Chapter

Innovations in Vector-Borne Disease Control in India

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Abstract

India is the second largest populous and democratic country in the world. Several geo-ecological settings are favorable for most of the vector borne diseases (VBDs) in the country. Malaria, Lymphatic Filariasis (LF), Japanese Encephalitis (JE), Dengue (DEN), Chikungunya (CHIK) and Kala-azar (KA) are major VBDs. Kyasanur Forest Disease (KFD), Plague and Chandipura virus (CHPV) infections have limited and localized foci, but needs attention. Crimean-Congo Hemorrhagic Fever (CCHF) and Zika are recent entries in India that also need to be handled on priority. National Vector Borne Disease Control Program (NVBDCP) is responsible for control and prevention of all these diseases. Malaria, LF, JE, DEN, CHIK and Zika are transmitted by different species of mosquitoes. KA and CHPV are transmitted by shadflies, while KFD, CCHF by ticks; plague by fleas. Scrub typhus (ST) responsible for acute encephalopathy syndrome (AES) is transmitted by *Leptotrombidium* mite species. It needs specific and strategic action plan in view of the diversified biodiversity. New innovations to strengthen the public health responses are the main intervention protocols. Already two diseases Guineaworm (*Dracunculiasis*) transmitted by different species of Cyclops, and polio have been successfully eradicated/eliminated from India. Such experience would be very helpful for the elimination of malaria, LF and KA, and all are on the elimination drive.

Keywords: vector-borne disease, malaria, lymphatic filariasis, Japanese encephalitis, Dengue, Chikungunya, kala-azar, Kyasanur forest disease, plague, Chandupura virus, Crimean-Congo hemorrhagic fever, Zika, elimination, surveillance, India

1. Introduction

India is a republic democratic and second most populous country in the world having a population of over 1.30 billion people in Asian continent entirely in the northern hemisphere. This is a country of great diversified ethnicities, religions, languages, cultures and food habits. One of the oldest civilizations in the world, Indo-Aryans (72%) of North India, Dravidians of South India (25%), Mongoloids (3%) and other minority populations constitute the ethnic groups. Dravidians are the original inhabitants of the country. The Indus Valley Civilization or the Harappan Civilization with a link to the Indo-Aryans migrated to the country at about 1800 BC. With this background, India has been a model country in many aspects. It is bounded by the Great Himalayas in the north, extends southwards covering Tropic of Cancer ultimately meets into the Indian Ocean between the Bay of Bengal on the east (east coast) and the Arabian Sea on the west (west coast). Both the coasts cover the Peninsular India and the Deccan Plateau. The mainland extends between Latitudes 8° 4′ and 37° 6′ North,

Longitudes 68° 7′ and 97° 25′ East and measures about 3214 km from North to South between the extreme Latitudes and about 2933 km from East to West between the extreme Longitudes. It has a land frontier of about 15,200 km. The total length of the coastline of the mainland, Lakshadweep Islands and Andaman & Nicobar Islands is 7516.6 km [1, 2].

There are several vector-borne diseases (VBDs) in India and most of them are transmitted by mosquitoes. These are malaria, LF, JE, DEN, CHIK and Zika. Sandfly-linked diseases are KA and CHPV, while KFD and CCHF by ticks, and ST by mites, while Plague by fleas mostly from rodent hosts. The vectors and the VBD control operations and preventions are implemented by the National Vector Borne Disease Control Program (NVBDCP) and National Centre for disease Control (NCDC) at national level. Many other national institutes under the aegis of Indian Council of Medical Research, Department of Biotechnology and Indian Council of Agricultural Research additionally support the program by doing research on these diseases. The research findings help in implementing the control of all VBDs. The respective state health departments implement the program following the guidelines provided by the NVBDCP. At present malaria, LF and KA are in the process of elimination; malaria by 2030 and the latter two diseases by 2020. A detailed action plan and proper implementation protocols are needed for achieving the goals.

2. Search methods

Searched MEDLINE (PubMed); CABS Abstracts; checked the reference lists of all studies identified by the search. Also performed Google Search on specific topics. Examined references listed in review articles and previously compiled bibliographies.

3. Mosquito-borne diseases

Mosquitoes are small flying insects that constitute the maximum species in the taxon of animal kingdom. They are considered as the deadliest animals in the world. As per the recent report, there are 3541 recorded number of mosquito species in the world distributed in 2 sub-families, 11 Tribes and 11 Genera. In India 404 species (11.4%), 50 Genera (44.6%) and 63 *Anopheles* species (13%) are recorded [3]. Several mosquito species are responsible for transmission of human diseases. In this chapter details of VBDs in India are discussed.

3.1 Malaria

Among all VBDs in India, malaria contributes the lion's share. India has contributed substantially on malaria research and strategies for its control, and is a signatory to the National Framework for Malaria Elimination (NFME) with an aim to eliminate this disease by 2030. Detailed information on malaria and its elimination process have been described earlier [4, 5]. Some recent information will be shared in this communication.

3.2 Lymphatic Filariasis

After malaria, human LF is the second most mosquito-borne disease in India, and among the tropical diseases, this disease stands after malaria and tuberculosis. LF is caused by the nematode parasites found in the lymphatic system, damage the system leading to deformities of body organs especially elephantiasis and hydrocoel,

relentless disability causing social stigma. Globally three parasites *Wuchereria bancrofti*, *Brugia malayi* and *Brugia timori* are responsible for LF. In India *W. bancrofti* is the most predominant species (98%) while *Brugia malayi* (2%) is limited to the coastal belts in Kerala, Goa and also in Gujarat. *Culex quinquefasciatus* is the main vector of *W. bancrofti*, while *Mansonia annulifera* is the main vector species of *B. malayi* transmission [6].

In India, National Filaria Control Program (NFCP) was launched in 1955 with an aim to control the disease following vector control, treatment of filarial cases, and thus making the endemicity delimited. A district level survey in 2000 revealed that of the 289 districts, 257 were endemic for LF [7]. In 2004, elimination of LF program was launched in 255 districts of 16 states and 5 union territories. In the beginning, diethylcarbamazine (DEC) was introduced under the Mass Drug Administration (MDA) program, and in 2006 Albendazole was added with DEC with an aim to eliminate LF by 2015. A review in December 2015 showed that of the 255 districts 222 had reported microfilaria rate 1%, and in 53 districts MDA was withdrawn as halt in transmission was indicated. Transmission Assessment Survey (TAS) was qualified for 68 districts. The remaining districts were struggling to achieve the goal making the MDA twice in a year.

The World Health Organization (WHO) estimated that LF is found in 80 tropical and subtropical countries with 120 million infected cases, and with one billion people at risk, 947 million people are threatened, whereas 40 million people are disfigured by this infection [8]. Four countries India, Indonesia, Bangladesh (all Asian countries) and Nigeria (Africa) contribute about 70% of the LF infection in the world. In 2000, WHO launched Global Program to Eliminate Lymphatic Filariasis (GPELF). In 2012, the WHO neglected tropical diseases roadmap reconfirmed the target date for achieving elimination by 2020. India also reemphasized its commitment for GPELF [8].

In the 10th GPELF meeting in New Delhi, India in June 2018, government of India launched Accelerated Plan for Lymphatic Filariasis Elimination (APELF). A triple drug therapy or IDA (Ivermectin, DEC and Albendazole) along with community engagement and fortified salt with DEC has been planned for accelerating the LF elimination in India [9]. IDA has been rolled out successfully across four districts as a pilot project in India. These districts are Arwal in Bihar (20 December 2018), Simdega in Jharkhand (10 January 2019), Nagpur in Maharashtra (20 January 2019) and Varanasi in Uttar Pradesh (20 February 2019). A total of 8.07 million people out of 10.7 million vulnerable people (75.4%) were benefitted with the IDA medicines. The Government of India has decided to scale up IDA approach in all endemic districts on a 'Mission Mode' approach to eliminate LF by 2021. The APELF provides free morbidity management and disability prevention services through kits and corrective surgeries [10].

3.3 Japanese Encephalitis

Japanese Encephalitis (JE) is one of the mosquito-borne diseases in India that has remained a troublesome for public health professionals. JE is caused by JE virus (JEV) under *Flaviviridae* family primarily infects the brain. The disease is spread by *Culex* mosquitoes. Pigs especially piglets as multiplying host and egret birds are hosts for JEV. This disease was first reported in 1871 and currently prevalent in 24 countries in Southeast Asia and Western Pacific regions which is the rice growing area [11]. About 3 billion people under risk in this region with 68,000 symptomatic cases and 17,000 deaths every year, often appear in huge outbreaks following high mortality [12].

The first human case in India was reported from North Arcot district of Tamil Nadu in 1955. Subsequently it was reported in 1973 from Bankura and Burdwan districts in West Bengal. Currently this disease is present all over the country mostly in the Eastern states. In India *Culex vishnui* subgroup mosquitoes *Cx. tritaeniorhynchus, Cx. vishnui*

and *Cx. pseudovishnui,* have been reported as major vectors of JE. Other species like *Cx. gelidus, Cx. epidesmus* have also been implicated in the transmission [13].

Though vector management is the main strategy for the control of JE, but due to many factors this remains to be the secondary option. However, use of long lasting insecticide nets (LLINs) both by humans and in pig sties has been very effective in Assam [14]. In India, the JEV is genotype III. The main containment is the use of SA 14-14-2 Chinese vaccine. But the coverage in endemic areas of Gorakhpur, Uttar Pradesh was very low at 42.3% [15]. The vaccine is covered in children under 15-year age. Now in 20 districts in the states of Assam, West Bengal and Uttar Pradesh, vaccination in adults aged between 15 and 65 has been recommended by NVBDCP since more number of adult JE cases were reported in these states [12]. A new Indian vaccine JENVAC—a single dose inactivated JE Vaccine has been developed. This Vero cell derived vaccine is prepared from an Indian strain (Kolar-821564XY) of the JEV [16].

3.4 Dengue, Chikungunya and Zika

Dengue, Chikungunya and more recently Zika epidemics are spreading throughout the world at a faster pace especially in the Americas. All these diseases are caused by arboviruses. Dengue and Zika are Flavivirus (Family *Flaviviridae*) while Chikungunya is Alphavirus under *Togoviridae* family. These diseases are primarily transmitted by two species of *Aedes* mosquitoes, *Ae. aegypti* and *Ae. albopictus*. Both are invasive and endemic species which can adapt with the local conditions, dispersed by their immaculate mechanism of their desiccation-tolerant eggs. Moreover, all these viral diseases are carried forward through the process of transovarian transmission. This means when a mother mosquito infected with virus are stored in their gonads (reproductive organs), the viruses are carried forward to the next generation. In most situations, these infected eggs when carried with the breeding containers especially through tyres establish in a new area [17, 18].

Currently about 4 billion cases of dengue in more than 128 countries are reported. About 390 estimated cases of dengue are recorded globally. There are 4 serotypes present in dengue virus and a fifth serotype of DENV was detected from Malaysia [19]. In India, epidemics of dengue have been reported from 1990, and all the 4 serotypes are present. In 1780, first epidemiology of dengue was described in Madras (now Chennai), and first outbreak was reported in Calcutta (now Kolkata) in 1963 [20]. Now this disease is reported almost all over India. There is no effective treatment for dengue. Recently one vaccine for dengue has been developed, but it is effective only on seropositive cases. In 2019, Sri Lanka, Philippines and Bangladesh have declared emergency situations in these countries [21–23]. So the situation is very grave and needs immediate solutions.

Chikungunya additionally is causing public health problem in the country. This disease was first reported in Tanzania in 1952-53. From this location it has spread in most of tropical Africa and Asia. In India, a huge outbreak was reemerged in 2006 after its first report in 1973 [24]. Currently this disease is reported almost in every state along with dengue. There is no specific treatment for this disease since it is self-limiting. It is assumed that this disease does not cause mortality in India, but certain report may say otherwise. In Ahmadabad city, there were excess deaths during Chikungunya outbreak in 2006 [18].

Zika is a new disease that rocked the Latin American countries mainly in Brazil in 2015. As of July 2019, a total of 87 countries and territories have had evidence of autochthonous mosquito-borne transmission of Zika virus (ZIKV), distributed across four of the six WHO Regions (African Region, Region of the Americas, South-East Asia Region, and Western Pacific Region) [25]. As such this disease

does not cause much clinical emergencies. In certain cases, neurological complications in adults and children with Guillain-Barré syndrome are associated with ZIKV. Its effect on fetuses in pregnant women is a matter of serious concern. The babies are born with microcephaly, preterm birth and miscarriage. In other word babies are born with small heads leading to several abnormalities. Several reports also indicated sexual route of transmission from asymptomatic carriers [26].

In India first report of Zika was reported in September 2018 from a 78 year-old women in Jaipur, Rajasthan. Immediately a rapid response team was formed and detailed investigations were made by the government of India. Massive surveillance all over India was initiated including in all international airports and ports as a part International Health Regulations. Special care was taken on pregnant women especially in the suspected areas. In 2018, 157 Zika cases have been detected, that included 63 pregnant women. All cases were confirmed by RT-PCR method. No cases of microcephaly or congenital Zika syndrome were reported. The government of India has established 34 laboratories for Zika surveillance and diagnosis to strengthen the especially established 'National Zika Action Plan' [27].

Recent news of 'First sexually transmitted dengue case confirmed in Spain' is a much disturbing matter and deep concern. This indicates that viral infections may affect gonad cells [28].

3.5 Sandfly transmitted diseases

3.5.1 Kala-azar

Kala-azar (KA) is considered the most devastating neglected tropical disease caused by the protozoan parasite *Leishmania*. There are over 20 species of *Leishmania* that is transmitted by over 90 species of Sandflies (*Phlebotomus* spp.). Generally, three forms of this disease are reported namely visceral leishmaniasis (VL), cutaneous leishmaniasis (CL) and mucocutaneous leishmaniasis (ML). This infection is mostly prevalent in the poorest people linked to malnutrition, poor living conditions and resources. Annually estimated new cases between 0.7 and 1 million and some 26,000–65,000 related deaths are reported in the world [29].

VL is commonly known as Kala-azar. The clinical cases may turn fatal if not treated in time. An estimated 50,000–90,000 new cases are reported annually, and most cases occur in Bangladesh, Brazil, China, Ethiopia, India, Kenya, Nepal, Somalia, South Sudan and Sudan. Post-Kala-azar dermal leishmaniasis (PKDL) is a complicated form of VL. It is also known as Post-Kala-azar dermatosis characterized by muscular, maculopapular and nodular rash on face, arm and upper part of the trunk. This is mostly found on patients recovered for VL [29].

The most common form of the disease is CL. It causes skin lesions leaving scar marks and stigma. It is estimated that 0.6–1 million new cases are reported from Afghanistan, Algeria, Brazil, Colombia, Islamic Republic of Iran, Iraq and the Syrian Arab Republic [29].

ML is responsible for a partial or total destruction of mucous membranes of the nose, mouth and throat. Over 90% of ML cases occur in Bolivia, Brazil, Ethiopia and Peru [29].

India is endemic for both VL and CL cases. PKDL cases are on the increasing trend. CL caused by *Leishmania major* and *L. tropica* mostly present in north-western states in India mainly in Rajasthan and Punjab. The worst area is Bikaner district of Rajasthan [30].

VL primarily caused by *L. donovani* was endemic in India especially in the eastern Uttar Pradesh, undivided Bihar and West Bengal. In fact, undivided Bengal is considered the oldest KA endemic area in the world. Drastic reduction

of cases was reported due to application of DDT during malaria eradication program in the 1960s. In India, government of India initiated KA elimination program in endemic states in 1990–91. Approximately 130 million people in 611 blocks are at risk. Currently drastic reduction of cases is recorded in the elimination phase. Many joint initiatives have been undertaken with potential partners like Bill and Melinda Gates Foundation, KalaCore Consortium and government like institutions ICMR-Rajendra Memorial Research Institute (RMRI) and National Center for Disease Control (NCDC) and WHO to eliminate this disease by 2017. However, this is aimed at 2020 to eliminate this disease. The office of the Prime Minister (PMO) and the health department are monitoring the progress of the work [30].

For elimination of KA a national roadmap has been created and shared to all the states for implementation at village-level. Continuous supply of Liposomal Amphotericin B (AmBisome) injection has been ensured since single day single dose has improved treatment compliance. Regular supply of rapid diagnostic test kit is also ensured. Government of India will compensate INR 500 for KA and INR 2000 for PKDL cases as loss of wages. Besides this, INR 300 to the Accredited Social Health Activist (ASHA) or health staff for KA patient surveillance and treatment. Additionally, ASHAs are INR 200 for the indoor residual spray and also community engagement and mobilization [30].

Miltefosine (MF) (hexadecylphosphocholine), a lysophospholipid analog, was mainly developed as an anticancer drug and in 2011, WHO added MF as essential medicine. MF has been used for VL, but due to possible resistance this drug has been kept under hold. However, this is prescribed in PKDL cases [31].

3.5.2 Chandipura virus

Chandipura virus (CHPV) belongs to the genus Vesiculovirus, family *Rhabdoviridae*. This infection was discovered during an acute febrile outbreak in Nagpur, Maharashtra state, India from two febrile cases in 1965. The available information suggests that sandflies are the vectors for this virus while antibodies against this have been detected in a wide range of vertebrate animals. In recent years, CHPV has emerged as encephalitic pathogen. Many outbreaks especially in children have been documented from different areas of India; in 2004, 2005, 2007 and 2008 from Andhra Pradesh, in 2005, 2009 to 2012 from Gujarat and in Vidarbha region of Maharashtra during 2007 and 2009–12 [32].

During the outbreaks in Maharashtra CHPV has been isolated from pools of Sandflies. However, CHPV has also been isolated from human samples during 1971–72 in Nigeria, and hedgehogs (*Atelerix spiculus*) during entomological surveillance in Senegal, Africa during 1990–1996. Recently this virus was also detected from Bhutan and Nepal, and from wild toque macaques (*Macaca sinica*) at Polonnaruwa, Sri Lanka during 1993. This suggests its circulation in many tropical countries. All these factors indicate that Sandflies are the vector of CHPV [32].

In 2019, a 5-year old girl reported died due to CHPV infection in Gujarat. This is an indication that this virus is still remains to be a cause of concern [33].

3.6 Mite-transmitted diseases

3.6.1 Scrub typhus

Scrub typhus (ST)—a rickettsial infection is caused by the gram-negative obligate intracellular coccobacillus pathogen *Orientia tsutsugamushi*. Its transmission to humans is by the bite of larval stage (chigger) of *Leptotrombidium* mites under

Trombiculidae family. This disease is endemic in Southeast Asia and Southwest Pacific regions generally known as *tsutsugamushi* triangle [34].

In India, first cases of ST were reported from Himachal Pradesh and were prevalent between 1960s and 1970s in many states and union territories. However, subsequently this disease disappeared possibly due to the use of insecticides for vector control and also the wide use of antibiotics to febrile cases with Tetracyclines and Chloramphenicol. ST is responsible for one of the causes of acute encephalopathy syndrome (AES) especially in children. WHO recognizes this disease is most underdiagnosed and under-reporting febrile illness demanding hospitalization. Post-monsoon is the most favorable period of ST as most of the cases are reported during this time. It is reported that the ongoing AES outbreaks in Gorakhpur areas in Uttar Pradesh were due to ST along with JE [35]. This made the public health officials to shift the treatment schedule. Doxycycline is recommended, thus saved many children. Similar observations were also recorded in Odisha and Assam states. This recent experience necessitated to undergo routine diagnostic tests for ST where AES is the most prevalent. Thus this disease can be contained and lives of many children can be saved [35]. Recently ICMR-DHR has drawn a generalized guideline for scientific management of ST [36].

3.7 Tick borne diseases

3.7.1 Kyasanur Forest Disease

Kyasanur Forest Disease (KFD) or generally called monkey fever by the local people is a forest tick-borne virus serocomplex of the genus *Flavivirus*, family *Flaviviridae*. The disease causes fever, hemorrhage, and encephalitis and has a 3–10% case-fatality ratio. It is not contagious transmits to man through bite of hard ticks primarily *Haemaphysalis spinigera* and many other *Ixodid* spp. The nymphs are active feeding form of the immature stage of the tick. This species is mostly prevalent in forest and feed on a number of small mammals, rodents, shrews, insectivorous bats, squirrels, rats and even many birds maintain the natural enzootic cycle of the virus in the forest ecosystem. Two non-human primates, black-faced langurs (*Semnopithecus entellus*) and red-faced bonnet macaques monkeys (*Macaca radiata*) get the virus infection by tick bite and are susceptible to the infection. Man is the dead end host. Cattle are the main hosts play an important role in maintaining the tick population [37].

KFD virus (KFDV) was first detected in a moribund black-faced langurs (*Semnopithecus entellus*) in Kyasanur forest near Baragi village in Sagar taluk of Shivamogga distirct, Karnataka state (erstwhile Mysore state) in 1957. In the beginning KFDV was restricted to three taluks i.e. Sagar, Shikaripur and Sorab of Shivamogga district. Subsequently it spreaded to other areas of Karnataka namely Udipi, Uttara Kannada, Mangaluru, Dakshina Kannada, Chikmagalur and Chamarajanagar district, Bandipur Tiger Reserve Forest, Karnataka. Outbreaks were reported in Thirthahalli taluk, Shivamogga district in 2014 and Belagavi district in 2016 Karnataka state. In 2015, outbreaks also occurred in four villages Northeast Goa. During serological studies, presence of KFDV were found in other areas of India such as parts of the Saurashtra region in Gujarat State, forested regions west of Kolkata, West Bengal State, and the Andaman Islands [38].

The increase in number of new foci and cases indicates that ecobiological changes due to deforestation and use of new land for farming and cattle grazing could lead to spread of KFD virus to newer geographical areas [38].

KFDV has been found only in monkeys, humans, and *Haemaphysalis spinigera* ticks in the KFD-epidemic region of south India. This virus was initially suspected as a Russian spring-summer (RSS) complex of viruses. But KFDV is only reported

from India. The other closely related to KFDV are Omsk hemorrhagic fever virus in Siberia, Alkhurma virus in Saudi Arabia and Nanjianyin virus in China [38].

3.7.2 Crimean-Congo hemorrhagic fever

Crimean-Congo haemorrhagic fever (CCHF) is a zoonotic viral hemorrhagic infection and the virus (CCHFV) belongs to the genus *Nairovirus* under the family *Bunyaviridae*. CCHF was recognized for the first time in 1944, in the West Crimean region of the former Soviet Union, during a large outbreak, and the virus was subsequently isolated in 1956 from a human case. The average case-fatality rate is 30–50%; this varies between 5 and 80% in various outbreaks. The disease is endemic in Asia, Africa, East Europe, and the Middle East countries, that include Iran, southern Russia, the Balkans, Turkey, Pakistan, China, Iraq, the United Arabic Emirates, Oman, Kuwait, and Saudi Arabia. Considered as an occupational disease, CCHFV is transmitted by the bite of infected ticks or through direct contact with the infected blood and tissues of animals as well as nosocomial infections. *Hyalomma marginatum* and *Ixodid* spp. of ticks are the main vectors of CCHFV [38, 39].

The existence of CCHF in India was first confirmed in 2011 in Gujarat state from a nosocomial source. This case started with an index case having a history of tick bites with a close contact with animals. Another nosocomial infection was recorded in June 2012 from Ahmadabad city ended with two fatalities. In 2013, a non-nosocomial CCHF outbreak in Amreli district, as well as positive *Hyalomma* tick, animal and human samples in various areas of Gujarat state, suggested that the virus is widespread in Gujarat state, India [40]. In September 2019, a high alert was sounded after two suspected siblings of CCHF surfaced in Jodhpur, Rajasthan state. On enquiry, it was found that their father was undergoing treatment for CCHFV in a hospital in Ahmadabad. All recovered from the infection [41].

The disease also transmitted man to man via nosocomial source. Once a man gets infected, the disease is transferred to other close family members who accompanied the infected individual to the hospital, lived in the same house, and attended the funeral of a person who had died due to CCHFV, or came in contact with infected body fluids. The normal route is through a bite from an infected tick. CCHFV circulates in nature in the enzootic route of 'tick-vertebrate-tick' cycle [38].

3.8 Flea-transmitted diseases

3.8.1 Plague

Plague is one of oldest vector-borne diseases known to mankind. It is a zoonotic disease that means an animal disease that can spread to humans—caused by a Gram-negative bacteria *Yersinia pestis*. It is transmitted to humans through the bite of infected fleas that live among rodents such as rats, squirrels, chipmunks, wood rats, prairie dogs, and rabbits. Usually epidemics of human plague are followed by rodent epizootics or rat fall in domestic and peri-domestic settings. There are three forms of the infection; (i) bubonic plague primarily affects the lymph nodes; (ii) septicemic plague affects the bloodstream and can be contracted by handling infected animals; (iii) pneumonic plague affects the lungs and can spread from person to person, though rarely, through contaminated air droplets [42].

Plague was mentioned in Bhagvata Purana (155–600 BC), as a disease. This disease also known as 'Black Death' in the fourteenth century panendemic was responsible for a major public health problem throughout India till the mid twentieth century AD. The epidemic was started in the year 1895–1896, and reached its peak

in 1907. During the two decades between 1898 and 1928 there were over 12 million deaths in undivided India. The mortality rate due to plague was calculated to be 1.8 per 100,000 populations between 1949 and 1958. Since then mortality had declined and reached zero level during 1967. The reason for drastic decline was attributed to the use of DDT mainly introduced during National Malaria Eradication Program, and also use of streptomycin and sulfanomide. In the subsequent years between 1959 and 1966 there was a resurgence of plague in the South Indian sates of Tamil Nadu, Andhra Pradesh, and Karnataka. This may be due to discontinuation of DDT in the national program. Following this, in 1994, a bubonic plague outbreak at Mamla village, Beed district, Maharashtra and a pneumonic plague outbreak in Surat, Gujarat were recorded. This costs heavy revenue due travels restrictions at national and international levels. In 2002, a localized outbreak of pneumonic plague occurred in Hatkoti, Shimla district, Himachal Pradesh, and a bubonic plague outbreak occurred in Dangud village, Uttarkashi district, Uttarakhand in 2004 [42].

Xenopsylla cheopis—the flea species the main vector of plague is believed to be originated from the valley of Nile. It is distributed throughout the world. *Xe. astia*is restricted in its distribution to the oriental region and in India it is widely distributed in peri-domestic and wild situations. *Xe. brasiliensis*, originally distributed from Africa was a very common species in domestic and peri-domestic settings in Peninsular India. However, currently this species is not abundant in India. In India, of the 128 species of rodents belonging to 46 genera 8 are considered to be the zoonotic reservoirs of various diseases. Domestic rats especially *Rattus rattus* and peri-domestic *Rattus norvegicus* are the most common hosts of these vector fleas. The sylvatic cycle of plague is maintained among the wild rodent hosts. It has been observed that most rodent species propagate their populations during the bamboo flowering seasons that occur once in every 10–12 years. Hence, proper prior preventive arrangements must be undertaken to prevent rodent-linked diseases and also huge damage to crops [42].

4. Discussion

India is a vast country with several geo-ecological diversities on ethnicities, languages, socio-cultural, and political settings. Most of the vector borne diseases in India or elsewhere are governed by the local environmental factors. In the present situation, climate change is a big threat to the entire world. There are unprecedented uncertainties in disease prediction resulting some unrelated outbreaks do occur in the present situation. To encounter this situation, a robust public health response mechanism must be in place in every state. On this direction, Integrated Disease Surveillance Program (IDSP) is in place to take immediate action to contain any outbreaks including VBDs.

In the present situation, malaria, LF and KA are under the process of elimination. Already two timelines of elimination for LF and KA have been extended, and now aiming to eliminate the two diseases by 2020. As per the present information, it may not be possible to achieve this goal by 2020. However, several efforts such as inclusion of ivermectin for ELF and strengthening of case detection and enhancement of incentives for each CL and PKDL for KA are highly encouraging. In case of malaria elimination, several initiatives have been taken. One such is Malaria Elimination Research Alliance—India (MERA—India). This will address the immediate research needs that will support the national program. Today the major issues are how to tackle the outdoor transmission, role of asymptomatic in malaria transmission especially in the high burden tribal areas where the real malaria problem exists. A robust smart surveillance system with application of artificial intelligence

and mechanical learning must be introduced for better program implementation with correct prediction. Studies on vector behavior and responses of existing drugs to the malarial parasites and insecticides to the local vectors especially *Anopheles culicifacies* in most rural areas; *An. fluviatilis* and *An. minimus* in hilly terrain areas; *An. dirus* in forest areas especially in Northeast India. Resistance of synthetic pyrethroids (SPs) to most vector species is a matter of concern, because these are used in LLINs and no other molecules are available to replace them. In this direction recent study on use of atovaquone adding on glass substrate led to the killing of *P. falciparum* parasites in blood-fed *Anopheles* mosquitoes. This can be applied on LLINs along with SPs for better results. Other sporontocidal antimalarial drug Tefenoquine can also be used [43]. A special action may be taken for *An. stephensi*—the main urban malaria vector. This invasive species is rapidly making its footprints with the fast urbanization process. Already reports indicate that it has invaded Sri Lanka and some African countries [44, 45]. This is indicative of strong implementation of International Health Regulation act.

NVBDCP is the nodal agency for all vector borne diseases in India. Dengue, Chikungunya and more recently Zika are all transmitted by the two species of *Aedes* mosquitoes namely *Ae. aegypti* and *Ae. albopictus*. These two species are also highly invasive and endemic—the former is more associated with domestic and peri-domestic environments; while the later in the forest-fringed areas. Efforts to control the vector population using the genetic engineering tools are encouraging, but needs correct and specific genetic analysis of the target species as the recent report in Brazil deems strategic introspection [46].

Cattle including pigs play an important role in maintaining the enzootic cycle of most of VBDs. In recent years, diseases transmitted by ticks and mites are on the rise. This may be attributed to more man and animal contacts. Due to population pressure man is encroaching new areas especially in the forest ecosystem. It has been observed that cattle are the main host for ticks and mites to maintain their population. It is, thus, important to grow cattle population under controlled conditions with the help of local veterinary department. Open grazing of such cattle in the affected areas must be prevented so as to boost the enzootic transmission of KFD, CCHF and ST types of diseases. ST was diagnosed as the main AES problem in Gorakhpur, UP especially in the children. Treatment with doxycline contained the outbreak of AES besides other additional containment measures [34].

Similarly, sandflies also depend on cattle for maintenance of their own population in the endemic areas of KA and CHPV. Pigs also grown in most wet areas since these are easy source of income generation especially in the poorer section of the society. This is not an organized sector. Steps must be taken so as to make proper sty and protected with LLINs by which pig-mosquito contact can be minimized [14]. Recently genetically engineered high protein-rich pink pigs have been produced that can convert into pin-revolution. In this way JE transmission can be prevented [47].

Cow dung is a good source of organic manure traditionally practiced in India for ages. It has been observed that cows are reared for milk and manure purpose almost in each village household of rural India. But in most of tribal areas a very few household rears cattle making a very low human and cattle ratio. This may be one of the potential factors resulting high human blood index in the main vector *An. fluviatilis* [48]. So promotion of cattle in all the tribal areas must be on priority. On the other hand, community-level cow dung-based biogas plant must be encouraged in each village. In this way, good quality manure and self-sustained biogas can make the rural community self-reliant. Moreover huge carbon emission from the cattle produce can be prevented and thus carbon-related green-house effects can be curtailed.

Irrigation system is intimately associated with VBDs. Most mosquito-borne diseases can be controlled if integrated irrigation can regulate the water supply preventing mosquito breeding and also water conservation. Application of blue green algae in rice field can significantly reduce the mosquito population especially *Culex* species responsible for JE [49].

India is now heading for many good initiatives aiming for better livelihood under which *Swachh Bharat Abhiyan* (Clean India Movement), providing housing to poor people, free from Open Defecation (OD) are gaining some results. Providing toilets to each village under OD program has two benefits. First, avoiding soil contamination for which anti-micobial resistance can be managed. Second, outdoor malaria transmission can be prevented especially among women community who generally go for OD in groups in the evening hours when malaria vectors take advantage of such situations. Thus, use of LLINs becomes less effective in such village settings. But construction of water storing tank in each toilet must be mosquito proofed, otherwise *Aedes*-related diseases may be introduced in new areas [4].

It has been observed that in most urban cities there are defects in architectural design for building constructions where making a box on each parapet attracts water collection when the outlet pipe is blocked. This becomes potential breeding ground for *Aedes* and *An. stephensi* mosquitoes. This design must be abandoned to avoid creating unnecessary artificial breeding grounds for potential vector mosquitoes [50].

In most water starving areas where local people store water in open cemented or plastic tanks support *Aedes* breeding. Such tanks must be replaced with mosquito-proof water storing tanks to avoid mosquito breeding [51].

India has a strong primary health care system. The primary health management begins from the Sub-center (SC) where local people report for any disease. This needs to be empowered for better health seeking behavior. Recently a health reform program *Ayushman Bharat* (long life for India) has been introduced in India. It has two arms; coverage of health insurance for poorest 500 million people up to $ 7000 (INR 500,000) of care per year, regardless of preexisting conditions, and reinvestment in primary care. These SCs have been converted into 'Health and Wellness Centers' to deliver comprehensive primary health care [52].

In 2018, the Uttar Pradesh (UP) government initiated a unique DASTAK campaign in association with UNICEF (United Nations Children's Fund) to control JE and other AES causing VBDs. The entire state machinery visited door-to-door campaign in 38 districts affected by JE and AES. It has been planned in every village of state's 75 districts to create awareness about communicable diseases. In this large-scale campaign, many state departments such as health, primary education, rural development will work together to spread awareness about diseases through mass media communication. The campaign will ensure availability of clean drinking water, promote sanitation drive, ensure vaccination and prompt treatment of diseases. Such program must be launched in every state because most VBDs are present throughout the country [53].

India is a democratic country where local working administration is governed by the elected members generally called *Panchayat Raj Institution*. It is the duty of the local health department to empower these members to take correct decisions and implementation of all health-related programs. However, social movement needs to strengthen the community engagement for achieving better health goals.

Already India has the required experience for eradication/elimination of Guinea worm and polio. This experience will help in better implementation of the VBDs under elimination process. However, the recent report by WHO has warned that malaria elimination is not possible in near future. This means malaria elimination is not possible by 2030. But India must take proper steps to eliminate malaria by 2030 [54].

5. Conclusion

As mentioned it is evident that there are needs of innovations in containing VBDs in India. In the present situation, there are many opportunities in India that must be put into actions to find solutions in containing VBDs. It is not at all good that two diseases LF and KA have failed to keep their elimination targets. That means there were some serious lapses in planning the elimination concept. The new target to eliminate both these diseases has been earmarked to 2020 and 2021, respectively. But the current situations do not seem to achieve this goal [55, 56]. However, renewed efforts should be made to fulfill the goal. On the other hand, dengue and other VBDs are posing a serious threat to the public health professionals. It has been observed that most of the VBDs are linked to epizootic environment. Hence, organized and organic farming should be given priority to reduce the man and vector contact. There are many government programs aiming to uplifting of general improvement of social status of the community. This will surely impact on the VBDs. Hence, it is the duty of all to accelerate the implementation of all programs related to VBDs and make India free from all Neglected Tropical Diseases (NTDs) to fulfill the Sustainable Development Goals (SDGs).

Conflict of interest

The authors declare no conflict of interest.

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