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Global impact of COVID-19 on animal health and welfare

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ABSTRACT

The COVID-19 pandemic is a global public health emergency that caused high scale morbidity and mortality in humans and billions got affected economically, psychologically and socially due to sudden change in lifestyle. Livestock sector involving millions of poor and marginal farmers was impacted due to movement restriction among humans. Animal health and disease management activities were delayed, halted, or abandoned due to pandemic. The industry slowed down for want of timely raw materials of livestock origin and also acute shortage of labourers due to pandemic. Though there are no estimates of economic loss incurred but indirect measures indicate significant direct and indirect losses to the sector. The animal health and disease data across world and the experience gained so far in handling pre-, post-, and during COVID-19 pandemic will provide essential inputs for preparedness to face future challenges.

Keywords: Animal, COVID-19, Disease, Global, Health, SARS-CoV-2

Historically, every time a new infectious disease emerges with potential to spread across geographic area, such diseases have impacted societies significantly and the effect persisted for generations (Reid 2005). The ongoing Coronavirus disease-2019 pandemic (COVID-19) is one such public health event which affected every walk of life directly or indirectly and the livestock sector is no exception. The poor and marginal farmers earn their employment from livestock sector who are in distress as the pandemic affected their livelihood. The impact may further result serious concern over the food security of the world population.

China reported a cluster of human cases of COVID-19 in early 2020 characterized by severe respiratory signs and all the cases were having an exposure factor of the wet seafood market (Huang *et al.* 2020). The search for identifying the cause of the 'pneumonia of unknown aetiology' finally ended with identification of virus as Sever Acute Respiratory Syndrome Coronavirus 2 (SARS Cov-2). Evidently, the virus was found to have origin from bat species and pangolin were suspected to be the intermediate hosts (Zho *et al.* 2020). Coronaviruses have accounted for many human pandemics in the past like SARS-CoV and MERS CoV. Till date more than 200 countries have reported COVID-19 with estimated 4 million deaths and 197 million cases (Fig.1) (WHO, COVID-19 Dashboard, 2021).

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Currently there are no antiviral therapies for COVID-19 cases, however a number of vaccines have been developed and released for human use. Rapid COVID-19 vaccination drives worldwide led to vaccination of 407 million people, covering the high-risk groups on priority (WHO, COVID-19 Dashboard, 2021).

The CoV are members of family *Coronaviridae* and divided into four genera on the basis of their phylogenetic relationships and genomic structures: *Alphacoronavirus*, *Betacoronavirus*, *Gammacoronavirus* and *Delta-coronavirus*. The genome of CoV is single-stranded positive-sense RNA of 27–32 kb in size and contains ORFs for replicase (Rep 1a and 1b), spike (S), envelope (E), membrane (M), and nucleoprotein (N) arranged in the order 5^2-Rep1a-1b-S-E-M-N-3´ and encode 16 non-structural proteins positioned between these genes (Fig. 2) (Huang *et al.* 2020). In humans, there are endemic strains of coronaviruses like Human Coronavirus-229E (H CoV-229E), H CoV-NL63, H CoV-OC43 and H CoV-HKU1 that are prevailing worldwide (van der Hoek 2007). These strains mostly cause self-limiting disease showing the signs typical of common cold, sometimes more severe manifestation such as bronchitis and pneumonia were also observed. The emerging species like SARS-CoV, MERS and the latest being SARS-CoV-2 are known to be highly contagious and cause increased morbidity and mortality in human. CoV have also been reported from cattle, pigs, horses, camels, rodents, cats, dogs, bats, palm civets, ferrets, mink, rabbits, snake, and several avian species causing respiratory, enteric,

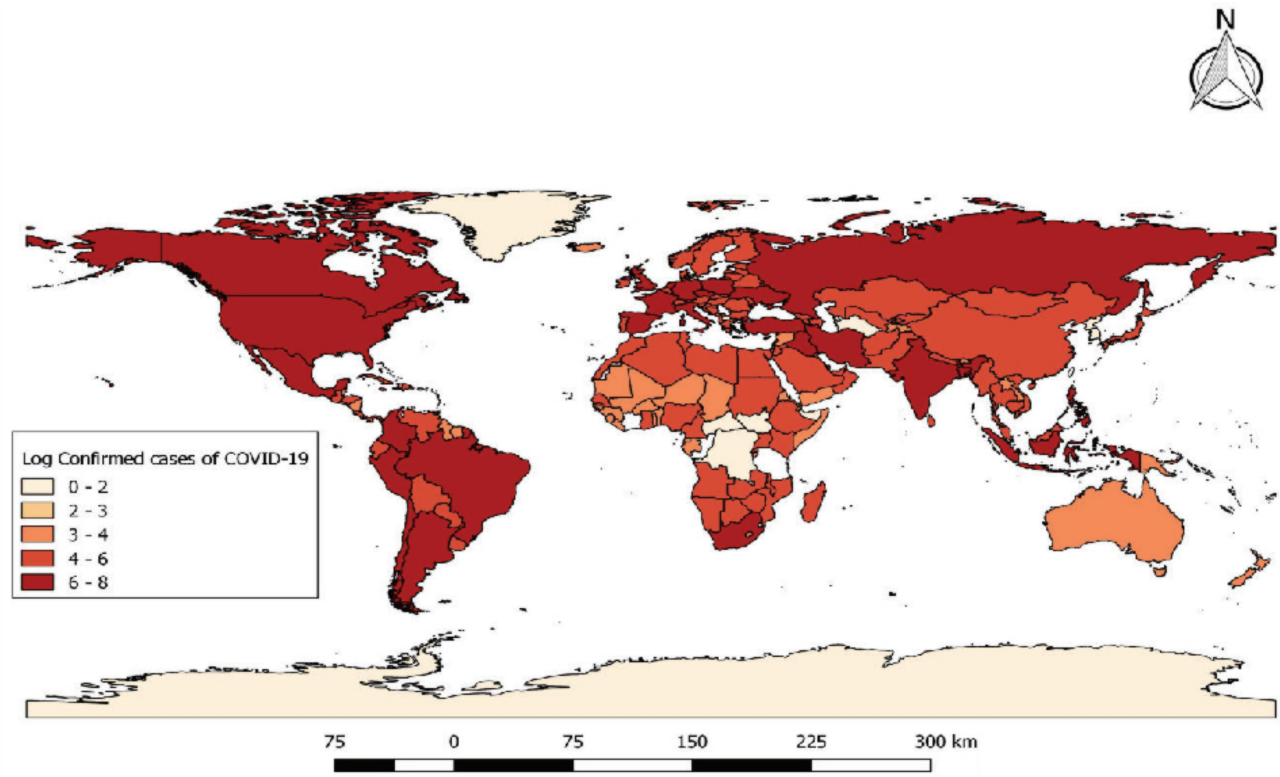

Fig. 1. Global distribution of confirmed cases of COVID-19 (*Data Source:* WHO).

Why livestock matter globally for livelihoods?

- Occupied about 30% of ice-free surface area of the globe
- Global asset more than 1.4 trillion US dollars
- About 70% of the world's rural poor rely on livestock for livelihoods
- Employs more than 1.3 billion globally
- Of 600 million poor livestock keepers in the world, around two-thirds are rural women.
- Contribute about 40% to Agricultural GDP (15–85%)
- 18% of kilocalorie and 39% of protein
- In the poorest countries, livestock manure comprises over 70% of soil fertility
- About 90% of animal products are produced and consumed in the same country or region

hepatic and neurologic diseases (Zhang *et al.* 2021). As in human, the emergence of new coronaviruses was also reported in livestock. In pigs, porcine epidemic diarrhoea (PED), transmissible gastroenteritis (TGE) and swine acute diarrhoea syndrome (SADS) are emerging porcine coronavirus disease that are causing large scale economic losses worldwide and spreading to new geographical area (Vlasova *et al.* 2020).

Livestock sector contributes significantly to national economies through employment generation and earning revenue via national and international trade. Livestock sector provides livelihood to more than 70% of world's rural poor with the value of USD 3.6 billion in the year 2019 (FAO 2018) (Box 1). Growth of livestock sector is directly linked to alleviation of poverty and malnutrition. The impact of COVID-19 is large on livestock sector which is yet to be estimated. Based on previous pandemic experience, such as the 1918 influenza pandemic (Bongiorno 2020), it is clear that the damage caused by COVID-19 might affect human society for years to come. SARS-CoV-2 is a 'new strain of coronavirus that has not been previously identified in humans,' according to the World Health Organization (WHO). The WHO named the COVID-19 outbreak a 'Public Health Emergency of International Concern' on January 30, 2020. COVID-19 was elevated to the highest level of global risk by the WHO on February 28, 2020 (WHO 2020).

Based on the initial understanding of the disease epidemiology, WHO announced the COVID-19 preventive measures at national, state/provincial and local levels (WHO-Timeline of Response to COVID-19 2020). Many countries quickly adopted the WHO recommendations which mainly targeted the human movement, enhanced cleanliness, and social distance to reduce human contact. The government responses to COVID-19 varied between

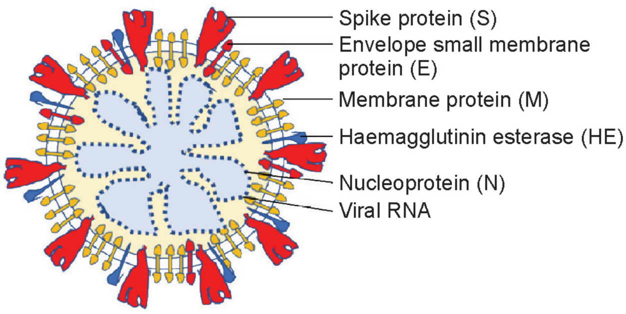

Fig. 2. Structure of SARS-CoV-2.

the countries but in general the responses can be broadly categorized into containment and closure measures, economic response, health system, vaccine policies etc., The current review provides the account of impact of COVID-19 pandemic globally with specific emphasis on animal health.

COVID-19 impact on non-human animals

Travel bans and social distance with 'shelter in place' orders have been used in response to the ongoing COVID-19 epidemic, resulting in abrupt changes in human activity and subsequent consequences on the global and national livestock economies.

The COVID-19 pandemic will have a global impact on many parts of civilization, from health care (Propper *et al.* 2020) to conservation (Corlett *et al.* 2020). In the field of animal health, we believe three effects are likely to occur: (1) an immediate one due to the sudden human confinement and inactivity; (2) a medium to long-term one due to the effects of the upcoming economic crisis on farming and veterinary services; and (3) a greater focus on the public health implications of coronavirus infections in animals, both in farms (Van der Waal and Deen 2018) and in the wild (Shi *et al.* 2020).

The World Organization for Animal Health, OIE lists national and regional veterinary regulation and inspection services, emergency response, disease prevention measures such as vaccination against diseases that have a substantial public health or economic impact, and prioritization of research activities. The food inspection and food safety are important activities that each country must continue throughout the COVID-19 crisis (Jawad *et al.* 2021). Although it is too early to make a thorough assessment, we believe the COVID-19 epidemic and the ensuing economic crisis will have a significant impact on animal health in a number of ways.

The impact of COVID-19 pandemic on animals could be direct effect in terms of disease transmission to non-human animals and its economic consequence, whereas the indirect effect includes impact on animal health and disease management.

Direct effect on animals

Impact of COVID-19 pandemic on wildlife conservation globally: SARS-CoV-2 is a beta coronavirus (β-CoV) that is closely related to SARS-CoV and MERS-CoV, all of which have caused significant illness epidemics in humans (Decaro and Lorusso 2020). All are likely to have originated in bats, with indications that intermediate, or bridge hosts are to blame for human transmission (Ji *et al.* 2020, Zhou *et al.* 2020, Zhang *et al.* 2020). SARS (Severe Acute Respiratory Syndrome) in humans has been linked to masked palm civets (*Paguma larvata*) (Wang *et al.* 2005), while MERS (Middle Eastern Respiratory Syndrome) in humans has been linked to dromedary camels (*Camelus dromedarius*) (Reusken *et al.* 2013, Chu *et al.* 2014). Despite the fact that SARS-CoV-2 may have started in bats, with its closest genetic ancestor (RATG13) recovered from the intermediate horseshoe bat (*Rhinolophus affinis*) (Zhou *et al.* 2020), the proximal cause of infection in humans is yet to be determined. On the basis of infection with a nearly related coronavirus in animals seized in southern China, Malayan pangolins (*Manis javanica*) have been the subject of some speculation (Lam *et al.* 2020).

A series of recombination events between bat and pangolin coronaviruses may have eventually led to the formation of SARS-CoV-2 and similar coronaviruses, according to sequence analysis of the spike glycoprotein (S) of SARS-CoV-2 and related coronaviruses (Flores-Alanis *et al*. 2020). However, because experimental infection resulted in substantial viral shedding (Freuling *et al*. 2020), raccoon dogs (*Nyctereutes procyonoides*), which were identified as prospective intermediate hosts for the SARS epidemic of 2002–2003 (Guan *et al.* 2003), have also been recommended as suitable intermediate hosts for SARS-CoV-2. Many different wild mammals (wild captured and farmed) and domesticated species have been reported in wildlife markets in South China, including pangolins and raccoon dogs (Webster 2004, Zhang *et al.* 2008). SARS-CoV-2 spill over reports enhanced our understanding of other species that may have aided the transition from wildlife to humans.

The sensitivity of animal hosts to SARS-CoV-2 is fast becoming known. Predictions based on the characteristics of the host cell receptor to which the virus binds in order to infect cells, demonstration of experimental infection of cell lines or individual animals, and confirmation of naturally acquired infection are all examples of evidence that can be used to infer the susceptibility of wild mammals (Fig. 3). The presence of coronaviruses in wild animal species with nucleotide similarity across all genes (including possible recent progenitors of SARS-CoV-2) may also be beneficial in predicting future infection risk.

Despite the fact that many viruses can hop species to infect new host populations, forward transmission and persistence are not guaranteed due to a variety of circumstances (Wasik *et al.* 2019). To result in a successful host jumping event, host susceptibility, behaviour, and demography must correspond with pathogen features (Plowright *et al.* 2017). As a result, we need to look beyond the evidence for susceptibility to infection alone to establish the most likely species of wild mammal and situations in which they might play a role in the epidemiology of SARS-CoV-2.

The transmission of SARS-CoV-2 from infected humans to domestic or captive animals has been linked to most cases of natural infection in non-human animals While there are significantly fewer opportunities for human-to-animal transmission, some activities involving direct contact, such as wildlife rehabilitation, field research, practical conservation work, and some wildlife-related tourism, may offer considerable dangers. Indirect transmission can occur when there are opportunities for human contamination of the environment (e.g. faeces in wastewater), supplemental

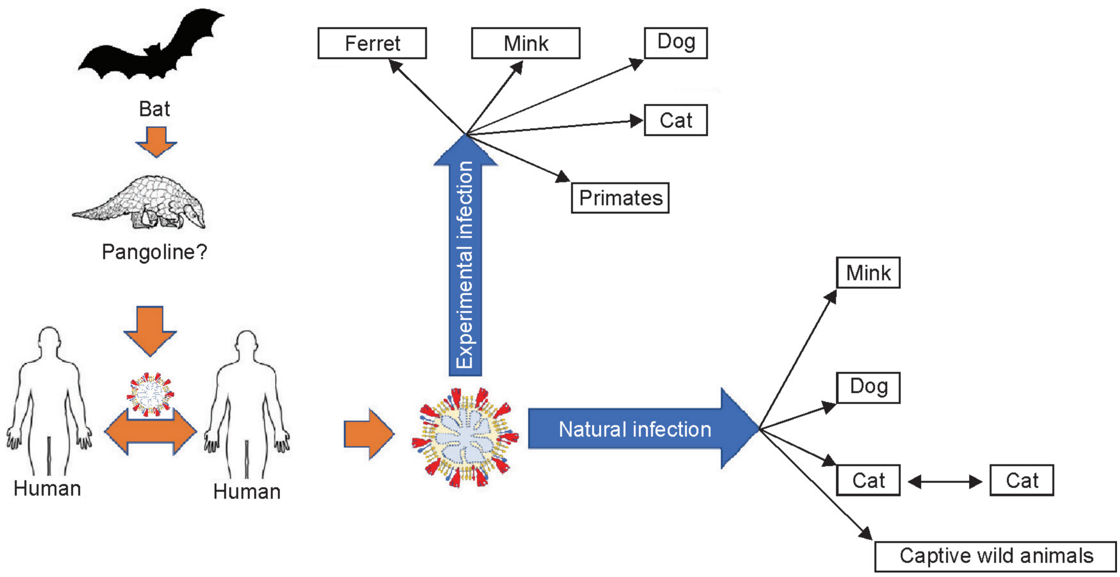

Fig. 3. SARS CoV-2 infection in wild and domestic animals.

food (deployed for wildlife watching, hunting, or pest control), urban waste, or fomites (e.g. surfaces of traps used for hunting or pest control that may be visited by animals that are either not killed or pass on infection before being killed). There will be instances where transmission from sick humans to animals in their care offers a potential channel for subsequent spread to wildlife, emphasising the significance of taking precautions when working with domestic and farmed animals (OIE 2017, FAO 2021).

Although the animal species responsible for human transmission is unknown, the causative coronavirus (SARS-CoV-2) is thought to have originated in bats. Human-to-animal transmission (zooanthroponosis of SARS-CoV-2) has occurred on numerous instances since the pandemic began, in multiple countries and with a variety of species, though there is only very limited evidence of SARS-CoV 2 infection in free-living wildlife to date (OIE 2021). However, because many coronaviruses have a broad host range (Vijaykrishna *et al.* 2007), it is quite likely that more instances in wildlife would arise, with the evident prospect that spillover from people might lead to the creation of a reservoir of infection in wild mammals (Banerjee *et al.* 2021).

Controlling pathogen transmission from wild animals to humans and domestic animals is highly difficult, therefore the introduction of a new reservoir of SARS-CoV-2 infection in wildlife could substantially impede disease control and elimination in humans. Infection in free-living wildlife would have significant practical ramifications for management, research, rehabilitation, and conservation efforts, as well as cause bad public perception of some species, leading to persecution and disengagement from conservation efforts (Gryseels *et al.* 2020). Direct and indirect negative effects on animals are possible, with implications for animal welfare, conservation, and global species diversity (Gortazar *et al.* 2020). These concerns are reflected in new recommendations on how wildlife workers should limit the danger of SARS-CoV-2 transmission to wild mammals (Gryseels *et al*. 2020, OIE 2020). However, risk reduction procedures must be extended to other members of the community who may come into touch with wildlife, such as where wild animals are caught and traded for food (Daszak and Olival 2019). Precautions like these are a good start, but in the face of widespread illness in humans, it's also necessary to consider the consequences of SARS-CoV-2 spreading to free-living wildlife. This necessitates a study of the possible significance of animal populations in infection epidemiology, with a focus on identifying the species and situations most likely to result in infection reservoirs. The relevant surveillance, preventative measures, and contingency plans can then be devised and targeted.

Disease reports in pet animals: While human population was struggling to come terms with changing situations due to COVID-19 pandemic, a serious concern prevailed among the pet owners with dogs getting positive for COVID-19 (Almendros 2020). The cases were confirmed positive by RT-PCR in both oral and nasal swab samples of dog (Almendros 2020, American Veterinary Medical Association AVMA 2020). Further, the infected dog also showed the antibodies specific to COVID-19 suggesting the active immune response to infection (Almendros and Gascoigne 2020). The disease investigation in dog revealed that the COVID-19 positive dogs were in close contact with SARS-CoV-2 positive owners. Under natural conditions it is observed that dogs and cats do not easily contract SARS-CoV-2 except for very close contact with COVID-19 positive cases (AVMA). However, under experimental conditions, dog, cat and ferret are getting infected but other domestic animals showed no such susceptibility (AVMA) (Fig. 4). In humans, Angiotensin-converting enzyme2 (ACE2) is a receptor through which SARS-CoV-2 mediates

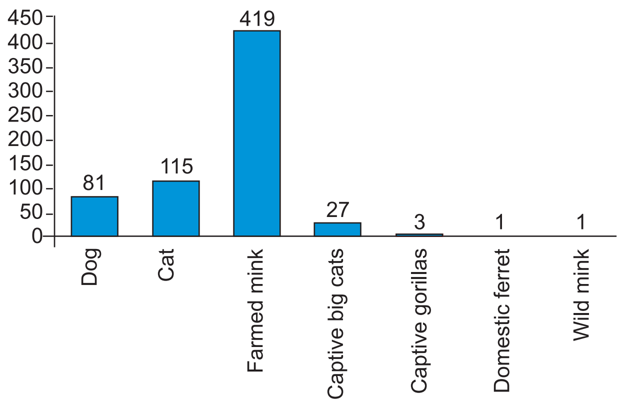

Fig. 4. SARS CoV-2 infections in non-human animals (*Data Source:* AVMA).

its entry into the target cells. Recent studies have shown that the ACE2 receptors in dog are similar to that of humans which might explain the susceptibility of dog to SARS-CoV2 viral infection (Sit *et al.* 2020).

Experimentally, cats when subjected to intra-tracheal inoculation of SARS-CoV resulted in successful infection suggesting their susceptibility to Coronavirus infection which was supported by cats getting positive in locality with high number of SARS human cases in Hongkong during SARS outbreak in 2002 (Martina *et al.* 2003). Similarly, among the domestic animals, cat showed high susceptibility to SARS CoV2 infection making them the best available animal model of COVID-19 (Muñoz-Fontela *et al.* 2020). Sero-surveillance of cats during COVID-19 outbreak in Wuhan showed that 14.2% (15/102) of the serum samples collected after the human outbreak were positive for COVID-19 (Zhang *et al.* 2020). This demonstrates that SARS-CoV-2 can infect cats during human COVID-19 outbreaks. In another study, 239 pet cats and 510 pet dogs serum samples were screened for SARS-CoV-2 exposure and results show an average sero-prevalence of COVID-19 in pet cats and dog as 8% and 3% respectively suggesting higher rates of seropositivity in cats than in pet dogs (Dileepan *et al.* 2021). A large-scale serological survey of SARS-COV-2 in dogs and cats in the UK also showed that low number of animals were tested positive suggesting unlikely role of pet animals as animal reservoir of SARS-CoV-2 (Smith *et al.* 2021).

Disease reports in minks: Minks are domesticated for fur in USA, Canada and few countries in Europe. As on year 2020, there are around 120 and 60 mink farms in USA and Canada respectively (Fur commission, USA and Canada Mink Breeders' Association). The overall business of mink farming in the world may be in millions. Mink is naturally infected with SARS-CoV2 and the first report of infection was reported in the Netherlands, to the end of January 2021. Later, the outbreaks have been confirmed in Denmark, Italy, Spain, Sweden, the United States, Greece, France, Canada, Lithuania and Poland (Pomorska *et al.* 2021). The direction of the disease transmission between human to mink and mink to human is possible with mink exhibiting both clinical and subclinical forms of the disease (Oude *et al.* 2021, Boklund *et al.* 2021). Thus, farmed minks were considered to be high risk species of animal that can lead to evolution of SARS-CoV2 leading to potential new strains. This led to clearance of all the farmed mink population incurring large scale economic loss to fur industry. The observations recorded to date indicate that source of infection to minks are infected humans and hence disease spread between the farms is also through the movement of infected human (Pomorska *et al.* 2021). Recent experimental studies have shown the high susceptibility of minks to SARS-CoV-2 infection and raising a question if minks are possible reservoirs that can pose danger to human by allowing emergence of new strains.

Disease reports in captive wild animals: Reports of naturally acquired SARS-CoV-2 infection in captive wild animals is documented and source of infection was infected humans (Fig. 4). Till date the captive tigers, lions, puma, snow leopard and western gorillas and wild minks were detected positive for SARS-CoV-2 (McAloose *et al.* 2020, Gibbons 2021). All the detected positive wild animals were from zoo captivities. The initial cases of wild animals were detected from New York city zoo in four tigers and three lions which were showing mild but abnormal respiratory signs (McAloose *et al.* 2020). The virus was detected in feces sample from all seven animals. The epidemiological investigation involving whole genome sequencing of SARS-CoV-2 indicated human to tiger transmission (McAloose *et al.* 2020). In San Diego Zoo, eight gorillas were showing mild symptoms, such as coughing and congestion which when tested found positive for SARS-CoV-2. Deaths in gorilla due to human respiratory infections were recorded previously and infections of SARS-CoV-2 has put high alert among the primatologists (Gibbons 2021). Ferrets kept as pet or working animal for rabbit hunting were also known to acquire naturally infection of SARS-CoV-2. Studies have shown severe acute respiratory syndrome coronavirus 2 RNA in 6 (8.4%) of 71 ferrets in central Spain (Gortázar *et al.* 2021)

Indirect effect on animals

The movement restriction, effective means of preventing the COVID-19 transmission affected the activities related to animal health and disease management in livestock. The international support in the form of veterinary services to needy countries affected significantly. Some of the OIE's key veterinary activities, such as prophylactic efforts against illnesses with a large public health or economic impact, are already working at a reduced intensity or have been suppressed during the lockdown in the near term. This, combined with other short-term consequences such as increased wildlife-livestock contact, weaker population control, or longer stock stays on-farm, will have an impact on the spread and incidence of transmissible animal diseases (O'Neill *et al.* 2020). The total capability of regional, national, and supranational veterinary services may be jeopardised if the economic crisis turns into a deep and long slump. As a result, COVID-19's long-term consequences on animal health will be heavily influenced by the impact of the crisis on farmer livelihoods and the capacity of animal health services (Woods 2011, Schwabenbauer 2012). The following actions may help to mitigate COVID-19's negative effects on animal health. Short-term advice includes avoiding, or at the very least limiting, interruptions to current vaccination or test and cull schemes, and paying specific attention to changes in pathogen distribution during and after confinement.

Adapting animal health management practises to available resources is one of the suggested long-term initiatives. For increased disease control success (Schwabenbauer 2012), understanding the socioeconomic environment is necessary, and the prospect for a future of concatenated shocks necessitates changes in both science and governance (Biggs *et al.* 2011). While animal health should remain a top priority despite the economic downturn, more co-funding from the private farming industry will be required, resulting in a shift of management and decision-making to the relevant sector. We also believe that it is past time to pay attention to One Health. This notion emphasises that pathogen ecology and disease management must consider human, animal, and environmental views, implying that doctors, veterinarians, and ecologists should work together to handle health issues effectively. According to the OIE, veterinarians are an important member of the global health community and play an important role in disease prevention and management, particularly for diseases that are transmissible to humans. Furthermore, veterinary laboratories are frequently better adapted for large-throughput PCR or ELISA testing than medical facilities, and as a result, many veterinary laboratories are currently devoted to COVID-19 under the supervision of health authorities. Similarly, increasing use of the capabilities of veterinary epidemiologists and ecologists should be beneficial in improving our collective understanding of SARS-CoV-2 and identifying the best intervention measures.

Health management: Animal health, human health and environmental health are intricately related and the importance of this interaction is being recognised and respected only recently. Animals, humans and pathogens co-evolved sharing the same environment, and whenever this balance was disturbed, it has adversely affected the harmony in the form of emergence of novel infectious agents some of which could be zoonotic also. Although animal disease directly affects the animal health, production and trade, historically even the human disease events have also indirectly affected livestock sector with COVID-19 being the latest example. There was non-availability of essential veterinary services, viz. treatment, vaccination, deworming artificial insemination and others.

Routine husbandry practices and labour shortage: Animals are an important source of nutritious food (egg, meat, milk), livelihood and economy (FAO 2011, Salmon *et al.* 2020). Global livestock production contributes 40% of total agriculture gross domestic product and support the livelihood of at least 1.3 billion people involved in the livestock production value chain (FAO 2018). COVID-19 pandemic affected economic growth of several sectors including the livestock sector (Hashem *et al*. 2020). Livestock production is a day-to-day affair requiring close monitoring and involvement of livestock farmers in cleaning, feeding/grazing, breeding, milking, vaccination of livestock including pets and other allied activities. The aforementioned activities are essential to keep the animals in good health and only such animals can produce nutritious and safe food which are essential for human nutrition, health and wellbeing. Most of the farm labours, who work in livestock farms are migrated from their native place from faraway states in search of job, education, livelihood, and better living status. Livestock husbandry is a skilful enterprise, and the migrant labours are well-versed with animal husbandry practices (milking, feeding, health monitoring) who indirectly contribute to total income of the farm especially the medium and large farms (Biswal *et al.* 2020). As we are all aware farm returns largely depend on how well the livestock are taken care of, the responsibility is best handled by the farm labours. However, in an effort to contain the spread of SARS-CoV-2, the restriction was imposed on human movement globally and varying degree of lockdown was imposed in several countries. Due to these strict regulations on human movement, lack of income, insecurity, fear, non-availability of food, and other daily essentials, forced these migrant labours to return back to their native states/countries and impacted the animal husbandry activities (FAO 2021).

Reduced access procurement/supply of animal feed and fodders: The restriction imposed for movement of human and vehicle, hampered the of livestock sector globally at least for a brief period. The impose also led to the shortage of livestock feed supply (FAO 2020, Kerala State Planning Board 2020). This was felt more by small and marginal farmers, who lack feed storage facilities and cannot afford to purchase feed at a higher price because of altered demand and supply and supply chain disruption due to lockdown (Kumar *et al.* 2020). It is estimated that in the United States, the value of livestock feed that declined due to decreased consumption in the wake of COVID-19 was amounted to 1.5 billion U.S. Dollars than when compared to base value for the year 2020 (Decision Innovation Solution 2020).

Livestock feed supply chain from point of raw material harvest till supply of the prepared feed to the farm gate involve several stakeholders. At the foremost, restriction on vehicle movement, social gathering, closure of feed ingredient markets, non-availability employees in feed plants, have all affected the livestock feed production, storage and distribution. Further, livestock farmers could not procure the feed as they could not access the local market and when the feed was finally available, it was priced too high due to high demand and short supply, increased cost of feed ingredients, higher transport cost etc. The non-availability of fodder seeds, saplings, manure, silage and other inputs have also contributed significantly to shortage of green fodder production.

In South Asian country, especially in India, the pigs are largely fed on kitchen waste and leftovers sourced from hotels, restaurants, fruits and vegetable markets. The sudden closure of hotels, restaurants, markets that are the principal source of feed for pigs made the pig farms to suffer from lack of feed. Further, as the hotels and restaurants stopped operating, there was no buyers for poultry, sheep, goat and pigs for meat purpose as the consumers were not visiting hotels. And it was an additional burden for the livestock farmers to feed these already fully grown animals at the farm and that created malnourishment of the younger stock leading to decreased bodyweight gain. Further, there were human COVID-19 outbreaks in meat processing facilities (Taylor *et al.* 2020, Pokora *et al.* 2021). Closure of such settings led to decrease in procurement of meat animals from the livestock farmers and production loss to processing plants (Ijaz *et al.* 2021).

Animal grazing: In developing countries, livestock husbandry is mainly undertaken by small and marginal farmers. Unlike the developed country where the factory farming system of livestock rearing is popular, the developing countries rely on small scale backyard farming. Due to the low input animal husbandry and high prices of livestock feed, it is a common practice by the livestock keepers to graze their animals in open fields to meet part of the required nutrition. It is also common practice in sheep and goat husbandry to follow pastoralism or nomadic system to graze the animals over a period of several days to months during the months of fodder scarcity (Centre for Pastoralism 2020, Catley 2020). In addition, during grazing animals get exercise, are at ease and have greater opportunity to express their natural behaviour which indirectly contribute for health, animal welfare and production to certain extent. However, the movement restrictions during the pandemic led to no or decreased opportunity to graze livestock in open fields. This also might have partly affected the production and wellbeing.

Impact on livestock origin products: Foods of livestock origin (egg, meat, milk) provide food security and help in reducing malnourishment due to high nutritive value. Due to their highly perishable nature, their supply chain should be carefully managed to preserve their quality and prevent loss associated with perishability. However, during the lockdown disrupted supply chain prevented the supply of these products to the consumers (FAO 2020). Further, the

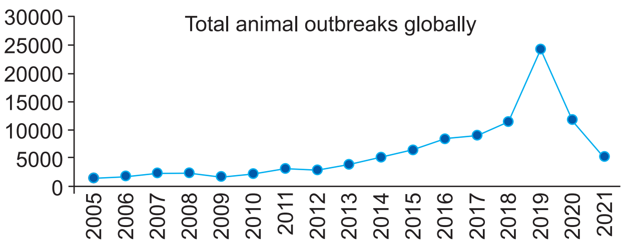

Fig. 5. Global animal outbreaks between 2005–2021 (*Data Source:* OIE-WAHIS) (X axis, Year; Y axis, Number of outbreaks).

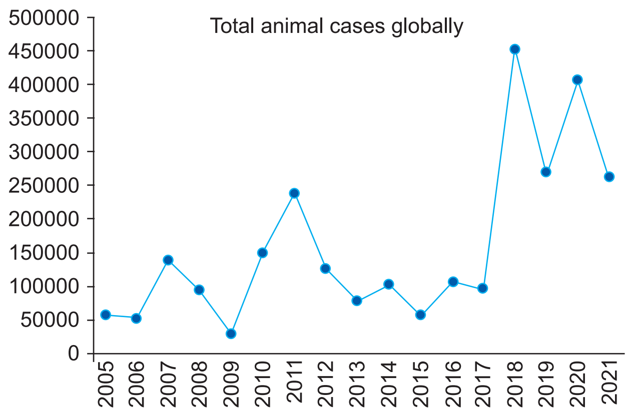

Fig. 6. Global animal cases between 2005–2021 (*Data Source:* OIE-WAHIS) (X axis, Year; Y axis, Number of cases).

demand for the livestock origin food was reduced due to the decreased purchasing power (Ijaz *et al.* 2021). The loss was also in part due to misinformation that the SARS CoV 2 could spread through consumption of poultry meat and egg. Because of this misinformation, poultry industry suffered an estimated loss of ₹13,000 crores during the initial phase of the pandemic (Hindustan Times 2020). It was estimated that due to COVID-19 restrictions, supply chain disruptions, production, processing, storage and distributions were hardly hit. According to an estimate, the economic loss to livestock sector in India will be 2711.2 thousand million due to impose of lock down (Swain *et al.* 2020).

Animal disease management: The movement restriction was a challenging measure adopted by many countries as most effective intervention for COVID-19 spread globally and locally. This has impacted the routine animal health services like treatment, vaccination, extension activities etc. The global animal outbreak data shows a gradual increase in the total number of disease outbreaks in animals from 2005 to 2018 with sharp peak in 2019 and there was decline in the outbreak number as it approached year 2021 (until June 2021) (Fig. 5). This indicates that there was increase in the number of outbreaks globally and reasons need to be ascertained and impact of COVID-19 needs to be better understood for planning control measures in animals. Like the total outbreaks, the total number of animal cases also increased gradually but it peaked in the year 2018 and gradually showing decreasing trend (until June 2021) (Fig. 6).

Veterinary service and routine treatment: COVID-19 pandemic has seriously impacted on the lives of individuals, communities, and societies around the world. It also brought changes in those working in the animal health sector. Preventive and clinical animal health care services provided by veterinarians (both government and private) to livestock farmers/customers have been badly affected as a result of the restrictions. It was difficult for private veterinarians to carry out their normal level of visits to livestock farms and for livestock keepers to perform their normal daily level of health inspection of their animals (FAO 2021). COVID-19 prevention protocols have reduced access to inputs and services for veterinary health care, animal breeding and production (FAO 2021). Movement restrictions and disruption of national and international trade routes have curbed farmer access to breeding materials and replacement stocks (e.g., DOCs and semen; FAO 2020). Further it also affected the supply chain of veterinary medical products due to decreased importation, distribution of products and decreased production of veterinary products (FAO 2021). Underdeveloped countries which are dependent on imports for most agricultural inputs from other parts of the world, having low veterinary infrastructure and human resources has worsened situation during the pandemic (Obese *et al.* 2021). Countries like Ghana, where livestock farmers are unable to access veterinary services for their livestock due to the relatively low number of veterinarians and high cost of services and medicines. Unfortunately, the COVID-19 pandemic has worsened this situation as the few service providers become more expensive and difficult to reach (Obese *et al.* 2021). Limited access to the veterinary dispensary or even veterinarians and also problems of transportation of animals to the polyclinic at the time of need led to a high level of morbidity and at times death of the animals. This limited health care in long run would greatly impact the reproductive efficiency and productivity of the animals (Biswal *et al.* 2020).

Vaccination campaigns: Countries around the globe carryout regular vaccination campaign against endemic livestock diseases for effective control and prevention measures. During the pandemic, vaccination campaigns are either postponed or suspended due to movement restrictions, decrease in vaccine availability and reduced vaccination staff (FAO 2021). Most recently, the COVID-19 pandemic has interrupted rabies vaccination in dog in Haiti (Kunkel *et al.* 2021) as well as other Latin America countries (Peru) (Raynor *et al.* 2020). In Haiti dog, vaccination campaign was cancelled and funds were diverted to support the COVID-19 response, whereas in Peru, veterinarians and other authorities have considered dog vaccination a high-risk activity during the pandemic or a non-essential veterinary activity (e.g., nonurgent or non-emergency care). This resulted in reemergent transmission of rabies virus in both countries (Raynor *et al.* 2020, Kunkel *et al.* 2021).

In India, the routine mass vaccination program carried out by the government under National Animal Disease Control Programme for Foot and Mouth Disease (FMD) at 6-monthly intervals, for both cattle and buffaloes. Mass vaccination drive was suspended owing to COVID-19, which resulted FMD outbreaks in certain states (Biswal *et al.* 2020). Abrupt interruption of vaccination campaign leads to epidemics of disease, escalation control cost and delay in elimination of disease. Despite the immediate threats posed by COVID-19, it is essential that countries continue to invest in control of major livestock diseases and other neglected communicable diseases (Kunkel *et al.* 2021).

Outbreak investigations and animal health surveillance: Prompt disease outbreak investigation, disease diagnosis, emergency response, disease reporting and regular animal health surveillance essential key factor in reducing the incursion or spread of animal diseases in livestock in their country. Recently, worldwide survey conducted by FAO on impact of COVID-19 on animal health indicated that the direct impacts on account of movement restrictions, and a fear of becoming infected with the virus, and indirect impacts which resulted from resources being directed away from animal health surveillance activities to COVID-19-related activities. Further, study showed that due the movement restriction, engagement of animal disease emergency response system and laboratory in COVID-19 related work, lack of PPE or laboratory reagents made it difficult for field agents to conduct surveillance activities and field investigations which delayed the notification of diseases and their capacity to respond to a new disease outbreak or natural disaster had been reduced (FAO 2021). Recent FAO's Global Early Warning System (GLEWS) of EMPRE SAH developed a survey to measure the impact of the COVID-19 pandemic on animal disease reporting by veterinary services in countries using the EMA-i tool. It has seriously affected their work on disease reporting (FAO 2021). Similarly, the halt of a surveillance program for the important livestock and poultry diseases undertaken by the international (FAO/OIE/WHO) and national agencies (Rahman 2021) results in non-reporting and under reporting of diseases which would cause a major setback towards disease forecasting and formulating advisory and contingency plans. The EuFMD conducted the survey across Europe on impact of COVID-19 on surveillance and response to transboundary animal diseases. The results specifically noted the scaling up of critical veterinary and animal health human resources was negatively impacted, due to internal and international travel restrictions, isolation and quarantine rules. Further survey indicated the potential for conflict in the prioritization of resources needed in the control of COVID-19 and the control of transboundary animal diseases by local disease control operations and there was concern on national inter-agency coordination (FAO 2021). Emergence of COVID-19 pandemic and its 'probable source from animals has re-emphasised the need for integrated one health approach for surveillance of new coronaviruses and other zoonoses (Bhatia 2020).

Emerging animal disease control and prevention: Worldwide, COVID-19 is disrupting control efforts in a plethora of infectious disease programs. Animal disease control programs including African Swine Fever and tuberculosis surveillance systems are also at risk (Gorta´zar and de la Fuente 2020). Early detection, rapid response to diseases and prevention of transboundary animal diseases is critical in minimizing and containing animal diseases thereby helping farmers to enhance their production and secure their livelihoods. Diseases such as African swine fever (ASF) and highly pathogenic avian influenza (HPAI) can cause an entire animal population to vanish in a matter of days, consequently threatening the livelihoods and food security of thousands of farmers and their families. In India, during COVID-19 pandemic, first case of ASF reported in

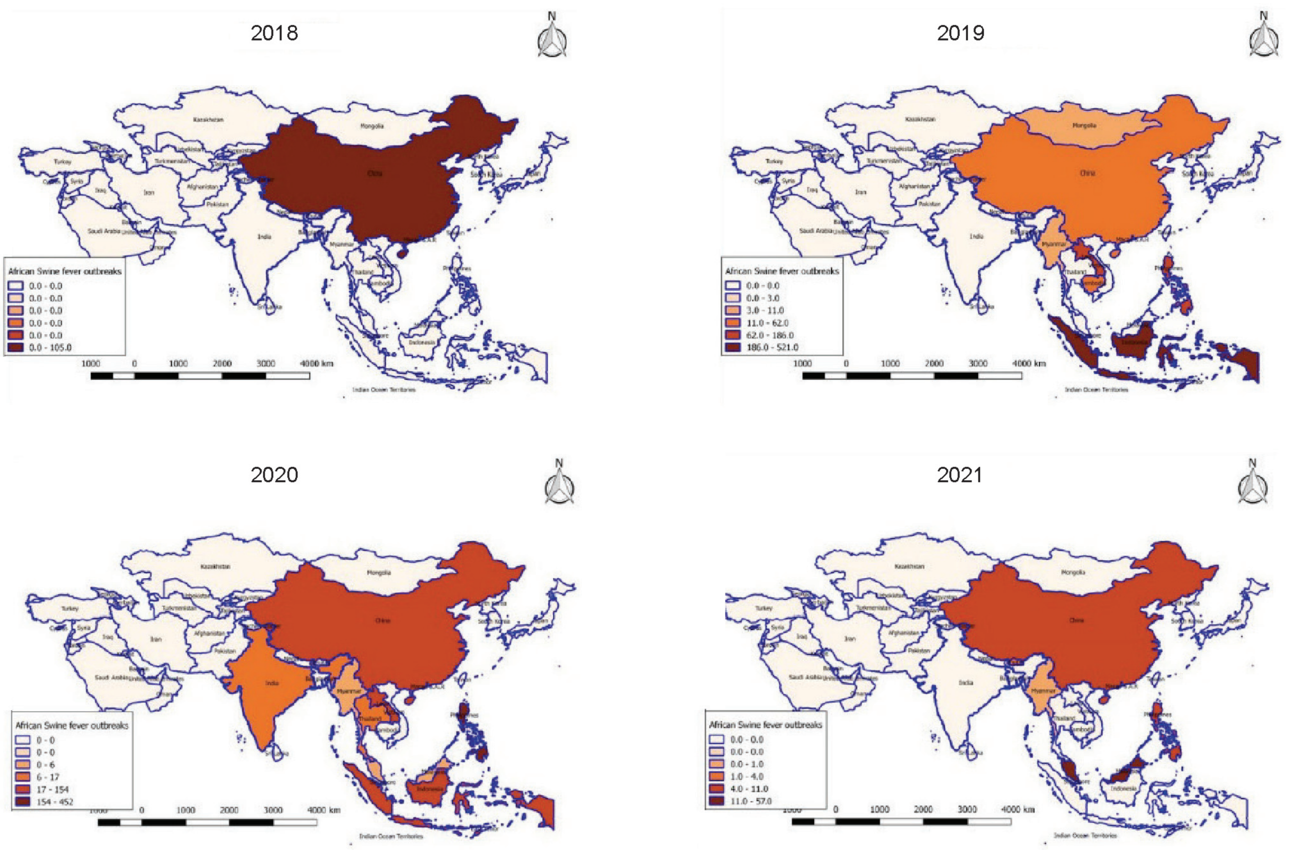

Fig. 7. Spread of African swine fever outbreaks in Asia from the year 2018 to 2021 (until June 2021). *Data Source:* OIE-WAHIS.

May 2020 and subsequently spread across the North Eastern state of India, causing huge mortality and significant economic loss to pig industry and threatened the farmers livelihood (www.downtoearth.org.in/swine-fever). Just before the COVID-19 pandemic, Lumpy Skin Disease, a transboundary and emerging bovine disease spread to China and South Asia (India, Bhutan and Bangladesh) which have the world's largest bovine populations. Subsequently, COVID-19 lockdown enforced in many Asian countries exacerbates already existing difficulties for veterinary services and laboratories trying to conduct timely outbreak investigation and disease diagnosis, which may result in delayed disease detection, reporting and implementation of control measures. This resulted in spread of LSDV throughout the country. Furthermore, the movement restrictions from COVID-19 pandemic mitigation measures hamper prompt laboratory diagnosis, outbreak investigation and control and prevention measures (Roche *et al.* 2020). Unfortunately, vital measures to control COVID-19 have had the negative trade-off of jeopardizing animal disease elimination and prevention activities. International organizations and multiple researchers raising concerns about the potential downstream impacts of the COVID-19 pandemic on the control of human, animal and neglected tropical diseases (Hogan *et al.* 2020, Toor *et al.* 2020).

African swine fever (ASF) is highly infectious and deadly disease (100% mortality) of pigs caused by African swine fever virus. The disease is characterized by high fever, anorexia, weakness, diarrhea and/or constipation, abdominal pain, respiratory distress, nasal and conjunctival discharge and abortion in pregnant females. Until recently the disease was restricted to Africa and much of Eastern Europe were considered as endemic to ASF. Recently the disease has spread to Asia. The recent emergence and spread of African swine fever in Asia, including India has led to huge economic loss to the piggery sector and it has also affected the global food supply chain. Small holder piggery farmers are the most vulnerable to the economic losses due to African swine fever (Woonwong *et al*. 2020). The African Swine fever outbreaks were restricted to Georgia until the year 2007 and it was reported from China in the year 2018 for the first time. During the year 2019, ASF spread to Cambodia, Hong Kong, Indonesia, North Korea, South Korea, Laos, Mongolia, Myanmar, Philippines, East Timor and Vietnam. In the year 2020, it further spread to India, Laos and Thailand and during the year 2021 it further spread to Bhutan (Fig.7). The probable reasons for spread of ASF within Asia may be due to illegal animal trade due to imposed lockdowns, poor quarantine measures and other factors which further needs to be investigated.

The use of antibiotics may have been increased during the pandemic and hence increasing the chances of antimicrobial resistance (Miranda *et al.* 2020). The excess use of antibiotics to manage COVID-19 patients and to treat secondary bacterial associated pneumonias can be major contributor for emergence of AMR pathogens in future.

Antimicrobial stewardship programs (ASPs) are advocated to minimize the antimicrobial usage and follow WHO guidelines for usage of antibiotics for COVID-19 patients to prevent the emergence of new AMR pathogens. It is also advised to for regular sensitivity testing to know the current pattern of AMR for timely mitigating strategies (Hashmi *et al.* 2020). The inappropriate use of antibiotics is on the rise during the ongoing pandemic with limited access to diagnostics for other conditions and practice of telemedicine (Rusic *et al.* 2021).

The impact of excess and inappropriate use of antibiotics in humans and emergence of AMR during current pandemic on animals need to be quantified and evaluated. It is unlikely that use of antibiotics in animals has increased during the ongoing pandemic because of limited access to veterinary services. Hence, there is need to adopt One health approach to tackle and mitigate the AMR problem at a global scale (Rhouma *et al.* 2021). However, use of antimicrobials in post-COVID period in farm animals and pet animals needs to be monitored with stringent regulations to prevent emergence of AMR (Samanta and Bandyopadhyay 2020).

Despite the negative economic impact created by COVID-19 worldwide, few countries reported that they had developed and implemented a national COVID-19 business continuity plan to perform pre-selected priority activities related to animal health amid the current pandemic (FAO 2021). In India, two national programs, namely, National Animal Disease Control Programme for FMD and Brucellosis for ensuring 100% free vaccination of cattle and farm animals was now actively taken up to control the endemic disease and creation of Animal Husbandry Infrastructure Development Fund would serve as triggering factors for reviving growth pace of the livestock sector (Biswal *et al.* 2020).

Capacity building: Capacity building programs in various countries on staff training, emergency simulation exercises including sharing of information from research to stakeholders, education on the National Strategic Action Plan, and training of field extension personnel have either been put on hold or restricted because of the COVID-19 pandemic (Obese *et al.* 2021, FAO 2021).

Positive effects of lockdown

The lockdowns imposed to contain the COVID-19 pandemic has also resulted in positive impact on the environment and reduced risk of diseases due to import and export of livestock and livestock products. The risk of entering African Swine fever into Japan was shown to be reduced due to coronavirus pandemic induced movement restrictions (Sugiura *et al.* 2021). There were some positive effects of lockdowns on atmospheric environment like reduction in the levels of nitrogen dioxide (NO_2), particulate matter (PM2.5 and PM10) and carbon emissions due to closure of industries and restricted air transportation (Bar 2020). There were also behavioural changes in wild animals, birds and other animals (Bar 2020) which will help to stabilise the ecosystem.

Future preparedness

Human contact with farm animals during transport, slaughter and food processing makes coronaviruses a potential threat to both humans and animals. Hence, there is need for monitoring and surveillance of animal coronaviruses (Khamassi *et al.* 2021) to prevent emergence of new zoonotic disease. There is interconnectedness and interdependencies between all the sectors, agriculture and allied sectors are also vulnerable to disturbances such as the ongoing COVID-19 pandemic. Hence, there is need to have a contingency plan to mitigate the consequences of the pandemics (Lioutas and Charatsari 2021). Some countries adopted a comprehensive multisectoral response group on welfare group with more than 34 organisations to mitigate the crisis and continuous care to animals. There is need to have such plans in other countries so that the impact of such pandemics on animal welfare is not compromised and it can also reduce the impact on economy of a country. It can not only help to ascertain the sustainable value chain in livestock production but also can support the livelihoods of farmers dependent on the livestock (Baptista *et al.* 2021).

Conclusion

The SARS-CoV-2 pandemic is a dramatic example of the interconnectedness of nature, domestic/farmed animals, and people' health. The pandemic made everyone to realise that human health depends on health of other living being and it is time to seriously consider the one health approach. The human death and suffering during the pandemic are beyond imagination. Consequent to impairment in human activities, the livestock activities have impacted greatly resulting in large scale economic loss. Livestock sector is the only sector where millions of poor and marginal farmers depend heavily on this sector for their livelihood and in turn, they earn food security for rest of the population. COVID-19 will have an immediate impact on animal health because of sudden human confinement and inactivity, as well as long-term effects on farmer livelihoods and veterinary service capacity because of the forthcoming economic crisis. The COVID-19 pandemic and the ensuing economic crisis will have a detrimental influence on disease control in the World, as well as on global ability to prevent and respond to new and emerging animal diseases in a timely manner. The pandemic episode created challenging situation to control and prevent the disease while maintaining the world economical growth. Livestock sector which feeds 7.9 billion human population in world needs a review of prevailing situation to formulate short term and long-term plans to boost the sector growth that stalled due to pandemics.

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