Environmental Change & Infectious Diseases

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Introduction

Since the 1940s, more than 335 infectious diseases have emerged globally, 60 to 80 percent of which have originated in animals. Although emergent diseases have caused deadly pandemics for millennia, these figures raise questions as to why zoonotic disease transmission to humans, and the often deadly pandemics which follow, have become the norm. Many factors are to blame, and while rapid and ongoing vaccine development and the strengthening of health systems are necessary channels for tackling the global spread of infectious diseases, we must also urgently address the conditions that allow for diseases to emerge or re-emerge in the first place. Crucially, environmental change and degradation have resulted in the disruption of the natural habitats of many animals. These disruptions mean that barriers between humans, animals, and the pathogens they carry are weakened. In other words, failure to prevent ongoing climate change, deforestation, and degradation of natural ecosystems will lead to a continued regularity of infectious disease outbreaks in humans. This paper outlines four modes of infectious disease transmission and emphasizes several types of environmental change which continue to fuel global disease emergence.
Infectious Disease Transmission

Four Main Types of Transmission

While it is essential to identify the type of pathogen responsible for an infection (e.g. virus, bacteria, protozoa), identifying the source of infection is fundamental to understanding how these pathogens spread to humans. Typically, infections are either anthroponotic (human source) or zoonotic (animal source), and within each of these categories, diseases are transmitted either directly or indirectly to humans.

**Anthroponoses**

**Direct Transmission**

Diseases may be transmitted from human to human through direct physical contact, or else via some type of material surface or matter (such as a door handle or table top). Examples of diseases transmitted directly between humans are HIV/AIDS, herpes, and other sexually-transmitted diseases, as well as tuberculosis, leprosy.
and measles. While direct human-to-human transmission is least tied to the physical environment, changes in ecosystems, land use, and weather patterns may affect human behaviours in such a way that risk for contact with pathogens is increased.

**Indirect Transmission**

Some anthroponoses are transmitted between humans indirectly, either via an intermediate, “vector” host, or via contact with contaminated water. Vector-borne anthroponoses include diseases like malaria, dengue, and Zika. Transmission is closely tied to the natural environment, with temperature, rainfall, and the abundance of vegetation all having an impact on the reproduction, survival, and biting rates of mosquitoes. Consumption or contact with contaminated water may also result in the transmission of diseases between humans, as is the cases for diseases such as cholera, schistosomiasis, and e. coli.

**Zoonoses**

**Direct Transmission**

Some animal diseases can be transmitted directly from animals to humans, often with subsequent human-to-human transmission. Some pathogens infect humans via animal bites or saliva, as is the case with rabies, while others such as avian influenza are airborne, infecting those working in close proximity to infected animals. Ebola is a complex zoonosis, transmitted to humans via close contact with the blood and other bodily fluids of infected wild animals such as primates and fruit bats. Changes to the environment which bring people in closer contact with wild animals are therefore of particular concern.

**Indirect Transmission**

Much like indirectly transmitted anthroponotic diseases, some zoonoses require water or vectors as intermediate pathogen hosts for transmission. Examples include Lyme disease and bubonic plague, transmitted from infected rodents to humans via tick and flea bites (respectively). West Nile virus is spread to humans by the bite of mosquitoes which have fed on infected birds. As with indirectly transmitted anthroponoses, the spread of these zoonoses is strongly linked to the environment and therefore sensitive to environmental changes which affect vector abundance.
Types of Environmental Change

Irrigation

Dramatic increases in the number of water resource development projects over the past seven decades have led to many global environmental transformations which have subsequent negative effects on human health. Irrigation canals and drainage networks can increase the availability of habitats for vector species across wide areas of farming land. Furthermore, the use of dams leads to yearlong water supply in some areas, allowing certain organisms to survive which would have normally perished during dry seasons. Irrigation has been developed in many countries without consideration for the effects on public health. Malaria, schistosomiasis, filariasis, Japanese Encephalitis, and onchocerciasis are all examples of high-burden diseases in such countries.

Resurgence of lymphatic filariasis in Egypt

Lymphatic filariasis (also known as elephantiasis) is a parasitic disease which weakens the lymphatic system and can cause extreme swelling and enlargement of the limbs, breasts, and scrotum. It is caused by microscopic worms which are spread from human to human by *Culex pipiens* mosquito bites. The Aswan High Dam, built in the 1960s in the southern Nile Delta, resulted in increased surface and sub-surface moisture and the subsequent rapid rise in the abundance of these *C. pipiens* mosquitoes. Consequently, prevalence of lymphatic filariasis in the region rose from less than one percent in 1965 to over twenty percent after the construction of the dam.
Agricultural Intensification

There are many examples of agricultural intensification leading to increased risk of zoonotic disease emergence. Intensification of livestock production itself (e.g., of swine and poultry) can facilitate transmission of certain diseases to those who work closely with livestock. However, agricultural intensification also leads to greater interaction between humans, livestock, and wildlife in zones where their ecosystems overlap. This increased interaction means that the spillover of previously unknown animal pathogens into livestock or humans is more likely. Furthermore, agricultural intensification may lead to overall biodiversity loss, causing environments to disproportionately favor specific pathogens, vectors, and/or hosts. Malaria, Venezuelan and Crimean-Congo haemorrhagic fevers, and Chagas disease are all examples of infectious diseases which have been able to spread more easily to humans due to agricultural intensification.

Chagas disease in Chile

Chagas disease is a potentially fatal disease caused by the Trypanosoma cruzi protozoan in the Americas. It is an indirectly transmitted zoonosis, primarily transmitted to humans by the insect vector Triatoma infestans, also known as the “kissing bug”, which is widespread in much of South America. Although Chagas disease is known to have infected humans as long as 9,000 years ago in northern Chile and southern Peru, it was primarily a disease of animals, with only accidental infection in humans, for the majority of human history. Only in the past two to three centuries has Chagas disease begun to pose a serious threat to humans. This relatively recent rise in the number of infections is largely due to the clearing of land for agriculture in endemic countries. Originally feeding predominantly on the blood of wild animals, agricultural intensification caused T. infestans to adapt to human-dominated environments and feed increasingly on humans and domestic animals. Today, Chagas disease is an endemic zoonosis in Chile and several other Latin American countries, with a reported incidence of up to 11 in 100,000 people in some regions as of 2017.
Urbanization

There are many ways in which the rapid urbanisation seen across the globe since the 18th century has led to the emergence and re-emergence of infectious diseases. While some aspects of living in a city are beneficial to human health (e.g., via higher incomes and better access to healthcare), there are often large discrepancies in health conditions between neighbourhoods within large cities. Over-crowded slum settlements characteristic of many rapidly expanding cities are often accompanied by poor sanitation, contaminated water supplies, lack of ventilation, and proximity to vectors and their breeding sites. Examples of diseases whose transmission has been facilitated by urbanization include cholera, dengue, Zika, severe acute respiratory syndrome (SARS), chikungunya, and cutaneous leishmaniasis. Alongside urbanization has come an increase in international air travel, which makes it easier for infected populations of mega-cities to come in contact with one another and potential vectors.

Zika virus in Brazil

Zika virus is transmitted to humans by Aedes mosquitoes, which also act as vectors for dengue and chikungunya viruses throughout the tropics. Although discovered in 1947 in Uganda, it was only in 2007 that a large outbreak was seen (in the Federated States of Micronesia). In 2013, the virus began to spread across other parts of Oceania and in 2015, a large outbreak in Latin America began in Brazil. The WHO declared Zika virus a Public Health Emergency of International Concern when it was discovered that infection during pregnancy can cause women to pass the virus to her foetus, potentially causing birth defects such as microcephaly. Although the peak of the outbreak has since passed, long-term disappearance of the disease is unlikely to occur without improvement of living conditions in the many slums across Brazilian and other South American cities.
Deforestation

Tropical deforestation has occurred at an alarming rate in recent decades, with over 1 million square kilometres of tropical forests cleared globally since 2000\textsuperscript{12}. As a consequence of this deforestation, humans have continued to interrupt the ecosystems of animals and insects, which often serve as hosts and vectors of infectious diseases. It is not only the movement of human populations into these ecosystems which causes the pathogens to spread from animals to humans. Forest clearing often results in a greater abundance of surfaces on which standing water may collect, thereby increasing the availability of breeding sites for certain mosquito vectors, for example. The ecosystem disruption caused by deforestation may also result in biodiversity loss, favouring the proliferation of some species of pathogen hosts and vectors over others. Ebola, malaria, visceral leishmaniasis, Lyme disease, Nipah virus, and oropouche are all examples of diseases whose emergence and spread have been affected by deforestation.

Nipah virus in Malaysia

The zoonotic Nipah virus is highly fatal in humans, resulting in a mortality rate of 40-75%\textsuperscript{13} with no effective vaccine yet developed. A large outbreak in Malaysia in 1998-1999 caused 265 cases of encephalitis and 105 deaths, with Nipah being spread via the movement of infected pigs between farms across the country\textsuperscript{14}. It was later discovered that the initial infection of pigs was likely from fruitbats, large populations of which had migrated in preceding years to orchards and pig farms due to deforestation of their native habitat.
Climate Change

For at least a decade, scientists have been deliberating the potential effects of climate change on infectious disease emergence and re-emergence. Although the exact response of infectious diseases to climate change will differ in a multitude of ways according pathogen, the message that disease risk will be modified in some way by changes in average temperatures and precipitation is clear. Examples of infectious diseases whose range and rate of spread have been and/or continue to be affected by climate change include hantavirus, red tide poisoning, and most vector-borne diseases.

Rift Valley fever in Kenya

Rift Valley fever is a mosquito-borne viral disease transmitted competently to humans by more than 30 species of mosquito. As with other vector-borne diseases, climate changes may impact all aspects of Rift Valley fever transmission, but rises in temperature and the consequent potential for increased mosquito abundance is of particular concern. While a low level of endemic transmission occurs in all rainy seasons, El Niño climate fluctuations have been associated with larger epidemics. An epidemic of haemorrhagic fever caused by Rift Valley fever was experienced in 1997–1998 in East Africa, namely north-eastern Kenya (where the disease was originally discovered in 1931). Another epidemic was seen in 2006; both were correlated with heavy rainfall due to El Niño. The increasing rainfall anticipated to occur in East Africa due to climate change means that many scientists assume the larger Rift Valley fever epidemics will continue to grow in frequency and severity.
Marine Pollution

Approximately forty percent of the global population lived within 100km from a coastline as of 2010\textsuperscript{18}. As such, coastal waters can become contaminated with pathogens via human and agricultural wastewater discharge from nearby communities, as well as from those communities which are near rivers and streams that flow into the sea. Humans then come into contact with these pathogens via recreational coastal activities (e.g., visits to the seashore), as well as via the consumption of seafood harvested from marine waters. These pathogens can result in outbreaks of gastrointestinal illness. Human viruses that have been identified in seawater include adenovirus, norovirus, enteroviruses, and hepatitis A\textsuperscript{19}. \textit{Staphylococcus aureus}, \textit{Salmonella}, and \textit{Pseudomonas} bacteria as well as \textit{Cryptosporidia} protozoa have also been found in seawater. The increased flooding many predict will be associated with climate change could also result in greater amounts of untreated wastewater discharge into coastal zones.

Norovirus in the United Kingdom

Norovirus, a highly contagious gastrointestinal infection, can lead to severe acute illness in humans characterised by fever, diarrhoea, abdominal pain, nausea, and vomiting. Coastal waters where shellfish are found can become contaminated with norovirus via wastewater discharge. Those marine environments which are near high-density human settlements are more likely to be contaminated, and the virus can persist in these environments for several days. Although proper cooking methods can inactivate norovirus, the consumption of raw shellfish such as oysters causes nearly 75,000 cases of norovirus in the UK each year\textsuperscript{20}. Continued human outbreaks of norovirus not only pose a threat to human health, but also to the UK aquaculture industry.

\textit{Figure 1. Shellfish areas and sewage outflow distribution in the UK. From Hassard et al. 2017\textsuperscript{20}.}
Ocean Warming

Approximately 90% of the excess heat added to the climate system since the 1960s has been estimated to be stored in the oceans. Bacterial pathogens which prefer warm seawater are of particular concern for human health. As such, certain areas of the globe may begin to see increased occurrence of pathogenic bacteria alongside the ocean warming associated with climate change. Vibrio species bacteria (of which Vibrio cholera is the most commonly associated) in particular have received increased attention as threats to the human populations in higher-latitude regions.

Vibrio bacterial infections in the Baltic Sea region

People living near the Baltic Sea have been suggested as being at particular risk for increasing illness from pathogenic vibrio bacteria due to ocean warming. The rate of warming of the Baltic Sea between 1987 and 2007 was sevenfold that of the global rate, making it the fastest warming marine ecosystem in the world. Although a low number of overall cases of human Vibrio infection were seen during these years, they were significantly associated with warmer sea temperatures.
Conclusion

Human activities are known to cause many detrimental effects to the environment, from local to global scales. These include biodiversity loss, climate change, species extinction and displacement, and habitat fragmentation. Importantly, ecosystems have been affected such that humans are increasingly coming into contact with the reservoirs and vectors of infectious pathogens. As such, addressing environmental degradation can have multiple benefits to human health, including the prevention of epidemics caused by emerging and re-emerging diseases. Combatting carbon emissions which lead to climate change, protecting biodiversity, supporting the development of clean water sources, and favouring sustainable agricultural and irrigation systems will be important tools in curbing the trend of pandemic disease becoming the global “norm”.
References


Endnotes

About The Rockefeller Foundation

For more than 100 years, The Rockefeller Foundation’s mission has been to promote the well-being of humanity throughout the world. Today, The Rockefeller Foundation pursues this mission through dual goals: advancing inclusive economies that expand opportunities for more broadly shared prosperity, and building resilience by helping people, communities and institutions prepare for, withstand, and emerge stronger from acute shocks and chronic stresses. To achieve these goals, The Rockefeller Foundation works at the intersection of four focus areas—advance health, revalue ecosystems, secure livelihoods, and transform cities—to address the root causes of emerging challenges and create systemic change. Together with partners and grantees, The Rockefeller Foundation strives to catalyze and scale transformative innovations, create unlikely partnerships that span sectors, and take risks others cannot—or will not.

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