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Impacts of Climate Change on Vector-Borne Diseases of Animals and Humans with Special Emphasis on Afghanistan: A Review

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ABSTRACT

Vectors are organisms that transmit pathogenic microorganisms among animals and humans. Infections transmitted by the bites of blood-sucking arthropods are called vector-borne diseases (VBDs). This review highlights the impacts of climate change on the distribution, seasonal variation, and socioeconomic effects of VBDs in affected countries, especially Afghanistan. There is good enough evidence indicating that recent climate change has affected the interaction of the vector-pathogen-host cycle in many parts of the world. The emergence and re-emergence of bluetongue virus (BTV), Rift Valley Fever (RVF), lumpy skin disease (LSD), West Nile Virus (WNV), and malaria in new areas previously considered free of the diseases, and shift of seasonal occurrence of many VBDs in endemic areas, are the clear examples of climate change impacts on VDBs. Although significant progress has been made regarding VBD surveillance systems, diagnostic capacity, vaccine development, and vector control programs in resource-rich countries, failure in adaptation programs and ineffective mitigation strategies against VBDs in developing countries, especially in low and middle-income countries (LMICs), including Afghanistan facilitate widespread distribution of VBDs in these regions. Furthermore, developing drug resistance among the pathogens and their vectors makes the conditions more suitable for VBDs wide dispersion. Such situations cause severe health and socio-economic burdens to affected countries. Developing early-warning systems for detecting VBDs, identifying and developing resistant livestock species and breeds, and applying interceptive measures based on integrated research programs are crucial to effectively reduce the harmful impacts of VBDs on human and animal populations.

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Introduction

Climate change and some anthropogenic factors change the epidemiology of many VBDs including BTV, LSD, WNV, RVF, Crimean-Congo hemorrhagic fever (CCHF), malaria, dengue fever, yellow fever, Zika virus disease, Lyme disease, Chikungunya, leishmaniasis and so many others that are transmitted by blood-feeding arthropods (Jourdain and Paty, 2019; Mekonnen, 2018; Ogden, 2017). Any infection transmitted through the bites of blood-sucking arthropods is called a vector-borne disease (VBD) (Halabi, 2020; Vonesch *et al*., 2016). Vectors transmit pathogens between vertebrates, including humans, livestock, companion animals, and wildlife (Khatoon *et al*., 2023). Many types of vectors, including mosquitoes, midges, ticks, fleas, and flies, maintain and transmit different pathogens of humans and animals. Accordingly, mosquitoes-borne, tick-borne, midge-borne, flies-borne, and fleas-borne diseases are the common types of VBDs in human and animal populations (Mekonnen, 2018; Byrd *et al*., 2020; Khatoon *et al*., 2023; Halabi, 2020; Yang, 2023).

Many VBDs limited to tropical zones have been reported now in temperate zones (Jourdain and Paty, 2019). The extent, rates, seasonality, and distribution of VBDs are altered due to several factors, including intercontinental human mobility and trade; however, climate change is considered the most crucial driver in this modification (Vonesch *et al*., 2016). Historically, Hippocrates (460 – 370 BC) recognized the effect of climate and weather on the incidence of infectious diseases and stated that the diseases are caused by changes in weather, wind, water, climate, food, soil nature, and people's habits (Vonesch *et al*., 2016). Therefore, climate change is a significant variation in the temperature, wind, precipitation, and other weather indicators that last for decades or longer. Such atmospheric modifications are caused by human activities and natural processes (Vonesch *et al*., 2016).

Historically, the rise and fall of many civilizations worldwide have been affected by infectious diseases of animals and humans. Plague outbreaks in the 2^{nd} and 5^{th} centuries BCE and Black Death epidemics in the 14^{th} century killed millions of humans in Europe. Subsequently, measles, smallpox, and influenza decimated almost all of the susceptible indigenous populations in many parts of the world. In recent years, outbreaks, epidemics, and pandemics of Ebola, Zika, SARS, MERS, and COVID-19 have infected and killed tens to hundreds of millions of people worldwide (Caminade *et al*., 2019).

Although Svante Arrhenius, at the end of the 19^{th} century, proposed that burning fossil fuels could have harmful effects on global temperature due to the emission and elevation of carbon dioxide in the atmosphere, it was just a few decades ago the scientific community realized the adverse effects of climate change on the ecosystem especially on the human health and animals' health (Jourdain and Paty, 2019). Based on the severe threats of climate change, the Intergovernmental Panel on Climate Change (IPCC) was founded in 1988; after that, many other national, regional, and international organizations have evaluated the impact of climate change on health, tourism, agriculture, economy, and many other areas worldwide (Jourdain and Paty, 2019). The effects of climate change, including climatic extremes, sea level rise, and air quality, are considered among the greatest threats to health in the 21st century (Caminade *et al*., 2019). However, due to low human and financial resources, the impacts of climate change on livestock health and production are much higher in developing countries (Magiri *et al*., 2021).

The intensity of climate conditions such as storms, flooding, drought, and heat waves due to climate change become more frequent, impacting the planet's life. Many VBDs that were common and confined to the tropical zones are now in areas that previously were not suitable for their vectors. Many diseases, including BTV, RVF, Ebola, Zika, Schmallenberg, CCHF, and many others, are emerging and re-emerging in cooler areas that were not previously reported. Meanwhile, new evidence indicated the effects of climate change, especially rainfall, on the occurrence and distribution of nematodes of veterinary importance in the new areas (Mekonnen, 2018). In Scotland, for example, the occurrence of diseases caused by *Fasciola hepatica*, *Nematodirus battus*, *Haemonchus contortus*, and *Teladorsagia circumcincta* in sheep flocks has increased due to climate change (Mekonnen, 2018). It's worth mentioning that non-climate drivers, especially socio-demographics, globalization, public health systems pathogens, and vector characteristics, also play critical roles in VBD patterns and distributions (Rocklöv and Dubrow, 2020).

In the past, the focus of most research that evaluated the effect of climate change on VBDs was malaria and dengue. Still, now it has become the five most dangerous human VBDs (malaria, dengue, Zika virus disease, yellow fever, and chikungunya) that cause high morbidity and mortality in humans globally. Initially, they all had a zoonotic nature, but now they are mainly transmitted from human to human by different species of *Anopheles* and *Aedes* mosquitoes (Ogden, 2017). On the other hand, the reservoirs of many other public health important VBDs, including WNV, viral equine encephalitis, Lyme disease, CCHF, etc., are domestic animals and wildlife, and their occurrence in human populations is primarily due to direct and indirect contact with such infectious sources (Ogden, 2017).

Many infectious diseases affecting livestock, including cattle, sheep, goats, and buffalo, are VBDs and cause heavy economic losses and food security issues in the affected areas (Yang, 2023). Meanwhile, of the total of known mostly deadly animal diseases in LMICs, 58% are climate-sensitive (Grace *et al*., 2015). However, many knowledge gaps are still present regarding the effect of climate and climate change on the emergence and re-emergence of some VBDs worldwide, especially in LMICs (Samy *et al*., 2016). Therefore, the burden of VBDs is much higher on the vulnerable, poor societies of LMICs that are already affected by climate extremes (Wilcox *et al*., 2019).

Due to climate change's direct and indirect effects, the burden of many livestock diseases has increased, the geographical distribution of climate-sensitive livestock diseases has expanded, and their seasonal patterns have changed. According to recent estimates, if the global temperature continues to increase at the same level observed in the past decades, about 20 to 30% of animal species will be at penitential risk of extinction (Mekonnen, 2018). Based on the mentioned points, VBDs pose severe risks to human and animal health;

therefore, this review highlights the impacts of climate change on the distribution, seasonal variation, and socioeconomic effects of VBDs in affected countries, including Afghanistan.

Climate and Climate Change

The climate is defined as "*the sum of sunshine, temperature, rainfall, and wind*," where the heat waves coming from the sun are the most critical drivers of the climate (Magiri *et al*., 2021). According to the definition of Intergovernmental Panel on Climate Change (IPCC), *"Climate change is a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer."* Human activity, such as deforestation, burning fossil fuels, and increased industrial activities, which create high concentrations of greenhouse gases above the natural level and cause global warming, are the most important drivers of climate change (Alves, 2021; Carlson *et al*., 2022; Khatoon *et al*., 2023; Jabeen *et al*., 2022). According to the Sixth Assessment Report (AR 6) of the IPCC, the average global temperature will increase by 1.5 °C in the next two decades, and if the emissions of green gas continue in the same trends, the global temperature may increase between 4 ºC to 5 ºC (Rocklöv and Dubrow, 2020; Ma *et al*., 2022). Such elevation will devastate ecosystems, increasing earth surface precipitation, melting glaciers, and rising sea levels. Such conditions caused extreme weather to become more frequent and exposed 30% of the global population to unpredicted, hard-to-manage annual natural disasters. Consequently, there would be fewer cold nights and days and more warm days and nights, some areas becoming drier and others becoming wetter. Moreover, increased global temperature and precipitation facilitate changing the seasonal patterns and affect the biology, pathology, and epidemiology of VBDs and their prevalence, which may cause 150,000 additional human deaths each year worldwide (Rocklöv and Dubrow, 2020; Ma *et al*., 2022; Jabeen *et al*., 2022).

Types of VBDs

Bacteria, viruses, and protozoa are the common pathogens of VBDs, which are mainly transmitted by blood-sucking arthropods such as ticks, mosquitoes, fleas, midges, and other types of vectors that have direct and indirect effects on animal and human health (Byrd *et al*., 2020; Halabi, 2020).

From the human perspective, malaria, leishmaniasis, dengue, Zika virus disease, yellow fever, chikungunya, lymphatic filariasis, onchocerciasis, schistosomiasis, Japanese encephalitis, and Chagas disease are the major globally significant VBDs. In contrast, West Nile fever, African trypanosomiasis, Crimean-Congo hemorrhagic fever, Lyme disease, and tick-borne encephalitis are regionally important VDBs of humans, and their outbreaks are primarily reported in specific countries. The reservoirs and amplifying hosts differ for VBDs, where humans are the primary hosts for VBD agents in only a few cases, while most others have more than one human and animal host (Rocklöv and Dubrow, 2020). From the veterinary perspective, RVF, BTV, LSD, and African horse sickness (AHS) are the major VBDs, which cause high morbidity and mortality in susceptible animal hosts Rocklöv and Dubrow, 2020; Vonesch *et al*., 2016; Caminade *et al*., 2019; Dahmana and Mediannikov, 2020). The hosts and other characteristics of VBDs are presented in Table 1.

Mosquitoes-Borne Diseases

Mosquitoes are among the most dangerous and threatening vectors transmitting deadly pathogens and parasites to humans and animals (Samy *et al*., 2016). *Aedes*, *Anopheles*, and *Culex* are the three most essential mosquito genera, transmitting most mosquito-borne pathogens to humans and animals (Dahmana and Mediannikov, 2020). Rift Valley fever, WNV, Wessel-born disease (WSL), and LSD are the most common mosquitoes-borne diseases of livestock, which affect cattle, sheep, and goats primarily and cause heavy socioeconomic losses to the affected countries (Magiri *et al*., 2021). Meanwhile, malaria, Dengue virus disease, Zika virus disease, chikungunya fever, yellow fever, and Japanese encephalitis are deadly mosquito-borne human diseases (Dahmana and Mediannikov, 2020).

Tick-Borne Diseases

Ticks and tick-borne diseases devastate animal and public health worldwide (Wilcox *et al*., 2019). Ticks are small, wingless, blood-sucking ectoparasitic arthropods that maintain and transmit a wide range of pathogens to animals and humans (Solomon and Tanga, 2020). They are considered the most common ectoparasites of mammals and birds worldwide, and in some parts of the world, 80% of the cattle population is infested by ticks (Oza *et al*., 2020). Besides the transmission of bacterial, viral, and protozoan pathogens to humans and animals, they increase the susceptibility of animals to other pathogens, reduce productivity, milk yield, and quality of skin and hide of infested livestock (Solomon and Tanga, 2020; Oza *et al*., 2020). At the same time, monetary expenses for tick control programs and the harmful effect of synthetic acaricides on human health are the indirect impacts of ticks and tick-borne diseases on the farmers and the general public, respectively (Wilcox *et al*., 2019).

Although *Ixodes* ticks are the vectors and reservoirs of a wide range of human pathogens, including bacterial (e.g., Lyme disease, ehrlichiosis), rickettsial (spotted fever rickettsioses), protozoal and viral diseases (eg. CCHF, *Flaviviridae* infections) (Caminade *et al*., 2019; Halabi, 2020; Samadi *et al*., 2021), theileriosis, babesiosis; anaplasmosis, heart-water disease, and African swine fever are the most common protozoan, chlamydial and viral tick-borne diseases of livestock respectively, which cause significant health problems and economic losses to the livestock industries worldwide (Magiri *et al*., 2021).

It is well known that there is a strong relationship between temperature, urbanization, increasing numbers of trekkers and wildlife lovers, and consequent increase in tick population and tick-borne disease distribution (Caminade *et al*., 2019; Magiri *et al*., 2021). At the same time, almost all of these tick-borne diseases are climate-sensitive, and their geographical distribution has expanded over the past decades (Caminade *et al*., 2019). It has been forecasted that climate change will change the ideal environmental conditions for the tick in some parts of the world and make a new perfect condition in the other parts by the 2050s. Such un-forecasting environmental changes will facilitate the distribution of tick-borne diseases to new areas and populations previously considered free from these diseases (Magiri *et al*., 2021).

Midge-Borne Diseases

Biting flies such as *Culicoides* spp., *Stomoxys* spp., and *Tabanus* spp. are common midges that can act as mechanical and biological vectors for many human and animal pathogens. Bluetongue disease (BTD) and AHS are domestic animals' two most critical midge-borne diseases, which cause high morbidity and mortality in small ruminants and horses, respectively (Magiri *et al*., 2021). Trypanosomiasis is another midge-borne disease of livestock that the tsetse fly transmits. Climate change severely affects the distribution of midge-borne diseases, and some of these diseases emerged recently in countries where they had never been reported before (Magiri *et al*., 2021).

Flea-Borne Diseases

Fleas are potential vectors for many VBD pathogens in humans and animals. From the animal health perspective, fleas are the most common ectoparasites of cats and dogs. They are the principal vectors for the agents of human plague, cat-scratch disease, and murine typhus. It has been shown that cat-scratch disease recently emerged in Europe, and its epidemiology is changing due to climate effects (Mekonnen, 2018).

Impacts of VBDs on Human Health

Available data and estimates show that about 17% of all human infectious diseases are caused by VBDs (Caminade *et al*., 2016; Jabeen *et al*., 2022). Different categories of VBDs threaten more than 80% of the world population and cause more than 700,000 human deaths annually. At the same time, it has been shown that 218 countries worldwide have suitable conditions for the survival and reproduction of arboviruses, the agents of devastating VBDs in humans and animals. Meanwhile, more than 3.9 billion people in 128 countries are at high risk of VBDs, where only mosquito-borne diseases cause 400,000 deaths each year. Based on the available data, the burden of VBDs is 300 times more significant in low-resource countries than in developed nations (Jabeen *et al*., 2022; Campbell-Lendrum *et al*., 2015; Ma *et al*., 2022).

Recent data showed that malaria and dengue are the fatal VBDs, which caused 620,000 and 40,500 deaths, and 209 million and 105 million cases only in 2017, respectively. At the same time, it has been estimated that 143 million people are living with schistosomiasis, 65 million with lymphatic filariasis, 21 million are infected by onchocerciasis, 6.2 million by Chagas disease and 4.1 million by leishmaniasis agents worldwide (Rocklöv and Dubrow, 2020).

Human malaria is the most widespread VBD worldwide, which is caused by different species of *Plasmodium* parasites transmitted by *Anopheles* mosquitoes. *P. falciparum* is the cause of 90% of the most severe clinical cases of human malaria worldwide. Although most cases of human malaria are reported in tropical zones, there has recently been an increased trend in malaria cases at higher altitudes, where the human population in these areas lacks protective immunity against the disease, which can cause high morbidity and mortality in these areas. Many studies indicated the harmful impacts of climate change on the distribution of malaria in the new highland areas of Africa. Some *Plasmodium* species (e.g., *P. knowlesi*), which mainly affect birds, mammals, and reptiles, sometimes can infect humans, which could create more challenges during the disease control and eradication programs (Caminade *et al*., 2019).

Many VBDs have a zoonotic nature, and the control and management of zoonotic diseases, including VBDs, are one of the primary responsibilities of veterinarians. They are vital in zoonotic disease diagnosis, surveillance, treatment, and prevention programs (Yang, 2023). Based on recent data, zoonotic diseases cause 2.5 billion cases and 2.7 million deaths each year worldwide, where most of which are VBDs (Halabi, 2020).

Impact of VBDs on Livestock Health and Production

It has been known that agriculture, especially livestock, is the most valuable source of income and food demands for most rural families in developing countries. The livestock sector alone provides over half the global agricultural value and one-third of developing countries' agricultural value. Due to the human population increase, the demand for livestock products has increased dramatically over the last decades; however, many factors, including climate change, threaten the survival and production of livestock globally (Magiri *et al*., 2021). Meanwhile, the global ratio between human and livestock population is about 1:5, and almost 81% of global livestock is present in developing countries, and about one billion poor people, primarily women around the world, keep livestock. Due to the high prevalence and incidence of livestock diseases in low-resource countries, ruminants' annual estimated mortality rates are about 20%, which is more than 50% for poultry. Such high morbidity and mortality of livestock diseases cause approximately 300 billion USD in yearly losses (Mekonnen, 2018; Grace *et al*., 2015).

It has been proven that climate change, mainly environmental changes such as global warming, precipitation, relative humidity, floods, and drought, severely affects livestock's health and productivity worldwide (Magiri *et al*., 2021; Nejash and Kula, 2016). However, the relationship between the livestock sector and climate change is bidirectional (Sánchez Mendoza *et al*., 2020). In one way, the livestock sector is responsible for the emission of greenhouse gases worldwide, mainly through rumen fermentation, manure storage and processing, livestock products processing, and transport. On the other hand, climate change has direct and indirect impacts on livestock health and productivity (Sánchez Mendoza *et al*., 2020).

Climate change severely affects the food production systems and water resources through heat waves, hurricanes and flash floods, and consequent VBDs expansion in animal populations (Caminade *et al*., 2019). Furthermore, climate change and consequent severe floods and droughts limit water and feed availability in affected areas and negatively impact animal production. At the same time, the unavailability of required high-quality feed for the animals reduces the competence of the animal's immune system, and the animals become more susceptible to obligate and even facultative pathogens. So, it has been confirmed that the effects of droughts are primarily on water and feed quantity and quality. At the same time, floods are mainly associated with disease spread rather than nutritional effects (Magiri *et al*., 2021).

The other factors contributing to the expansion of VBDs and affecting livestock production due to climate change are the destruction of pastures and livestock grazing areas in the areas/lands previously occupied by wild animals. In such cases, the spillover of pathogens from livestock to wildlife and vice versa occurs, some of which may have a zoonotic nature. For example, there is evidence that some roundworms, especially *Onchocerca* spp., *Dipetalonema* spp., *and Loaina* spp., are transmitted from wild mammals to livestock and humans (Wilcox *et al*., 2019).

Most research that evaluated climate change's impacts has been chiefly directed toward human VBDs, and principally, less attention has been given to livestock VBDs. This bias may increase the burden of VBDs on livestock health, rural community livelihoods, and food security, mainly in LMICs (Kimaro *et al*., 2017). On the other hand, most of the research has focused on the direct effects of climate change on the ecology of VBDs. In contrast, the indirect impacts of such changes and their associated burden on society's capability to manage and mitigate diseases are mostly ignored (Ogden, 2017). Furthermore, the livestock production level and its growth are much lower than the demand for these products in most developing countries, and this issue increases the imports of livestock products and subsequently affects the economic stability of these countries (Magiri *et al*., 2021).

Besides the importance of the issues mentioned above on global food security, while assessing the climate impacts, little attention is paid to livestock production compared to other issues, such as crop production. However, livestock is considered the most essential livelihood resource, even in regions severely affected by climate change where crop production is limited or impossible. These factors caused the wide distribution of VBDs and associated morbidities and mortalities, water and food shortages, poor growth rate and reproduction performance, decreased quality and quantity of livestock production, livestock products shortage, and food-borne diseases. All these factors increase the costs of livestock production, decrease the production level of food-producing animals, reduce the income level of the farmers and affected communities, and finally affect the national economy of the affected countries (Magiri *et al*., 2021).

Although climate change can affect the health and productivity of animals everywhere, the impact of climate change varies based on extensive or intensive production systems. In a comprehensive system, single or multiple livestock species are managed mainly by the farmer's family members, and their feeding is entirely dependent on the natural conditions of the field. However, in an intensive system, many single livestock species are kept in a small area managed using new technology. More than 90% of the feed is mostly from external sources produced in nearby regions or imported from other places. Due to climate change effects such as flood, drought, and extreme heat waves, as a consequent decline in agriculture production, pasture destruction, and heat stress, the feed resources for livestock are diminished. The feed price increased, and the livestock's feed intake decreased, severely affecting livestock health and productivity. It has been proven that an extensive livestock system is more vulnerable to climate change effects than an intensive system since the implementation of adaptive measures against potential damage caused by climate change is somehow difficult or even impossible in the extensive system due to monetary, technology, and other resources limitations (Sánchez Mendoza *et al*., 2020).

Table 1: Important human and animal VBDs, their etiology, vectors, reservoirs, and definitive hosts

Disease	**Etiology**	**Vector**	**Primary reservoir hosts**	**Definitive hosts**
Malaria	*Plasmodium* spp.	*Anopheles* mosquito	Humans	Humans
Leishmaniasis	*Leishmania* parasite	*Phlebotomine* sand flies	Rodents, dogs, and other mammals	Humans and dogs
Dengue	*Flavivirus*	*Aedes aegypti* and *Aedes albopictus* mosquitoes	Humans	Humans
Yellow fever	*Flavivirus*	*Aedes aegypti* and *Aedes albopictus* mosquitoes	Humans	Humans
Zika	*Flavivirus*	*Aedes aegypti* and *Aedes albopictus* mosquitoes	Humans	Humans
Japanese encephalitis	*Flavivirus*	*Culex* mosquitoes	Pigs, birds	Humans
Tick-borne encephalitis	*Flavivirus*	*Ixodes* ticks	Small rodents	Humans
West Nile fever	*Flavivirus*	*Culex* mosquitoes	Birds	humans, horses, and other mammals
Chikungunya	*Alphavirus*	*Aedes aegypti* and *Aedes albopictus* mosquitoes	Humans	Humans
RVF	*Phlebovirus*	*Aedes* and *Culex* spp. Mosquitoes	livestock (cattle, sheep, and goats), bats, rodents, and dogs	Humans and animals
Crimean-Congo hemorrhagic fever	*Orthonairovirus*	*Ixodes* ticks	Ruminants and ostrich	Humans
Schmallenberg	*Schmallenberg* virus	*Culicoides* Midges	cattle, sheep, goats, and bison	Animals
BTV	*Orbivirus*	*Culicoides* Midges	Ruminants	Ruminants
Lyme disease	*Borrelia* spirochete	*Ixodes* ticks	White-footed mouse and other small mammals, birds	Humans

Disease	Etiology	Vector	Primary reservoir hosts	Definitive hosts
Tularaemia	*Francisella tularensis*	Ticks and mosquitoes	Rodents	Humans, sheep, cats, dogs, horses and rodents
Lymphatic filariasis	Various filarial nematodes	Different mosquito genera	Humans	Humans
Schistosomiasis	*Schistosoma* trematode	Freshwater snail	Humans	Humans
Onchocerciasis	*Onchocerca volvulus* nematode	*Simulium* (black fly)	Humans	Humans
Chagas disease	*Trypanosoma cruzi* parasite	*Triatomine* bug	Mammals	Humans
African trypanosomiasis	*Trypanosoma brucei* parasite	*Glossina* (tsetse fly)	Wild and domestic animals	Humans, cattle, horses

Impact of Climate Change on Wildlife and Associated Diseases

One of the factors that have severely affected wildlife and decreased the population more than expected is infectious diseases (Pongsiri and Roman, 2007). In addition, wildlife is considered the maintenance hosts and reservoirs of many contagious diseases in animals and humans, and such a condition is one of the most challenging issues in the control and eradication programs of infectious diseases in domestic animals and humans (Artois, 2012).

Climate change and irrational land use increase the chance of cross-species infectious disease agents to geographically isolated wildlife species previously free of such agents. Since most infectious agents infecting humans and animals are circulating silently in wildlife populations, such conditions facilitate the spillover of zoonotic agents directly from wildlife to humans or domestic animals (Carlson *et al*., 2022). At the same time, due to rapid environmental changes, living conditions for many wildlife species are not suitable in their original habitats, and they have moved to new places to find food and living conditions. It is projected that due to such changes, many species will shift 100 kilometers or more to the latest geographical locations. During this process, many infectious agents will spread into new environments, posing high threats to global health and security and causing epidemics and pandemics in susceptible populations. It's projected that ~10,000 potentially zoonotic viruses are present in the wildlife population that eventually could reach the human population. Human immunodeficiency virus (HIV), severe acute respiratory syndrome Coronavirus (SARS-CoV), COVID-19, and so many others are clear examples of such spillover from wildlife to human populations (Carlson *et al*., 2022).

Impacts of Climate Change on the Ecology of Vectors and Vector-Borne Diseases

One of the most threatening direct and indirect impacts of climate change is changing the epidemiology and geographic distribution of VBDs of human and animal importance (Khatoon *et al*., 2023; Yang, 2023; Ma *et al*., 2022; Jourdain and Paty, 2019). As described, arthropods and some other vectors are cold-blooded organisms, and due to increased global temperature and precipitation, their activities, breeding, feeding, and survival have been changed worldwide. Besides that, the increased temperature may alter non-human reservoir habitats of VBD agents, which can indirectly affect the vectors and geographical distribution of VBDs (Rocklöv and Dubrow, 2020). For example, from 2004 to 2016, about ten new VBDs were reported in the United States, and the annual human cases of VBDs doubled during this period (Halabi, 2020).

There are some specific reasons why VBDs are more affected by climate change. Arthropods are ectothermic organisms, and environmental conditions regulate their body temperature. In addition, specific humidity conditions and water bodies are required for the developmental stage of vectors in the environment. Meanwhile, the biting rate of vectors is high in the upper-temperature threshold of the vectors, and the pathogen development and replication within the vectors and outside is faster in higher temperatures. Furthermore, the length of most VBDs transmitted by the vectors will likely increase at higher temperatures. Finally, the geographical distribution of some animal species significantly, including wild animals and birds, has changed due to climate change, which expands some vectors and VBDs into new areas (Caminade *et al*., 2019).

Generally, the effects of climate change on VBDs are multidimensional, affecting the transmission dynamics and seasonal cycle length, geographical distribution, emergence, and re-emergence patterns through direct and indirect effects on the vector, maintenance, end hosts, and pathogens. The suitable local climate conditions for different types of vectors and associated VBDs are different. For example, the suitable temperature for the transmission of rodents-borne diseases is 20 °C to 30 °C, while the most suitable temperature range for mosquitoes-borne diseases is 23 °C to 29 °C. Extreme climate events such as heat waves in Europe and cool waves in Africa positively impact the distribution of VBDs. At the same time, floods wash away mosquitoes' developmental stages and eggs from their breeding sites.

In contrast, the remaining water after the flood will create new suitable conditions for other mosquitoes (Ma *et al*., 2022). On the other hand, most people store rainwater, which facilitates extra breeding sites for the vectors (Rocklöv and Dubrow, 2020). Meanwhile, increased precipitation in arid areas has positive effects, while humid regions negatively affect rodent-borne diseases (Ma *et al*., 2022).

Climate change, directly and indirectly, affects the habitats and living conditions of human and non-human hosts of vectors and pathogens of VBDs. For example, human displacement and wild animal migration due to the unavailability of water and feed as a result of climate change could expose the naïve human population to new pathogens and facilitate the introduction of the vectors or pathogens to the new locations, respectively (Rocklöv and Dubrow, 2020). At the same time, the Hantavirus outbreak in the southwest US in 1993 occurred after a six-year drought preceded by heavy rainfall and snow (Mekonnen, 2018).

Ixodes ticks' life cycle, and habitats are affected by specific environmental conditions such as rainfall, moisture, and temperature. These ticks prefer conditions with at least 85%

relative humidity, and when the temperature exceeds about 7ºC, they search the hosts for blood biting. Therefore, climate change facilitates the ideal conditions for the ticks to expand their geographical territories and effectively invade many hosts for feeding, which increases the chance of VBD transmission to many hosts. For example, the sheep tick *Ixodes ricinus*, which transmits many bacterial and viral pathogens, recently expanded its seasonal activity and geographical distribution in Europe, reaching the northern parts, including Norway and Sweden. In the UK, for example, it has been shown that the diseases associated with *Ixodes ricinus* in animals and humans correlated with drought in the affected areas (Mekonnen, 2018). Prolonged spring and autumn seasons and milder winters increased vegetative cover and, consequently, increased deer activities carrying the ticks, facilitating the introduction of the tick into newly suitable regions in this and many other parts of Europe. Due to such a shift in the tick distribution, the cases of Lyme disease, which is transmitted by *Ixodes* spp., gradually increased in Europe and the United States from the 1990s forward. Almost the same increases in Lyme disease cases have been observed from 2009 to 2016 in Canada (Caminade *et al*., 2019).

One of the widest-spread mosquito-borne infections is WNV, which can infect humans, birds, horses, and other mammals; it is transmitted mainly by *Culex* mosquitoes. Many studies demonstrated the effects of climate change on the outbreak and epidemic occurrence of WNV in endemic and newly affected regions. Although cases of WNV have been detected in Africa since the 1930s, many outbreaks and epidemics of WNV have been documented in many new areas, including the United States, the Mediterranean region, Russia, Belarus, Ukraine, Romania, and the Balkan areas. Milder winter conditions, extreme rainfall events, and drought during the wind season were associated with an increased risk of WNV transmission (Caminade *et al*., 2019).

Another example of mosquito-borne disease is RVF, whose geographical distribution is changed due to climate change impacts from its endemic African countries to new areas (Martin *et al*., 2008). The outbreaks of RVF are almost correlated with prolonged heavy rainfall. The RVF virus survives for years in *Aedes* eggs during the drought period. After a rainfall, large numbers of mosquitoes are produced from the eggs that feed on ruminants and human populations present in the area, thus causing RVF outbreaks (Mekonnen, 2018). The disease causes high mortality and abortion in ruminants and influenza-like syndrome and occasionally severe complications such as hepatitis and encephalitis and sometimes death in infected humans. RVF cases have been recorded since 1950 in many African countries; however, in Sep 2000, Saudi Arabia and Yemen confirmed the cases of RVF, the first cases outside the African continent (Martin *et al*., 2008).

The emergence of BTV in northern Europe in 2006 is a clear example of the climate change effect of midge-borne livestock diseases. Bluetongue is a non-contagious disease of ruminants, which is transmitted by *Culicoides* spp. In 1998, a large outbreak of BTV occurred in southern Europe, where *Culicoides imicola* (the Afrotropical midge vector) was responsible for it. However, an indigenous *Culicoides* species (*C. obsoletus*) transmits BTV in Scandinavia and northern Europe's cold climate and has caused many BTV outbreaks with substantial financial costs to European ruminant industries. It has been concluded that climate conditions and the heat wave that hit Europe during 2006 made living conditions suitable for C. imicola and increased the activities of C. obsoletus, which transmits BTV in northern Europe and persists in the area. At the same time, wind dispersal of the infected vector midges and the movement of infected animals in the area also play critical roles in expanding BTV in Europe (Caminade *et al*., 2019).

Malaria was eradicated in Europe in 1975, but recent studies confirmed its reoccurrence in Italy and Greece, which is mainly linked to temperature and precipitation changes in the area. Meanwhile, the Schmallenberg virus (SBV) recently emerged in northern parts of Europe (Vonesch *et al*., 2016). Meanwhile, there is some evidence that BTV and SBV were introduced in the United Kingdom through wind-blown midges in 2006 and 2012, respectively (Mekonnen, 2018).

Effect of Climate Change on VBDs in Afghanistan

Although climate change and its adverse effects on the epidemiology of VBDs is a global issue, south Asian countries, including Afghanistan, Pakistan, and India, are highly vulnerable to such conditions. Emerging and re-emerging VBDs such as CCHF, dengue, Japanese encephalitis, WNV, LSD, malaria, leishmaniasis, schistosomiasis, and so many others, and changing the seasonal patterns and geographic distribution of these diseases could be due to the adverse consequence of climate change in these countries. Their emergence and seasonal pattern changes cause significant direct and indirect economic losses to the affected countries (Khatoon *et al*., 2023; Yang, 2023; Jabeen *et al*., 2022; Siddiqui *et al*., 2022).

Over 40 years of conflict, combined with climate change, damaged the irrigation and water systems and diminished the health services, forcing the emigration of people, which together facilitated a high incidence of infectious diseases, malnutrition, and poverty in landlocked Afghanistan (USAID, 2016). Meanwhile, the annual minimum and maximum temperature rise are higher than the global average in Afghanistan, severely impacting ecosystems, livestock population, human health, and livelihoods (WBG, 2020).

Based on the recent classification, six climate zones have been defined in Afghanistan. The climate is arid and semi-arid based on the country's geography, where the southwestern region is mostly deserted, and the north-central region is mainly mountainous. Summer dust storms and winter blizzards are moved throughout the country by strong winds. Based on the available data on Afghanistan's historical climate since the 1960s, the average annual temperature has increased by 0.6°C, the frequency of hot days and nights has increased, and the average total rainfall from March to May slightly decreased, while it has risen somehow during summer and fall (June to November). At the same time, it is projected that Afghanistan's temperature could increase from 1.5°C to 5.4°C by the 2080s and the 2090s, compared with the baseline of 1986-2005 (WBG, 2020).

Based on the available data, Afghanistan experienced many drought cycles, and the condition from 1998 to 2006 was the longest and most severe drought in the country's history (USAID, 2016). Meanwhile, this drought period was one of the key drivers in a 50% reduction in the livestock population in Afghanistan (WBG, 2020). Furthermore, due to severe drought, the wheat yields decreased by more than 60% in 2018, and about 550 million USD extra budget was needed to feed the livestock populations throughout the country (WBG, 2020).

All of the above factors reduce Afghanistan's adaptation capabilities to the devastating impacts of climate change, the geographical distribution of VBDs expands, and new diseases emerge in the country (WBG, 2020). It is already proven that the impacts of climate change will be high in already deprived societies in LMICs like Afghanistan, with poor sanitation, poverty, low access to clean water and food, weak health services, and unstable political situations (Caminade *et al*., 2019). Many VBDs of human and animal health importance are already endemic in Afghanistan. Malaria, leishmaniasis, CCHF, and LSD are the most common human and animal VBDs in Afghanistan; however, dengue virus and some other vital VBDs are also reported in some parts of the country (Adegboye *et al*., 2017; WHO, 2017; Todd *et al*., 2016; Samadi *et al*., 2021; Madadi *et al*., 2023; Sangary *et al*., 2023).

According to recent data, Afghanistan is one the most affected countries by malaria, which is placed at the fourth position worldwide outside of Africa and has second position in the Eastern Mediterranean region. Furthermore, about 14 million people live in high-risk areas of malaria in Afghanistan (Adegboye *et al*., 2017; Siddiqui *et al*., 2022).

Leishmaniasis is the third most common VBD worldwide. It is caused by different species of Leishmania and is transmitted by sandflies. It has been estimated that >75% of global cutaneous leishmaniasis cases occurred in ten countries, of which Afghanistan is one (Adegboye *et al*., 2017; Siddiqui *et al*., 2022). More than 23 million people live in high-risk areas of cutaneous leishmaniasis in 24 provinces of Afghanistan, and the majority of cases have been reported in Kabul (WHO, 2017). Open sewerage, poor waste management, poor sanitation, poor quality health services, insufficient vector control, mass migration of people, and the presence of endemic neighboring countries are the most common risk factors for cutaneous leishmaniasis. Furthermore, many zoonotic cutaneous leishmaniasis cases have also been reported from Mazar-Sharif, where the natural reservoirs of such species are rodents (Adegboye *et al*., 2017; Madadi *et al*., 2023). The results of a joint spatial time-series epidemiological analysis of malaria and cutaneous leishmaniasis infection conducted by Adegboye *et al.* (2017) indicated the co-existence of malaria and cutaneous leishmaniasis in specific areas of Afghanistan. They found that climate change, especially temperature and precipitation, affected the occurrence and distribution of these diseases in Afghanistan. Furthermore, Todd *et al.* (2016) tested 809 people for some zoonotic and VBDs in Afghanistan and found that 2.1% of tested persons had antibodies against the dengue virus.

Lumpy skin disease is a VBD of cattle that recently emerged in Afghanistan, and its cases have been detected all over the country. The disease has caused high morbidity and mortality in the affected cattle population and a severe socio-economic burden in Afghanistan (FAO, 2023; Sangary *et al*., 2023).

LSD was first reported in Zambia in 1920 but soon spread to other African countries and is now endemic in most of sub-Saharan Africa, the Arabian Peninsula, Turkey, Azerbaijan, Iran, Armenia, Greece, Russia, Georgia, Kazakhstan, Albania, Bulgaria, Montenegro, North Macedonia, and Serbia. Some countries, especially in the European Union, controlled the disease, and no other countries reported LSD cases from 2017 to 2018 in this region. In 2019, LSD emerged in Central Asia, where China, Bangladesh, and India reported their first cases this year. After that, the disease increased its extent in this region and reached Bhutan and Nepal in 2020. The disease also moved to Southeast Asia in the same year, namely Hong Kong, Myanmar, Sri Lanka, and Vietnam. In 2021, LSD was reported in new Asian countries such as Mongolia, Pakistan, and Taiwan and continued to spread toward Southeast Asia, as Cambodia, Thailand, and Malaysia reported their first cases. Finally, in 2022, Afghanistan and Indonesia reported the first cases of LSD. Such continuous spread of the diseases to the new geographical areas could be due to various factors, where climate change could be the primary driver (Sangary *et al*., 2023; Bianchini *et al*., 2023).

Although specific research to determine the primary source of LSD infection for the cattle population of Afghanistan has not been conducted yet, the available evidence suggests that the LSD virus may be transmitted from Pakistan to Afghanistan. According to the available data, the disease was confirmed for the first time on October 28, 2021, in the Bahawalpur district of Punjab, Pakistan. Still, widespread outbreaks occurred in February 2022 in this country (Haider *et al*., 2023). The initial outbreak of LSD was reported in the spring autumn of 2022 in the eastern regions of Afghanistan, especially Laghman and Nangarhar provinces (https://www.bakhtarnews.af/en/lsd-animals-skin-disease-spread-in-nangarhar-laghman/), soon the virus spread to other regions of the country, including Khost, Paktia, Paktika, Logar, Kabul, Kandahar and other parts of Afghanistan. Consequently, a large epidemic of the disease occurred in the country. During 2023, many cases and outbreaks of LSD happened in the cold regions of the country, such as Bamyan and Daikundi, where insects are usually much less active (Personal communication with the field veterinarians). This problem may be caused by the transmission of the virus by nomadic herds to these areas or, to a greater extent, climate change facilitating the suitable conditions for insect activities and spreading the virus to the susceptible cattle population in these areas (Bianchini *et al*., 2023).

Mitigation Strategies to Decrease the Effects of Climate Change on Human Health and Livestock Health and Production

As mentioned, many climates and non-climate factors have impacts on the emergence, re-emergence, distribution, and endemicity of VBDs, their pathogens, and vectors; therefore, different mitigation strategies should be applied to reduce the harmful effects of climate change and other anthropological factors. All countries worldwide must fulfill the Paris Climate Agreement goal of limiting global warming to no more than 1.5 °C above preindustrial levels. For such a goal, political wells should be encouraged to reduce the emission of greenhouse gases in all energy production sectors (Rocklöv and Dubrow, 2020).

Livestock breeds resistant to the effects of climate change should be identified and developed in all countries. Some studies indicated that indigenous cattle breeds, including Sanga, Tuli, and Boran cattle breeds in Africa, have high adaptation levels and suffer less from climate change impacts compared to those with a high percentage of new genetic characteristics. Therefore, it is recommended to discourage indiscriminate cross-breeding policies in livestock populations in affected areas (Magiri *et al*., 2021).

Seasonal long-distance moving of livestock searching for water and new pastures should be limited to decrease exposure of the livestock to the infected blood-feeding arthropods, and constructing specific fences to protect farmland and feeding areas and improving biosecurity and sanitation are essential protective measures against VBDs (Magiri *et al*., 2021). Rural and pastoral communities should be empowered with new knowledge and skills to adapt well to the impacts of climate change (Magiri *et al*., 2021). Therefore, strengthening adaptive capacity through community-based participatory methods against climate change impacts is a practical approach, especially in LMICs (Wilcox *et al*., 2019). In Tanzania, for example, the effects of climate change on cattle VBDs, especially African animal trypanosomiasis and East Coast fever (ECF), were effectively evaluated by the participatory epidemiology method among pastoral communities (Kimaro *et al*., 2017). Such methods can be effectively applied in Afghanistan, especially among nomadic, pastoral, and rural communities.

The development of new diagnostic tests for rapid detection of VBDs in infected animals and humans (Mekonnen, 2018), as well as the development of new vaccines and effective drugs against vectors and pathogens, are vital to control and prevent VBDs effectively (Caminade *et al*., 2019). Irrational use of chemicals and drugs against vectors and VBD agents eventually causes resistance in vectors and parasites. In such conditions, the vectors and pathogens are controlled in the initial phase. In contrast, in the later phase, false confidence among the health providers and societies develops, eventually facilitating the outbreaks and epidemics of VBDs in the area (Wilcox *et al*., 2019). Since livestock and poultry are the most important reservoirs of VBD agents, and many of these agents mutate in these sources, which causes epidemics and pandemics in animal and human populations (Halabi, 2020); veterinarians are always on the frontlines of the battle against zoonotic diseases including VBDs (Yang, 2023; Khatoon *et al*., 2023). Therefore, improving animal health service delivery and promoting One Health and Eco-health, especially in vulnerable communities, could effectively reduce the burden of VBDs in affected countries in the future (Grace *et al*., 2015).

Although vaccination of livestock will significantly reduce the outbreak of diseases such as LSD, BT, RVF, AHS, and other important VBDs in affected areas, the occurrence of VBD outbreaks in irregular intervals and seasonal shifting of these diseases will make problems for the farmers to predict the most effective time for the livestock vaccination campaigns.

Nevertheless, good enough vaccine doses should be stored in the stocks for endemic and emerging VBDs. For example, although effective vaccines providing lifelong immunity are available against yellow fever, during the re-emergence of this disease in Africa and Brazil in 2015-2016 and 2017-2018, WHO-approved vaccines were shortened significantly in the global stocks (Caminade *et al*., 2019).

Developing early warning systems at global, regional, and national levels could province effective decision support for the management of the diseases, and the application of prevention and intervention measures based on integrated research programs is crucial to effectively reduce the harmful impacts of VBDs in human and animal populations (Martin *et al*., 2008; Grace *et al*., 2015). In addition, integrated activities, including surveillance systems, deworming, and vaccination programs considering human and animal health, should be encouraged among veterinary and public health sectors (Caminade *et al*., 2018; Magiri *et al*., 2021). Surveillance systems should focus more on rural areas and slums where vectors' presence, reproduction, and activities are more predominant (Caminade *et al*., 2019). Furthermore, arthropod control activities, conducting new research on VBDs and their vectors to increase the awareness of health professionals, and improved preparedness for the occurrence of new-emerging and re-emerging diseases are practical actions to reduce the future impacts of VBDs on human health and livestock health and production (Baylis, 2017).

Conclusion

Climate change transforms the distribution and prevalence of VBDs worldwide and poses new challenges for public and veterinary health sectors in affected areas. Besides the importance of VBDs in the animal health sector, most of the VBDs have a zoonotic nature. Therefore, these emerging and re-emerging diseases threaten public health more than at any time in the history of human beings. Due to the shared nature of most VBDs, integrated One Health and Echo-Health is the only practical approach to tackle these global health issues effectively. Applying all health interventions based on integrated research program results is crucial. Furthermore, rural and pastoral communities should be empowered with new knowledge and skills to adapt well to the impacts of climate change.

Conflict of interest

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References

Adegboye, O. A., Al-Saghir, M., & Leung, D. H. (2017). Joint spatial time-series epidemiological analysis of malaria and cutaneous leishmaniasis infection. *Epidemiology & Infection*, *145*(4), 685-700.

Alves, C. (2021). Preventing new diseases by tackling Climate Change. Academia Letters, Article 2338. https://doi.org/10.20935/AL2338.

Artois, M. (2012). The role of wildlife in the control of domestic animal diseases. *OIE Comm. Régionale Eur*, *8*.

Baylis, M. (2017). Potential impact of climate change on emerging vector-borne and other infections in the UK. *Environmental Health*, *16*(1), 45-51.

Bianchini, J., Simons, X., Humblet, M. F., & Saegerman, C. (2023). Lumpy skin disease: a systematic review of transmission mode, risk of emergence and risk entry pathway. *Viruses*, *15*(8), 1622.

Byrd, B., Richards, L. R., Runkle, D. J. Margaret M. Sugg, M. M (2020). Vector-borne Diseases and Climate Change: North Carolina's Policy Should Promote Regional Resilience, NCMJ 81(5).324-330.

Caminade, C., McIntyre, K. M., & Jones, A. E. (2019). Impact of recent and future climate change on vector-borne diseases. *Annals of the New York Academy of Sciences*, *1436*(1), 157-173.

Caminade, C., McIntyre, M. K., & Jones, A. E. (2016). Climate change and vector-borne diseases: where are we next heading? *The Journal of Infectious Diseases*, *214*(9), 1300-1301.

Campbell-Lendrum, D., Manga, L., Bagayoko, M., & Sommerfeld, J. (2015). Climate change and vector-borne diseases: what are the implications for public health research and policy? *Philosophical Transactions of the Royal Society B: Biological Sciences*, *370*(1665), 20130552.

Carlson, C. J., Albery, G. F., Merow, C., Trisos, C. H., Zipfel, C. M., Eskew, E. A., ... & Bansal, S. (2022). Climate change increases cross-species viral transmission risk. *Nature*, *607*(7919), 555-562.

Dahmana, H., & Mediannikov, O. (2020). Mosquito-borne diseases emergence/resurgence and how to effectively control it biologically. *Pathogens*, *9*(4), 310.

FAO (2023). TCP/AFG/3901-E & OSRO/AFG/2018/CHG - Lumpy skin disease vaccination program in Afghanistan, Retrieved from: https://mediabase.fao.org/stock-photo-21-march-2023-nuristan-province-afghanistan--fao-representative-images-image00278193.html

Grace, D., Bett, B. K., Lindahl, J. F., & Robinson, T. P. (2015). Climate and livestock disease: assessing the vulnerability of agricultural systems to livestock pests under climate change scenarios. *CCAFS Working Paper*.

Haider, A., Maryam, H., Waqas, U., Fatima, M., Abbas, Z., *et al*. (2023). The Economic Impact of Lumpy Skin Disease and Cost-Effectiveness of Vaccination for the Control of Outbreaks in Pakistan. *Vet Med Animal Sci*. 6(1), 1125.

Halabi, S. F. (2020). Adaptation of animal and human health surveillance systems for vector-borne diseases accompanying climate change. *The Journal of Law, Medicine & Ethics*, *48*(4), 694-704.

Jabeen, A., Ansari, J. A., Ikram, A., Khan, M. A., & Safdar, M. (2022). Impact of climate change on the epidemiology of vector-borne diseases in Pakistan. *Global Biosecurity*, *4*.

Jourdain, F., & Paty, M. C. (2019). The impact of climate change on vectors and vector-borne diseases in France. *Les Tribunes de la sante*, *61*(3), 41-51.

Khatoon, S., Bhattacharya, P., Karuveettil, V., Mahapatra, B., Mathew, S., Thakur, R., ... & John, D. (2023). Association of climate change and vector-borne diseases in South Asia: a systematic review protocol. DOI: https://doi.org/10.21203/rs.3.rs-3257293/v1

Kimaro, E. G., Toribio, J. A. L., & Mor, S. M. (2017). Climate change and cattle vector-borne diseases: Use of participatory epidemiology to investigate experiences in pastoral communities in Northern Tanzania. *Preventive veterinary medicine*, *147*, 79-89.

Ma, J., Guo, Y., Gao, J., Tang, H., Xu, K., Liu, Q., & Xu, L. (2022). Climate Change Drives the Transmission and Spread of Vector-Borne Diseases: An Ecological Perspective. *Biology*, *11*(11), 1628.

Madadi, S., Arif, S., Ansari, M., Amiry, G. Y., Ziaulhaq Kaihan, Z. (2023). A cross-sectional study on the prevalence of cutaneous leishmaniasis in Kabul, Afghanistan from 2020 to 2021. *Afghanistan Journal of Infectious Diseases*, 1(1), 14-18.

Magiri, R., Muzandu, K., Gitau, G., Choongo, K., & Iji, P. (2021). Impact of climate change on animal health, emerging and re-emerging diseases in Africa. *African Handbook of Climate Change Adaptation*, 1-18.

Martin, V., Chevalier, V., Ceccato, P., Anyamba, A., De Simone, L., Lubroth, J., ... & Domenech, J. (2008). The impact of climate change on the epidemiology and control of Rift Valley fever.

Mekonnen, N. (2018). The Impact of Climatic Change on Animal Disease Ecology, Distribution and Emergence: A Review. *Archives of Applied Science Research*, 10 (1), 14-20.

Nejash, A., & Kula, J. (2016). Impact of climate change on livestock health: A review. *Global Veterinaria*, *16*(5), 419-424.

Ogden, N. H. (2017). Climate change and vector-borne diseases of public health significance. *FEMS microbiology letters*, *364*(19), fnx186.

Oza, J., Bhatt, D., Patel, K., & Trivedi, J. (2020). Study of prevalence of tick Hyalomma excavatum (Acari: Ixodidae) on Bubalus bubalis in Patan District, Gujarat state, India. *Journal of Biological Studies*, *3*(2), 69-78.

Pongsiri, M. J., & Roman, J. (2007). Examining the links between biodiversity and human health: an interdisciplinary research initiative at the US Environmental Protection Agency. *EcoHealth*, *4*(1), 82-85.

Rocklöv, J., & Dubrow, R. (2020). Climate change: an enduring challenge for vector-borne disease prevention and control. *Nature Immunology*, *21*(5), 479-483.

Samadi, A., Amiri, M., Abi, A.J., Hakim, H., Alizada, M.N., Sangary, M, Rahpaya, S.S. (2021). A survey of tick infestation of animals before Eid-al-Adha as suspected cases of Crimean-Congo Hemorrhagic Fever (CCHF) in Kabul city's streets and live animal markets, *Veterinary Medicine and Public Health Journal (VMPH*), 2, (2), 57-63.

Samy, A. M., Elaagip, A. H., Kenawy, M. A., Ayres, C. F., Peterson, A. T., & Soliman, D. E. (2016). Climate change influences the global potential distribution of the mosquito Culex quinquefasciatus, a vector of the West Nile virus and lymphatic filariasis. *PloS one*, *11*(10), e0163863.

Sánchez Mendoza, B., Flores Villalva, S., Rodríguez Hernández, E., Anaya Escalera, A. M., & Contreras Contreras, E. A. (2020). Causes and consequences of climate change in livestock production and animal health. Review. *Revista mexicana de ciencias pecuarias*, *11*, 126-145.

Sangary, M., Olfat, G. H., & Faqiri, R. (2023). A Cross-Sectional Study of Lumpy Skin Disease and Knowledge of Livestock Farmers Regarding the Disease in Istalif District of Kabul, Afghanistan. *Nangarhar University International Journal of Biosciences (NUIJB),* 2(3), 11-19.

Siddiqui, J. A., Aamar, H., Siddiqui, A., Essar, M. Y., Khalid, M. A., & Mousavi, S. H. (2022). Malaria in Afghanistan: Challenges, efforts and recommendations. *Annals of Medicine and Surgery*, *81*, 104424.

Solomon, A., & Tanga, B. M. (2020). The first investigation of tick vectors and tick-borne diseases in extensively managed cattle in Alle District, Southwestern Ethiopia. *Veterinary medicine international*, *2020*.

Todd, C. S., Mansoor, G. F., Buhler, C., Rahimi, H., Zekria, R., Fernandez, S., ... & Yingst, S. L. (2016). Prevalence of zoonotic and vector-borne infections among Afghan national army recruits in Afghanistan. *Vector-Borne and Zoonotic Diseases*, *16*(8), 501-506.

USAID (2016). Climate Change Risk in Afghanistan: Country Fact Sheet, Climate Change Risk Profile Afghanistan, Climate Change Adaptation, Thought Leadership and Assessments (ATLAS) Task Order

No.AID-OAA-I-14-00013

Vonesch, N., D'Ovidio, M. C., Melis, P., Remoli, M. E., grazia Ciufolini, M., & Tomao, P. (2016). Climate change, vector-borne diseases and working population. *Annali dell'Istituto superiore di sanita*, *52*(3), 397-405.

WBG (2020). Climate Risk Country Profile, Afghanistan. World Bank Group and Asian Development Bank.

WHO (2017). Leishmaniasis, Afghanistan. Eastern Mediterranean region, Retrieved from: https://www.emro.who.int/afg/programmes/leishmaniasis.html#:~:text=Afghanistan%20has%20a%20high%20burden,cases%20were%20reported%20in%202017.

Wilcox, B. A., Echaubard, P., de Garine-Wichatitsky, M., & Ramirez, B. (2019). Vector-borne disease and climate change adaptation in African dryland social-ecological systems. *Infectious diseases of poverty*, *8*(1), 1-12.

Yang, L. (2023). Impact of climate change on vector-borne diseases in veterinary medicine: A global perspective. *J Vet Med Allied Sci*. 7(4), 153.