory syndrome coronavirus (MERS-CoV) was identified in Saudi Arabia in 2012. In the 21st century, the emergence of two highly pathogenic coronaviruses namely SARS-CoV and MERS-CoV, in the human population resulted in severe respiratory illnesses and raised significant public health concerns regarding emerging coronaviruses [72]. COVID-19 is a zoonotic disease, with bats as common hosts. Horseshoe bats of *Rhinolophus* spp. are the major hosts, often using another species as an intermediary (Fig. 3). The first confirmed case of COVID-19 infection in Kerala, India, was reported on January 27, 2020, according to official authorities [73]. India has a yearly production capacity of over 3 billion doses for the COVID-19 vaccine, making it a major player in the vaccine industry [74]. India has developed and manufactured COVAXIN® (BBV152), India's first locally produced inactivated vaccine against COVID-19 by the collaboration of NIV and ICMR on 16 January 2021 (Fig. 4; Tables 2 and 3). Similarly, COVOVAX® and Covishield® (Serum Institute of India Pvt. Ltd.) and DNA-based vaccines like ZyCoV-D (M/s Cadila Healthcare Ltd.) and Sputnik-V (Dr. Reddy's Laboratories, M/s Gamaleya Institute & M/s Panacea Biotec Ltd. Russia) are also involved in the development of COVID-19 vaccines [75]. India has also developed the world's first protein subunit vaccine (CORBEVAX™), the world's first mRNA vaccine (GEMCOVAC™-19), and the world's first intranasal COVID-19 vaccine (iNCOVACC; M/s Bharat Biotech) (Tables 2 and 3). In a comparable vein, several COVID-19 vaccines have been granted approval for limited utilization in emergency scenarios within the country. These include the Moderna vaccine is a mRNA vaccine manufactured by Cipla Ltd., a recombinant vaccine Janssen produced by Johnson & Johnson and Biological E limited. Similarly Gennova Biopharmaceuticals developed an mRNA is GEMCOVAC-OM, the HGCO-19 created by Genova with collaboration of DBT and Biological E Limited; Hyderabad manufactured CORBEVAX in India (Table 3).

2.14. West Nile fever (WNF)

The West Nile virus (WNV) is a flavivirus transmitted by mosquitoes (Fig. 3), primarily found in West Asia, Africa, Europe, and the Middle East. It recently made its debut in the New York City region in 1999. In 1952, researchers in Bombay (Maharashtra) discovered antibodies against WNV in India [76]. In addition to three full inactivated viral vaccines (Vetera WNV, WN Innovator™ and Prestige® WNV), there is also a live chimeric virus vaccine called Recombitek™ Equine WNV, which expresses the prM/E gene from the canarypox virus (Table 2) [77]. There are no specific drugs available for the treatment of WNF, but ribavirin is prescribed for some symptoms [78].

2.15. Measles, mumps and rubella

Measles poses a substantial public health challenge in developing countries such as India, where measles virus is classified within the *Paramyxoviridae* family (Fig. 2) and has exhibited a notable surge in prevalence during the year 2022, as evidenced by the confirmation of 540 cases (Fig. 5). The measles vaccine has been part of the Universal Immunization Programme (UIP) since 1985. The live-attenuated measles vaccine developed by the Serum Institute of India, known as MR-VAC, is currently accessible in India (Tables 2 and 3) [79]. Indian Immunologicals Ltd. (IIL) has obtained authorization from the Pharmaceuticals Controller General of India to produce the measles-mumps-rubella (MMR) vaccine in India [80]. The collaboration between the Center for Research and Production of Vaccines and Biologicals, Polyvac, and Indian Immunological Ltd. aims to facilitate the production of the MMR vaccine within India. Mumps virus, also belonging to the *Paramyxoviridae* family, affects children in educational settings and can cause orchitis in 25% of post-pubescent boys and oophoritis in teenage girls [81]. The Serum Institute of India manufactured live-attenuated vaccine is MR-VAC™ and TRESIVAC to combat rubella against MMR (Tables 2 and 3) [82]. Serum Institute is the manufacturer of the Abhay-Vac 3 MMR vaccine, which is sold by Indian Immunological. GSK Biologicals Ltd. produces the live, attenuated MMR vaccine Priorix (Table 2). Measles, mumps, and rubella vaccines, as well as autism disorders, may be treated with acetaminophen, ibuprofen, or Naproxen sodium [83]. Some other causative agent of chickenpox is the varicella-zoster virus emerged in India. The Indian pharam industry like GSK Biologicals Limited (Varilrix®), Merck Sharp and Dume (Variped®), Changchun Bcht Biotechnology Co (Chikvax®), and Changchun Keygen Biological Products Co. Ltd. (Bio Pox™) produced vaccine against varicella.

2.16. Monkeypox

Monkeypox, a zoonotic disease (Fig. 3), was first identified in 1958 of Congo and has since spread through close personal contact. On July 23, 2022, the outbreak was officially designated a public health emergency of international concern. In Kerala, India, the first case was recorded on

July 14, 2022, with further instances reported within 1–2 days. Tecovirimat has been granted authorization for treatment by both the FDA and CDC (Table 2) [84]. Additionally, the ICMR has issued a call to drug companies to develop diagnostic tests and vaccines [85]. The FDA has authorized the use of an attenuated live virus vaccination called JYNNEOS (also known as Imvamune or Imvanex) to protect against monkeypox (Table 2) [86].

3. Conclusion

Novel infectious diseases arise due to aging populations, international travel, urbanization, and weather changes (Fig. 1). Current responses are inefficient, and vaccine manufacturers can use platform technology to reduce time, costs, and regulatory processes. Stakeholders, including scientists, businesses, governments, and international organizations, propose solutions, but a governing body is needed for strong leadership and coordinated action [87]. The scenario focuses on emerging infection and vaccine development in India and Southeast Asia, highlighting the importance of innovation, government support, industrial knowledge, and market forces [88,89]. The sustainable vaccination industry has emerged due to new market and the need for new vaccine in developing countries. Public-private partnerships (PPPs) and public efforts to create markets can succeed by incorporating lessons learned from industrial vaccination efforts. India's history of vaccination has been marked by skepticism, resistance, and gradual acceptance, with inequitable coverage persisting due to operational difficulties. To guide current vaccination initiatives, lessons from the past have been analyzed. Expanding vaccination coverage to every eligible person can inform policy objectives. The future of vaccine production will not occur in isolation or emergencies, but requires innovative approaches through sectorial and cross-organizational alliances. New technologies for vaccine production, such as continuous flow processing, additive manufacturing, and integrative manufacturing, will be developed through financial and strategic investments. The ecosystem has expanded to include pandemic infectious illnesses like COVID-19, resulting in faster vaccination and monoclonal antibody development. However, gaps remain in global financing and enabling sciences and product development, emphasizing the need for enhanced operation [90]. India's rapid expansion of production capacity during the pandemic contributed to its success. Government investment and involvement should focus on fostering collaboration between academic institutions, businesses, and startup incubators, as well as public-private partnerships. Indian culture and ethos must encourage experimentation and change to export cutting-edge ideas and achieve “Atmanirbhar Bharat” (self-reliant India) by providing technopreneurs with the necessary tools to grow their businesses from startup to industrial stage.

Contributions of author

Jiban Kumar Behera: Writing-review and editing of the main manuscript draft; **Pabitra Mishra, Anway Kumar Jena:** Validation, writing, figure preparation and reviewing; **Bhaskar Behera** and **Manojit Bhattacharya:** Reviewing and supervision.

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All data included within the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Abbreviations

UNICEF	United Nations International Children's Emergency Fund
DTP	Diphtheria, Tetanus, Pertussis
UN	United Nations
BCG	Bacille Calmette-Guérin
DPT	Diphtheria, Pertussis, Tetanus
CHIKV	Chikungunya virus
COVID-19	Coronavirus disease 2019
AIDS	Acquired immunodeficiency syndrome
EIDs	Emerging infectious diseases
RIDs	Re-emerging infectious diseases
SARS	Severe acute respiratory syndrome
CHPV	Chandipura virus
BPL	Beta-Propiolactone
HFMD	Hand, foot, and mouth disease
FDA	Food and Drug Administration
HPV	Human papillomavirus
DBT	Department of Biotechnology
BIPP	Biotechnology Industry Partnership Programme
WHO	World Health Organization
MERS-CoV	Middle East respiratory syndrome coronavirus
WNV	West Nile virus
UIP	Universal Immunization Programme
ICMR	Indian Council of Medical Research

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