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Transboundary Animal Diseases in the Perspective of North East India: A Review

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ABSTRACT

Transboundary animal diseases (TADs) are a serious threat to food security and human health. North-East India shares international borders with five countries that include China, Bangladesh, Myanmar, Nepal and Bhutan. Geographical locations and climatic conditions of North East India with respect to other parts of India are different. Although this part of the country is well known for its natural beauty, customs and unique cultures but the porous international borders made it highly prone to TADs. The porcine reproductive and respiratory syndrome (PRRS) in pigs is believed to be entered in Mizoram, India from Myanmar. The recent outbreaks of African swine fever (ASF) in India are also initiated in Arunachal Pradesh and Assam and originated from China. The vulnerability of this region to be a potential entry point for TADs, which might have potential zoonotic value, warrants a critical review of the border situation of NER India. The current review emphasizes on awareness about TADs and the factors responsible for their emergence.

Key words: North East India, TADs, Zoonoses.

The quality of life in the world has enhanced with modernization and intensive farming activities to meet the demand of the increasing human population, which probably disturbed the natural ecosystem leading to the emergence of new infectious and non-infectious diseases of humans and animals (Lindahl and Grace, 2015). Most non-infectious diseases are preventable by adopting healthy living practices. But emerging infectious diseases (EIDs) are somewhat difficult to prevent and control because of their contagious nature and relative ease in international or intercontinental transmission. Animal diseases capable to cross the international border are called transboundary animal diseases (TADs) (FAO, 2004), which have very serious implications on food security, the health of both humans and animals and the economy of affected countries (McElwain and Thumbi, 2017). Some TADs are restricted to animals, but other TADs may affect both animals as well as humans (Zoonoses). Multiple factors are responsible for the emergence of TADs include international trade, globalization, industrialization, biotechnological manipulation in the genome of pathogens, intensive agriculture and livestock farming, illegal transport of wildlife, ecological manipulation, *etc.* (Brown, 2010; Cartín-Rojas, 2012; Yadav *et al*., 2020). Agriculture, food security and international trade are being very badly affected by TADs (Domenech *et al*., 2006; Islam, 2016).

The North East region of India consists of eight states,*viz,* Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Tripura and Sikkim. The entire region is surrounded by porous international borders with China, Bangladesh, Myanmar and Bhutan. The region is well known for its picturesque topography, cultural heritage, ethnic beauty, rich biodiversity and other natural resources. Due to porous international borders, the region remains highly vulnerable to the illegal trade of wildlife, livestock and their products, which provides easy access of TADs to enter the region in particular and in the country in general. Like the rest of India, livestock in North East India consist of diverse species of cattle, pigs, goat, mithun, buffaloes, sheep, yak, horse and ponies and poultry (Joseph Koireng *et al*., 2018). It means the North East region of India can act as an entry point for the diseases prevalent in the neighboring countries into India due to the presence of susceptible hosts, illegal trade of livestock and wild animals and unrestricted movement of humans along porous international borders. Also, the movement of wildlife including birds across international borders and continents is an important factor for the transboundary transmission of diseases (Liu *et al.,* 2020). Outbreaks of transboundary animals diseases in North East India like classical swine fever (Malik *et al*., 2020), porcine reproductive and respiratory syndrome virus (Rajkhowa *et al*., 2015) and porcine circovirus-2 (Mukherjee *et al*., 2018) and most recently in early 2020 the outbreak of African swine fever (Bora *et al.,* 2020) has highlighted the importance of this region in term of gateway to transboundary animal diseases entrance. In August 2019, lumpy skin disease (LSD) was reported from China (Lu *et al.,* 2020). At the same time (August 2019), LSD was first time detected

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in India from Odisha state (Kumar *et al.,* 2021). Later on LSD was also reported from West Bengal and Assam states. There is no exact evidence available about the route of introduction of LSD into India, but the possibility of entry through international borders along with North East India cannot be overlooked. The present review offers salient highlights on the importance of international borders along with the North East India concerning possible entry of TADs in India.

Transboundary animal diseases (TADs)

TADs put a huge impact on multiple sectors like animal health, public health, food security and the economy of the entire world (McElwain and Thumbi, 2017). According to the FAO, TADs are those diseases that have an essential impact on the economy, trade and/or food security of a group of countries, which can be easily spread to other countries, reaching epidemic proportions and that require control and eradication cooperation between different nations (FAO, 2004). TADs are mainly classified into two types: the first type of TADs remain restricted to animals, while the second type of TADs is zoonotic and poses a serious threat to both animal health and public health besides the impact on economic and international trade. Foot-and-Mouth Disease, Rinderpest, Contagious bovine pleuropneumonia, Rift Valley Fever, Peste des petits ruminants, African swine fever, Transmissible gastroenteritis, Swine vesicular disease, African horse sickness, West Nile fever, Eastern equine encephalomyelitis, Western equine encephalomyelitis, Venezuelan equine encephalomyelitis, Nipah, Hendra virus, SARS coronavirus, Bovine spongiform encephalopathy (BSE) and Scrapie are few notable TADs appeared in the world (Yadav *et al*., 2020).

Factors responsible for the emergence of TADs

New diseases are emerging very fast and are capable of transboundary transmission. Emergence of new transboundary diseases are possible impacts of climate change, leakage of infectious agents from its ecological niches and biotechnological manipulation in the genome of pathogenic agents (Lederberg *et al.,* 2003). Climate change is responsible for the change in the geographic distribution of vectors and intermediate hosts (El-Sayed and Kamel, 2020). All organisms inherently try to evolve to the changing environment surrounding them for better survival. Climate change causes evolution by creating selection pressure in previous pathogenic microorganisms lead to the emergence of modified microorganisms, which may be either more or less pathogenic than the original form (https://www.who.int/globalchange/summary/en/index5.html). Many tropical diseases (dengue fever, rabies, *Mycobacterium ulcerans* infection, trachoma, yaws, leprosy, Chagas disease, trypanosomiasis, leishmaniasis, dracunculiasis, cysticercosis, echinococcosis, foodborne trematodiases, lymphatic filariasis, onchocerciasis, schistosomiasis and soil-transmitted helminthiases) can re-emerge in the developed countries due to climate change particularly global warming (El-Sayed and Awad, 2018; Mitra and Mawson, 2017). It may be possible that an unknown pathogenic agent already present in their reservoir host (in wildlife) and is restricted to its niches. Human activities like deforestation, movements to an inaccessible part of the earth for the sake of either adventure or research lead to leakage of new pathogenic agents into a susceptible host. There are many examples of forest-associated emerging infectious diseases like Yellow fever, Ebola virus infection, Nipah virus infection, SARS, Rabies, Malaria, Sleeping sickness, *etc* (Wilcox and Ellis, 2006). Normally, the biotechnological manipulation in the genome of pathogens was created mostly for benefit to the human civilization like vaccine production, genomic modified microorganism for the production of specific products (proteins and enzymes) and modified plants to protect them from disease (Khan *et al.,* 2016). Besides that, biotechnological manipulations were also done to create bio-weapons to modify a new form of already known pathogen that is more pathogenic with the faster host-to-host transmission (Aken and Hammond, 2003).

Transboundary transmission of TADs

Various factors like climate change, international trade, feature of pathogenic agents, human movements, wildlife movement across international borders and continents, trans-border illegal trade of live animals and their products are responsible for the transboundary transmission of TADs (Randolph and Rogers, 2010).

Globalization and international trade of live animals and animal products

Globalization of market and international trade related to living animals and animal products is one of the major factors responsible for transboundary transmission of animal diseases (Akalu, 2017; Cartín-Rojas, 2012). Selling live animals and animal products anywhere in the world is an important component for the global economic growth (Surugiu and Surugiu, 2015). India's exports of animal products during 2019-20 was US$ 3,694.29 millions, which include the buffalo meat, mutton/chevon, poultry products, dairy products, animal casing, processed meat, albumin and natural honey (http://apeda.gov.in/apedawebsite/six_head_product/animal.htm#:~:text= The%20export%20of%20Animal%20Products,products%20like%20Buffalo%20Meat%20 (Rs.). Correlation between the role of globalization and international trade of live animals and animal byproducts in the transboundary transmission of animal disease is proven by phylogenetic analysis of pathogens detected in different geographical locations. Phylogenetic analysis of the FMD virus isolated from the 2001 FMD outbreak in the UK showed the highest similarity with South African FMDV (Pharo, 2002). Similarly, porcine epidemic diarrhea (PED) strains detected in the United States were identical to PED strains of China (Huang *et al.,* 2013). The outbreak of African swine fever (ASF) virus in China has its origin in Eastern Europe (Zhou *et al.,* 2018).

The outbreak of FMD in Egypt during 2012 was due to live animal trade from East Africa (Ahmed *et al.,* 2012).

Transportation

International or intercontinental transportation played a very crucial role in the overall development of human civilization through the exchange of culture, social life, business, economy, *etc*. The new generation transportation can transport the animals and animal products to any place of the world from any other places within 24 hours. Most of the infectious diseases have an incubation period of minimum 3-5 days, which means at a time when infected live animals reach another place they may look healthy due to a lack of clinical symptoms. Transmission of classical swine fever from England to Sweden occurred through the transport of boars (Birch, 1917). Porcine reproductive and respiratory syndrome (PRRS) was first introduced in Switzerland in 2012 through imported boar semen from Germany (Nathues *et al.,* 2016) even though boars in Germany were regularly screened for PRRS (Guimera *et al*., 2005).

Agent factors

Agent factors include those characteristics of an infectious agent that help them to spread to a longer distance, resist the food processing procedures and able to withstand adverse environmental conditions during storage of raw and processed animal products. African swine fever virus can survive 11-1000 days in raw and processed pork products including chilled, fried, smoked, offals, blood, skin, *etc* (FAO, 2013). Similarly, the FMD virus is highly stable under a different environmental condition like pasteurization of milk (at 72°C for 15 seconds), salting, curing and drying of hides of infected cattle has not been effective in inactivating the virus (Callis *et al*., 1975; Cottral, 1969). Classical swine fever virus can survive over years in frozen meat (at -70°C) (Blome *et al*., 2017).

Environmental factors

Climate change leads to the spread of human infections beyond their geographic distribution (Watts *et al.,* 2018). Anthropogenic activities changes the climatic conditions (pH, temperature, precipitation, *etc.*), which ultimately lead to the emergence of new pathogens, a shift in the geographical distribution of vectors and host, host jumping, *etc.* In the case of the Nipah virus, fruit bats (*Pteropus* spp.) act as natural reservoirs, whereas swine act as amplifiers.It had been reported that deforestation activities in Malaysia and Sumatra caused drought conditions during the year 1997. This man-made disaster leads to change in bat migration routes and feeding behavior that brings the bats and pigs in close proximity of each other, which are the major ecological disruptors associated with facilitating for the first time introduction of this virus in Malaysian pig farms. In addition, pig farm size and intensive pig farming system lead to the circulation of this virus in the pig population and from there to the human population (Olival and Daszak, 2005). Number of dengue fever cases have doubled every decade since 1990 and a similar pattern was seen in other diseases, *viz,* Yellow Fever, Chikungunya, Mayaro and Zikaas a result of climate change (Hales *et al*., 2002; Stanaway *et al*., 2016).

Impact of TADs

TADs have serious consequences not only on the affected country, but also on to rest of the world due to their impact on a wide range of aspects like public health, socio-economic, international trade and food security.

Impact on public health

The zoonotically potential TADs have threatened global public health due to their capability to spread rapidly. In recent past highly pathogenic avian influenza (HPAI), bovine spongiform encephalopathy (BSE), West Nile fever, Rift Valley fever, severe acute respiratory syndrome (SARS) Coronavirus, Hendra virus, Nipah virus, Ebola virus, Zika virus and Crimean Congo haemorrhagic Fever (CCHF) and many more adversely affected animal and human health (Malik and Dhama, 2015; Munjal *et al*., 2017; Singh *et al.,* 2017; Singh *et al*., 2019). In 1977, Rift valley fever (RVF) affected 2,00,000 humans with 600 deaths in Egypt (Helmy *et al*., 2017). A recent outbreak of RVF was observed in 2018-19 from Mayotte, France, where 142 persons were infected (Fawzy and Helmy, 2019). In an estimate by World Bank, an economic burden of US$80 billion was beard by specific countries due to zoonotic diseases between 1997 and 2009 (Gerrard and Nichol, 2007). Most of the newly emerging infectious diseases have zoonotic potential. Spanish flu, Swine flu, SARS and more recently SARS-COVID19 are the best examples to see the impact of zoonotic transboundary animal diseases on public health. Also, many research reports are available indicating that many animal pathogens evolving, which may help them to either shift or increase their host range (Longdon *et al*., 2014).

Socioeconomic Impact of TADs

TADs have a great impact on the socio-economic condition of a country. Due to highly contagious nature it causes a heavy economic burden in terms of production and productivity of animal and their products there off. In 1887, the first outbreak of rinder pest in East Africa caused the mortality of 90 per cent population of Ethiopia's cattle and more than 10 million cattle in the whole continent. In 1930, an estimated annual loss of 230 million KSh in Kenya was reported due to an outbreak of FMD, of which 30 per cent loss was due to a reduction in milk yield. In Mexico, 13.6 million birds were destroyed due to outbreaks of Newcastle disease in 2000. In 1997, about 3.8 million pigs were slaughtered due to an outbreak of FMD in Taiwan. In 1994, about 40,000 cattle and yaks were killed by rinder pest in Pakistan (Akalu, 2017). In 1990, Belgium experienced serious economic losses of about US$ 280 million due to classical swine fever (Marsh *et al*., 2005). Every year 20 million cattle, 11 million pigs, 11 million goats and 9 million sheep get affected by FMD, which cost approximately US$ 5043 million (Knight-Jones and Rushton, 2013). A loss to the world economy, which cost over US$ 50 billion as a result

of expenditure on treatment cost and loss in the tourism industry due to SARS was recordedin 2003 (http://www.emro.who.int/pdf/about-who/rc61/zoonotic-diseases.pdf?ua=1). During the outbreak of RVF in Kenya, an average loss of US$500 was borne by each house hold as a result of low productivity and treatment costs. In 2001, UK faced a loss of over US$ 9 billion due to the FMD outbreaks. In 2004, more than 150 million chickens died or were disposed of offin South East Asia to control HPAI (H5N1). Between 1997 and 1998, an economic loss of US$ 2.5 billion was suffered by the Netherlands to classical swine fever (Yadav *et al*., 2020).

Impact on international trade

In most of the under developed and developing countries, livestock rearing is done by small-scale marginal farmers under the unorganized sector and provide income source to them. Livestock rearing is also considered a boon to landless farmers. International trade of live animals and animal products plays an important role to uplift the socio-economic status of landless and small-scale marginal farmers by selling their live animals and animal products anywhere in the world. Also, the wastage of excess produce from animals due to lack of storage facilities can be minimized if the international market is available. To protect the local livestock health and farmer's economic health from TADs, disease-free countries may impose a complete ban or restricted importation with precautionary measures, so that entry of TADs can be prevented. RVF outbreaks cut off exports from the Horn of Africa to parts of the Middle East in 1997-1998, 2000 and 2007 (Abbas *et al*., 2014). In 2005/2006, Egyptian has faced a trade ban on animal and animal products (Leforban, 2005). In 2003, the USA and Canadian beef exporters have faced trade bans due to the BSE (Marsh *et al*., 2005). The FMD outbreak in Korea in 2000 ended its trade with Japan for US$ 300 million (Cartín-Rojas, 2012). Recently, China bans the import of pigs and wild boar from India due to an outbreak of African swine fever in May 2020 (https://www.thehindu.com/news/international/china-to-ban-pork-imports-from-india/article31697495.ece #:~:text =A%20joint%20notice%20 issued% 20by, safety% 20of%20 China%27s%20animal%20husbandry).

Impact on food security

Recent trend shows that protein sources in human nutrition are shifting from plant to animal due to its high protein value and bioavailability. It is estimated that the demand for proteins derived from animals will be doubled by 2050 (Henchion *et al*., 2017). The four pillars of food security, *viz.,* availability, food access, stability and food utilization are under great threat due to highly contagious TADs with high rate of mortality (FAO, 2016). During any outbreak of TADs, not only infected animals but also healthy animals are slaughtered either in a particular region or throughout the country depending upon the severity of diseases to control and prevent the further spreading of disease leads to huge socioeconomic loss. A loss of more than 40% of the global food supply is due to pests and animal diseases (FAO, 2006). During the last decade of the 20th century, the annual growth of meat products was decreased by 2% due to bovine spongiform encephalopathy (Kumagai *et al*., 2019).

North East India is a possible gateway for TADs

The North East region of India is located at 89°46″ to 97°30″E and latitude 21°57″ to 29°30″N. The entire area is connected to the Indian mainland by a 22 km land corridor through Siliguri in the state of West Bengal, popularly known as "Chicken's neck" (Nath and Nath, 2004). The region is best known for its picturesque topography, cultural heritage, ethnic beauty and rich natural biodiversity resources. The region is covering an area of 2,62,185 sq. km, which is nearly 8 per cent of the total geographical area of the country. The region has a population of 389.84 lakh that is 3.79 per cent of the total population of India. It has vast coverage of forests nearly 55 per cent of the total geographical area. The states of the region are surrounded by China, Bangladesh, Myanmar and Bhutan. The region has a long international border of (5,182 km), which is more than 99 per cent of its total geographical boundary. There are frequent international movements of men/material/animals including vector population bears a constant threat of incursions of exotic and transboundary diseases to India's mainland through this North-East corridor (http://neradslab.res.in/). Moreover, the recent outbreak of African swine fever is recorded in this region (Kumar *et al.,* 2020), which is suspected to be entered from china through the Indo-China border of Arunachal Pradesh (https://www.timesnownews.com/india/article/has-china-spread-another-virus-in-india-after-covid-19-african-swine-fever-surfaces-in-indiaafter-100-years/627134). Previously, the first outbreak of PRRS was reported from Mizoram, India, which might have entered from Myanmar through a porous international border in Mizoram (Rajkhowa *et al*., 2015). Recently, porcine circovirus-2 (PCV-2), an emerging TAD, was confirmed circulating in the pig population of the North eastern region of the country including Meghalaya, Assam, Mizoram and Tripura (Mukherjee *et al.,* 2018). Lumpy skin disease (LSD) is another important TAD of cattle was first time reported in India from Odisa in August 2019 (Kumar *et al*., 2021). Later on, it was reported from West Bengal and North East India, particularly, Assam. Interestingly, LSD was also first time reported in China in August 2019 (Lu *et al*., 2020). Although there are no scientific evidence available about the route of introduction of LSD into India, but there is a possibility that it might have entered through international borders along with North East India. The illegal trade of wildlife is also a big challenge to handle in this region. There are frequent reports of illegal wildlife trade along the international border of this area. These events are indicating the importance of the international border surrounding North-East India. There is an urgent need for establishment of effective surveillance system to prevent the entrance of TADs into the country. The development of indigenous and cost-effective screening tests with high sensitivity and specificity will help in the early

diagnosis of TADs so that immediate steps can be undertaken to restrict the further spread across. The pen side tests would be more appropriate for diagnosis and screening of TADs at the field level without wasting much time for getting laboratory results. The early warning and response mechanism at the regional level and national levels can be helpful to tackle in time. Moreover, there is a need to develop a national policy regarding on prevention and management of TADs to prevent the devastating consequences on both animal and human health, socioeconomic effects, international trade and food security.

Control and management of TADs

Despite various control and preventive measures adopted by different countries, TADs are continued to spread across the world, which warrants the urgent need to re-evaluate the strategies. In addition, all the countries should adopt serious measures to curb the illegal trading of wild flora and fauna for medicinal and food purposes.

Strict regulations related to international trade of animals and animal products

There should be a strict ban on the trade of live animals and animal products from the affected countries to the virgin areas. Ban imposition, duration of the ban and upliftment of ban should be a fair act and free from business forces. International organizations like OIE, FAO, WHO and WTO should keep active surveillance on the TADs' presence worldwide and assess their impact on human health, animal health, food security and the socio-economy of the world. These organizations and international communities should help the affected countries to cope with the situation and control and prevent the spread of the diseases.

Quarantine facilities

A quarantine facility is important to prevent the spread of diseases across the countries. There should be proper and strict arrangements to quarantine the imported live animals and animal products. There is no fixed quarantine period but a quarantine period of 30 days is followed. The length of the quarantine period depends upon the time required for observations and testing. The governments should make effort to prevent the illegal movement of live animals and animal products across the border, but at the same time to make the legal transportation and quarantine procedure easy. Great care is needed where uncontrolled animal movements across borders because of nomadism, transhumance, the influx of refugees, *etc* are frequent. The quarantine facilities for animals and animal products are playing an important role to tackle this problem. Besides, due to the movement of live animals and animal byproducts, infectious agents can cross the boundary of a country indirectly either through fomites or vectors (Randolph and Rogers, 2010). Even human can help in the transboundary transmission of animals diseases because there is no strict provision of quarantine and screening of infectious diseases for humanity in general (except in special cases like a pandemic or serious threat) while traveling from one country to other (Islam, 2016; Otte *et al*., 2004).

Restriction of cross border movement of wild animals and vectors

The distribution of wild animals and vectors is specific to particular geographical conditions. But, it is a very well-known fact that cross-border movement of wild animals and vectors posing challenges in controlling the spread of diseases across international borders. Even some birds travel from one continent to another continent providing transmission routes for diseases from the site of origin to distant places. These wild animals' movements facilitate the cross-border movement of vectors along with them. As restriction of cross border movement of wild animals is impractical, an active surveillance system should be established along the international borders, which keeps checking on movements of wildlife and occurrence of infectious diseases in wild animals and their timely reporting to appropriate authorities. On the death of wild animals including birds, a proper investigation should be done to identify the cause of death. The illegal trade of wild animals across the border should be seriously addressed by the respective Governments. The recent outbreak of African swine fever in India in May 2020 might be the result of cross border movement of animals.

The emergency of preparedness (EMPRE)

To tackle any infectious disease outbreaks, an effective standard operating procedure should be kept ready as emergency preparedness (Khankeh *et al*., 2019). Emergency preparedness has two basic components: The early warning system and the early reaction system. An effective early warning system, which provides forecast about current disease pattern helps in early detection and save golden time to take preventive steps to stop the spread of disease. An effective early reaction system at the national or state or regional level helps to keep the disease outbreaks restricted to their point of origin and prevent further spread. In nutshell, EMPRE helps in reducing the time interval between the occurrence of outbreaks and steps taken to prevent it. For proper deployment of EMPRE continuous research in the field of disease epidemiology, development of diagnostic kits and vaccines and development of disease diagnostic labs at national, state and regional levels must be undertaken. All the notifiable diseases should be reported properly to OIE.

Movements of human

Human movement across the most of world is unrestricted and playing a key role in the spreading of disease from infected areas to disease-free areas (Kraemer *et al*., 2017). Circulation of the pathogen in an area depends upon the transport infrastructure (Nasir *et al*., 2016), which is influenced by economic (Simini *et al*., 2012; Weiss *et al*., 2018), tourism (Deville *et al*., 2014) and religion spots in

that area (Lessler *et al*., 2014). Also, the illegal movement of humans across porous borders becoming a serious factor for disease spread. Also, not only humans but things that were taken by them can help the TADs to spread to other countries. Evidence of such events is available in past. ASF in 2017 in the Czech Republic and in 2018 in Hungary was first introduced by Ukrainian workers through contaminated food (Beltran-Alcrudo *et al.,* 2019). The outbreak of ASF in Santa Catarina State, Brazil, was believed to happen due to bringing of infected pigs by war refugees from Angola (Moura *et al.,* 2010). Similarly, the ASF outbreak in Tanzania was due to the introduction of infected pigs into refugee camps from Uganda or Burundi (Wambura *et al.,* 2006). The ongoing COVID-19 pandemic, which affected the entire world, is a good example of the role of human movements in disease spread worldwide within a short period and in an uncontrolled way.

Vaccination

Vaccines have played a crucial role in the eradication of diseases in the past, such as rinder pest (Greenwood, 2014). Vaccination of healthy animals is an effective way to prevent disease occurrence and spread. New generation DIVA vaccines (subunit vaccine, DNA vaccines, RNA vaccines) and vaccines with easy delivery systems (oral vaccines) are the need of the present time to tackle re-emerging and emerging transboundary animal diseases. Polyvalent vaccines should be preferred as they can save money and time.

One health approach

The emergence and re-emergence of infectious diseases and their geographical transmission is the consequence of anthropogenic activities, change in farming systems and change in the environment. So, it is impossible to tackle emerging and re-emerging diseases without a holistic “One Health” approach (Rabozzi *et al*., 2012). One health is the multi-disciplinary and collaborative approach of multi-sectors to achieve optimum human health. The principle of ‘One Health’ is based on that optimum human health cannot be achieved without considering the health of animals, plants and the environment, which is shared by all these with humans. The health of livestock, poultry and fish is important for food security and human health. Intensive livestock farming system to meet the food demand of increasing human population helping the pathogenic agents for their easy circulation and maintenance in the animal population. Also, intensive and integrated agriculture farming creating a new niche for the development of new pathogens and the evolution of existing pathogens at a faster speed. Similarly, change in climate due to human activities and farming system providing heaven for faster evolution of pathogens including the emergence of new pathogens. In the present time, we cannot expect the welfare of humans by neglecting the other components of our ecosystem, which include animals, plants and the environment.

Surveillance

Surveillance is an important activity to keep watch on the pattern and distribution of a pathogenic agent in the region (Van Seventer and Hochberg, 2017). Active disease surveillance in the susceptible regions is important. The susceptible population should be regularly tested for diseases. Animals should be tested before importation. Illegal wildlife trade and unrestricted movement of animals across international borders is the key driver of TADs. So, there is a need to continuously observe the illegal movement of humans and illegal trade of wild animals across the borders. The use of artificial intelligence and global positioning system can be helpful to monitor the movement of wildlife (Jawalker *et al*., 2017).

Way forward

TADs affect multiple sectors like animal health, food security, public health and the economy worldwide. There is a need for active participation from all countries to properly address, control and prevent the transboundary transmission TADs and the emergence of new TADs. The development of diagnostics and vaccines including new generation vaccines considering the new strains of the pathogens, which can be stored at room temperature, is crucial. There is a need to develop pen-side tests for easy diagnosis of diseases at the field level to save time and money. A disease monitoring and forecast network system is needed for active surveillance of pathogenic microorganism, host and vector, so that movement of the pathogen can be predicted and appropriate steps can be taken to prevent the spread of diseases and also constant monitoring of the ecosystem of infectious agents and host to forecast the pattern of infectious diseases and emergence of new diseases.

REFERENCES

Abbas, B., Yousif, M.A. and Nur, H.M. (2014). Animal health constraints to livestock exports from the Horn of Africa. Revue Scientifiqueet Technique. 33(3): 711-721.

Ahmed, H.A., Salem, S.A.H., Habashi, A.R., Arafa, A.A., Aggour, M.G.A. and Salem, G.H. (2012). Emergence of foot-and-mouth disease virus SAT 2 in Egypt during. Transbound Emerg Dis. 59: 476-81.

Akalu, B. (2017). Review on Common Impact and Management of Transboundary Animal Diseases. Journal of Immuno Virology. 2(2): e555583.

Aken, J. and Hammond, E. (2003). Genetic engineering and biological weapons. EMBO Reports. 4: 557-571.

Beltran-Alcrudo, D., Falco, J.R., Raizman, E. and Dietze, K. (2019). Transboundary spread of pig diseases: The role of international trade and travel. BMC Veterinary Research. 15(1): 1-14.

Birch, R.R. (1917). Hog cholera transmission through infected pork. American Veterinary Journal. 51: 303. doi: 10.1186/s12 917-019-1800-5.

Blome, S., Staubach, C., Henke, J., Carlson, J. and Beer, M. (2017). Classical swine fever-An updated review. Viruses. 9(4): 86. doi: 10.3390/v9040086.

Bora, M., Bora, D.P., Manu, M., Barman, N.N., Dutta, L.J., Kumar, P.P., Poovathikkal, S., Suresh, K.P. and Nimmanapalli, R. (2020). Assessment of risk factors of African swine fever in India: perspectives on future outbreaks and control strategies. Pathogens. 9(12): 1044. doi: 10.3390/pathogens9121044.

Brown, C. (2010). Emerging diseases: The global express. Veterinary Pathology. 47: 9-14.

Callis, J.J., Hyde, J.L., Blackwell, J.H. and Cunliffe, H.R. (1975). Survival of foot-and-mouth disease virus in milk and milk products. Bulletin de l'Office International des Epizooties. 83 (3-4): 183-191.

Cartín-Rojas, A. (2012). Transboundary animal diseases and international trade. International Trade from Economic and Policy Perspective. 143: 166. doi: 10.5772/48151.

Cottral, G.E. (1969). Persistence of foot-and-mouth disease virus in animals, their products and the environment. Bulletin - Office International des Epizooties. 71(3/4): 549-568.

Deville, P., Linard, C., Martin, S., Gilbert, M., Stevens, F.R., Gaughan, A.E., Blondel, V.D. and Tatem, A.J. (2014). Dynamic population mapping using mobile phone data. Proceedings of the National Academy of Sciences. 111(45): 15888-15893.

Domenech, J., Lubroth, J., Eddi, C., Martin, V. and Roger, F. (2006). Regional and international approaches on prevention and control of animal transboundary and emerging diseases. Annals of the New York Academy of Sciences. 1081(1): 90-107.

El-Sayed, A. and Awad, W. (2018). Brucellosis: Evolution and expected comeback. International Journal of Veterinary Science and Medicine. 6: S31-S35.

FAO, (2006). Livestock's Long Shadow: Environmental Issues and Options. FAO, Rome, pp. 493. http://www.fao.org/3/a-a0701e.pdf.

FAO, (2013). Food Outlook Biannual Report on Global Food Markets. ISSN: 0251-1959. http:// www.fao.org/3/a-I5703E.

FAO, (2016). Economic Analysis of Animal Diseases. FAO Animal Production and Health Guidelines. No. 18. Rome. ISBN 978-92-5-109166-1. http://www.fao.org/3/a-i5512e.pdf.

FAO, (2004). The Global Framework for the Progressive Control of Transboundary Animal Diseases (GF-TADs). Rome: FAO, Rome, pp. 40. http://www.fao.org/3/a-ak136e.pdf.

Fawzy, M. and Helmy, Y.A. (2019). The one health approach is necessary for the control of Rift Valley fever infections in Egypt: A comprehensive review. Viruses. 11(2): 139. doi: 10.3390/v11020139.

Gerrard, S.R. and Nichol, S.T. (2017). Synthesis, proteolytic processing and complex formation of N-terminally nested precursor proteins of the rift valley fever virus glycoproteins. Virology. 357: 124-133.

Greenwood, B. (2014). The contribution of vaccination to global health: Past, present and future. Philosophical Transactions of the Royal Society B: Biological Sciences. 369(1645): p. 20130433.

Guimera R., Mossa S., Turtschi A. and Amaral L.A.N. (2005). The worldwide air transportation network: anomalous centrality, community structure and cities' global roles. Proceedings of the National Academy of Sciences of the United States of America. 102: 7794-7799.

Hales, S., De Wet, N., Maindonald, J. and Woodward, A. (2002). Potential effect of population and climate changes on global distribution of dengue fever: An empirical model. The Lancet. 360(9336): 830-834.

Helmy Y.A., El-Adawy H., Abdelwhab E.M. (2017). A comprehensive review of common bacterial, parasitic and viral zoonoses at the human-animal interface in Egypt. Pathogens. 6: 33. doi: 10.3390/pathogens6030033.

Henchion, M., Hayes, M., Mullen, A.M., Fenelon, M. and Tiwari, B. (2017). Future protein supply and demand: strategies and factors influencing a sustainable equilibrium. Foods. 6(7): 53. https://doi.org/10.3390/foods6070053.

Huang, Y.W., Dickerman, A.W., Piñeyro, P., Li, L., Fang, L., Kiehne, R., Opriessnig, T., Meng, X.J. (2013). Origin, evolution and genotyping of emergent porcine epidemic diarrhea virus strains in the United States. MBio. 4(5): e00737-e00713.

Islam, M.A. (2016). Transboundary diseases of animals: Concerns and management strategies. Research in Agriculture Livestock and Fisheries. 3(1): 121-126.

Jawalkar, M.S., Desale, N., Suratwala, F., Lamkhade, A., Mahalle, P.N. and Railkar, P.N. (2017). Intelligent wildlife tracking using ubiquitous technological suite. International Journal of Synthetic Emotions. 8(1): 44-59.

Joseph Koireng, R., Rolling Anal, P.S., Kalyan Jana and Priya Devi, K.H. (2018). Prospects of Sustainable Livestock Farming in NEH Region of India. International Journal of Current Microbiology and Applied Sciences. 7(1): 1285-1292.

Khan, S., Ullah, M.W., Siddique, R., Nabi, G., Manan, S., Yousaf, M. and Hou, H. (2016). Role of recombinant DNA technology to improve life. International Journal of Genomics. e2405954. doi: 10.1155/2016/2405954.

Khankeh, H.R., Hosseini, S.H., Farrokhi, M., Hosseini, M.A. and Amanat, N. (2019). Early warning system models and components in emergency and disaster: A systematic literature review protocol. Systematic Reviews. 8(1): 1-4.

Knight-Jones, T.J. and Rushton, J. (2013). The economic impacts of foot and mouth disease - what are they, how big are they and where do they occur? Preventive Veterinary Medicine. 112(3-4): 161-173.

Kraemer, M.U., Faria, N.R., Reiner Jr, R.C., Golding, N., Nikolay, B., Stasse, S., Johansson, M.A., Salje, H., Faye, O., Wint, G.W. and Niedrig, M. (2017). Spread of yellow fever virus outbreak in Angola and the Democratic Republic of the Congo 2015-16: A modelling study. The Lancet Infectious Diseases. 17(3): 330-338.

Kumagai, S., Daikai, T. and Onodera, T. (2019). Bovine spongiform encephalopathy- A review from the perspective of food safety. Food Safety (Tokyo, Japan). 7(2): 21-47.

Kumar, N., Chander, Y., Kumar, R., Khandelwal, N., Riyesh, T., Chaudhary, K., Shanmugasundaram, K., Kumar, S., Kumar, A., Gupta, M.K. and Pal, Y. (2021). Isolation and characterization of lumpy skin disease virus from cattle in India. Plos One. 16(1): e0241022.

Kumar, S., Dutta, T.K., Roychoudhury, P., Das, H., Akter, F. and Subudhi, P.K. (2020). African swine fever: An emerging threat to pig husbandry in India. Indian Journal of Animal Health. 59: 11-16.

Lederberg, J., Hamburg, M.A. and Smolinski, M.S. (2003). Microbial threats to health: Emergence, detection and response, 1st Edn. National Academies Press.

Leforban, Y. (2005). Report of a mission on foot and mouth disease in Ethiopia. Proposals for a strategic plan for a control program oriented to the export. 1022: 1242.

Lessler, J., Rodriguez-Barraquer, I., Cummings, D.A., Garske, T., Van Kerkhove, M., Mills, H., Truelove, S., Hakeem, R., Albarrak, A., Ferguson, N.M. and MERS-CoV Scenario Modeling Working Group, (2014). Estimating potential incidence of MERS-CoV associated with Hajj pilgrims to Saudi Arabia. PLoS Currents. 6: e25685624.

Lindahl, J.F. and Grace, D. (2015). The consequences of human actions on risks for infectious diseases: A review. Infection Ecology and Epidemiology. 5(1): e30048.

Liu, J., Yong, D.L., Choi, C.Y. and Gibson, L. (2020). Transboundary frontiers: An emerging priority for biodiversity conservation. Trends in Ecology and Evolution. 35(8): 679-690.

Longdon, B., Brockhurst, M.A., Russell, C.A., Welch, J.J. and Jiggins, F.M. (2014). The evolution and genetics of virus host shifts. PLoS Pathology. 10(11): e1004395.

Lu, G., Xie, J., Luo, J., Shao, R., Jia, K. and Li, S. (2020). Lumpy skin disease outbreaks in China, since 3 August 2019. Transboundary and Emerging Diseases. 68: 216-219.

Malik, Y.S. and Dhama, K. (2015). Zika virus-an imminent risk to the world. Journal of Immunology and Immunopathology. 17(2): 57-59.

Malik, Y.S., Bhat, S., Kumar, O.R., Yadav, A.K., Sircar, S., Ansari, M.I., Sarma, D.K., Rajkhowa, T.K., Ghosh, S. and Dhama, K. (2020). Classical swine fever virus biology, clinicopathology, diagnosis, vaccines and a meta-analysis of prevalence: A review from the Indian Perspective. Pathogens. 9(6): 500. doi: 10.3390/pathogens9060500.

Marsh, T.L., Wahl, T. and Suyambulingam, T. (2005). Animal Disease Outbreaks and Trade Bans. World Trade Organization Impacts on US Farm Policy.

McElwain, T.F. and Thumbi, S.M. (2017). Animal pathogens and their impact on animal health, the economy, food security, food safety and public health. Revue Scientifique Et Technique (International Office of Epizootics). 36(2): 423-433.

Mitra, A.K. and Mawson, A.R. (2017). Neglected tropical diseases: epidemiology and global burden. Tropical Medicine and Infectious Disease. 2: 36. doi: 10.3390/tropicalmed2030036.

Moura, J.A., McManus, C.M., Bernal, F.E.M. and De Melo, C.B. (2010). An analysis of the 1978 African swine fever outbreak in Brazil and its eradication. Revue Scientifique Et Technique. 29(3): 549-563.

Mukherjee, P., Karam, A., Barkalita, L., Borah, P., Chakraborty, A.K., Das, S., Puro, K., Sanjukta, R., Ghatak, S., Shakuntala, I. and Laha, R.G. (2018). Porcine circovirus 2 in the North Eastern region of India: Disease prevalence and genetic variation among the isolates from areas of intensive pig rearing. ActaTropica. 182: 166-172.

Munjal, A., Khandia, R., Dhama, K., Sachan, S., Karthik, K., Tiwari, R., Malik, Y.S., Kumar, D., Singh, R.K., Iqbal, H.M.N. and Joshi, S. (2017). Advances in developing therapies to Combat Zika virus: current knowledge and future perspectives. Frontiers in Microbiology. 8: 2677. doi: 10.3389/fmicb.2017.01469.

Nasir, Z.A., Campos, L.C., Christie, N. and Colbeck, I. (2016). Airborne biological hazards and urban transport infrastructure: Current challenges and future directions. Environmental Science and Pollution Research. 23(15): 15757-15766.

Nath, M.K. and Nath, M.K. (2004). Mapping north east on india's foreign policy: Looking past, present and beyond. The Indian Journal of Political Science. 65(4): 636-652.

Nathues, C., Perler, L., Bruhn, S., Suter, D., Eichhorn, L., Hofmann, M., Nathues, H., Baechlein, C., Ritzmann, M., Palzer, A., Grossmann, K. (2016). An outbreak of porcine reproductive and respiratory syndrome virus in Switzerland following import of boar semen. Transboundary Emerging Disease. 63(2): e251-e261.

Olival, K.J. and Daszak, P. (2005). The ecology of emerging neurotropic viruses. Journal of Neurovirology. 11(5): 441-446.

Otte, M.J., Nugent, R., McLeod, A. (2004). Transboundary animal diseases: Assessment of socio-economic impacts and institutional responses. Rome, Italy: Food and Agriculture Organization (FAO). pp: 119-126.

Pharo, H.J. (2002). Foot-and-mouth disease: an assessment of the risks facing New Zealand. New Zealand Veterinary Journal. 50(2): 46-55.

Rabozzi, G., Bonizzi, L., Crespi, E., Somaruga, C., Sokooti, M., Tabibi, R., Vellere, F., Brambilla, G. and Colosio, C. (2012). Emerging zoonoses: The "one health approach". Safety and Health at Work. 3(1): 77-83.

Rajkhowa, T.K., JaganMohanarao, G., Gogoi, A., Hauhnar, L. and Isaac, L. (2015). Porcine reproductive and respiratory syndrome virus (PRRSV) from the first outbreak of India shows close relationship with the highly pathogenic variant of China. Veterinary Quarterly. 35(4): 186-193.

Randolph, S.E. and Rogers, D.J. (2010). The arrival, establishment and spread of exotic diseases: patterns and predictions. Nature Reviews Microbiology. 8: 361-371.

Simini, F., González, M. C., Maritan, A. and Barabási, A.L. (2012). A universal model for mobility and migration patterns. Nature. 484: 96-100.

Singh, R.K., Dhama, K., Chakraborty, S., Tiwari, R., Natesan, S., Khandia, R., Munjal, A., Vora, K.S., Latheef, S.K., Karthikh, K., Malik, Y.S., Singh, R., Chaicumpaj, W. and Mourya, D.T. (2019). Nipah virus: Epidemiology, pathology, immunobiology and advances in diagnosis, vaccine designing and control strategies-A comprehensive review. Veterinary Quarterly. 39(1): 26-55.

Singh, R.K., Dhama, K., Malik, Y.S., Ramakrishnan, M.A., Karthik, K., Tiwari, R., Khandia, R., Munjal, A., Saminathan, M., Sachan, S., Desingu, P.A., Kattoor, J.J., Iqbal, H.M.N. and Joshi, S.K. (2017). Ebola virus-epidemiology, diagnosis and control: threat to humans, lessons learnt and preparedness plans-An update on its 40 year's journey. Veterinary Quarterly. 37(1): 98-135.

Stanaway, J.D., Shepard, D.S., Undurraga, E.A., Halasa, Y.A., Coffeng, L.E., Brady, O.J., Hay, S.I., Bedi, N., Bensenor, I.M., Castañeda-Orjuela, C.A. and Chuang, T.W. (2016). The global burden of dengue: An analysis from the Global Burden of Disease Study 2013. The Lancet Infectious Diseases. 16(6): 712-723.

Van Seventer, J.M. and Hochberg, N.S. (2017). Principles of infectious diseases: Transmission, diagnosis, prevention and Control. International Encyclopedia of Public Health. 22. doi: 10.1016/B978-0-12-803678-5.00516-6.

Wambura, P.N., Masambu, J. and Msami, H. (2006). Molecular diagnosis and epidemiology of African swine fever outbreaks in Tanzania. Veterinary Research Communications. 30(6): 667-672.

Watts, N., Amann, M., Ayeb-Karlsson, S., Belesova, K., Bouley, T., Boykoff, M., Byass, P., Cai, W., Campbell-Lendrum, D., Chambers, J. and Cox, P.M. (2018). The Lancet Countdown on health and climate change: from 25 years of inaction to a global transformation for public health. The Lancet. 391(10120): 581-630.

Weiss, D.J., Nelson, A., Gibson, H.S., Temperley, W., Peedell, S., Lieber, A., Hancher, M., Poyart, E., Belchior, S., Fullman, N. and Mappin, B. (2018). A global map of travel time to cities to assess inequalities in accessibility in 2015. Nature. 553(7688): 333-336.

Wilcox, B.A. and Ellis, B. (2006). Forests and emerging infectious diseases of humans. UNASYLVA-FAO. 57(2): 11-18.

Yadav, M.P., Singh, R.K. and Malik, Y.S. (2020). Emerging and Transboundary Animal Viral Diseases: Perspectives and Preparedness. In Emerging and Transboundary Animal Viruses Springer, Singapore. pp: 1-25.

Zhou, X., Li, N., Luo, Y., Liu, Y.E., Miao, F., Chen, T., Zhang, S., Cao, P., Li, X., Tian, K. and Qiu, H.J. (2018). Emergence of African swine fever in China, Transboundary and Emerging Diseases. 65(6): 1482-1484.