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ECO-EPIDEMIOLOGY OF INFECTIOUS DISEASES AND CLIMATE CHANGE

EKOEPIDEMIOLOGIA CHORÓB ZAKAŹNYCH A ZMIANY KLIMATU

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Wkład autorów:
A. Study design/planning
zaplanowanie badań
B. Data collection/entry
zebranie danych
C. Data analysis/statistics
dane – analiza i statystyki
D. Data interpretation
interpretacja danych
E. Preparation of manuscript
przygotowanie artykułu
F. Literature analysis/search
wyszukiwanie i analiza literatury
G. Funds collection
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Summary

Climate change is causing weather conditions to abruptly change and is directly impacting the health of humans. Due to climate change, there is an upsurge in conditions suitable for infectious pathogens and their carriers to survive and multiply. Infections that were eliminated decades ago are regaining their grounds among humans. Climate change is increasing the possibility of new outbreaks for these vector-borne, airborne, or waterborne infections. While adverse impacts of these outbreaks are only subject to the predictions, nevertheless, it is certain that these outbreaks will affect health status, mortality status and economy at local and international levels. However, these threats may be minimized if national and international public health departments would be willing to implement research- and evidence-based advanced preparedness strategies. This scientific review aims to explore how climate change is facilitating the spread of vector-borne (tick-borne encephalitis, dengue, West Nile virus, leishmaniasis), airborne (by weather conditions like storms), and waterborne infectious diseases (due to floods and droughts) and is triggering new outbreaks among humans.

Keywords: vector borne diseases, climate change, zoonoses, disease outbreak, communicable diseases, public health

Streszczenie

Zmiany klimatyczne gwałtownie modyfikują warunki pogodowe i mają bezpośredni wpływ na zdrowie ludzi. Ze względu na zmiany klimatyczne, pojawia się coraz więcej warunków odpowiednich do przetrwania i namnażania się zakaźnych patogenów i ich nosicieli. Powracają u ludzi infekcje, które zostały wyeliminowane kilkadziesiąt lat temu. Zmiany klimatyczne zwiększają możliwość powstawania nowych ognisk tych chorób, przenoszonych przez wektory, drogą powietrzną czy wodną. Chociaż negatywne skutki tych ognisk są jedynie przedmiotem przewidywań, to jednak pewne jest, że wpłyną one na stan zdrowia, śmiertelność i gospodarkę na poziomie lokalnym i międzynarodowym. Te zagrożenia mogą być zminimalizowane, jeżeli krajowe i międzynarodowe departamenty zdrowia publicznego będą skłonne do wdrożenia zaawansowanych strategii gotowości, w oparciu o badania i dowody. Celem niniejszego przeglądu naukowego jest zbadanie, w jaki sposób zmiany klimatu ułatwiają rozprzestrzenianie się chorób zakaźnych przenoszonych przez wektory (kleszczowe zapalenie mózgu, denga, wirus Zachodniego Nilu, leiszmanioza), przenoszonych drogą powietrzną (na skutek warunków pogodowych, takich jak burze) oraz przenoszonych drogą wodną (wskutek powodzi i suszy), wywołując nowe ogniska chorób wśród ludzi.

Słowa kluczowe: choroby wektorowe, zmiany klimatu, choroby odzwierzęce, ognisko choroby, choroby zakaźne, zdrowie publiczne

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Introduction

In recent years, there has been a substantial increase in the amount of evidence authenticating climate change. Due to the growing evidence, the European Union Parliament declared climate change a climate and environmental emergency [1]. However, environmental manifestations of climate change are adversely affecting human health [2]. The World Health Organization has predicted that an additional 250,000 annual deaths from 2030 to 2050 may occur due to climate change [3]. Changes in climatic conditions are altering annual temperatures and precipitation rates, which further results in extreme environmental events [2]. Existing evidence has projected that these extreme events could impact the transmission of infectious diseases among humans. Infectious diseases that have significantly declined or been eradicated can now cause new outbreaks due to the growing suitability for the livelihood of pathogens [4]. These infections could spread in areas previously untouched by them. For example, infectious diseases like anthrax, Zika, West Nile virus, and tick-borne encephalitis are expanding their territories. As climate change results in more frequent hurricanes, dust storms, droughts, and floods these natural calamities are becoming good grounds for airborne and waterborne infections. In addition, climate change is triggering the arctic glaciers to melt; hence, opening up the possibility for human exposure to new pathogens buried under the ice leading to the emergence of new infectious diseases [5].

Aim of the work

This scientific review aims to explore how climate change is facilitating the spread of vector-borne (tick-borne encephalitis, dengue, West Nile virus, leishmaniasis), airborne (by weather conditions like storms), and waterborne infectious diseases (due to floods, and draughts) and is triggering new outbreaks among humans.

Climate change and vector-borne infections

Vector-borne diseases are infections caused by pathogens transmitted to humans through the bite of blood-sucking insects like ticks, mosquitoes, and flies. The life span, geographical presence, and population changes of these insects rely heavily on climate factors such as temperature, humidity, and rainfall. Hence, climate changes can profoundly influence the incubation period and transmission cycle of these vector pathogens [6]. Further, this makes vector-borne diseases highly sensitive to weather and climatic conditions [7]. Due to the gradually increasing temperature and continuous drastic changes in weather conditions, climate change can provide suitable environmental conditions for vectors and vector pathogens to thrive. Such alterations in climate can increase the chances of an already endemic vector-borne infection becoming an epidemic and help vectors expand to regions previously absent from their presences [8]. This article will begin by expanding on climate change's effects on four main infectious diseases: tick-borne encephalitis, West Nile virus, dengue, and leishmaniasis.

Tick-borne encephalitis

Tick-borne encephalitis (TBE) is a zoonotic infection caused by the tick-borne encephalitis virus (TBEV). Humans can be infected by either a bite from a tick or by ingesting unpasteurized infected milk or milk products [9]. Generally, the infection exhibits mild symptoms but can lead to serious neurologic conditions such as meningitis and encephalitis. Every year, thousands of cases of TBEV-induced neurologic illnesses are reported around the globe [10].

In Western Europe, *Ixodes ricinus* is the recognized vector of TBEV, whereas, in Eastern Europe and Siberia, the known vector is *I. persulcatus* [11]. These ticks are commonly found in dense forests (Europe and Asia) but have recently been expanding their geographic footprint. In the last couple of years, these ticks have been found in personal gardens, public parks, and in higher altitudes and latitudes where these ticks previously could not survive due to unfavorable climatic conditions [12].

Climate change is influencing the vector's survival because the lifecycles of ticks are dramatically affected by weather conditions. These ticks are more active in high temperatures. This means ticks are predominately active from May to August. However, the gradual increases in temperatures of other months have allowed these ticks to stay active for longer periods leading to more tick-borne encephalitis cases. For example, the milder winters in Sweden have resulted in an exponential rise in tick-borne encephalitis cases since the mid-1980s [13]. Whereas in Russia, some of the northern regions (Archangelsk region, Komi republic, and Karelia republic) are experiencing an upward trend in tick-borne encephalitis cases [14] because the *Ixodes* ticks have shifted by 150-200 km towards northern Russia in the last 40 years [15]. Future projections have suggested that by 2040-2060, tick habitats will enlarge and extend towards higher altitudes due to global warming [16], causing an increased number of tick-borne infections ultimately resulting in increased mortality, morbidity, and economic loss.

To illustrate this further, data from the European Centre for Disease Prevention and Control's (ECDC) surveillance atlas has been reporting the number of tick-borne encephalitis cases within the European Union (EU) and European Economic Area (EEA) from the past 10 years and these findings are represented in Table 1 and Figure 1 [17].

Table 1. Dataset of tick-borne encephalitis cases in the EU from 2012-2020 [17]

Region	Reported cases								
	Tick-borne encephalitis								
	2012	2013	2014	2015	2016	2017	2018	2019	2020
EU/EEA	2148	2906	1984	1911	2679	2561	3094	3243	3734
EU	2141	2900	1971	1902	2667	2545	3068	3208	3693
Austria	38	100	81	79	96	123	170	106	250
Belgium	1	1	0	1	1	3	3	4	7
Bulgaria	---	----	0	2	0	1	0	1	2
Croatia	45	44	23	26	6	10	22	13	14
Czech Republic	572	625	410	349	564	687	714	771	849
Denmark	---	---	---	---	---	---	4	---	----
Estonia	178	114	82	115	80	84	85	82	70
Finland	39	38	47	68	61	82	79	69	91
France	1	1	9	10	15	2	25	4	46
Germany	195	420	263	221	353	486	583	444	705
Greece	0	0	1	1	0	0	2	0	0
Hungary	42	27	26	22	14	14	30	17	18
Ireland	0	0	0	0	0	0	0	1	0
Italy	---	0	0	5	48	24	39	37	55
Latvia	72	230	149	141	91	178	100	118	149
Lithuania	351	487	353	336	633	474	384	711	679
Luxembourg	---	---	0	1	0	0	0	0	0
Netherlands	---	---	---	---	---		6	3	5
Norway	7	6	13	9	4	3	26	35	41
Poland	119	136	131	115	12	16	148	197	114
Romania	3	3	1	0	211	196	4	0	0
Slovakia	31	157	115	80	83	102	156	161	185
Slovenia	164	308	100	62	238	0	153	111	187
Spain	0	0	0	0	0	0	0	1	0
Sweden	287	209	178	268	0	1	359	355	267
UK	3	---	2	----	169	75	2	2	---

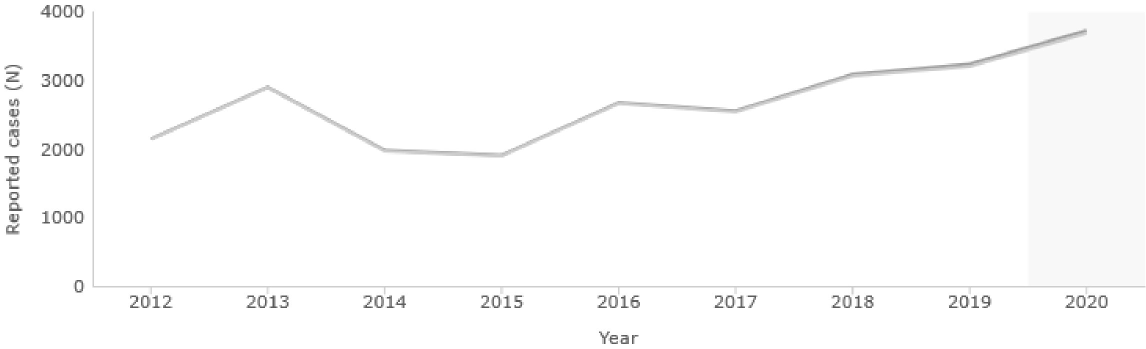

Figure 1. Cases of tick-borne encephalitis in the EU from 2012-2020 [17]

West Nile virus

West Nile viral fever is a mosquito-borne flavivirus infection. Usually, this infection causes flu-like symptoms, but like tick-borne encephalitis, severe infections can occur and may be fatal for some individuals [18]. Some studies have indicated that the West Nile virus can be transmitted from human to human via intrauterine [19], breastfeeding [20], blood transfusion [21], organ transplant [22], and contact with environmentally contaminated material [23]. Decades ago, West Nile virus-related illnesses were rare, but in recent years, numerous outbreaks have been observed around the globe. Currently, endemic outbreaks are more frequent in Africa, temperate regions of America, temperate regions of Europe, Asia, and Oceania than they used to be [24].

In 2007, 2,215 confirmed cases of West Nile virus infection were reported among Canadians. Of these, 98% of the cases occurred in the Canadian prairie provinces (1285 cases — Saskatchewan, 578 cases — Manitoba, and 318 cases — Alberta) [25]. Future modeling of the West Nile virus has forecasted temperatures to rise in Canada by 1-7°C and precipitation to increase by 21-46 mm, which will lengthen the activity period of mosquitoes carrying the West Nile virus from June-August to May-September. Additionally, the projected temperature change will facilitate the expansion of mosquitoes carrying the West Nile virus by 1.06-2.56 times the current geographic area and West Nile infections by 1.08-2.34 times the current geographic area [26].

In the last couple of decades, West Nile virus infections have increased among the Mediterranean countries [27]. For instance, in 2000, Israel had a sharp increase in cases of West Nile fever during the summer months [28]. Subsequently, in 2010, an outbreak re-emerged during the summer [29]. However, the outbreak in 2010 began earlier than expected according to disease seasonality due to an increase in temperatures [30]. Furthermore, in 2010, the outbreak of West Nile fever cases occurred in the Central Macedonia region of Northern Greece, Turkey, Italy, Spain, Greece, Gibraltar, and Morocco simultaneously [31,32]. During the following years, these outbreaks continued to re-emerge frequently. An investigation into the cause of these frequent outbreaks indicated elevated temperatures as the main cause [33]. Therefore, gradual increases in global warming increase the possibility of frequent West Nile virus outbreaks among populations around the globe.

To illustrate further, data from the ECDC surveillance atlas reporting the number of West Nile cases within the EU and EEA from the past 10 years and these findings are represented in Table 2 and Figure 2 [34].

Table 2. Dataset of West Nile virus cases in the EU from 2012-2020 [34]

Region	Reported cases								
	West Nile Virus								
	2012	2013	2014	2015	2016	2017	2018	2019	2020
EU/EEA	274	293	75	122	226	201	1549	425	322
EU	274	293	75	122	226	201	1549	425	322
Austria	0	0	2	6	5	6	21	4	0
Belgium	0	0	0	0	0	0	0	0	0
Bulgaria	2	0	0	2	2	1	15	5	1
Croatia	6	20	1	1	2	5	58	0	0

Cyprus	0	0	0	0	1	0	1	23	0
Czech Republic	0	1	0	0	0	0	5	1	0
Estonia	0	0	0	0	0	0	0	0	0
Finland	0	0	0	0	0	0	0	0	0
France	0	0	0	1	0	2	27	2	0
Germany	---	---	---	---	---	---	1	5	14
Greece	161	86	15	0	0	48	315	227	144
Hungary	17	35	10	18	44	20	215	36	3
Iceland	---	---	---	---	---	0	0	0	0
Ireland	0	0	0	0	0	0	0	0	0
Italy	73	126	24	61	76	0	610	54	69
Latvia	0	0	0	0	0	0	0	0	0
Lithuania	0	0	0	0	0	53	0	0	0
Luxembourg	0	0	0	0	0	0	0	0	0
Malta	0	0	0	0	0	0	0	0	0
Netherlands	0	0	0	0	0	0	0	0	8
Norway	0	0	0	0	0	0	0	0	0
Poland	0	0	0	0	0	0	0	0	0
Portugal	---	---	----	1	0	0	0	0	0
Romania	15	24	23	32	93	0	277	67	6
Slovakia	0	0	0	0	0	0	0	1	0
Slovenia	0	1	0	0	0	0	4	0	0
Spain	0	0	0	0	3	0	0	0	77
Sweden	0	0	0	0	0	66	0	0	0

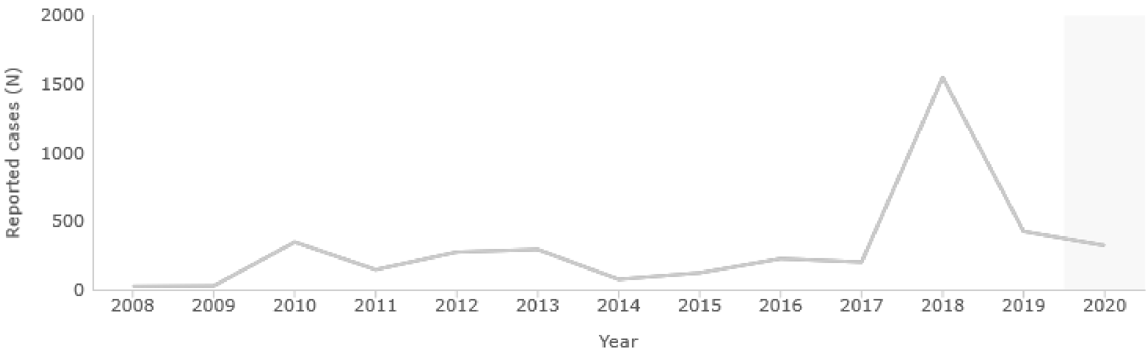

Figure 2. Cases of West Nile virus in the EU from 2012–2020 [34]

Dengue

Dengue fever is a mosquito-borne viral disease caused by the *Aedes aegypti* and *Aedes alborpictus* species [35]. The common symptoms of dengue include fever, headache, and musculoskeletal pain. However, there is a higher possibility of this infection developing into a fatal form that can lead to hemorrhagic fever and dengue shock syndrome. Dengue fever is endemic and epidemic in more than 100 countries in Africa, the Americas, Eastern Mediterranean, Southeast Asia, and the Western Pacific with the Asian parts more severely affected [36]. Overall, more than half of the world's population is under the threat of dengue fever. According to estimations, the occurrence rate of dengue infections has increased by 30 times over the past 50 years globally [37], classifying it as one of the most significant global health threats.

Decades ago, Australia considered dengue as a travel-associated infection. However, in recent years, the situation has changed. While most of the dengue cases are travel-associated, the number of locally acquired cases has increased in the country [38]. Different projections and forecasting studies indicate global warming and favorable climatic conditions have allowed dengue mosquitoes to expand to southern and western parts of Australia with a possibility for it to expand to the whole country, making dengue an endemic national health problem [39,40]. In 2009, 931 dengue cases and one death were reported in north Queensland and cost the Queensland government around 3 million Australian dollars [41]. A recent analysis concluded that the reason behind the increase in locally acquired dengue cases in Australia is the elevated temperatures and increased rainfall [42]. The data of locally acquired dengue cases in Queensland, Australia, from 2005 to 2014 is presented in Table 3 [43].

Table 3. Cases of locally acquired dengue cases in Australia from 2005-2014 [43]

Year	Locally acquired	Proportion locally acquired	Total cases
2005	76	66%	116
2006	37	49%	79
2007	47	39%	119
2008	127	55%	229
2009	915	89%	1026
2010	79	27%	288
2011	69	37%	186
2012	28	11%	244
2013	222	45%	490
2014	182	46%	395
Total	1782	56%	3169

Another example is China; from 1949 to 1977, there was no record of dengue outbreaks in the country. However, since 1978, frequent dengue fever cases have occurred in the Hainan, Guangxi, Fujian, and Zhejiang provinces [44]. While dengue has steadily faded out of the Hainan province since the 1980's dengue outbreak, it is still active in the Southern parts of China [45]. The main reason behind persistent dengue outbreaks is the elevated temperatures due to global warming [46].

Additionally, it has been observed that due to climate change and more suitable conditions for dengue mosquitoes, there is a possibility of a substantial increase in *Aedes aegypti* in Europe, especially Southern Europe. Furthermore, it has been estimated that countries like Greece, Italy, and Spain will be most affected, while European cities like Paris and Berlin have a possibility to be dengue victims in the next 30-40 years [47]. As climate change facilitates more favorable conditions for the geographical expansion of dengue mosquitoes it too will result in more frequent dengue outbreaks in the future. This will not only impact human health but will also pose an enormous burden on state health services.

Leishmaniasis

Leishmaniasis is a zoonotic disease caused by flagellated parasites transmitted to humans via the bite of a phlebotomine sandfly. It is one of the neglected tropical diseases. Leishmaniasis is endemic in approximately 98-100 countries around the globe, causing approximately 700,000 cases every year [48-50]. There are three types of leishmaniasis: visceral leishmaniasis, cutaneous leishmaniasis, and mucocutaneous leishmaniasis [48]. Visceral leishmaniasis is a severe form of leishmaniasis with clinical manifestations such as fever, spleen and liver enlargement, weight loss, and anemia [51]. Visceral leishmaniasis can be fatal if left untreated.

Temperature and humidity are the main climatic factors that impact vectors' development and survival. Generally, a temperature around 25°C and air humidity of 60% are the most suitable conditions for the different vector species [52]. Low temperature is associated with low vector activity. However, global warming can help the vector to stay active even in the winter months [53].

For the last decade, leishmaniasis has started expanding toward Northern Italy [54] while becoming endemic in Hungary [55]. A modeled study estimated that by the end of the year 2060; Western Europe could face substantial increases in the population of sandflies. Additionally, there could be a considerable increase in hospitable conditions for sandflies in the Balkans, Mediterranean basin, and Carpathian basin [56]. While there have been no human cases of leishmaniasis detected in the USA, another modeled study predicted that in the future, climate change could increase the risk of human exposure to leishmaniasis in the United States and parts of Canada [57]. Extending climatic suitability for sandflies poses a worldwide leishmaniasis risk. Table 4 illustrates the geographical presence and status of leishmaniasis around the globe.

Table 4. Status of endemicity of visceral leishmaniasis around the globe in 2020 according to Global Health Observatory data repository [58]

Status of endemicity of visceral leishmaniasis			
2020			
Countries	**Status**	**Country**	**Status**
Afghanistan	Endemic	**Bosnia and Herzegovina**	Endemic
Albania	Endemic	**Botswana**	No autochthonous cases reported
Algeria	Endemic	**Brazil**	Endemic
Andorra	No autochthonous cases reported	**Brunei Darussalam**	No autochthonous cases reported
Angola	Previously reported cases	**Bulgaria**	Endemic
Antigua and Barbuda	No autochthonous cases reported	**Burkina Faso**	No autochthonous cases reported
Argentina	Endemic	**Burundi**	No autochthonous cases reported
Armenia	Endemic	**Cabo Verde**	No autochthonous cases reported
Australia	No autochthonous cases reported	**Cambodia**	No autochthonous cases reported
Austria	No autochthonous cases reported	**Cameroon**	Endemic
Azerbaijan	Endemic	**Canada**	No autochthonous cases reported
Bahamas	No autochthonous cases reported	**Central African Republic**	Previously reported cases
Bahrain	No autochthonous cases reported	**Chad**	Endemic
Bangladesh	Endemic	**Chile**	No autochthonous cases reported
Barbados	No autochthonous cases reported	**China**	Endemic
Belarus	No autochthonous cases reported	**Colombia**	Endemic
Belgium	No autochthonous cases reported	**Comoros**	No autochthonous cases reported
Belize	No autochthonous cases reported	**Congo**	No autochthonous cases reported
Benin	No autochthonous cases reported	**Cook Islands**	No autochthonous cases reported
Bhutan	Endemic	**Costa Rica**	Endemic
Bolivia	Endemic	**Côte d'Ivoire**	Endemic
Croatia	Endemic	**Ghana**	No autochthonous cases reported
Cuba	No autochthonous cases reported	**Greece**	Endemic
Cyprus	Endemic	**Grenada**	No autochthonous cases reported
Czech Republic	No autochthonous cases reported	**Guatemala**	Endemic
Republic of Korea	No autochthonous cases reported	**Guinea**	No autochthonous cases reported
Republic of the Congo	Endemic	**Guinea-Bissau**	No autochthonous cases reported
Denmark	No autochthonous cases reported	**Guyana**	No autochthonous cases reported
Djibouti	Endemic	**Haiti**	No autochthonous cases reported
Dominica	No autochthonous cases reported	**Honduras**	Endemic
Dominican Republic	No autochthonous cases reported	**Hungary**	No autochthonous cases reported
Ecuador	No autochthonous cases reported	**Iceland**	No autochthonous cases reported
Egypt	Endemic	**India**	Endemic
El Salvador	Endemic	**Indonesia**	No autochthonous cases reported

Equatorial Guinea	No autochthonous cases reported	**Iran (Islamic Republic of)**	Endemic
Eritrea	Endemic	**Iraq**	Endemic
Estonia	No autochthonous cases reported	**Ireland**	No autochthonous cases reported
Eswatini	No autochthonous cases reported	**Israel**	Endemic
Ethiopia	Endemic	**Italy**	Endemic
Fiji	No autochthonous cases reported	**Jamaica**	No autochthonous cases reported
Finland	No autochthonous cases reported	**Japan**	No autochthonous cases reported
France	Endemic	**Jordan**	Endemic
Gabon	No autochthonous cases reported	**Kazakhstan**	Endemic
Gambia	Previously reported cases	**Kenya**	Endemic
Georgia	Endemic	**Kiribati**	No autochthonous cases reported
Germany	No autochthonous cases reported	**Myanmar**	No autochthonous cases reported
Kuwait	No autochthonous cases reported	**Namibia**	No autochthonous cases reported
Kyrgyzstan	Endemic	**Nauru**	No autochthonous cases reported
Lao People's Democratic Republic	No autochthonous cases reported	**Nepal**	Endemic
Latvia	No autochthonous cases reported	**Netherlands**	No autochthonous cases reported
Lebanon	Endemic	**New Zealand**	No autochthonous cases reported
Lesotho	No autochthonous cases reported	**Nicaragua**	Endemic
Liberia	No autochthonous cases reported	**Niger**	Endemic
Libya	Endemic	**Nigeria**	Previously reported cases
Lithuania	No autochthonous cases reported	**Niue**	No autochthonous cases reported
Luxembourg	No autochthonous cases reported	**Norway**	No autochthonous cases reported
Madagascar	No autochthonous cases reported	**Oman**	Endemic
Malawi	No autochthonous cases reported	**Pakistan**	Endemic
Malaysia	No autochthonous cases reported	**Palau**	No autochthonous cases reported
Maldives	No autochthonous cases reported	**Panama**	No autochthonous cases reported
Mali	No autochthonous cases reported	**Mauritius**	No autochthonous cases reported
Malta	Endemic	**Mexico**	Endemic
Marshall Islands	No autochthonous cases reported	**Micronesia (Federated States of)**	No autochthonous cases reported
Mauritania	Endemic	**Monaco**	Endemic
Mauritius	No autochthonous cases reported	**Mongolia**	No autochthonous cases reported
Mexico	Endemic	**Montenegro**	Endemic
Micronesia	No autochthonous cases reported	**Morocco**	Endemic
Monaco	Endemic	**Mozambique**	No autochthonous cases reported
Mongolia	No autochthonous cases reported	**Papua New Guinea**	No autochthonous cases reported
Montenegro	Endemic	**Paraguay**	Endemic
Morocco	Endemic	**Peru**	No autochthonous cases reported
Mozambique	No autochthonous cases reported	**Slovenia**	Endemic
Philippines	No autochthonous cases reported	**Solomon Islands**	No autochthonous cases reported
Poland	No autochthonous cases reported	**Somalia**	Endemic
Portugal	Endemic	**South Africa**	No autochthonous cases reported
Qatar	No autochthonous cases reported	**South Sudan**	Endemic
Republic of Korea	No autochthonous cases reported	**Spain**	Endemic
Republic of Moldova	No autochthonous cases reported	**Sri Lanka**	Endemic

North Macedonia	Endemic	**Sudan**	Endemic
Romania	Endemic	**Suriname**	No autochthonous cases reported
Russian Federation	No autochthonous cases reported	**Sweden**	No autochthonous cases reported
Rwanda	No autochthonous cases reported	**Switzerland**	No autochthonous cases reported
Saint Kitts and Nevis	No autochthonous cases reported	**Syrian Arab Republic**	Endemic
Saint Lucia	No autochthonous cases reported	**Tajikistan**	Endemic
Saint Vincent and the Grenadines	No autochthonous cases reported	**Thailand**	Endemic
Samoa	No autochthonous cases reported	**Timor-Leste**	No autochthonous cases reported
San Marino	No autochthonous cases reported	**Togo**	No autochthonous cases reported
Sao Tome and Principe	No autochthonous cases reported	**Tonga**	No autochthonous cases reported
Saudi Arabia	Endemic	**Trinidad and Tobago**	No autochthonous cases reported
Senegal	Endemic	**Tunisia**	Endemic
Serbia	Previously reported cases	**Turkey**	Endemic
Seychelles	No autochthonous cases reported	**Turkmenistan**	Endemic
Sierra Leone	No autochthonous cases reported	**Tuvalu**	No autochthonous cases reported
Singapore	No autochthonous cases reported	**Uganda**	Endemic
Slovakia	No autochthonous cases reported	**Ukraine**	Endemic
United Arab Emirates	No autochthonous cases reported	**Vanuatu**	No autochthonous cases reported
United Kingdom	No autochthonous cases reported	**Venezuela**	Endemic
United Republic of Tanzania	No autochthonous cases reported	**Viet Nam**	No autochthonous cases reported
United States of America	No autochthonous cases reported	**Yemen**	Endemic
Uruguay	Endemic	**Zambia**	Endemic
Uzbekistan	Endemic	**Zimbabwe**	No autochthonous cases reported

Climate change and airborne infections

Temperature and humidity

Temperature and humidity play a vital role in the direct and indirect transmission of airborne infections. An airborne infection, such as influenza, requires low humidity and a cold environment to spread. Therefore, as global warming continues the rate of infection by influenza may be reduced. However, airborne infections will start to merge and remerge regardless of global warming. As the planet is warming, the summers are getting longer. Seasons like spring and autumn are getting warmer every year due to the gradual increase in temperatures globally. Therefore, longer summers will compel people to use air conditioning [59], and this will have a direct impact on the transmission of airborne infections. This is due to the fact that when using the air conditioner, all the windows and doors must remain closed to keep rooms and buildings cool which eliminates good ventilation. This situation allows for pathogens to thrive indoors and transmit infections. The growing concern is that climate change will increase temperatures leading to greater use of air-conditioning in houses, schools, universities, and hospitals. This indoor environment facilitated by air-conditioning will directly impact airborne infection rates [60]. In the recent outbreak of COVID-19, studies have been conducted evaluating how the novel coronavirus affected people sitting in restaurants. It was found that transmission of the virus was promoted by air-conditioning [61].

Dust and sandstorms

Dust and sandstorm events introduce significant amounts of foreign microorganisms into different atmospheric environments and are classified as one of the most far-reaching vehicles for the transport of invasive and pathogenic species of microorganisms, and can reach across thousands of miles of land and sea [62,63]. Dust clouds commonly contain a significant proportion of bacteria and fungi [64]. While the exchange of microorganisms is vital to maintaining the various ecosystems and maintaining biodiversity around the globe [65], however, these dust storms also exchange highly invasive and pathogenic microorganisms [66]. African dust was correlated with meningitis outbreaks [67], whereas other dust storms were linked to hospital emergency visits due to asthma and other health complications related to respiratory and cardiovascular conditions [68,69].

Dust storms are predicted to increase in the future. Due to global warming, drylands are expanding and will keep expanding throughout the 21st century [70]. This expansion in drylands could increase the incidences of dust storms. The microorganisms from these dust storms are the main health concern. The microorganisms present in drylands have adapted to flourish in rough environmental circumstances such as limited water and nutrient availability, extreme temperatures, and ultraviolet irradiation [71,72]. With time, microorganisms inhabiting the drylands evolved to their environment, which is one of the major contributors to their survival, even in an alienated hostile environment [73]. Dust storms contain different bacterial taxonomies including Actinobacteria, Bacteroidetes, Proteobacteria, Firmicutes, and Cyanobacteria [74]. Fungal communities of Alternaria, Aspergillus, Cladosporium, and Penicillium are also common [75].

Dust storms impact one's health by inhaling warm, dry, and dusty air. It further impairs host immune responses leading to an increase in the colonization of airborne bacterial pathogens within the nasopharyngeal pathway. From here, pathogens are easily disseminated into the lungs, blood, and brain [67]. For example, Kawasaki disease is a fatal heart condition acquired during childhood. In Japanese children, this condition was correlated to *Candida* species that were found in tropospheric winds originating in China. Similarly, a significant correlation was found between strong winds originating in central Asia and seasonal cases of Kawasaki disease among US children [74]. Additionally, pulmonary tuberculosis cases caused by *Mycobacterium tuberculosis* have been associated with Asian dust storms in China [75]. Hence, a level of certainty exists that an increase in desertification will increase dust storm events, and these dust storms will play a crucial role in transmitting microbiota that may lead to serious health complications [62]. However, on one side, climate change may reduce airborne infections that thrive on low temperatures and low humidity. On the other side, it will increase the transmission rate of airborne infectious diseases via indirect ways such as increasing the use of air-conditioning and increasing the incidences of dust storms.

Climate change and waterborne infections

Waterborne infections are infections transmitted via contaminated water that contains pathogens like bacteria, viruses, and protozoa. These infections can cause mild to severe complications such as flu-like symptoms, fever, diarrhea, neurological diseases, kidney damage, liver damage, and even death. The most common waterborne infectious illnesses are diarrheal diseases that place a high burden on global public health. Changes in climatic conditions will impact the quantity of water, facilitating changes in interactions among microbial communities and species [76,77]. Such conditions may lead to the exponential expansion of different pathogens and their associated infections [78]. Therefore, even small changes in climatic conditions can influence waterborne infection outbreaks and produce a substantial increase in health complications [79].

Flooding

Flooding has a long-lasting relationship with infectious disease outbreaks such as leptospirosis [80,81], anthrax [82], and spreading health complications linked to pathogens — *Cryptosporidium hominis* [83], *Escherichia coli*, *Campylobacter jejuni*, *Giardia lamblia* [84], and *Salmonella enterica* [85]. Globally, floods caused by heavy rainfall were reported as the key responsible factor behind climate-related waterborne infections. Floods facilitate the cross-connection between water and other environmental factors that contaminate different freshwater resources (rivers, lakes, and other natural and man-made water supplies) [85]. The contaminated surface water or flood water following a flood or heavy rainfall is not the only thing driving these outbreaks, but the sediment left behind after a flood or heavy rainfall has been observed to cause disease outbreaks [86]. In addition, floods can damage residential properties leading to a deterioration in living conditions. Furthermore, this can compel people to move to overcrowded emergency shelters where everyone shares the toilet and bathroom facilities, and have limited access to medical care. All these factors have the potential to cause an outbreak [87].

Flooding always facilitates conditions that exacerbate the possibility of a serious infectious disease outbreak. However, as climate change is happening faster due to anthropogenic activities, there is a possibility that climate change may alter the risk of floods on a large regional scale. Changes in precipitation, humidity, and temperature are significant climatic factors that may raise the risk of future floods [88]. More floods would mean more infectious disease outbreaks, and more infectious disease outbreaks result in more health-related complications, and more health-relation complications increase the burden on state health systems.

Droughts

Global warming and drastic changes in the climate will lead to more droughts. The increased occurrences of droughts will result in a scarcity of safe drinking water, which can lead to poor hygiene. The droughts will increasingly influence the numbers of communities as those affected by droughts are compelled to collect and save rainwater [89]. Investigated samples of collected rainwater from these communities have contained different harmful pathogens such as *Aeromonas hydrophila*, *Campylobacter jejuni*, *Pseudomonas aeruginosa*, *Salmonella* spp., *Shigella* spp., *Staphylococcus aureus*, *Yersinia* spp., and *L. pneumophila*. These pathogens can cause serious health complications within a community [90]. An increase in drought incidences will increase the outbreaks of infectious diseases and pose a significant risk to the population's health.

Discussion

Climate change is affecting everyone's health whether a person is living in the countryside, a small town, an island, or a coastal city. Climate change is predicted to be the most influential factor in the occurrence of infectious diseases [91]. While awareness regarding climate change is growing among human societies, there is still a lack of emphasis on the consequences of climate change on human health, especially when it comes to the link between the spread of infectious diseases and climate change. Notably, new infections are emerging while the eradicated infectious diseases are re-emerging more rapidly with the rapidly changing climatic conditions. The new emerging infections have complex epidemiology as pathogens are taking advantage of the climate changes to prolong their survival rate among humans. There is a crucial need to focus on infectious diseases that are highly sensitive to climate change. There is an immediate need for more studies on such infections to be better able to forecast outbreaks. It will require the development of new strategies to be able to detect these outbreaks. These strategies are essential to understand the risks of such outbreaks and to find out the solutions and approaches that can be applied effectively to deal with such situations. Undoubtedly, there is hope, as the world is becoming more advanced, we can make the world more prepared against such outbreaks, but only if we are able to create better outbreak forecasting. Continuous research should take place to understand the association between changes in climatic conditions and the spread of infectious diseases. Furthermore, there should be a greater investment in the innovation of different and effective disease detection methods. Most importantly, warning systems need to be developed that can work as a mediator between responsible epidemiological bodies and the public to generate preventive public health messages from time to time. In addition, health care providers should be trained to suspect the emergence of new infections among their community healthcare centers and to report it to public health officials.

Conclusions

In the future, subtle and gradual changes in climatic conditions are going to impact the geographical distribution and intensity of infectious diseases. This can impact global health adversely. Therefore, countries and national public health departments must make working on possible solutions a higher priority. This will make it easier to tackle these possible future health threats. Failure to invest and work on human health impacted by climate change can result in an upsurge of severe adverse consequences.

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