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Editorial

Climate Change, Aquatic Ecosystems and Human Infectious Diseases in a Globalised World

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One of the greatest challenges that human society currently faces is the hazard of climate change with respect to human health. In this Special Issue, our aim is to update the information related to the impact of climate change on human infectious diseases, especially those in which the vectors or parasites are related to aquatic ecosystems. This Special Issue, entitled "Impacts of Climate Change on Human Infectious Diseases related to Water Ecosystems", includes studies about infectious diseases such as vibriosis and water contamination by coliforms [1,2], yellow fever [3], malaria [4] and cholera [5]. These studies, which are related to different diseases caused by viruses [3], bacteria [1,2,5] and protozoa [4], are all focused on the aquatic environment. Many aquatic ecosystems play a role in the distribution of pathogens through rivers and sea currents [1,2,5], and eventually affect drinking water sources. In other cases, the vectors that transmit the disease, such as mosquitoes, require natural or artificial liquid collections to complete their biological cycle. Therefore, state policies have been developed for the desiccation of liquid accumulations considered unhealthy, such as wetlands, rice fields, marshes, etc. [6], which have affected wide areas of coastal wetlands of great biodiversity value [7]. Moreover, changes in climatic tendencies can directly affect the pathogens or the vectors that transmit the disease, or indirectly, by influencing the conditions of the water surfaces that they require to proliferate or complete their biological cycle. Furthermore, the rise in sea level, as well as extreme events—such as storms and hurricanes—can facilitate the contamination of drinking water in coastal areas [1] or near great lakes, favoring the proliferation of pathogens associated with water. The studies grouped in this Special Issue, although they were carried out in America [1], Asia [2] and Europe [3,4], provide, as a whole, a global perspective [5], as they provide worldwide representative case studies. Moreover, some of the diseases addressed in these studies are transmitted by vectors [3,4], while others are not [1,2,5].

Understanding the link between climatic conditions and the transmission of infectious diseases requires global attention, due to their implications for our capacity to predict the time and magnitude of epidemic and/or pandemic outbreaks. An example of this, in our time, is the coronavirus disease (COVID-19) pandemic caused by SARS-CoV-2. Furthermore, understand this relationship better would allow for better modeling of the possible damage derived from climate change and its possible consequences in the short and medium range [8]. Thus, Table 1 presents a synthesis of the main infectious diseases related to the aquatic environment that repeatedly appear in expert panels about climate change, highlighting the main climatic variables involved.

Table 1. Main infectious diseases related to aquatic ecosystems and variables related to climate change that may be involved.

Disease	Agent	Transmission Mode	Variables Related to the Aquatic Environment that May Be Involved
Chikungunya	Chikungunya virus	Mosquito (*Aedes* spp.)	Increased temperatures (up to 40 °C) and rainfall
Cholera	*Vibrio cholerae*	Water	Increase in water and air temperature, extreme events associated with precipitation, ENSO, sea level rise, drought, salinity, etc.
Dengue	*Flavivirus*	Mosquito (*Aedes aegypti*, *A. albopictus*)	High temperature, humidity and rainfall
Fecal coliforms	*Escherichia*, etc.	Water	Increased temperatures
Leishmaniasis	*Leishmania* spp.	Sandflies (Phlebotominae)	Increases in temperature and rainfall (specially mean temperature of the coldest quarter, annual temperature range, temperature of the warmest quarter and precipitation of the warmest quarter)
Malaria	*Plasmodium*	Mosquito (*Anopheles* spp.)	Monthly temperatures of spring and summer (maximum, minimum and mean) and, to a lesser extent, precipitation and humidity.
Rift valley fever	*Phlebovirus*	Mosquito (*Aedes*, *Culex*)	Heavy rains
Vibriosis	*Vibrio*	Water	Extreme events related to precipitation (floods and overflows), storms, hurricanes, coastal water temperatures, etc.
West Nile Virus	*Flavivirus*	Mosquito (*Culex*, *Aedes*)	High temperatures and heavy precipitation
Yellow fever	*Flavivirus*	Mosquito (*Aedes aegypti*)	High temperature and heavy rain (specially humid winters and springs, warm summers)
Zika virus	*Flavivirus*	Mosquito (*Aedes* spp.)	Increased temperatures, ENSO

The data were gathered from the studies included in this Special Issue [1–5] and from some reviews [9–13]. Table 1 is not a thorough compilation of these infectious diseases related to aquatic ecosystems; it rather provides a general view of those which are gathered in different reports and expert panels. Therefore, the climate variables shown in it cannot have universal application, although they provide an orientation about the climate factors that may be influencing each disease. For readers who would like to consult a more detailed and comprehensive review of water-related infectious diseases, we recommend the review by Nichols et al. [13] and the WHO [10]. Of all the pathologies included in Table 1, the most important one, based on the number of diseased and deaths worldwide, is malaria, with 409,000 deaths and 229 million people infected, distributed over 87 countries, in the year 2019 alone [14].

This Special Issue includes two full studies related to hygiene and water; one of them addresses coastal ecosystems and the other tackles wells and rivers. Frank et al. [1] developed a relative risk evaluation model to determine the vulnerability to non-choleraic *Vibrio* spp. due to the floods caused by hurricanes and storms in South Carolina (USA). The authors concluded that the greatest risk is associated with coastal areas that are more exposed and more densely inhabited by vulnerable populations. On their part, Ochirbold et al. [2] evaluated the presence of total coliforms, fecal coliforms, and *Escherichia coli* bacteria in surface waters and wells of the Kharaa River (Mongolia). The authors attempted to establish associations between the increase in temperatures related to climate change and the hygienic quality of surface waters and shallow groundwater. Their results indicate that greater warming may increase the risk of microbiological contamination of the water, and they highlighted the importance of implementing hygiene and prevention measures.

Both studies show that vibriosis and diseases caused by fecal contamination of drinking water can have a relevant impact on the health of vulnerable sectors of the population in the context of climate change. Therefore, it is fundamental to develop strategies for prevention and risk monitoring networks based on models that study the potential impact of changes in climate conditions. According to these authors [2], different serious outbreaks of diseases that have been transmitted through water have been associated with extreme hydrometeorological events. An example of this is the incident of 1993, when cysts of *Cryptosporidium* passed from Lake Michigan to the drinking water, resulting in 52 deaths and more than 400,000 people being infected [15]. Another example is the Walkerton case (Canada), where very intense rains in the year 2000 contaminated the drinking water with enterhemorrhagic *E. coli* and *Campylobacter jejuni*.

Christaki et al. [5] analyzed the main risk factors of cholera infection linked to climate change, and how these factors can alter the expansion, propagation or potential of the disease. Moreover, they reviewed the main cholera pandemics throughout the 19th and 20th centuries, as well as the most relevant cholera strains and how different climate factors can favor its expansion. The obtained results show that pandemics of infectious diseases such as cholera occurred repeatedly during the 19th and 20th centuries, every certain period of time. During the 19th century, six pandemics took place, which were attributed to contaminated water from rivers or swampy waters, first in coastal populations, and later scattered by maritime activity. As in the case of the previous studies, the authors highlight the importance of monitoring and control through national, regional and global networks that generate epidemiological data about risk areas, both existing and emerging, of infections by *Vibrio*, with the aim of preventing future pandemics. Although there are networks currently working in some areas of the world, related to cholera and *Vibrio*, this network must be expanded and integrated in early-alert systems that include climate variables and remote sensing spatial data that allow us to estimate significant global climate tendencies relevant for institutional control.

Other studies are focused on infectious diseases transmitted by vectors, more specifically mosquitoes, whose life cycle is linked to inland aquatic ecosystems. This would be the case of *Aedes aegypti* and *Anopheles atroparvus*, as vectors that transmit yellow fever and malaria, respectively. In this sense, [3] analyzed the controversy around the climate causes of a yellow fever epidemic in the early 19th century in Southern Spain. This study shows that the climate conditions of Southern Spain in the year 1800 (humid winter and spring, warm summer) were adequate for the mosquito species *Aedes aegypti* and the epidemic outbreak. This author demonstrates the importance of historical epidemiology and historical climatology to better understand the complex relationships between climate and infectious diseases. Moreover, he shows that the scientific discussions that took place in the 19th century regarding this yellow fever outbreak contributed to improving the meteorological knowledge in Spain and promoted research on the local climate. In addition, the *Aedes* genus can also transmit other emerging and re-emerging infectious diseases such as dengue viruses, chikungunya virus or Zika virus. These mosquitoes are abundant and particularly important in urban environments, where they use natural and artificial water-holding containers for rearing of larvae and feed nearly exclusively on human [16].

Sousa et al. [4] analyzed the spatio-temporal distribution of malaria in Spain throughout the 19th and 20th centuries. This disease is caused by protozoa of the genus *Plasmodium* which, in the Spanish case, were transmitted through the sting of *Anopheles atroparvus* and, to a lesser extent, through *Anopheles labranchiae*. These authors combined very different data sources (historical epidemiological archives, meteorological records, georeferenced data of mosquitoes, relationships with aquatic ecosystems, etc.) and they integrated them through geographic information systems (GIS). The authors addressed autochthonous and imported malaria separately, highlighting that the drivers of both types of malaria are different. In fact, later studies showed that the effect of temperature as a driver of the phenology of autochthonous malaria cannot be directly extrapolated to cases of imported malaria [17]. This study concluded that the main epidemic outbreaks of malaria in Spain during the

20th century were greatly influenced by military conflicts, population movements and the worsening of hygienic and sanitary conditions. Although the meteorological variables did not play a key role in these epidemic episodes, they did contribute to the latter by creating the suitable conditions for their intensification [17]. Thus, the authors of [4] asserted that modern research on this type of infectious diseases must delve into the drivers that explain the historical distribution of the disease, with the aim of differentiating the relevance of each of them in the prevalence of malaria. In this sense, as in the article by Rodrigo about yellow fever [3], it is shown that historical studies can increase the knowledge on the regional or local distribution of vectors and provide a much better understanding about the effects of the meteorological variables. Despite the influence on epidemic outbreaks of some infectious diseases due to local climate conditions, it is very difficult to establish how such pathologies could be affected by climate change in the long term [18]. It is still a challenge to separate the role of the drivers and the interactions among them, requiring a large amount of spatio-temporal information.

From the combined reading of the studies presented in this Special Issue, some global reflections can be extracted to improve research and knowledge on infectious diseases related to aquatic ecosystems in the current context of climate change and globalization. One of the major challenges to society, in the new scenario of climate change in the 21st century, is to eradicate infectious diseases from traditionally endemic areas, to reduce the risk of re-emergence in wide regions in which they have been eradicated, and to limit their spreading to regions that have never been affected to date.

The significant changes in climate variables—such as temperature, humidity and more irregular precipitation—must be analyzed in the context of the current economic model, which implies intense and rapid changes in land uses in many countries (i.e., one of the determining factors of climate change). This economic model involves great displacements of goods and people, in the shortest periods of time in history, which makes it even more difficult to establish the role of climate. Moreover, large migratory movements are still taking place due to economic causes, employment situation and military conflicts. These factors can have a synergistic effect to favor the spread of infectious diseases, as has been previously commented in some of the articles of this Special Issue.

A common conclusion of most of the studies included in this Special Issue is the need to implement or develop national and international systems of early alert and monitoring of infectious diseases. Historical epidemiology shows that pandemics and epidemics of infectious diseases will be a recurring element in the coming decades. In a world with a globalized economy, we cannot expect foci of infectious diseases to remain confined in endemic regions and/or countries forever. Imported malaria can be an example of geographic changes in the distribution of infectious diseases. In most developed countries, autochthonous malaria was eradicated during the second half of the 20th century. However, during the 21st century, the number of cases of imported malaria has continued to increase in those countries [17]. The globalization of the economy favors the globalization or, at least, spreading of some infectious diseases. Expanding the knowledge on the epidemic outbreaks of infectious diseases in the past, along with the modelling of future scenarios of climate change, can help to better understand the risk of future epidemics and pandemics. This view on the past may also allow for designing better alert, monitoring and prevention systems involved in mitigation and adaptation plans for the near future.

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