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Impact of global climate change on livestock health: Bangladesh perspective

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Abstract

The global carbon emission rate, due to energy-driven consumption of fossil fuels and anthropogenic activities, is higher at any point in mankind history, disrupting the global carbon cycle and contributing to a major cause of warming of the planet with air and ocean temperatures, which is rising dangerously over the past century. Climate change presents challenges both direct and indirect for livestock production and health. With more frequent extreme weather events including increased temperatures, livestock health is greatly affected by resulting heat stress, metabolic disorder, oxidative stress, and immune suppression, resulting in an increased propensity for disease incidence and death. The indirect health effects relate to the multiplication and distribution of parasites, reproduction, virulence, and transmission of infectious pathogens and/or their vectors. Managing the growing crossbreeding livestock industry in Bangladesh is also at the coalface for the emerging impacts of climate change, with unknown consequences for the incidence of emerging and re-emerging diseases. Bangladesh is now one of the most vulnerable nations to global climate change. The livestock sector is considered as a major part of food security for Bangladesh, alongside agriculture, and with one of the world's largest growing economies, the impacts are exaggerated with this disaster. There has been no direct study conducted on the impact of climate change on livestock health and the diseases in Bangladesh. This review looks to explore the linkage between climate change and livestock health and provide some guidelines to combat the impact on livestock from the Bangladesh perspective.

Keywords: Animal health, Climate change, Food security, Heat stress, Oxidative stress..

Introduction

Climate change is the complex and multidisciplinary change in global or regional climate patterns, which pose a significant risk for human and natural systems. The most intricate multifactorial global challenge, which jeopardizes human and natural system, is similarly threatened livestock production and productive performance. It is projected that global mean surface temperature will be increased by about 3.7°C (likely range of 2.6°C–4.8°C) by 2100 (IPCC, 2013), and with changes to the frequency, intensity and duration of extreme weather events will be evident (Howden *et al.*, 2008). Such the changes will directly and indirectly impact the production and health parameters of livestock and include a complex suite of interacting biophysical parameters that influence growth performance; meat and milk yield and quality; egg yield, weight, and quality; reproductive performance; metabolic and health status; and carcass traits as some examples (Nardone *et al.*, 2010; Henry *et al.*, 2012). The direct health impacts for livestock due to climate change by temperature-related illness, changes in metabolic functions, and morbidity due to extreme weather events pose a significant challenge (Nardone *et al.*, 2010). This coupled with the indirect impacts on livestock health, making it vulnerable to unprecedented diseases by the effects of any climate change, hard to predict. A vast

number of studies have been demonstrated on climate change leading to impaired health and adverse effects on the animal immune system that can be compromised with distribution, growth, and incidence of diseases and reproductive health (Thornton *et al.*, 2009; Lacetera, 2012; Bett *et al.*, 2017; Caminade *et al.*, 2019). Heat load and subsequent heat stress (HS) alone result in economic losses and health management costs in the USA of over \$900 million/year for dairy industry and over \$300 million/year for beef and swine industry (St-Pierre *et al.*, 2003).

The world population is projected to grow by 33% from 7.2 to 9.6 billion by 2050 (UNDESA, 2017). Hence, it is estimated that up to 70% of increases in agricultural productivity will be required to meet the future demand for the standard of living and food security (O'Mara, 2012). As an example, the global demand of milk and meat production predicted for 2050 to meet the global demand is estimated to increase 1,077 and 455 million tonnes, respectively, equating to almost double that of 2006 production (Alexandratos and Bruinsma, 2012). Global climate change represents a major challenge to achieve the predicted productivity growth required to meet those future demands. The additional factors that pose an impact are contributions of the agricultural sector itself directly to the livelihoods of the poorest populations in the world, which currently estimated

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to employ 1.1 billion people (Hurst *et al.*, 2005). Any impact on this sector directly affects the most vulnerable populations. In case of milk production, it is forecasted that about 1,077 million tonnes of milk will be produced in 2050 up from 664 million tonnes produced during 2006, and in the same way, meat production will be doubled from 258 to 455 million tonnes (Alexandratos and Bruinsma, 2012). Bangladesh has the eighth highest population density (people per sq. km of land area) in the world, with a unique geographical location, classified as a tropical area locating on a deltaic plain. It is dominated by floodplains, with significant expanses of low elevation, making it vulnerable to rising sea levels and flooding (Mahmood, 2012; World Population Review, 2019). Currently, new generations in Bangladesh are suffering from mounting adverse effects comparatively from the previous generations (Mahmood, 2012). Bangladesh is considered to be one of the developing countries with lower energy demand and spotted low carbon print, as well as low carbon emission country (World Bank, 2014). However, it is identified as one of the top 10 nations in the world vulnerable to global climate change (UNDESA, 2017). Bangladesh's livestock and agriculture resources are considered an important part of food security for the nation, and with one of the world's largest growing economies, the impacts of climate change are exacerbated. The livestock sector in Bangladesh consists of 24.23 million cattle, 1.48 million buffalo, 3.53 million sheep, 26.26 million goats, 289.28 million chickens, and 57.75 million ducks. This sector is contributed to animal protein production predominantly milk (9.923 million metric tons), meat (7.514 million metric tons), and eggs (171.1 nos) (DLS, 2019). Changing climate is considered as a threat to livestock production because of the impact on the quality of concentrate and roughage feeds, availability of clean drinking water, meat and milk production, disease prevalence and incidence, reproduction, and biodiversity (Thornton *et al.*, 2009; Nardone *et al.*, 2010; Henry *et al.*, 2012). Globally, it is estimated that livestock disease reduces productivity by 25% with the heaviest burden falling on the poor (Grace *et al.*, 2015). Every year, several reports from industry and government are demonstrating the alarming incidence of infectious, noninfectious, and reproductive health issues of livestock throughout Bangladesh. The objective of this study is to describe the direct and indirect effects of global climate change on livestock health performance in Bangladesh.

Definition of climate change

Climate change is defined as an average weather condition of an area that is characterized by its own internal dynamics, and it can affect by changing its external factors. The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as the change resulting from long-term direct and indirect activities that induce changes

in the compared time, which are much more than the natural change (UNFCCC, 1992). On the other hand, the weather is a set of all the phenomena occurring in a given atmosphere at a given time (Stephenson *et al.*, 2008). Climate change is an association of multidimensional effects on climate including physical characteristics, causes, and consequences (Visschers, 2018).

Impact of climate change on livestock health

The projected average increase of surface temperatures by the IPCC (IPCC, 2013) is primarily due to an increase of global atmospheric temperature and greenhouse gases mostly carbon dioxide (CO₂) concentration, precipitation variation, and/or permutation of these factors (Henry *et al.*, 2012). Temperature plays a central role on livestock by affecting rainfall, forage, production, reproduction, and health. Forage productions are influenced by increased temperature, CO₂, and/or combination of precipitation variation (Sawalhah *et al.*, 2019). However, livestock health is mainly affected by increased temperature and precipitation variation. The factors that influence livestock health are extremely complex, involving environmental forces including ecological, social, economic interest, individual, and/or community behavior (Forastiere, 2010). Climate change will have many knock-on effects, both direct and indirect. The direct effect of climate change on livestock health includes temperature related to frequent disease incidence and death. The indirect effect follows more intricate pathways and includes the climate influences on pathogen density and distribution and multiplication of vectors as well as vector-borne diseases and soil-, food-, and water-borne diseases. These are discussed in the following context of their impact on livestock production for Bangladesh.

Direct effects

The increases in the frequency, severity, and duration of temperature to the edge of extremity are anticipated in the near future as a result of global climate change and directly impairing animal production systems due to health effects. The direct effect of climate change on animal health has been described as a reduced competence of the host to mount a response to infection (Bett *et al.*, 2017). These effects are compounded by thermal stress or HS conditions. Depending on the degree, duration, and severity of heat exposure, livestock health can be affected by causing metabolic disorder, oxidative stress, immune suppression, decreased reproductive performance, and death.

Heat stress

HS can simply be defined as the point when animals cannot dissipate an adequate amount of heat from the body to balance the body thermal condition (Mondal and Reddy, 2018). To avoid HS, every animal has an ideal ambient temperature to maintain a thermoneutral condition. The impact of ambient conditions on animals' performance can be estimated by calculating

temperature–humidity index (THI) by considering ambient air temperature and humidity. The formula for THI calculations are defined as follows: when the ambient temperature is expressed in F-scale (LPHSI, 1990), $THI = dbt\ ^\circ F - \{(0.55 - 0.55 RH) (dbt\ ^\circ F - 58)\}$, where dbt is the dry bulb temperature ($^\circ F$) and RH = relative humidity %/100.

Interpretation: If the calculated value is <72 = absence of HS, 72 to <74 = moderate HS, 74 to <78 = severe HS, and 78 and more = extreme severe HS.

When ambient temperature expressed in Celsius scale (Marai *et al.*, 2001), $THI = dbt\ ^\circ C - \{(0.31 - 0.31 RH) (dbt\ ^\circ C - 14.4)\}$

Interpretation: If the calculated value is <22.25 = absence of HS, 22.2 to <23.35 = moderate HS, 23.3 to <25.65 = severe HS, and 25.6 and more = extreme severe HS.

Due to the increasing demand of animal protein in Bangladesh, gradually non-descriptive native cattle have been replaced by crossbred cattle from 1975 to 1976. Now, a total of 2.3 million high-yielding crossbred cattle are available in Bangladesh. The crossbreed was developed by crossing native cattle with Holstein–Friesian/Sahiwal/Sindhi cattle over time to increase the productivity (Hamid *et al.*, 2017). Now, it has been established that the higher production cows are less tolerant to HS than low production cows (Staples and Thatcher, 2011). Holstein–Friesian dairy cows are renowned for their milk production but predominantly susceptible to HS (West, 2003). When the ambient temperature is over $25^\circ C$, high yielding dairy cows become heat stressed with primary signs shown as increased body temperature and respiration rates (Staples and Thatcher, 2011). As body temperature increases, concurrently feed intake and milk production decrease (Du Preez *et al.*, 1990). Staples and Thatcher (2011) reviewed that milk production can decrease from 22.4 to 19.2 kg/day if body temperature (rectal) increased from $38.8^\circ C$ to $39.9^\circ C$. From these studies, it can be inferred that the crossbred cows in Bangladesh will succumb to similar production limitations due to HS.

Metabolic disorders

The livestock is physiologically homeothermic animals, and they respond to high ambient temperatures by increasing heat loss while concurrently decreasing the internal heat production rate. This is possible by increasing respiratory and sweating rates and decreasing feed intake (Lacetera, 2019). Metabolic disorders occur during this physiological process, and its impacts are described as follows:

(a) *Lameness*: Cook and Nordlund (2009) revealed that HS influences the lameness of farm animals by the contribution of ruminal acidosis or increased output of bicarbonate. The heat-stressed animal eats less frequently during cooler times of the day but consumes more during each feeding (Shearer, 1999). Hence, there was a reduced feed intake in the hotter part of the day, followed by increased feed intake at below

ambient temperature of the day, which is considered as a major cause of ruminal acidosis by increased output of bicarbonate, resulting in laminitis (Stone, 2004). HS also affects an animals' behavior such as lying behavior in pen. The relationship between the proportions of cows standing with ambient temperature is linear. On the other hand, an inverse relationship was found between the proportions of cows lying down and ambient temperature (Zähner *et al.*, 2004). Hence, longtime standing may aggravate changes in claw by compromising the structure of the claw, and consequently, reductions in lying per day have been correlated with lameness in dairy cows (Cook *et al.*, 2004).

(b) *Ketosis*: Ketosis is a metabolic disease characterized by a relatively high concentration of ketone bodies such as acetone, β -hydroxybutyrate, and acetoacetate with a concurrent decrease of blood glucose levels (Dann *et al.*, 2005). It is developed while animal affected in the severe state of negative energy balance, suffers forceful lipomobilization, and accumulates ketone bodies, which develops from inadequate catabolism of fat (Lacetera, 2019). During HS, animals' reduced feed intake combined with increased energy requirement for fulfillment of body physiological demand may cause negative energy balance that influences the mobilization of adipose tissue consequently, resulting in the development of ketosis (Abuajamieh, 2015). When cattle are affected by ketosis, they lose weight and produce less milk.

The climate change also affects animal health by hampering endocrine status, liver functionality, glucose, protein and lipid metabolism (Bernabucci *et al.*, 2006), saliva production, salivary HCO_3 content, and fitness and longevity (King *et al.*, 2006).

Oxidative stress

In the past decades, the oxidative stress on livestock by HS has been increasing research demands (Akbarian *et al.*, 2016). In livestock, oxidative stress may be related in a number of pathological conditions, including conditions that are relevant for livestock production and the general welfare of animals (Lykkesfeldt and Svendsen, 2007). It is caused due to imbalance between oxidant and antioxidant molecules by increasing oxidants and/or decreasing antioxidants. Mirzad *et al.* (2017) demonstrated that total serum antioxidant levels decrease during the summer and postpartum periods in heifers and found a correlation between them with HS. It was also identified that total carotenes and Vitamin E level were reduced during summer. Finally, HS has been associated with an increased activity of antioxidant enzymes such as superoxide glutathione, dismutase, and catalase peroxidase, which can interrupt adaptation response to increase the levels of reactive oxygen species (ROS) (Trevisan *et al.*, 2001). The other ROS such as hydrogen peroxide (H_2O_2), superoxide anions (O_2^-), and hydroxyl radicals (OH^-) have a negative impact on lipid peroxidation, and the enzyme

inactivation process causes cell damage (Mondal and Reddy, 2018).

Immune suppression

The immune system is a complex physiological defense mechanism that protects individuals from pathogens. It has been demonstrated to be compromised by several factors (Lacetera 2012). Several studies reported that HS may have a negative impact on the immune system in livestock. In brief, chronic exposure to HS has been demonstrated to impair immune response in poultry (Regnier and Kelley, 1981), with reduced colostrum immunoglobulins such as IgG and IgA in dairy cows, which impair calf immunity (Nardone *et al.*, 1997), depression in lymphocyte function that hampers the efficacy of vaccinations (Lacetera *et al.*, 2005), and impaired function of neutrophils that are important for defense against bacteria (Lecchi *et al.*, 2016). The immune suppression accelerates the chance of infections resulting in the potential for the increased use of antimicrobials. The increased use of antimicrobials potentially leads to an increase in antimicrobial resistance (AMR) which is ranked as one of the current global challenges. About 7,000,000 people die every year due to AMR, and it is expected that it will rise by up to 10 million deaths per year by 2050 (O'Neill, 2016). Researchers have reported a high prevalence of the resistance of bacteria to most antibiotics including reserve group antibiotics (Colistin) in Bangladesh, demonstrating AMR to be an important and growing issue (Ahmed *et al.*, 2019; Rousham *et al.*, 2019). Mastitis is the major health problem in the dairy industry worldwide. Several studies reported that mastitis incidences are increased during summer and have a significant correlation with HS due to suppressed immunity, thermal injury of the udder, increased survival capacity, and spread of pathogens in the summer (Chirico *et al.*, 1997; Vitali *et al.*, 2016). In Bangladesh, subclinical mastitis is a great concern in growing dairy sectors and prevalent in 20%–44% of cows tested by the California mastitis test (Islam *et al.*, 2010).

Effect on reproduction

HS affects the reproductive performance by changing blood flows and production of different hormones, with reductions of 20%–30% in conception rates and anoestrus in ruminants during summer seasons (King *et al.*, 2006). Talukder *et al.* (2018) demonstrated an increased incidence of post-partum anoestrus in cattle during the summer season in the selected areas of Bangladesh reaching up to 14.43%. The pig industry suffers considerably due to impaired reproductive disturbances during late summer and early autumn months compared to spring and winter. It is called seasonal infertility with pigs influenced by photoperiod and temperature (Auvigne *et al.*, 2010). HS also impacts semen quality (Nichi *et al.*, 2006), estrus cycle (Wolfenson *et al.*, 2000), and oocyst and embryo development (Stewart *et al.*, 2011).

Mortality

A number of studies have reported increases in animal mortality rate during once temperature above the average range and increased mortality incidence during extreme weather situation (Vitali *et al.*, 2009; Vitali *et al.*, 2015). Temperature increases between 1°C and 5°C above average have been suggested to give rise to higher mortality in grazing livestock (Howden *et al.*, 2008). The daily THI reached between 80 and 70, where 80 is the maximum value and 70 is the minimum value, which can induce dairy cows' mortality rate (Vitali *et al.*, 2009). It is also revealed that daily upper and lower critical maximum and minimum THIs are 87 and 77, respectively, above which the threat of heat-induced mortality rate becomes maximum. Finally, THIs (78.5 and 73.6) were the thresholds, which increase mortality rate significantly during transport and lairage, respectively. Purusothaman *et al.* (2008) reported an increased mortality in Mecheri sheep during the summer season in India due to HS. There have been many reports published on the increase of livestock mortality during extreme weather events. In France during summer 2003, pigs, poultry, rabbits, and also over 35,000 people died due to extreme and prolonged heat waves (Lacetera, 2019). Vitali *et al.* (2015) described that the mortality of farming animals increases on the day of a heat wave compared to a day without heat wave. Bangladesh has recorded dramatic increases in the maximum summer temperatures over the past 40 years. Over the past 63 years, Bangladesh has recorded monthly maximum, minimum, and average temperature increases at 0.12°C, 0.08°C, and 0.56°C, respectively (Ahmed and Hossen, 2014). These diverse documented effects of increasing temperature on livestock health have not been collected and systematically recorded in Bangladesh; however, considering the evidence of broad health impacts from increased temperatures, the livestock sector of Bangladesh needs to prepare and implement the strategies to accommodate for the adverse effect of increasing temperatures on animal production systems.

Indirect effects

The indirect effect of climate change on livestock health is associated with climate-driven ecosystem changes and physiological adaptations which could trigger vectors or pathogen virulence and/or genome diversity and vector–pathogen–host exposure (Bett *et al.*, 2017). The emergence and re-emergence of vector-borne pathogens have globally provided evidence for the relationship between climate change and effects on the human/animal health interface (Caminade *et al.*, 2019). In the disease process, three epidemiological factors such as the agent, host, and environment are closely entangled and persist in ecosystems. The climate change could enhance pathogen replication and/or virulence which can negatively affect livestock health (Harvell *et al.*, 2002). The indirect effect of climate change on livestock health is defined as follows.

Vector-borne pathogen

The global warming and changes in precipitation and humidity positively affect the reproduction and spread of vector-borne pests such as midges, flies, ticks, and mosquitoes (Thornton *et al.*, 2009). This in turn has the potential to increase the geographic spread of vector-borne diseases such as bluetongue, lumpy skin diseases (LSDs), anaplasmosis, babesiosis, and theileriosis. The IPCC 2007 report warned that global climate change patterns could positively affect the spatial distribution of vectors such as mosquitoes and ticks (IPCC, 2007). These transmission dynamics of vector-borne diseases could be affected in two ways including (i) vector survival and geographical range changes and (ii) nature of vector activity, efficiency, and susceptibility to infectious changes. Arthropod vectors are very fragile to fluctuations in temperature and humidity. Several researchers reported that the warmer conditions accelerated disease transmission into the host (Thornton *et al.*, 2009). About 18% of body weight can decrease by tick infestation in climate change condition in Australian livestock simulated by White *et al.* (2003). A model simulated by Wittmann *et al.* (2001) demonstrated that an increase of 2°C of environmental temperature can extensively spread *Culicoides imicola*, which is responsible for the transmission of bluetongue virus in sheep, cattle, goats, and also wild ruminants. So far, to the best of authors' knowledge, the bluetongue virus is not identified yet in Bangladesh, but it is frequently identified in the Indo-Bangladesh borders (Rao *et al.*, 2016; De *et al.*, 2019). With currently changing weather patterns, it is possible that bluetongue virus may be found in Bangladesh, and the epidemiological investigation is needed to monitor for this. This virus has been spreading globally since 1990, and the spread is being enabled by global warming (Lacetera, 2019).

Hemoprotozoan infection is an important protozoan health hazard of livestock in tropical countries that can be transmitted by ticks. As a tropical country, the livestock of Bangladesh suffers severely with hemoprotozoan infection such as *Babesia* spp., *Anaplasma* spp., and *Theileria* spp. with a prevalence of 19%, 43%, and 33%, respectively. Here, the overall prevalence in cattle is found to be 50% with a breakdown between high-yielding cross-breed cattle (80%) and indigenous cattle (22%), demonstrating a significantly increased susceptibility in the popular new emerging cross-breed cattle (Bary *et al.*, 2018). Tick reproduction has also been demonstrated to increase as humidity increases to 85% (Caminade *et al.*, 2019), as a result of blood protozoan infestation during summer season increasing in Bangladesh cattle (Bary *et al.*, 2018).

On 14th July 2019, for the first time, Bangladesh confirmed an outbreak of LSD in cattle and notified the OIE. The morbidity rate was recorded as 18.33% (66/360) with no associated mortality (OIE, 2019).

LSD is a vector-borne viral infectious disease of cattle caused by *Capripoxvirus* under *Poxviridae* family (Woods, 1988). The mosquito *Aedes aegypti* acts as a potential mechanical vector for LSD transmission (Chihota *et al.*, 2001). A report has been published that the density of *A. aegypti* becomes 13 times higher in Dhaka city during 2019 than 2018 when LSD emerged in Bangladesh (Prothomalo, 2019), and climatic factors can influence the population of *Aedes* mosquitoes (Karim *et al.*, 2012). Climate change has been demonstrated to impact vector populations and distribution and as such may influence the transmission of LSD in Bangladesh and further the risk of spread across a wide geographical area (Tjaden *et al.*, 2018). This outbreak of LSD is a sign of continuous influences of climate change on livestock in Bangladesh.

Deforestation and vegetation clearance are also contributing to ecological imbalance by increasing local temperature and humidity that accelerate the spread of vectors. In Bangladesh since 1930–2014, a total of 39.1% (from 23,140 km² to 9,054 km²) deforestation has occurred with continued annual deforestation at about 0.77% (2006–2014) (Reddy *et al.*, 2016).

Parasites and helminths

Climatic variables directly affect an increase in the abundance, prevalence, severity, and geographical distribution of helminths. It has been observed that the development rates of free-living larval stage of the *Haemonchus contortus* become increased in the tropical regions with increased temperature (Fox *et al.*, 2015). This worm sucks blood from the stomach of sheep and causes severe anemia and death. Kim *et al.* (2012) shown that the development of *Ascaris suum* eggs through enhanced embryonation becomes accelerated when ambient temperature increases from 25°C to 35°C in a laboratory condition. Global climate change could influence the rapid development of parasites in their invertebrate intermediate hosts like snails. The lifecycle of lungworms is also reliant on weather conditions and increases incidence in the summer/autumn than the winter season. Fascioliasis, schistosomiasis, and nematodiasis including heterakiasis and different trichostrongylidiasis are the helminth diseases that are mostly influenced by climatic changes (Fox *et al.*, 2012). On the other hand, climate change influences land-use changes, particularly with the development of dams and irrigation schemes for agricultural productivity, which can contribute to a positive impact on livelihoods and henceforth nutritional status, and can also have a substantial negative effect on human and animal health. Standing water from these systems results in higher localized humidity that can trigger the development of a range of vectors. Pfeiffer *et al.* (2005) reported rift valley fever outbreaks occurred in dams and irrigated areas in Egypt, Sudan, and Mauritania/Senegal. Other parasitic diseases like trematodiasis (fascioliasis and schistosomiasis) became endemic in this area

due to standing water masses and increased humidity influences of the development rates of intermediate hosts (snails) and cercariae. Afshan *et al.* (2014) reported an increased incidence of fascioliasis in animals occurring in an irrigation area of Punjab province of Pakistan. A similar study was conducted in Tanzania that *Fasciola gigantica* and paramphistomes in cattle were higher in irrigation areas than non-irrigation areas and absent in non-grazing areas (Nzalawahe *et al.*, 2014). The overall parasite incidence in cattle in different geographical areas of Bangladesh is 81% in hilly areas (Nath *et al.*, 2016), 64% in Chattogram District (Chowdhury *et al.*, 2017), 73% in Sylhet District (Paul *et al.*, 2016), 66% in Sirajganj District (Karim *et al.*, 2015), and 51% in Mymensingh District (Ghosh *et al.*, 2016). These records report the incidence of parasites and helminths in Bangladesh and provide researchers with information to further explore the relationship between increasing incidence and climate change.

Mycotoxins

Most of the roughage and concentrate feeds are perishable in the environment. The altered environmental temperature and humidity due to climate change can directly affect livestock feed quality and consistency of nutrients ingredients, altering the growth of molds in feeds. The growth of molds and association of mycotoxins production are closely related to temperature and degree of moisture, which are dependent on weather conditions during harvest and techniques for drying and storage (Mannaa and Kim, 2017). The major mycotoxins are aflatoxin, ochratoxin, T2, fumonisin, and zearalenone, which are a metabolic product of mycotoxicogenic molds produced at the optimum temperature of 25°C–37°C and moistures of 80%–85% (Coppock *et al.*, 2018). It can cause acute disease cases when animal consumes above the critical level of contaminated feeds and has a negative effect on different organs such as the liver, kidney, gastrointestinal tract, and reproductive tract (Nwangburuka *et al.*, 2019). The chronic exposure of these mycotoxins even at low levels dangerously leads to immune suppression and reduces production performance and quality of end product as a result of downgrading (Hoerr, 2017; Bernabucci *et al.*, 2011). Aflatoxin type B1 is more toxic and has a significant public health impact due to hepatotoxic and its carcinogenic properties in humans (McCullough and Lloyd, 2019). Fakruddin *et al.* (2015) reported that about 50% of nuts and pulses of livestock feeds from Bangladesh are contaminated with *Aspergillus flavus* and contained at least three aflatoxigenic genes, and 90% of them can produce aflatoxin B1 ranging 7–22 µg/g in agar, which are alarming for public health.

Other pathogens

Climate change leads to extend diseases to spread through pathogen biodiversity since pathogen copes with the new situation and causes unhabitual outbreaks (out of season diseases). Furthermore, the

most important climate change plays a significant role in pathogen evolution in general. Temperature and humidity play a substantial role on pathogens that maintain a part of their lifecycle outside of the final host body such as those responsible for black quarter, dermatophiloses, and anthrax. Anthrax is a deadly zoonotic disease caused by *Bacillus anthracis* spores. This spore can be viable for up to 10–20 years in pasture land. Temperature and other climatic conditions such as humidity, rainfall, pH, water activity of soil, and availability of nutrients all affect the successful germination of anthrax spores. Heavy rainfall, soil erosion, and drought may stir up the dormant spores and increase the exposure of an animal (WHO, 2008). In the bank of Jamuna River of Bangladesh, there are four districts (Pabna, Shirajgonj, Rajbari, and Bogura) considered endemic zones for anthrax, and every year, a significant number of outbreaks occur in both livestock and humans (as a cutaneous form) (Islam *et al.*, 2018). Global climate change affects the seasonal temperature variation of migratory birds traveling from the Arctic area to a tropical area such as Bangladesh. Evidence exists that during migration, they carry and disperse avian influenza virus through contact with riverside domestic ducks in Bangladesh during the winter season, with these migratory birds identified as the potential source of avian influenza spread in Bangladesh (Haider *et al.*, 2017; Sarker *et al.*, 2017).

Natural disasters in Bangladesh

Bangladesh is the worst sufferers for global warming and climate change due to low elevation geography and its disaster-prone areas. According to the CRI 2019 (Global Climate Risk Index 2018) report, Bangladesh is ranked eighth as a high-risk country for suffering extreme weather events (Eckstein *et al.*, 2018). Salinity has caused significant negative effects on fodder and feed crop production as well as access to fresh drinking water for both human and animal consumption. Saline intrusion is the major cause of salinity in the coastal belt of Bangladesh, and it is an effect of rising sea level due to global warming (Chen *et al.*, 2012). About 1.5–2 m sea level rise was recorded in the coastal belt of Bangladesh (Ortiz, 1994). The coastal belt of Bangladesh consists of 19 districts that cover 32% of the total land area (Alam *et al.*, 2017). During 1973, salinity level was 0.9–2.1, but now it has increased 26% in the past 35 years in the coastal belt areas, significantly impacting land usage (Iftekhar and Islam, 2004). It has a significant impact on livestock health and production with many negative consequences such as nutritional deficiency, lack of fresh water, increased incidence of diarrhea, skin diseases, liver fluke, loss of bodyweight, and breakdown of the immune system (Alam *et al.*, 2017). Additional concerns for Bangladesh include temporal variations to drought characteristics as a result of climate change (Mohsenipour *et al.*, 2018). The climate change has influenced average rainfall, evapotranspiration, and atmospheric water storage and thereby changed precipitation patterns in dry

seasons, especially in the northern area of Bangladesh, having downstream impact disease distribution, in turn influencing factors causing diseases in livestock (Bett *et al.*, 2017). The incidence and intensity of the extreme events such as cyclones, tidal surges, floods, salinity intrusions, and droughts have increased significantly in recent decades in Bangladesh due to global climate change (Dastagir, 2015).

Conclusion

Climate change is now a global concern due to its multidimensional effects and impact on humans, animals, plants, and environment. Research has established that changes in global or regional climate patterns due to climate change are affecting livestock health directly and indirectly. Bangladesh is listed as one of the most vulnerable countries for global climate change due to its unique geographical location. Livestock sectors of Bangladesh are growing rapidly to fulfill the increased demand of animal protein of the world's eighth densely populated country. However, it is suffering with increased disease loads and often reporting emerging and reemerging infectious diseases. Climate changes are increasing HS by a lingering hot season and increased heat waves in the summer, resulting in an increased disease incidence for homoeothermic farm animals. This paper reviewed the relationship between climate change and livestock health in Bangladesh and the potential for increased impact for the livestock sector and identified a lack of systematic research globally and an absence of information in Bangladesh on this topic. Specific recommendations for adaptation and mitigation of the impact of climate change on animal health in Bangladesh are as follows:

- a. Research on climate-resilient technology for livestock and their adaptation.
- b. Follow the good farm practice, strict farm biosecurity, and herd health management.
- c. Development of updated vaccines and therapeutics combating for endemic and emerging diseases.
- d. Design the animal sheds considering HS, animal comfort, animal behavior, and climate change.
- e. Conservation and development of local animal genetic resources. A long-term policy of breeding for disease resistance traits through continuous challenge and natural selection.
- f. Development of saline and drought-tolerant fodder varieties and modern feeding management practices.
- g. Development and application of the methodology to link climate data with animal disease surveillance system.
- h. A comprehensive and coordinated study on real-time impacts of climate change on livestock and making a corrective policy decision.

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Ethical approval

This article does not contain any studies performed on animals.

Conflict of interest

The authors declare that they have no conflict of interest.

References

- Abuajamieh, M.K.A. 2015. Effects of heat stress or ketosis on metabolism and inflammatory biomarkers in ruminants and monogastrics. Graduate Theses and Dissertations. Iowa State University, Ames, Iowa, p 14762. Available via <https://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=5769&context=etd> (Accessed 23 September 2019)
- Afshan, K., Fortes-Lima, C. A., Artigas, P., Valero, M. A., Qayyum, M. and Mas-Coma, S. 2014. Impact of climate change and man-made irrigation systems on the transmission risk, long-term trend and seasonality of human and animal fascioliasis in Pakistan. *Geospat. Health*. 1, 317–334.
- Ahmed, A. and Hossen, M.J. 2014. Spatial and temporal variations of temperature in Bangladesh: an analysis from 1950 to 2012. *Orient. Geogr.* 58, 89–110.
- Ahmed, I., Rabbi, M.B. and Sultana, S. 2019. Antibiotic resistance in Bangladesh: a systematic review. *Int. J. Infect. Dis.* 80, 54–61.
- Akbarian, A., Michiels, J., Degroote, J., Majdeddin, M., Golian, A. and De Smet, S. 2016. Association between heat stress and oxidative stress in poultry; mitochondrial dysfunction and dietary interventions with phytochemicals. *J. Anim. Sci. Biotechnol.* 7, 37.
- Alam, M.Z., Carpenter-Boggs, L., Mitra, S., Haque, M., Halsey, J., Rokouzzaman, M., Saha, B. and Moniruzzaman, M. 2017. Effect of salinity intrusion on food crops, livestock, and fish species at Kalapara Coastal Belt in Bangladesh. *J. Food Qual.* 2017, 1–23.
- Alexandratos, N. and Bruinsma, J. 2012. World agriculture towards 2030/2050: the 2012 revision. ESA Working paper 2012; No. 12–03. Rome, Italy: FAO. Available via <http://www.fao.org/3/a-ap106e.pdf> (Accessed 23 September 2019).
- Auvigne, V., Leneveu, P., Jehannin, C., Peltoniemi, O. and Sallé, E. 2010. Seasonal infertility in sows: a five year field study to analyze the relative roles of heat stress and photoperiod. *Theriogenology* 74, 60–66.
- Bary, M.A., Ali, M.Z., Chowdhury, S., Mannan, A., Nur e Azam, M., Moula, M.M., Bhuiyan, Z.A., Shaon, M.T. and Hossain MA. 2018. Prevalence

- and molecular identification of haemoprotozoan diseases of cattle in Bangladesh. *Adv. Anim. Vet. Sci.* 6, 176–182.
- Bernabucci, U., Colavecchia, L., Danieli, P.P., Basiricò, L., Lacetera, N., Nardone, A. and Ronchi, B. 2011. Aflatoxin B1 and fumonisin B1 affect the oxidative status of bovine peripheral blood mononuclear cells. *Toxicol. Vitro* 25, 684–691.
- Bernabucci, U., Lacetera, N., Basiricò, L., Ronchi, B., Morera, P., Serene, E. and Nardone, A. 2006. Hot season and BCS affect leptin secretion of periparturient dairy cows. *Dairy Sci.* 89, 348–349.
- Bett, B., Kiunga, P., Gachohi, J., Sindato, C., Mbotha, D., Robinson, T., Lindahl, J. and Grace, D. 2017. Effects of climate change on the occurrence and distribution of livestock diseases. *Prev. Vet. Med.* 137, 119–129.
- Caminade, C., McIntyre, K.M. and Jones, A.E. 2019. Impact of recent and future climate change on vector-borne diseases. *Ann. N. Y. Acad. Sci.* 137, 119–129.
- Chen, C.C., McCarl, B. and Chang, C.C. 2012. Climate change, sea level rise and rice: global market implications. *Clim. Change* 110, 543–560.
- Chihota, C.M., Rennie, L.F., Kitching, R.P. and Mellor, P.S. 2001. Mechanical transmission of lumpy skin disease virus by *Aedes aegypti* (Diptera: Culicidae). *Epidemiol. Infect.* 126, 317–321. Available via doi:10.1017/s0950268801005179
- Chirico, J., Jonsson, P., Kjellberg, S. and Thomas, G. 1997. Summer mastitis experimentally induced by *Hydrotaea irritans* exposed to bacteria. *Med. Vet. Entomol.* 11, 187–192. Available via doi:10.1111/j.1365-2915.1997.tb00312.x
- Chowdhury, R., Sen, A., Kar, J. and Nath, S.K. 2017. Prevalence of gastrointestinal parasitism of cattle at Chandaniash Upazilla, Chittagong, Bangladesh. *Int. J. Adv. Res. Biol. Sci.* 4, 144–149.
- Cook, N.B. and Nordlund, K.V. 2009. The influence of the environment on dairy cow behavior, claw health and herd lameness dynamics. *Vet. J.* 179, 360–369.
- Cook, N.B., Nordlund, K.V. and Oetzel, G.R. 2004. Environmental influences on claw horn lesions associated with laminitis and subacute ruminal acidosis in dairy cows. *J. Dairy Sci.* 87, E36–E46.
- Coppock, R.W., Christian, R.G. and Jacobsen, B.J. 2018. Aflatoxins. In *Veterinary toxicology*, 3rd ed. Chapter 69—basic and clinical principles. Eds., Gupta, R.C. Cambridge, MA: Academic Press, pp: 983–994.
- Dann, H.M., Morin, D.E., Bollero, G.A., Murphy, M.R. and Drackley, J.K. 2005. Prepartum intake, postpartum induction of ketosis and periparturient disorders affect the metabolic status of dairy cows. *J. Dairy Sci.* 88, 3249–3264.
- Dastagir, M.R. 2015. Modeling recent climate change induced extreme events in Bangladesh: a review. *Weather Clim. Extrem.* 7, 49–60.
- De, A., Das, T.K., Chand, K., Debnath, B.C., Dey, S., Hemadri, D., Barman, N.N., Chaudhary, J.K., Muthuchelvan, D., Saxena, A. and Tewari, N. 2019. Seroprevalence of bluetongue and presence of viral antigen and type-specific neutralizing antibodies in goats in Tripura, a state at Indo-Bangladesh border of northeastern India. *Trop. Anim. Health Prod.* 51, 261–265.
- DLS (Department of Livestock Services). 2019. Livestock economy at a glance, Department of Livestock Services. Available via <http://www.dls.gov.bd/site/page/22b1143b-9323-44f8-bfd8-647087828c9b/Livestock-Economy> (Accessed 23 September 2019).
- Du Preez, J.H., Giesecke, W.H. and Hattingh, P.J. 1990. Heat stress in dairy cattle and other livestock under southern African conditions. 1. Temperature humidity index mean values during the four main seasons. *J. Vet. Res.* 57, 77–87.
- Eckstein, D., Hutfils, M.L. and Winges, M. 2018. Global climate risk index 2019. Bonn, Germany: Germanwatch eV. Available via www.germanwatch.org/en/crri (Accessed 23 September 2019).
- Fakruddin, M., Chowdhury, A., Hossain, M.N. and Ahmed, M.M. 2015. Characterization of aflatoxin producing aspergillus flavus from food and feed samples. *SpringerPlus* 4, 159.
- Forastiere, F. 2010. Climate change and health: a challenge for epidemiology and public health. *Int. J. Public Health* 55, 83–84.
- Fox, N.J., Marion, G., Davidson, R.S., White, P.C. and Hutchings, M.R. 2012. Livestock helminths in a changing climate: approaches and restrictions to meaningful predictions. *Animals* 2, 93–107.
- Fox, N.J., Marion, G., Davidson, R.S., White, P.C. and Hutchings, M.R. 2015. Climate-driven tipping points could lead to sudden, high-intensity parasite outbreaks. *Royal. Soc. Open Sci.* 2, 140296.
- Ghosh, P.K., Kader, M.A., Riaz, M. and Rahman, M.M. 2016. Retrospective study on parasitic diseases of cattle at Mymensingh district of Bangladesh. *Vet. Res. Int.* 4, 144–147.
- Grace, D., Bett, B., Lindahl, J. and Robinson, T. 2015. Climate and livestock disease: assessing the vulnerability of agricultural systems to livestock pests under climate change scenarios. CCAFS Working Paper no. 116. Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Available via <https://ccafs.cgiar.org/publications/climate-and-livestock-disease-assessing-vulnerability-agricultural-systems-livestock-0#.XYi8vEYzBIU> (Accessed 23 September 2019).
- Haider, N., Sturm-Ramirez, K., Khan, S.U., Rahman, M.Z., Sarkar, S., Poh, M.K., Shivaprasad, H.L., Kalam, M.A., Paul, S.K., Karmakar, P.C. and Balish, A. 2017. Unusually high mortality in waterfowl caused by highly pathogenic avian

- influenza A (H5N1) in Bangladesh. *Transbound. Emerg. Dis.* 64, 144–156.
- Hamid, M.A., Rahman, A., Zaman, M.A. and Hossain, K.M. 2017. Cattle genetic resources and their conservation in Bangladesh. *Asian J. Anim. Sci.* 11, 54–64.
- Harvell, C.D., Mitchell, C.E., Ward, J.R., Altizer, S., Dobson, A.P., Ostfeld, R.S. and Samuel, M.D. 2002. Climate warming and disease risks for terrestrial and marine biota. *Science* 296, 2158–2162.
- Henry, B., Charmley, E., Eckard, R., Gaughan, J.B. and Hegarty, R., 2012. Livestock production in a changing climate: adaptation and mitigation research in Australia. *Crop Pasture Sci.* 63, 191–202.
- Hoerr, F.J. 2017. Mycotoxicoses. In *Diseases of poultry*. Eds., Swayne D.E. John Wiley & Sons, Inc; Location: New Jersey, USA. Chapter 31. pp: 1271–1286. Available via doi:10.1002/9781119421481.ch31
- Howden, S.M., Crimp, S.J. and Stokes, C.J. 2008. Climate change and Australian livestock systems: impacts, research and policy issues. *Aust. J. Exp. Agric.* 48, 780–788.
- https://data.worldbank.org/indicator/EN.ATM.CO2E.PC?most_recent_value_desc=false (Accessed 26 March 2020).
- Hurst, P., Termine, P. and Karl, M. 2005. Agricultural workers and their contribution to sustainable agriculture and rural development. Rome, Italy: FAO. Available via <http://www.fao.org/tempref/docrep/fao/008/af164e/af164e00.pdf> (Accessed 23 September 2019).
- Iftekhar, M.S. and Islam, M.R. 2004. Managing mangroves in Bangladesh: a strategy analysis. *J. Coast. Conserv.* 10, 139–146.
- IPCC (Intergovernmental Panel on Climate Change). 2007. Climate change 2007: synthesis report. In Contribution of working groups I, II and III to the fourth assessment report of the intergovernmental panel on climate change. Eds., Pachauri, R.K. and Reisinger, A. Geneva, Switzerland: IPCC, p. 104. Available via <https://www.ipcc.ch/report/ar4/syr/> (Accessed 23 September 2019).
- IPCC (Intergovernmental Panel on Climate Change). 2013. Summary for policymakers. In Climate change 2013: the physical science basis. Eds., Stocker T.F., Qin D., Plattner G.K., Tignor M., Allen S.K., Boschung J., Nauels A., Xia Y., Bex V. and Midgley P.M. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press. Available via <https://www.ipcc.ch/report/ar5/wg1/> (Accessed 23 September 2019).
- Islam, M.A., Rahman, A.K.M.A., Rony, S.A. and Islam, M.S. 2010. Prevalence and risk factors of mastitis in lactating dairy cows at Baghabari milk shed area of Sirajganj. *Bangl. J. Vet. Med.* 8, 157–162.
- Islam, S.S., Chakma, S., Akhter, A.T., Ibrahim, N., Talukder, F. and Chowdhury, G.A. 2018. Investigation of animal anthrax outbreaks in the human–animal interface at risky districts of Bangladesh during 2016–2017. *J. Adv. Vet. Anim. Res.* 5, 397.
- Karim, M.N., Munshi, S.U., Anwar, N. and Alam, M.S., 2012. Climatic factors influencing dengue cases in Dhaka city: a model for dengue prediction. *Indian J. Med. Res.* 136, 32–39.
- Karim, M.R., Mahmud, M.S. and Giasuddin M. 2015. Epidemiological study of bovine fasciolosis: prevalence and risk factor assessment at Shahjadpur Upazila of Bangladesh. *Immunol. Infect. Dis.* 3, 25–29.
- Kim, M.K., Pyo, K.H., Hwang, Y.S., Park, K.H., Hwang, I.G., Chai, J.Y. and Shin, E.H. 2012. Effect of temperature on embryonation of *Ascaris suum* eggs in an environmental chamber. *Korean J. Parasitol.* 50, 239.
- King, J.M., Parsons, D.J., Turnpenny, J.R., Nyangaga, J., Bakari, P. and Wathes, C.M. 2006. Modelling energy metabolism of Friesians in Kenya smallholdings shows how heat stress and energy deficit constrain milk yield and cow replacement rate. *Anim. Sci.* 82, 705–716.
- Lacetera, N. 2012. Effect of environment on immune functions. In *Environmental physiology of livestock*. Eds., Collier, R.J. and Collier, J.L. Chichester, UK: Wiley-Blackwell, pp: 165–179.
- Lacetera, N. 2019. Impact of climate change on animal health and welfare. *Anim Front.* 9, 26–31.
- Lacetera, N., Bernabucci, U., Scalia, D., Ronchi, B., Kuzminsky, G. and Nardone, A. 2005. Lymphocyte functions in dairy cows in hot environment. *Int. J. Biometeorol.* 50, 105–110.
- Lecchi, C., Rota, N., Vitali, A., Cecilian, F. and Lacetera N. 2016. In vitro assessment of the effects of temperature on phagocytosis, reactive oxygen species production and apoptosis in bovine polymorphonuclear cells. *Vet. Immunol. Immunopathol.* 182, 89–94.
- LPHSI. 1990. Livestock and poultry heat stress indices agriculture engineering technology guide. Clemson, SC: Clemson University.
- Lykkesfeldt, J. and Svendsen, O. 2007. Oxidants and antioxidants in disease: oxidative stress in farm animals. *Vet. J.* 173, 502–511.
- Mahmood, S.A.I. 2012. Impact of climate change in Bangladesh: the role of public administration and governments integrity. *J. Ecol. Nat. Environ.* 4, 223–240.
- Mannaa, M. and Kim, K.D. 2017. Influence of temperature and water activity on deleterious fungi and mycotoxin production during grain storage. *Mycobiology* 45, 240–254.
- Marai, I.F.M., Ayyat, M.S. and El-Monem, U.A. 2001. Growth performance and reproductive traits at

- first parity of New Zealand White female rabbits as affected by heat stress and its alleviation under Egyptian conditions. *Trop. Anim. Health. Prod.* 33, 451–462.
- McCullough, A.K. and Lloyd, R.S. 2019. Mechanisms underlying aflatoxin-associated mutagenesis–implications in carcinogenesis. *DNA Repair* 77, 76–86.
- Mirzad, A.N., Tada, T., Ano, H., Kobayashi, I., Yamauchi, T. and Katamoto, H. 2017. Seasonal changes in serum oxidative stress biomarkers in dairy and beef cows in a daytime grazing system. *J. Vet. Med. Sci.* 17, 0321.
- Mohsenipour, M., Shahid, S., Chung, E.S. and Wang, X.J. 2018. Changing pattern of droughts during cropping seasons of Bangladesh. *Water Resour. Manag.* 32, 1555–1568.
- Mondal, S. and Reddy, I.J. 2018. Impact of climate change on livestock production. In *Biotechnology for sustainable agriculture emerging approaches and strategies*, Eds., Singh, R.L. and Mondal, S. Cambridge, UK: Woodhead Publishing, pp: 236–245. doi:10.1016/B978-0-12-812160-3.00008-8
- Nardone, A., Lacetera, N., Bernabucci, U. and Ronchi, B. 1997. Composition of colostrum from dairy heifers exposed to high air temperatures during late pregnancy and the early postpartum period. *J. Dairy Sci.* 80, 838–844.
- Nardone, A., Ronchi, B., Lacetera, N., Ranieri, M.S. and Bernabucci, U. 2010. Effects of climate change on animal production and sustainability of livestock systems. *Livest. Sci.* 130, 57–69.
- Nath, T.C., Islam, K.M., Ilyas, N., Chowdhury, S.K. and Bhuiyan, J.U. 2016. Assessment of the prevalence of gastrointestinal parasitic infections of cattle in hilly areas of Bangladesh. *World Sci. News* 59, 74–84.
- Nichi, M., Bols, P.E.J., Züge, R.M., Barnabe, V.H., Goovaerts, I.G.F., Barnabe, R.C. and Cortada, C.N.M. 2006. Seasonal variation in semen quality in *Bos indicus* and *Bos taurus* bulls raised under tropical conditions. *Theriogenology* 66, 822–828.
- Nwangburuka, C.C., Denton, L., Chioma, G.O., Oyekale, K.O., Tayo, G.O., Ajayi, B., Olarinmoye, A.O., Ezekiel, C., Taiwo, E.A. and Babalola, O.O. 2019. Effect of levels of equisetin and fumonisin mycotoxins on blood parameters of broiler chicks. *Mycopath.* 15, 55–59.
- Nzalawahe, J., Kassuku, A.A., Stothard, J.R., Coles, G.C. and Eisler, M.C. 2014. Trematode infections in cattle in Arumeru District, Tanzania are associated with irrigation. *Parasite. Vector.* 7, 107.
- O'Mara, F.P. 2012. The role of grasslands in food security and climate change. *Ann. Bot.* 110, 1263–1270.
- O'Neill, J. 2016. Tackling drug-resistant infections globally: final report and recommendations. London, UK: HM Government and Wellcome Trust. Available via https://amr-review.org/sites/default/files/160518_Final%20paper_with%20cover.pdf (Accessed 23 September 2019).
- OIE . 2019. Lumpy skin disease, Bangladesh, Available via https://www.oie.int/wahis_2/public/wahid.php/Reviewreport/Review?page_refer=MapFullEventReport&reportid=31742 (Accessed 23 September 2019).
- Ortiz, C.A. 1994. Sea-level rise and its impact on Bangladesh. *Ocean Coast. Manag.* 23, 249–270.
- Paul, A., Baishnab, P.C., Kobir, H., Akhter, S., Chowdhury, T.J., Jha, B. and Matiur, M.M. 2016. Status of internal parasitism of cattle at Sylhet Government Dairy Farm, Bangladesh. *Int. J. Nat. Sci.* 6, 54–34.
- Pfeiffer, D., Pepin, M., Wooldridge, M., Schudel, A., Pensaert, M., Collins, D., Baldet, T., Davies, G., Kemp, A., Martin, V. and Paweska, J. 2005. The risk of a Rift Valley fever incursion and its persistence within the community. *EFSA J.* 238, 1–128.
- Prothomalo. 2019. Number of Aedes mosquitoes increased by 13 times in city. Available via <https://en.prothomalo.com/bangladesh/Number-of-Aedes-mosquitoes-increased-by-13-times> (Accessed 27 September 2019).
- Purusothaman, M.R., Thiruvenkadan, A.K. and Karunanithi, K. 2008. Seasonal variation in body weight and mortality rate in Mecheri adult sheep. *Livestock Res. Rural Dev.* 20, 150.
- Rao, P.P., Hegde, N.R., Reddy, Y.N., Krishnajyothi, Y., Reddy, Y.V., Susmitha, B., Gollapalli, S.R., Putty, K. and Reddy, G.H. 2016. Epidemiology of bluetongue in India. *Transbound. Emerg. Dis.* 63, e151–e164.
- Reddy, C.S., Pasha, S.V., Jha, C.S., Diwakar, P.G. and Dadhwal, V.K. 2016. Development of national database on long-term deforestation (1930–2014) in Bangladesh. *Glob. Planet. Change* 139, 173–182.
- Regnier, J.A. and Kelley, K.W. 1981. Heat-and cold-stress suppresses in vivo and in vitro cellular immune responses of chickens. *Am. J. Vet. Res.* 42, 294–299.
- Rousham, E.K., Islam, M.A., Nahar, P., Lucas, P.J., Naher, N., Ahmed, S.M., Nizame, F.A. and Unicomb, L. 2019. Pathways of antibiotic use in Bangladesh: qualitative protocol for the PAUSE study. *BMJ Open* 9, e028215.
- Sarker, R.D., Giasuddin, M., Chowdhury, E.H. and Islam, M.R. 2017. Serological and virological surveillance of avian influenza virus in domestic ducks of the north-east region of Bangladesh. *BMC Vet. Res.* 13, 180.
- Sawalhah, M.N., Holechek, J.L., Cibils, A.F., Geli, H.M. and Zaied, A. 2019. Rangeland livestock production in relation to climate and vegetation trends in New Mexico. *Angeland Ecol. Manag.* 72, 832–845.

- Shearer, J.K. 1999. Foot health from a veterinarian's perspective. Proc. Feed Nutr. Manag. Cow Coll. Virg. Tech. 33–43.
- Staples, C.R. and Thatcher, W.W. 2011. Heat stress: effects on milk production and composition. In: Encyclopedia of dairy sciences, 4 vols, 2nd edn. Oxford, UK, Academic Press, pp: 561–566.
- Stephenson, D.B., Diaz, H.F. and Murnane, R.J. 2008. Definition, diagnosis, and origin of extreme weather and climate events. Clim. Extrem. Soc. 340, 11–23.
- Stewart, B.M., Block, J., Morelli, P., Navarette, A.E., Amstalden, M., Bonilla, L., Hansen, P.J. and Bilby, T.R. 2011. Efficacy of embryo transfer in lactating dairy cows during summer using fresh or vitrified embryos produced in vitro with sex-sorted semen. J. Dairy Sci. 94, 3437–3445.
- Stone, W.C. 2004. Nutritional approaches to minimize subacute ruminal acidosis and laminitis in dairy cattle. J. Dairy Sci. 87, E13–E26.
- St-Pierre, N.R., Cobanov, B. and Schnitkey, G. 2003. Economic losses from heat stress by U.S. livestock industries. J. Dairy Sci. 86, E52–E77.
- Talukder, M.A., Rahman, S.M., Miah, M.A., Shahjahan, M., Ali, M.Y., Alam, M.A., Kabir, M.H., Munira, S., Billah, M.M. and Habib, M.R. 2018. Prevalence of different dairy cattle diseases in selected dairy areas and farms of Bangladesh. Asian-Australas J. Biosci. Biotechnol. 3, 331–336.
- Thornton, P.K., van de Steeg, J., Notenbaert, A. and Herrero, M., 2009. The impacts of climate change on livestock and livestock systems in developing countries: a review of what we know and what we need to know. Agric. Syst. 101, 113–127.
- Tjaden, N.B., Caminade, C., Beierkuhnlein, C. and Thomas, S.M. 2018. Mosquito-borne diseases: advances in modelling climate-change impacts. Trends Parasitol. 34, 227–245.
- Trevisan, M., Browne, R., Ram, M., Muti, P., Freudenheim, J., Carosella, A.M. and Armstrong, D., 2001. Correlates of markers of oxidative status in the general population. Am. J. Epidemiol. 154, 348–356.
- UNDESA. 2017. World population prospects, the 2017 Revision, Volume I: comprehensive tables. New York United Nations Department of Economic & Social Affairs. 2017. Available via <https://www.un.org/development/desa/publications/world-population-prospects-the-2017-revision.html> (Accessed 23 September 2019).
- UNFCCC. 1992. Definitions of climate change. 7. Available via https://unfccc.int/files/essential_background/background_publications_htmlpdf/application/pdf/conveng.pdf (Accessed 23 September 2019).
- Visschers, V.H. 2018. Public perception of uncertainties within climate change science. Risk Anal. 38, 43–55.
- Vitali, A., Bernabucci, U., Nardone, A. and Lacetera, N. 2016. Effect of season, month and temperature humidity index on the occurrence of clinical mastitis in dairy heifers. Adv. Anim. Biosci. 7, 250–252.
- Vitali, A., Felici, A., Esposito, S., Bernabucci, U., Bertocchi, L., Maresca, C., Nardone, A. and Lacetera, N. 2015. The effect of heat waves on dairy cow mortality. J. Dairy Sci. 98, 4572–4579.
- Vitali, A., Segnalini, M., Bertocchi, L., Bernabucci, U., Nardone, A. and Lacetera, N. 2009. Seasonal pattern of mortality and relationships between mortality and temperature-humidity index in dairy cows. J. Dairy Sci. 92: 3781–3790.
- West, J.W. 2003. Effects of heat-stress on production in dairy cattle. J. Dairy Sci. 86, 2131–2144.
- White, N., Sutherst, R.W., Hall, N. and Whish-Wilson, P., 2003. The vulnerability of the Australian beef industry to impacts of the cattle tick (*Boophilus microplus*) under climate change. Clim. Change 61, 157–190.
- WHO. 2008. Anthrax in humans and animals. Geneva, Switzerland: World Health Organization. Available via <https://www.who.int/csr/resources/publications/AnthraxGuidelines2008/en/> (Accessed 23 September 2019).
- Wittmann, E.J., Mellor, P.S. and Baylis, M. 2001. Using climate data to map the potential distribution of *Culicoides imicola* (Diptera: Ceratopogonidae) in Europe. Rev. Sci. Tech. OIE 20, 731–740.
- Wolfenson, D., Roth, Z. and Meidan R. 2000. Impaired reproduction in heat-stressed cattle: basic and applied aspects. Anim. Reprod. Sci. 60, 535–547.
- Woods, J.A. 1988. Lumpy skin disease-A review. Trop. Anim. Health Prod. 20, 11–17.
- World Bank. 2014. World Bank data on CO2 emissions (metric tons per capita) https://data.worldbank.org/indicator/EN.ATM.CO2E.PC?most_recent_value_desc=false (accessed 23 September 2019).
- World Population Review. 2019; <http://worldpopulationreview.com/countries/bangladesh-population/> (Accessed 23 September 2019).
- Zähner, M., Schrader, L., Hauser, R., Keck, M., Langhans, W. and Wechsler, B. 2004. The influence of climatic conditions on physiological and behavioral parameters in dairy cows kept in open stables. Anim. Sci. 78, 139–147.