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The impact of climate change and other factors on zoonotic diseases

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Abstract

Approximately 60% of emerging human pathogens are zoonoses. The complex nature of the human-animal interface is constantly influenced by the effects of climate change, anthropogenic and natural factors. Geoclimatic change most markedly affects zoonotic diseases transmitted by arthropod vectors. Travel, tourism and trade are the major human factors impacting the epidemiology of zoonotic diseases. The re-emergence of zoonotic diseases is also driven by pathogen adaptation and animal migration. All these factors converge to make zoonotic diseases such as West Nile fever and Lyme disease of great public health concern in the developed world. However, the effects of climate change are predicted to be worse for the developing world where challenging socioeconomic and political environments are exacerbated by a lack of epidemiological studies on zoonotic diseases.

Keywords: Climate change, Zoonotic diseases, Zoonoses

Introduction

Interactions at the animal-human interface are increasingly recognized as the source for potential epidemics and the generation of novel pathogens. It has been estimated that 60% of emerging human pathogens are zoonotic [1]. For the purposes of this review a zoonotic disease is defined as one that is transmitted from animals to humans, occurs naturally in animals and is not well adapted to human to human transmission [2].

The World Health Organization defines an emerging zoonosis as one that is "newly recognized or newly evolved, or that has occurred previously but shows an increase in incidence or expansion in geographical, host or vector range" [3]. The distribution and incidence of zoonotic diseases relate, in part, to their degree of climate sensitivity [4]. The contributing factors leading to the emergence and spread of zoonotic diseases are due to pathogen, host and vector or ecological determinants and in many scenarios a combination of the above factors.

This article aims to review the current literature on the impact of climate change, human and natural factors on zoonotic diseases, with an emphasis on developing countries.

Global warming and climate change

The influence of geoclimatic change on zoonotic disease epidemiology is evident by changes in reservoir and vector dynamics. Climatic variation creates new ecological niches for vectors hence altering temporal and spatial distribution of disease [5].

Land temperatures

Global temperatures are rising at an unprecedented rate and this is mostly attributed to the anthropogenic emission of greenhouse gases. Temperature increases of 0.2°C per decade has been projected by the Intergovernmental Panel on Climate Change with a predicted mean temperature rise ranging between 1.8°C and 4°C by the end of the 21st century [6].

Vector distribution and therefore disease risk is expected to increase for vector-borne zoonotic diseases. Arthropod vectors are the most sensitive to climatic temperature variability. Mosquitoes, ticks and sandflies are ectothermic and have life cycles that are dependent on ambient temperatures. Disease transmission is likely to occur if there are changes at the ex-

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tremes of temperature (14-18°C at the lower end and 35-40°C at the upper end). Vector densities are expected to be their greatest at 30-32°C [7].

Temperature has a direct effect on mosquitoes. It leads to increased activity, increased reproduction and therefore increased frequency of blood meals and faster digestion of blood [8]. Pathogens harboured by mosquitoes also mature faster. Increased water temperature cause mosquito larvae to develop faster also increasing overall vector capacity [9]. The density of the competent vector *Aedes albopictus* in Italy contributed to the first outbreak of Chikungunya infection in a temperate climate [10].

Warmer climates allow ticks to survive at higher latitudes and altitudes. Brownstein et al used a climate suitability model, and found potential expansion of tick populations causing Lyme disease [11]. Higher temperatures increase the developmental rate of ticks and the over-winter survival rate is also increased. However it has been postulated that earlier arrival of spring may not necessarily be advantageous to ticks as vertebrate numbers at that time may still be low. Humans however, may be at higher risk for tick bites, as ticks will bite earlier and for longer periods [12].

The effect of global warming can also be seen in leishmaniasis transmission with sandflies as vectors. Sandflies are more active at higher temperatures and take more frequent bloodmeals, which in turn increases transmission. Increased temperatures also increase the development of leishmania parasites [13]. The vectors spread into neighbouring regions as shown by the potential spread of leishmaniasis in North America due to vector distribution and expansion [14].

Rodents are the main reservoir in hantavirus infections. With warmer climates and decreasing snowfall, the protective environment provided by snow is removed and rodents seek shelter within human habitats, increasing transmission of hantavirus, as seen in Scandinavia [15].

Ocean temperatures, sea level and acidity

As a consequence of rising sea temperatures, melting of polar ice caps and glaciers, increase in sea levels is also of concern. Rising sea levels will lead to coastal flooding and risks for water-borne zoonoses. Carbon uptake by the oceans leads to a decrease in pH and marine ecosystems are being threatened [6].

Rainfall patterns

The effect of precipitation on vectors is indirect. Increased precipitation creates more potential breeding sites for mosquitoes. The vegetation is dense after rainfalls and this provides shelter and resting grounds for vectors [7].

Outbreaks of Rift Valley fever (RVF) are associated with periods following heavy rainfall. *Aedes* spp. are the most important mosquito vectors and they have a transovarial transmission of virus. They are floodwater breeders and eggs are deposited during heavy rains. These eggs remain viable even during periods of droughts and hatch when conditions are favourable again. Heavy rainfall and larval development creates increased vector capacity and outbreaks occur if vertebrate reservoirs are available. *Culex* and *Anopheles* spp. can then serve as secondary vectors for propagation of the outbreak. Inter-epizootic periods can last for 5-35 years [8]. Heavy rainfalls are predicted for East Africa and therefore more RVF outbreaks. RVF in West Africa will be less affected by climate change and disease emergence may be due to decreasing herd immunity [16].

In general, increased rainfall leads to more crops and food, which may increase rodent populations and rodent-borne zoonoses. Flooding increases the risk of water-borne zoonoses. Heavy rains upstream to water treatment plants may have contributed to the cryptosporidium outbreak in Milwaukee, USA [17].

Chikungunya and West Nile outbreaks may be associated with heavy rainfalls and even with periods of drought. Droughts decrease the mosquito predators, increasing vector abundance post-drought, and the concentration of reservoir hosts around watering holes facilitates ease of disease transmission [18].

Other extreme weather events

The El Niño-Southern Oscillation (ENSO) cycle is a global climatic phenomenon consisting of hot and warm phases and contributing to increased extreme weather events [19]. The ENSO has contributed to heavy rainfalls and Rift Valley fever outbreaks in East Africa [20]. ENSO and global warming is also expected to influence fascioliasis in the Andes [21]. However, the impact of global warming on the ENSO is as yet unknown [22].

Soil conditions

Soil moisture is a factor in the developmental stages of ticks, with mortality related to dry conditions and soil evaporation. However, hyalomma ticks, the vector for Crimean-Congo haemorrhagic fever, are more adapted to surviving in dry conditions than other ticks [12].

Soil composition determines the distribution of *Bacillus anthracis* spores. Optimal soil factors include humus rich, high calcium and alkaline (pH>6.1) conditions for spore survival [23]. The occurrence of disease also requires susceptible vertebrate hosts and human factors.

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Human factors

There are various anthropogenic factors leading to the emergence, persistence and spread of zoonotic diseases.

Travel and tourism

The ease of transmission of emerging pathogens is facilitated by intercontinental travel. Efficient air and land travel links make disease containment difficult as illustrated by the SARS-coronavirus outbreak [24].

Tourism to more exotic locations and eco-adventure travel is gaining popularity. Volunteer work is also common in Africa and Asia. This exposes non-immune travelers to endemic diseases. Adventure sports expose athletes to "recreational zoonoses". Water sports e.g. canoeing, kayaking, river rafting has been related to leptospirosis outbreaks as animals shed the organism in their urine [25].

Trade

Globalization has seen goods transported via air, rail, sea and land to any virtually any destination on the planet. The trade in used tyres provided the breeding ground for mosquitoes adapted to urban environments and small-container breeding (*Aedes aegypti* and *Aedes albopictus*). This allowed the rapid invasion of the Asian tiger mosquito and thus a shift from the historical sylvatic transmission of chikungunya to cause widespread human epidemics [20].

Live animal markets in Asia bring multiple exotic species in close contact creating a melting pot for inter-species disease transmission. In the case of the SARS coronavirus (SARS-CoV) outbreak in Guangdong Province, civet cats were found to harbour coronaviruses with 99% similarity to the outbreak strain [26]. Although they are not the natural reservoirs, civet cats played a role in transmission to humans which originated in these trading markets.

Pets

Zoonotic transmission of diseases harboured by companion animals is relating to the close contact with their owners. Human salmonellosis is associated with keeping exotic reptile pets. Petting zoos are popular in urban areas and animal contact has lead to *Escherichia coli* O157:H7 outbreaks [27].

The recent emergence of zoonotic leishmaniasis in Europe is partly due to the domestic dog being the major reservoir host. *Leishmania infantum* causes cutaneous and visceral leishmaniasis in the Mediterranean region and may spread due to travel and importation of infected dogs [13].

Domestic cats are the main reservoir for *Bartonella* spp. Diseases including Cat -scratch disease, bacillary angiomatosis and peliosis are therefore likely to persist and even increase as the reservoirs are unlikely to be eliminated [28].

Agricultural practices and Livestock farming

The human population explosion creates increased demand for food and increased land use for agriculture and livestock farming which disrupts natural ecosystems.

Dams and canal built for agricultural practices are potentially new breeding sites for mosquito vectors.

Large scale animal husbandry is rising to compensate for consumer demand. The large numbers of animals or multiple species being farmed together facilitate infection across species barriers [1]. Farming animals allows new pathogens to increase their numbers exponentially. This 'high intensity' farming allows pathogens e.g. *E.Coli* O157:H7 strains that may occur in small numbers to spread rapidly.

Domestic animals themselves are reservoirs of zoonotic diseases. Voss et al described one of the first cases of pig-farming related methicillin-resistant *Staphylococcus aureus* (MRSA) in the Netherlands [29]. These porcine ST398 strains are non-typeable by conventional methods and are spreading throughout Europe. Farming is now considered a risk factor for Livestock-associated MRSA (LaMRSA).

Antibiotics used in livestock farming to improve growth and treat infection apply selective pressure leading to the emergence of antimicrobial resistant strains in livestock and poultry as will be discussed below [30].

Food-borne

Food-borne zoonotic pathogens are increasing due to large scale food production, food processing and distribution. Enterohaemorrhagic *E. Coli* O157:H7 outbreaks are associated with undercooked meat [30]. The emergence of flouroquinolone-resistant *Campylobacter* spp. was associated with antibiotic addition to chicken feed [31]. Multi-drug resistant strains of *Salmonella* spp. (*S.* Typhimurium DT104 and *S.* Newport) are also emerging [32,33].

Deforestation and Urban expansion

The loss of biodiversity due to deforestation has an impact on the transmission of zoonotic diseases by the "dilution effect". It is reasoned that in areas of high biodiversity, more species sustain vectors and the disease is diluted. If there are fewer species, the burden of disease is higher [34]. Wolfe et al describes how clear-cut logging doesn't increase the zoonoses risk, but selective logging may do so as the forest biodiversity is maintained [35].

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Deforestation alters ecosystems disrupts the natural balance between diverse species. New ecological niches are created for certain vectors e.g. water puddles in deforested areas have decreased acidity and are better breeding sites for mosquitoes [34].

Population expansion and the encroachment of human settlements into natural habitats increases the number of contacts between humans and wildlife and this facilitates ease of transmission of zoonotic diseases. In Malaysia, this has been illustrated in the transmission of *Plasmodium knowlesi* from macaques to humans [36].

Urbanization also attracts foreign settlers. Human migration for employment or asylum has the possibility of importation of new vectors or diseases. Human entering new frontiers also have no immunity to diseases in the new environment. In developing countries these settlements are generally informal with poor infrastructure and creates opportunities for rodent and tick borne zoonoses. The development of road and rail networks facilitates easier spread of emerging diseases. New roads bring rural, non-immune populations into contact with novel diseases [35].

Bushmeat and hunting

Hunting in the developing world is aided by the processes of deforestation and logging. The trade of bushmeat in some countries e.g. Cameroon has lead to increasing hunting activities. Hunting of non-human primates has historically been known to lead to the emergence of novel pathogens. The butchering of carcasses in forests, carry a high risk of transmission of airborne, droplet and contact spread zoonoses. The act of cooking and consuming the meat may be less of a risk [35].

Host susceptibility

Changes in human susceptibility to infections in general are increased with the advent of organ transplantation, immunosuppressive drugs, chemotherapy and the emergence of HIV/AIDS. Patients with HIV/AIDS have increased co-infections with leishmaniasis. Bacillary angiomatosis, peliosis and cryptosporidium are also more common [13, 28].

Political factors

Civil conflict, war and political instability leads to breakdown in health care infrastructure and public health control measures that may lead to an upsurge of infectious diseases in general e.g. poor vector control measures.

A decrease in the hunting of hares due to the World War 2 occupation of the Crimea lead to an increase in the hare population and a subsequent increase in the tick population. When Russian troops reoccupied the area they had no immunity and an outbreak of Crimean-Congo haemorrhagic fever occurred [16].

Natural factors

Although human and climate factors dominate the emergence and spread of zoonoses, pathogen characteristics and animal behaviour also need to be considered.

Pathogen adaptation

Zoonotic pathogens may acquire novel virulence traits that offer survival advantages. Chikungunya is an example of pathogen adaptation with the A336V mutation that is only found in strains from *A. albopictus* mosquitoes contributing to the recent outbreaks [20].

Antibiotic-resistance may emerge due to the selective pressure from antibiotic usage as seen in multi-drug resistant *Salmonella* spp. Multidrug-resistance *Yersinia pestis* has emerged in Madagascar [37].

Animal migration

RVF distribution is partly due to migration of herds. Any changes to this as a result of deforestation or changed land use may lead to the introduction of RVF in new areas.

Migration of wild birds is involved in WNF transmission. With alteration in seasons, changes in migration patterns and duration may be seen [16].

Wild aquatic birds are the natural reservoir for highly pathogenic avian influenza (HPAI) and these migratory birds have been shown to excrete and act as long distance vectors for HPAI [38].

Role of Wildlife

Opportunities for the emergence of zoonotic diseases depend on the frequency of contacts between wildlife species and humans. Some animals may be the known hosts for unknown pathogens that may cross the species barrier unexpectedly e.g. long-tailed and pig-tailed macaques are the known natural reservoir for *P. knowlesi* which has recently been found to be transmitted to humans by simio-anthropophagic *Anopheles cracens* mosquitoes [39].

Other known pathogens may have an as yet unknown animal source e.g. the discovery of SARS-like coronaviruses in bats as the likely natural reservoir for SARS-CoV [40]. This reflects the important role of this diverse and widespread species for emerging zoonotic diseases e.g. Hendra virus, Nipah virus, Marburg, Ebola and variant rabies.

Conclusion

West Nile fever, Chikungunya fever and Lyme disease are excellent examples of how climate change, anthropogenic and

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natural factors converge to result in the emergence of zoonoses. The emergence and spread of these diseases are generally well-described in the literature. The epidemiology of zoonotic diseases affecting Africa however, has not been as well documented.

Importantly, the outcomes of climate change will vary regionally with the effects being disproportionately felt in Africa [7, 41]. Africa has largely unexplored biodiversity that could see the discovery of yet unknown species as seen by the recent discovery of a novel arenavirus, the Lujo virus from a Zambian woman that lead to a nosocomial outbreak in South Africa [42]. Other challenges in Africa include poor vector control which is more difficult in remote rural populations and in outdoor breeding sites. A paucity of adequate healthcare and collapse of public health measures are common due to poverty and conflict. Cross-border mobility and immigration is another contributing factor in African countries with poor boundary controls. This has lead to the emergence of rabies in the Limpopo region of South Africa. Poor dog vaccine uptake by rural communities, high dog turnover with high numbers of susceptible animals and lack of resources are some of the other reasons for the outbreak in humans [43]. Movement of infected livestock from RVF endemic areas to non-endemic countries could see regional spread of the disease if competent vectors and reservoirs are also available.

To mitigate the impact of climate change on the world and especially on Africa, further studies on the epidemiology of zoonotic diseases are required with a focus on the effects in developing countries. The Centre for Diseases Control (CDC) has outlined 11 priority actions to address climate change, including identifying populations at greatest risk [44]. The establishment of baseline data in the vulnerable developing countries is imperative to enable further tracking and predictive models [45]. Multidisciplinary approaches and a concerted global effort are necessary to predict and prevent outbreaks and emerging zoonoses.

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