# Regional Epidemiology and Associated Risk Factors of PPR

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**Abstract**

Peste des petits ruminants (PPR) is an acute, highly contagious, world organization for animal health (OIE) notifiable and economically important transboundary viral disease of sheep and goats and caused by PPR virus (PPRV), which belongs to the genus Morbillivirus of the family Paramyxoviridae. The disease is endemic across Asia, the Middle East and African regions and is considered to be a major obstacle to the development of sustainable agriculture across the developing world due to huge burden for the economy and development of the affected countries and has recently been targeted by the OIE and the Food and Agriculture Organization (FAO) for eradication with the aim of global elimination of the disease by 2030. In this review, the regional epidemiology of PPR outbreaks and associated risk factors with special reference to the PPR-affected countries in South, Central and East Asia is comprehensively discussed.

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**Abstract:**

*Peste des petits ruminants*(PPR) is an acute, highly contagious, world organization for animal health (OIE) notifiable and economically important transboundary viral disease of sheep and goats and caused by PPR virus (PPRV), which belongs to the genus *Morbillivirus* of the family *Paramyxoviridae.*The disease is endemic across Asia, the Middle East and African regions and is considered to be a major obstacle to the development of sustainable agriculture across the developing world due to huge burden for the economy and development of the affected countries and has recently been targeted by the OIE and the Food and Agriculture Organization (FAO) for eradication with the aim of global elimination of the disease by 2030.

In this review, the regional epidemiology of PPR outbreaks and associated risk factors with special reference to the PPR-affected countries in South, Central and East Asia is comprehensively discussed.

***Key Words:*** *Regional Epidemiology, PPR, PPRV, Risk Factors, Targeted disease, Eradication.*

**Introduction:**

Peste des Petits Ruminants (PPR) is a worldwide prevalent infectious disease of domestic and wild small ruminants and a threat to food security, sustainability and the prosperity of animals and humans across Asia, the Middle East and Africa (Baron et al., 2017; Kumar et al., 2014; OIE, 2016), characterized by fever, oculonasal discharges, stomatitis, diarrhea and pneumonia. The morbidity rate of PPR is 100 % and in severe outbreaks mortality reaches to 100 % (Radostits et al., 2000). Morbidity and mortality rates vary but may reach up to 100 % (Lefevre et al., 1990). These rates are usually lower in endemic areas (mortality 20 % or less) and sero-surveillance is sometimes the only indicator of the infection (Roeder et al., 1999). Diallo et al. (2007) has reported that in acute cases, mortality varies from 70 to 80 % with death between 10 and 12 days. Despite efforts, PPR is emerging transboundary infection in new regions in the world affecting major animal and economic damages. Based on epidemiological data existing, the virus is present in 65 countries with an additional more than 20 countries being categorized as "at risk". A recent cost-benefit analysis study concluded that global eradication of PPR would see a return of $74 billion over 15 years (Jones et al., 2016). Over 90% of the world's sheep and goat population is found in developing countries, providing food, revenue from trade in animals and their products, plus improved economic stability and resilience for smallholder farmers (Herrero et al., 2013). Following the global eradication of Rinderpest in 2011, the OIE and FAO have joined target PPR as the next animal disease to eradicate (Lancelot et al, 2016; OIE, 2016; OIE, & FAO, 2015). Epidemiological approaches toward eradication of PPR would likely provide considerable sustainability and welfare benefits to vulnerable communities across Asia, the Middle East and Africa. This review will provide a regional road map of China, Mongolia, India, Pakistan, Bangladesh, Nepal, Afghanistan and Tajikistan for the scientist, policy makers and stick holders of OIE/FAO vision 2030 for the eradication of PPR, through understanding the regional epidemiology, PPRV lineage distribution, regional distribution of host, impact of regional animal movements during PPR outbreaks and associated risk factors.

**Global PPR Status**

PPR infection was first described in Côte d'Ivoire West Africa in 1942. In 1987, PPR appeared in the Middle East and has since then been confirmed in Arabia (Abu-Elzein et al., 1990), Jordan (Lefevre et al., 1991), southern India (Shaila et al., 1989, Nanda et al., 1996), Bangladesh (Sil et al., 1995), Pakistan (Amjad et al., 1996), Iraq (Barhoom et al., 2000), Afghanistan (Abdollahpour et al., 2006), Turkey (Ozkul et al., 2002; Toplu, 2004; Anderson and Sammin, 2005; Yesilbag et al., 2005), Kazakhstan (Lundervold et al., 2004) and Tajikistan (Kwiatek et al., 2007), Nepal (Banyard et al., 2010), China (Wang et al., 2009) and Bhutan (Banyard et al., 2010). PPR has received a growing attention because of its continuing spread and economic impacts (Lefevre and Diallo, 1990). As per May 2019, among the 198 countries recognized by the United Nations, 57 have already have PPR-free status according to OIE Standards, while 67 are infected and 74 have never reported PPR (FAO/OIE, 2015). Although the primary hosts of PPR are goats and sheep, the host range of PPR has been continuously expanding and reported to infect various animal hosts over the last decades, which could bring a potential challenge to effectively control and eradicate PPR globally (Dou et al., 2020).

PPR is caused by PPR virus (PPRV) which belongs to the genus*Morbillivirus* of the family *Paramyxoviridae* (sub family*Paramyxovirinae* ) under the order *Mononegavirales* , like Measles virus, Rinderpest virus, Distemper virus and Newcastle disease (ND) virus (Salami et al., 2014). PPRV has a tropism for both epithelial and lymphoid cells (Kumar et al., 2014). Clinical signs in small ruminants typically start with dullness and fever, progressing to mucopurulent oral, ocular and nasal discharge, followed by oral lesions, bronchopneumonia and diarrhoea (Albina et al., 2013; Balamurugan et al., 2014; Kumar et al., 2014). Animals can excrete PPRV prior to the onset of clinical signs (OIE, 2016; Parida et al., 2015), with large quantities of PPRV

excreted in discharges from infected animals. However, PPRV is not stable in the environment and requires direct transmission in fluids for infectious spread (OIE, 2016; Parida et al., 2015). The extent of clinical signs, morbidity and mortality can depend on the viral strain, the environment and the immune status of the animal (Parida et al., 2015; Ratta et al., 2016; Santhamani et al, 2016). The virus has a high morbidity and mortality, reaching to 100% and over 90% in naïve herds, respectively (Parida et al., 2015). Mortality occurs between 5 and 10 days of onset of infection, with the few recovering animals developing strong lifelong immunity (OIE, 2016; Parida et al., 2015). Phylogenetically, based on the fusion (F) and nucleocapsid (N) genes, PPRV can be classified into four distinct lineages. PPRV lineages I and II are exclusively isolated from the countries in West Africa where PPRV originated. Lineage III is restricted to the Middle East and East Africa. Lineage IV is currently most prevalent in Asian countries and becoming overwhelmed lineage in Africa. (Munir et al., 2013; Banyard et al., 2010; Dhar et al., 2002; Dundon et al., 2014; Muniraju et al., 2016; OIE, 2016). Lineage IV historically only affected Asia, although has spread into Western and central Africa over the last two decades and northern Africa with PPRV described in Morocco 2008 and 2015, Algeria 2010 (OIE, 2016; Parida et al., 2015). PPRV Lineage III has also been described in the Middle East (OIE, 2016).

**Regional PPR Status in Asia**

PPR is considered to be the most significant economic threat to the development of sustainable small ruminant's production across the developing world, particularly in Asia. The infection in Asia was first described in southern India and cause significant economic losses. For example, in India, the estimated annual loss caused by PPR in sheep and goats was about US$ 1,297 million per year (Shaila et al., 1989, Nanda et al., 1996, Singh et al, 2014). PPR remains endemic in most of the SAARC countries in the region except Sri Lanka Maldives and Bhutan had sporadic outbreaks. There is high risk of incursion of the virus through animal movements and imports of small ruminants even in the countries, region and areas which are free and/or have sporadic assurances. The countries in South Asian region have varied capacities, capabilities and facilities in the fields of epidemiology, diagnosis and vaccine production. India is implementing PPR control programme in a phased manner. Bangladesh, Nepal and Pakistan have their localized control programmes for PPR. Also Bangladesh, India, Nepal, Pakistan has developed national action plan for the eradication of PPR in accordance with global eradication campaign (Samad et al., 2019). As per July 2018 according to OIE Standards, among the 48 countries in Asia recognized by the United Nations, only two countries (Singapore and Philippines) have PPR-free official status.

**South Asia:**

**India:** India has twenty-eight states and seven union territories. The country possesses about 200 million sheep and goats (Ministry of Agriculture, Government of India, 2009). PPR is endemic in India and is a major threat to about 200 million small ruminant population of the country (Dhar et al., 2002), causing an economic loss of about 1800 million Indian rupees annually (Bhadyopadhyay, 2002). Close contact is the most important way of transmitting the disease. It is suspected that the infectious materials can also contaminate water, feed troughs and bedding, turning them into additional sources of the infection. These are however short-term sources, since the PPRV, like its close relative the Rinderpest virus, would not be expected to survive for a long time outside the host (Diallo, 2003). In addition to these sources of infection movement of animals across the boundaries of states commonly acts as source of PPR epidemics. There is no known carrier state in PPR and the infected animal may transmit the disease itself during the stage of incubation period. However, the PPR infected animal's seroconvert and become immune to PPR and RP viruses (Sudarshan et al., 1995). Singh et al. (2004) discussed the relation of migration of animals with that of maintenance and transmission of PPRV in nature. The close relations between PPR outbreaks and transportation of sheep and goats' flocks have been reported (Boniwell, 1980; Dhand et al., 2002; Kataria et al., 2007; Shankar et al., 1998). Migration may also spread infection to cattle (Shaila et al., 1989).

In India, animal rearing is practiced in two major ways: one is unorganized back yard rearing (where 5–10 sheep or goats are reared in backyards and fed up on the agriculture byproduct) and the other is the traditional rearing of sheep and goats by nomadic communities (where the animals are fed on pasture lands and uncultivated or barren fields during the course of migration). Most of the earlier studies from India

were conducted on sheep and goats of non-migratory flock (Singh et al., 1996, 2004; Kataria et al., 2007; Bhanuprakash et al., 2008) but the present study covered animals of both migratory and non-migratory flocks. According to Mahajan et al. (2012), the risk of PPR is higher in migratory flocks than in non-migratory flocks. The animals of these migratory flocks were brought from hilly areas through different routes after the completion of their seasonal migration to escape severe winters. This seasonal movement of animals may increase the chance of transmission among the migratory flocks. Moreover, in migratory flocks, there is transportation stress, underfeeding and underlying parasitic infection which may decrease the immunity, thereby increasing the susceptibility of animals to disease. These facts were also supported by the findings of other workers who reported outbreaks of PPR in migratory herds in Himachal Pradesh (Joshi et al., 1996) and Rajasthan (Singh et al., 1996). Similarly, Khan et al. (2007) reported higher sero-prevalence of PPR in southern and western parts of Punjab of Pakistan where nomadic rearing of sheep and goats was common.

The virus spreads through close contact via respiratory route. Viremia develops 2-3 days post infection. Fine infective droplets from the secretions and excretions of the infected animals are released into the air (Sen et al., 2010). Transmission could also occur through contaminated water, feed troughs and bedding (Lefèvre and Diallo, 1990). In India, animals are allowed to share common grazing land and water sources are risk factors. Besides, migration of animals between various states is common especially, in the sub-Himalayan region and western dry land areas such as Rajasthan and Gujarat (Nanda et al., 1996; Singh et al., 2004). Mixing of these migrated populations with local population may contribute to the disease transmission. Further, during the festival seasons, animals are shipped to various states for meat purposes. These unrestricted movements of animals contribute significantly to the epidemiology of the disease. In India, the disease occurs round the year and the maximum outbreaks reported during the winter and rainy seasons. Therefore, vaccination just takes place prior to the onset of rainy/ winter season. Initially, PPRV was classified in to 4 lineages I–IV based on the F gene sequencing (Dhar et al., 2002; Shaila et al., 1996); lineage I-III viruses were reported in several countries of Africa and lineage IV (Asian lineage) mainly in Middle East and Asia (Banyard et al., 2010; Dhar et al., 2002; Ozkul et al., 2002). Currently, N gene is preferred over F gene due to its better molecular separation (Kwiatek et al., 2007). In the recent past, many researchers report the presence of lineage IV in African countries (Maganga et al., 2013; Salami et al., 2014). Till now, only lineage IV viruses have been reported in India. The PPRV goat strain isolated during the recent outbreak at Tripura showed 99.2 to 99.6% nucleotide identities with the Bangladesh strains (Muthuchelvan et al., 2014). The overall epidemiological investigation confirms the transboundary transmission of PPRV with the neighboring countries including china, Mongolia, India, Pakistan, Bangladesh, Nepal and Afghanistan.

**Pakistan:** PPR was recognized in Pakistan in early 1990s but got importance during the Participatory Disease Surveillance (PDS) of Rinderpest Eradication Campaign. Lot of research work has been initiated during last decade towards disease epidemiology, risk factor recognition, laboratory diagnosis, vaccination and demonstration of control strategies (Abubakar et al., 2015). In Pakistan PPR is endemic, during the last decade, PPR outbreaks have increased to an alarming level involving newer areas (Ali, 2004). According to Zahur et al. (2011) PPRV is circulating in the small ruminant population throughout Pakistan. As, on the basis of clinical and serological methods, an outbreak of PPR was reported in goat flocks of Livestock Production and Research Institute (LPRI), Bahadurnagar, Okara, Pakistan (Khan et al., 2005). According to another report based on observations from 50 laboratory confirmed outbreaks of PPR and provides details of the presence or otherwise of PPRV in 427 tissue/organ samples from small ruminants in Pakistan. PPR is more severe in goats than sheep and the frequency of disease outbreaks are greater between the months of January to April. Spatial distribution of PPR in various locations of Pakistan indicate that the disease pattern, although both goats and sheep are susceptible to infection and may show disease yet they are not always affected simultaneously, for example, in Africa PPR is seen most commonly in goats, while in western and South Asia sheep are usually the most noticeable victims (FAO, 1999). But if we see the picture in Pakistan, PPR affect both goats and sheep but in many villages, it is seen that only goats are affected usually Taylor et al. (2005) and this concept is much supported by findings of Abubakar et al. (2008). In different districts of Sindh province, overall PPR seroprevalence in sheep is 49.5 % as compare to goats which is 56.3 %. According to (Obi et al., 1983; Durojaiye et al., 1983; Abubakar et al., 2011), most cases

of PPR emerge with the start of summer season and cases get peak during the months of April to July and then the prevalence drop again that indicate the temporal pattern of disease Khan et al. (2008) reported the antibody prevalence of PPRV in small ruminants in Punjab 51.3 %. The antibodies frequency against PPRV recorded 67.7 %, 71.1 % and 60.2 % in the months of December, January and February and 50.7 % and 53.0 % in the months of September and October, respectively. Less local fodder availability and poor nutritional status of the animals may play a key role in the transmission of disease. Zahur et al. (2011) has reported distribution of PPRV in different districts of Pakistan that is over all 48.30 %. Jalees et al. (2013) investigated that disease is more prevalent in young sheep and goats than adult and predilection site of the PPRV remained the lymph nodes.

The true sero-prevalence of PPR in Pakistan estimated to be 48.5 % (95 % CI, 46.6–50.3), and 52.9 % (95 % CI, 50.7–55.1) and 37.7 (95 % CI, 34.4–41.0) for goats and sheep, respectively. The sheep and goats exhibited a different seroprevalence pattern with a quite higher prevalence in goats. The highest prevalence was recorded in animals over 2 years of age: 49.29 % of sheep and 65.94 % of goats were seropositive for PPR (Zahur et al., 2011).

In Pakistan different vaccination programs are introduce with the live attenuated virus belonging to Lineage I. Despite of the strict vaccination programs and other preventive and clinical measures the PPR outbreaks are frequent. Moreover, different type of PPR vaccines including conventional, thermostable, recombinant and edible vaccines has been developed and used from control/eradication of said disease world widely (Abubakar et al. 2011; Abubakar et al. 2012; Abubakar et al. 2015 and Odo, 2003).

Currently, vaccination is recommended in certain areas of the country. This vaccination is based on Nig75/1, which belong to lineage II, while field isolates from Pakistan are grouped in lineage IV. Genetic characterization of field strains will provide foundations for construction of vaccines from domestic strains as has recently been practiced in India (Anees et al., 2013). While, tissue culture based live freeze-dried PPRV (PPR 75–1) vaccine has been produced by Abbas et al. (2012) using Vero cell line and checked for validation, safety, sterility and efficacy. They concluded that this PPR vaccine would be an effective tool to limit PPR disease in goats as well as to reduce economic losses due to this disease in Pakistan. Currently, although the PPR vaccine production capacity is present in the two places in the country yet there is no organized PPR vaccination campaign going on. With the current population of more than 90 million of small ruminants and endemic situation of PPR, there is continuous threat from PPR in terms of food security.

International authorities working on animal health (OIE and FAO) have recognized PPR as the next target disease for control and possible eradication from the world. So there is need of the time to have national and regional PPR control program in the country and neighbors. After the successful Rinderpest eradication campaign, OIE has officially declared PPR as next candidate disease, to be eradicated. Therefore, serious efforts have been started towards the disease understanding and possible measures for its eradication.

Although there are some projects completed towards the progressive control of the disease in country yet there is need to understand the epidemiology of disease and to established a national level control and eradication program for PPR which will link with the regional control and eradication setup. Also there is need to have comprehensive social economic surveys, disease hot spot recognition and identification of role of other species like yolk, cattle, buffalo, camel and wildlife in disease transmission. With combined efforts of local and national authorities and political will, there is high likelihood that this devastating disease can be controlled and eventually eradicated in near future (Abubakar et al., 2015).

**Bangladesh:** In Bangladesh, PPR was first reported in goats in 1993 and since then it has become endemic in the country (Islam et al. 2001). Most of the previous PPR studies conducted in Bangladesh were based on either serology or clinical signs except a few recent publications with genetic characterization (Chowdhury et al. 2014; Rahman et al. 2016). Phylogenetically, the Bangladeshi PPRV strains belong to the PPRV lineage IV and formed a separate subgroup and these are closely related with China-Tibet/07 and Indian/TN/VEL/2015 PPRV isolate. The overall PPR sero-prevalence was 21% in 2008, ranging from 6% to 49% in different geographical locations/districts in Bangladesh (Bhuiyan, 2012). A study conducted

in 2009–2010 on laboratory confirmed outbreaks of PPR in Black Bengal goats resulted in 75% and 59% flock morbidity and mortality, respectively, with a case fatality rate of 74% (Chowdhury et al. 2014). Approximately 84 000 veterinary clinical cases of PPR were recorded in 2010 in Bangladesh, but it might not represent the actual burden of the disease as they all were not laboratory confirmed and presumptive diagnosis by veterinarians only has a moderate predictive value (Chowdhury et al. 2014; Haider et al. 2016). Bangladesh Livestock Research Institute (BLRI) has developed a homologous cell culture attenuated PPR vaccine which is very potent against PPR (Anonymous, 1999). But vaccination program has not yet covered the total population of the country. So supportive therapy of atropine aided antibiotic, fluid therapy and antihistaminic aided antibiotic, fluid therapy as well as combined therapy can save the life of PPR affected patient in field condition (Chakrabarti, 2003). According to Parvez et al. (2014), reported prevalence of PPR in goats at Chittagong district, Bangladesh was 8.99. The prevalence regarding PPR among kid, young and adult goats were found to be 6.19% 11.72% and 7.52% respectively with the significant p value (P=0.000). Thus the reported prevalence of PPR was higher in young goats over the adults and kids agreed with the results of Islam et al., (2012), Sarker and Islam (2011), Rahman et al., (2011) and Singh et al., (2004. This research also revealed that, the highest prevalence of PPR was recorded in Black Bangle goats 10.11% in compare to Jamunapai goats 7.44% and other cross breed goats with significant p value (P=0.005). So that the Black Bangle goats were much more prone to PPR in compare to Jamunapari along with other cross breed goats similarity with the findings of Islam et al., (2012).Sarker and Islam (2011) and Mondal et al., (1995). They observed that Black Bangle goats were more susceptible to the PPR in compare to other goat breeds. Prevalence of PPR in goats due to seasonal variation revealed that highest prevalence had been seen in rainy season 11.30% in comparison to summer 6.40% as well as winter season 8.25% with significant p value (p=0.000). This variation might be due to different geographical region and study period. The highest prevalence of PPR at present study was observed in the month of August 13.75% and October 11.51% in contrast with the findings of Sarker and Islam (2011); Abubakar et al., (2009) who recorded highest prevalence in the month of December (31.68%) and January (30.34%); 32.57% in March and 19.43% in April respectively. Results revealed that the lowest occurrence was in May (4.09%) in contrary with this result Abubakar et al., (2009) and Sarker & Islam (2011) who reported lowest prevalence in the month of June, i.e., 1.71% and 9.52%, respectively. This variation might be due to different geographical location, research period, and different management practices. Bangladesh faces a little bad analogous issue as existing in the neighbor's countries like India and Pakistan regarding the epidemiology, risk factors, pattern of disease, virus linage distribution and future control and eradication targets. Proper epidemiological studies are needed to be conducted in near future linked with neighbor's countries to control and eradicate the roots of PPR from the region.

**Nepal:** PPR is epidemic disease of small ruminants which has caused significant economic losses in Nepal (Acharya et al., 2018). In Nepal, first outbreak of PPR was reported in 1995 (Banyard et al., 2010; Dhar et al., 2002) from the Dhanusha, Mahottari, Bara, Sarlahi, Rauthat and Gorkha districts (Jha et al., 2013) and about 68 districts of Nepal have reported the PPR outbreaks covering all eco-zones and developmental regions (DoAH, 2015). A study done by Regional Agricultural Research Station (Goats), Bandipur under the National Agriculture Research Council in Syangja and one other district has reported PPR as the major infectious disease of goats and recorded 33.48% mortality, investigative efforts were made to determine sero-prevalence of PPR in unvaccinated goat population of Syangja and Kaski districts and associated risk factors (Khakural, 2003). The PPR virus circulating in different countries of Asia i.e. Nepal, India, Bhutan, China, Iran, Iraq, Israel, Kuwait, Bangladesh, Pakistan, Saudi Arabia, Tajikistan, Turkey is of lineage (IV) (Parida et al., 2015) however, the F and N gene sequencing based study has shown that the virus found in Nepal, India and Bangladesh is more closely related than virus found in rest of the countries (Dhar et al., 2002). According to Acharya et al. (2018), Eco zone wise distribution of PPR showed that the PPR outbreaks were reported the highest in mountain followed by hills and the lowest in Terai. The highest outbreaks in mountain may be due to excessive movements of nomadic herd of sheep and goat, common pasture, low vaccine coverage in mountain whilst in hill region due to geographic difficulty and low sero-conversion of vaccine. Hence, strategic vaccination campaigns, proper biosecurity, movement control, risk analysis and early diagnosis need to be implemented for the control of PPR in the country and also do the same strategies

for the region. The above studies justify the regional links of virus transmission, temporal and spatial pattern of disease distribution in the region, virus lineage distribution and other complex phenomenon of the virus regionally.

**Central Asia:**

**Afghanistan:** PPR are endemic throughout Afghanistan (Azizi and Farid, 2010). PPR is a transboundary disease of major importance for the government in a country where 75% of the population are rural and depend on animals and animal products for their livelihoods. The majority of the country's 30 million sheep and goats are owned by Kuchi nomadic pastoralists, and these livestock are their most important economic asset. Their migratory routes traverse vast areas of the countryside, with periodic stops at animal markets, summer pastures, and in settled villages during the winter. The Kuchi pastoralists were identified as the primary target group for regional epidemiology of PPRV because their nomadic way of life and animal movements mean that the potential for infectious disease spread is high inside countries and to neighbor countries particularly to Pakistan and Tajikistan. In 2015, the General Directorate of Animal Health and Production of the Ministry of Agriculture, Irrigation and Livestock (MAIL) initiated Afghanistan's formal programme for PPR control and eradication. It did so in collaboration with FAO, the implementing organization, funded by the Government of Japan. The programme was aligned with the OIE/FAO Global Strategy for the Control and Eradication of PPR (PPR–GCES), and the objective of the intervention was to take the country to Stage 2 of the GCES pathway.

In April 2016, at the Regional Roadmap meeting in Nepal, Afghanistan qualified as being in Stage 1, and was carrying out many Stage 1 and Stage 2 activities of the GCES progressive pathway. After a successful pilot project in 2015, which targeted 270,000 small ruminants belonging to the Kuchi community in three provinces, the programme has continued to expand each year. In 2018, the total number of animals vaccinated since 2015 were expected to reach 12.5 million sheep and goats, all belonging to the Kuchi community and throughout all 34 provinces of Afghanistan. In addition to the targeted vaccination of animals, 3,004 serum samples (2015 to 2017) were collected pre- and post-vaccination, which were submitted to the Central Veterinary Diagnostic and Research Laboratory for testing and analysis, with another 3,000 samples were planned to take in 2018 (Ministry of Agriculture, Irrigation, and Livestock, Kabul, Afghanistan). Afghanistan is war affected country having lack of advanced diagnostic tools and research institutions so scare data is available on PPR in Afghanistan, however there is animal movement from Afghanistan to Khyber Pakhtunkhwa and Baluchistan provinces of Pakistan; hence it is observed in these provinces that PPR are reported in large scale by Pakistani veterinarians and researches (Personal Observation). So it is necessary to investigate PPR from grass root and to know the epidemiology of disease for better contribution in the region.

**Mongolia:** The 2016–2017 introduction of PPRV into livestock in Mongolia was followed by mass mortality of the critically endangered Mongolian saiga antelope and other rare wild ungulates (Pruvot et al., 2020). In the fall of 2016, an outbreak of PPRV among domestic sheep and goats in western Mongolia was confirmed, probably originating from uncontrolled transboundary livestock movements (Shatar et al., 2017; Ts Uuganbayar et al., 2017). In total, 83,889 small ruminants from 1,081 households were reportedly affected by PPR in 14 soums (districts) of 3 aimags (provinces), of which 12,976 small ruminants died (overall case-fatality risk 15.5%) (FAO, 2019). After this initial outbreak, control measures included vaccination of 4,632,200 sheep and 5,800,318 goats in and around the outbreak area in October 2016. Although the vaccination campaign successfully curbed the epidemic in livestock, on December 27, 2016, deaths among the Mongolian saiga antelope (subspecies*Saiga tatarica mongolica* ) from PPRV infection were confirmed; later, deaths from PPRV infection of Siberian ibex (*Capra sibirica* ) and goitered gazelle (*Gazella subgutturosa* ) were also confirmed (Young et al., 2010). In the following months, thousands of critically endangered Mongolian saiga died.

The Mongolian saiga antelope (hereafter saiga) is a nomadic antelope that now occupies <20% of its historic range in 2 provinces of Mongolia (Khovd and Gobi-Altai), representing 36,000 $km^2$ of desert steppe bordered by high mountain ranges, lakes, and sand dunes (Young et al., 2010). The saiga range partially overlaps that of mountain ungulates, including Siberian ibex, Argali sheep (*Ovis ammon* ), and other plains ungulates

such as goitered gazelle and Mongolian gazelle (*Procapra gutturosa* ). It is also dominated by livestock; >1.5 million sheep and goats in the 8 soums overlapping the saiga range (Livestock census, 2016) are seasonally grazed over both mountain and desert steppe areas (Lkhagvadorj et al., 2013). PPRV outbreak mapping suggested that wildlife may have been infected earlier (possibly July 2016) than the first confirmed case (December 2016) and that wildlife infections closely followed the timing of the livestock outbreak. The absence of laboratory confirmation of PPRV infection for these initially unconfirmed clusters warrants cautious interpretation, but strong epidemiologic evidence indicates that these suspected cases were part of the same PPRV outbreak. The apparent spatial discontinuity between the 2 outbreak foci supports the hypothesis that the spread of PPR was mainly driven by livestock movement, because the wild mountain ungulates (ibex in the first putative outbreak focus) are relatively resident and unlikely to move long distances across multiple ecotypes. This spatial discontinuity also suggests multiple spillover events from livestock to different wildlife populations, which will require further analysis based on genetic data.

The early onset of PPRV in ibex and the lower and more prolonged incidence of cases in this species (at least until January 2018) are in contrast with the rapid transmission through the saiga population (apparently ceased by June 2017). This contrast in incidence suggests different dynamics of PPRV transmission in the 2 species, influenced by population structure, habitat, and interspecies-intraspecies interactions. Further work, including identification of shared resources between species (e.g., watering points, residual snow patches, and mineral licks), contact rates, and modeling should be conducted to better determine the most likely transmission routes and the respective roles of these wild and domestic ungulates in this multi host system. The probable 5-month delay between the first unconfirmed cases documented and the first confirmation in saiga underscores the value of maintaining operational wildlife health surveillance systems for early detection of wildlife illness and deaths. The spatiotemporal patterns of cases among wildlife were similar to those among livestock affected by the PPRV outbreak, suggesting spillover of virus from livestock at multiple locations and time points and subsequent spread among wild ungulates. Estimates of saiga abundance suggested a population decline of 80%, raising substantial concerns for the species' survival. Consideration of the entire ungulate community (wild and domestic) is essential for elucidating the epidemiology of PPRV in Mongolia, addressing the threats to wild ungulate conservation, and achieving global PPRV eradication (Pruvot et al., 2020).

**Tajikistan:** PPR was reported in Tajikistan annually between 2005 and 2014. In 2005, samples from sick and dead goats from farms in Tajikistan demonstrated for the first time the occurrence of PPR in Central Asia (Orynbayev et al., 2005). In 2006, seroprevalence of PPR in small ruminants was reported in Tajikistan and Kyrgyzstan in samples taken from livestock before the vaccination campaign started in the Central Asian region; however, no virus was isolated (Orynbayev et al., 2006). A study conducted by Kwiatek et al. (2007) in which sporadic occurrence of PPR in three districts of Tajikistan is described. The causal strain (PPR Tajikistan) was characterized and the sequence of its N gene was compared with that of 43 other strains isolated since 1968 in Africa, the Middle East and Asia. The study demonstrated the value of the N gene as a target in comparing isolates obtained over an extended period of evolution, and that clustering was related to the geographical origin of strains. The local veterinarians described the outbreaks as Pasteurellosis, but later on it was sporadic occurrence of PPR in Tajikistan. The country is deficit in research and innovation so limited work has been reported on PPR; however, the disease is endemic in adjacent neighbor countries like Pakistan, Iran and Afghanistan. So it is important to include Tajikistan in the regional control and eradication program in future to tear out the root of disease (PPR) from the geo-strategically and socioeconomically deep rooted and interconnected neighbor's countries in the region including China, Mongolia, India, Pakistan, Bangladesh, Nepal, Afghanistan, Tajikistan and Kazakhstan.

**Kazakhstan**

A serological survey of livestock in Kazakhstan was carried out in 1997-1998 in which seroprevalence of several OIE List A diseases in Central Kazakhstan was investigated during the transition to post-Soviet agriculture, and relate the results to changing practices in farming and disease control. Much of Kazakhstan is semi-arid rangeland unsuitable for agriculture, so traditionally Kazakhs are nomadic livestock producers.

Serum samples from 958 animals (cattle, sheep and goats) were tested for antibodies to different diseases including PPR and reported few seropositives for PPRV (Lundervold et al., 2004). Till the end of 2014, no cases of PPRV were officially reported to the OIE from Kazakhstan. Kock et al. (2015) reported first time clinicopathological, epidemiological and genetic characterization of PPRV in 3 farm level outbreaks in Zhambyl region (oblast), southern Kazakhstan. Phylogenetic analysis based on partial N gene sequence data confirms the lineage IV PPRV circulation, similar to the virus that was circulated in China. The isolated viruses were 99.5–99.7% identical to the PPRV isolated in 2014 from Heilongjiang Province in China and therefore this investigation provide evidence of transboundary spread of PPRV. There is a risk of further maintenance of virus in young stock despite vaccination of adult sheep and goats, along livestock trade and pastoral routes, threatening both small livestock and endangered susceptible wildlife populations throughout Kazakhstan and a threat to the neighboring regions.

**East Asia:**

**China:** As per retrospective analysis of 2014, PPR infection caused extensive agricultural losses across China. In 2007, PPRV was detected for the first time in the Ngari region of southwestern Tibet (Wang et al., 2009). This emergence was thought to have arisen through the circulation of mild forms of PPRV infection and the unfamiliarity of agricultural workers and professionals (e.g., veterinarians, farmers, livestock owners) with the disease and the inability to differentiate between mild forms of PPRV infections and other diseases of small ruminants. PPRV was controlled by using stamping-out procedures, animal movement control, and increased screening of herds. The disease was controlled without the use of vaccines in 2008 while vaccination was used in 2010 (ProMed China., 2014).

Six years passed after the first reports of PPR in Tibet of China before the virus was detected in Xinjiang, China's largest administrative division, in December 2013. Xinjiang, an area of 1.6 million $km^2$, borders Afghanistan, India, Kazakhstan, Kyrgyzstan, Mongolia, Pakistan, Russia and Tajikistan, several of which have reported PPRV infection. Within 2 months, PPRV had caused 3 outbreaks with rates of illness (and death) of 17% (2%), 58% (11%), and 79% (19%), respectively. Measures to contain these outbreaks were implemented as in 2007; however, during April and May 2014, the number of PPRV outbreaks increased sharply across much of China, including in Anhui, Guizhou, Guangxi, Hubei, Hunan, Shanxi, Xinjiang, Yunnan, and Zhejiang Provinces. The origin of these outbreaks remains undefined; however, the ability of the virus to circulate causing mild clinical disease and its presence in numerous neighboring countries suggest several possibilities regarding the source of disease, including potentially spread from the original outbreaks in China. A study was conducted to investigate the epidemic characteristics of PPR outbreaks in China from 2013 to 2018. A total of 41,876 PPR outbreaks were recorded in small ruminant populations in PR China during that period. Data from February to June 2018 were used to study new developments in the PPR epidemic in China. Spatio-temporal clusters and temporal distribution patterns were studied based on PPR notifications. In this study it was investigated that observed patterns of seasonality were characterized by peaks in April of 2014. Spatio-temporal clusters occurred in Yunnan, Jiangsu, Anhui, Heilongjiang province and Chongqing municipality. Hunan province reported PPR occurrences every year from 2014 to June 2018. Yunnan, Jiangsu and Anhui province have 56, 33 and 30 epidemic locations, respectively. PPR infections were first reported as the cause of death for 19 wild bharals in Qinghai province in 2018. All of this suggests that domestic trading of sheep and goats may be closely related to the spread of PPR. Prophylactic immunization in suspected animal populations or areas is recommended for the control of PPR and wild small ruminants should be monitored. It is concluded that to provide improved knowledge about PPR dynamics in PR China, which could be helpful in designing more effective prevention strategies. Similarly, the threat of further spread from China to neighboring countries cannot be ignored (Gao et al., 2019).

**Regional distribution of host in the region**

Goats and sheep are natural host of PPRV but goats affected more severely than sheep (Lefevre et al., 1990). Sheep rarely suffer clinical disease (El Hag et al., 1988; Roeder et al., 1994) although high morbidity and mortality has been reported but exceptionally is assumed that sheep hold innate resistance to clinical

disease (Shaila et al., 1989). Field outbreaks are reported from a zoological collection in Alain (Furley et al., 1987). World widely this disease has been reported in Gazelle and deer (Abu Elzein et al., 1990), Antelope and Dorcas Gazelles (Gazella dorcas), Nubian Ibex (Capra ibex nubiana), Laristan sheep (Ovis orientalis laristani), gemsbok (Oryx gazella) and Nigale (Tragelaphinae) (Abu Elzein et al., 2004). Similarly said disease has been investigated in domesticated/farm animals i.e. sheep, goat, cattle, buffaloes, camels and yak (Abubakar et al., 2011; Ismail et al., 1995; Khan et al., 2008; Pruvot et al., 2020). Finally evidence of PPR has been found in free living wild animals i.e. Sindh Ibex, saiga antelope (Saiga tatarica mongolica) (Abubakar et al., 2011; OIE, 2000; Pruvot et al., 2020).

**Regional transmission dynamics**

As PPR is an acute and highly contagious viral disease of small ruminants, the inter-territorial and transboundary transmission of PPRV in healthy animals is matter of dire attention. Transmission PPRV in healthy animals occurred by direct contact with infected animal and contaminated materials i.e. oculonasal and oral discharges, the loose faeces, hold large amount of the virus. Small infective droplets release into the air from these secretions and excretions, especially when affected animals cough or sneeze (Abubakar et al., 2011; Abubakar et al., 2012; Bundza et al., 1988, Taylor, 1984). Likewise, transboundary animal's movement plays a key role in transmission because some neighbor's countries have free animal movements, purchases system, nomadic system, infected migratory animals etc. These nutritional deficiencies which lead to poor immunity of animal might be a cause of rapid transmission of PPRV which results in heavy outbreaks in endemic situation.

The spread of PPR is considered to be a result of transboundary movement of small ruminants (Dhar et al., 2002; Kumar et al., 2014; Liu et al., 2018), with the rapid trading of small ruminants also contributing to the propagation of outbreaks (Balamurugan, Das et al., 2014). All holder farmers affected economically so importance of PPR is increasing in Laos region (Burns et al., 2018; Windsor et al., 2017). Although the goat industry in Laos is the smallest livestock sector, recent increase of mutton prices in China and Vietnam have spiked a "goat boom" in SE Asia, leading industry professionals to estimate that the Lao goat population has more than doubled since the 2011 agricultural census (Burns et al., 2018; Windsor et al., 2017). In that census, 6% of households raised goats (Anonymous, 2012). There are minimal data on the occurrence of PPR in Southeast Asia. China has experienced two major outbreaks of PPR in the last decade, although it was previously free from the disease. The first outbreak occurred in Tibet in 2007. This outbreak was likely caused by importation of goats from neighboring India, Pakistan, and Tajikstan, resulting in the loss of 30.8% of the local population of small ruminants (Bao et al., 2011; Liu et al., 2018). Stamping out of suspected infected herds, delivery of effective vaccination programs, and implementation of nationwide surveillance strategies, led to eradication of PPR in China by 2010 (Liu et al., 2018). The second outbreak occurred in Xienjiang in 2013-14. This outbreak spread to 32 other counties, including an outbreak in Yunnan on the northern Lao border, a thoroughfare for trade between the Association of Southeast Asian Nations (ASEAN) countries (Li et al., 2017; Liu et al., 2018; Wu et al., 2016). PPR lineage studies suggest this outbreak was likely due to transboundary movement of animals into China rather than a re-emergence of the disease from Chinese herds (Wu et al., 2016). Prior to these outbreaks in China, PPR antibodies were discovered in apparently healthy mountainous goats in northern Vietnam, yet any attempts to identify the virus and other investigations have not been reported (Maillard et al., 2008). To date, there have been no reports of PPR outbreaks in Laos. However, the occurrence of similar endemic diseases and poor veterinary infrastructure may lead to PPR being missed or underdiagnosed. Differential diagnoses for PPR in Laos may include foot and mouth disease virus (FMD) (Nampanya et al., 2013), ovine parapoxvirus induced Contagious Ecthyma (Windsor et al., 2017), Coxiellosis (Burns et al., 2018), Brucellosis (Burns et al., 2018) and intestinal parasites (Windsor et al., 2018). Laos is considered as being "at risk" of PPRV incursion due to: proximity and trade with PPR-endemic China; it is a landlocked country with "porous" borders enabling livestock trade between ASEAN countries; and the relatively poor veterinary infrastructure with suboptimal capacity to detect and respond to emergency and/or emerging disease outbreaks (Bastiaensen, Kamakawa, & Varas, 2011; Nampanya et al., 2013). PPR is an eminent disease and eradication needs to be prioritized for poverty alleviation and food security, because of the high morbidity and mortality in small ruminants

commonly owned by resource-constrained farmers. However, to further support disease control policies, there is need for further research on several epidemiological features, such as transmission dynamics among known and/or novel hosts raised either under similar or different production systems (Jost et al. 2007). In addressing the risk of PPR to regional aspect to protect the livelihoods of small ruminant smallholder farmers from losses, it is important to investigate the regional epidemiology of PPR.

**Temporal and spatial distribution of PPR outbreaks in the region**

In Pakistan, during the last decade, PPR outbreaks have increased to an alarming level involving newer areas (Ali, 2004). As, on the basis of clinical and serological methods, an outbreak of PPR was reported in goat flocks of Livestock Production and Research Institute (LPRI), Bahadurnagar, Okara, Pakistan (Ahmad et al., 2005) but amazingly no serological evidence of PPR was found in healthy sheep on same form. According to another report based on observations from 50 laboratory confirmed outbreaks of PPR and provides details of the presence or otherwise of (PPRV) in 427 tissue/organ samples from small ruminants in Pakistan. It was concluded that the disease outbreaks were more severe in goats than sheep and the frequency of disease outbreaks was greater between the months of January to April. Based on the data of 50 outbreaks (427 samples), Abubakar et al. (2008) reported the prevalence of PPR in small ruminants was 40.98 %. A greater number of positive cases were observed in the southern and northern parts of the country (30–60 %) as compared to west and south-west (10–30 %). The OIE World Animal Health Organization in 2000 also confirmed the outbreak of PPR with IcELISA at a wildlife breeding center of Faisalabad, Punjab, Pakistan. Similarly, in district Chitral, North West Frontier Province (NWFP) now Khyber Pakhtunkhwa, Pakistan in June 2006, an outbreak of (PPR) was investigated in goat flocks. Based on competitive and immuno-capture ELISA, 09 (39.15) animal were positive for PPR antibodies (Abubakar et al., 2008).

**Disease pattern and Seasonal occurrence**

Movement of animals from one region to other with in the same country or transboundary is determining factor of disease occurrence. In dry season, animals usually travel long distance in search of fodder and water (Nanda et al., 1996). In humid areas, PPR always occurred in an epizootic form with 80–90 % morbidity and 50–80 % mortality. PPR is often fatal and usually occur as a subclinical in arid and semi-arid areas (Lefevre & Diallo, 1990). Young animals between age of three to four months are more susceptible to PPRV (Srinivas & Gopal, 1996) due to decrease in natural immunity (maternal antibodies) (Saliki et al., 1993). There is constant circulation of virus between ages of 4 to 24 months (Taylor et al., 1979). High morbidity and mortality have been reported in all of the age groups (Abu Elzein et al., 1990). Abubakar et al. (2009) reported that prevalence of PPR in small ruminants in Pakistan is 40.98 % and disease is severe in goats mostly. Zahur et al. (2011) found a higher prevalence in goats (52.9) than in sheep (37.7 %) in Pakistan while Singh et al. (2009) reported an almost similar prevalence for sheep (36.3 %) and goats (32.4 %) in India. A field survey in Nigeria showed that the disease rate of PPR in sheep (57 %) appears to be more than that in goats (44 %) (Taylor and Abegunde), (1979). So in short a regions discrepancy about disease severity is present across the globe and more is linked to regional environment as well as animal breeds and socioeconomic status of nomadism and local farmers.

In addition, PPR-associated abortions could occur in PPRV-infected pregnant dams. Abubakar et al. (2008) has reported that serum samples from the aborted dams found positive for PPRV antibodies so the PPR disease has a possible association of mortality and prevalence with high rate of abortions in goat. Moreover, if the animal is infected with PPRV abortions may occur at any stage of gestation. This leads toward economic losses and discourage the farmer communities.

PPR occurrence is affected by Climatic factors. In rainy season outbreaks minimized due to decreased movement of animals as more fodder availability and increase nutritional and health status. In Dec-Feb the dry and dusty season in combination with poor nutrition cause disease spread and cases get peak in April. In Pakistan, Khan et al. (2008) reported high PPR seroprevalence in December to February and September and October while Abubakar et al. (2009) reported the disease frequency greater in January to April and 33 % of cases reported in March. So we may say that the disease occurrence is throughout the year with

the severity variation in different weathers. A study conducted in china regarding patterns of seasonality of disease which were characterized by peaks in April of 2014 (Gao et al., 2019). According to (Obi et al., 1983; Durojaiye et al., 1983 and Abubakar et al., 2011), most cases of PPR emerge with the start of summer season and cases get peak during the months of April to July and then the prevalence drop again that indicate the temporal pattern of disease.

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