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Adverse human health effects of climate change: an update

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Abstract

Background*. The world is currently facing a process of climate change, which may adversely impact human health in many different ways. The safety of food, water and urban environments is endangered by the consequences of climate change. Sea level and temperature rise, along with more frequent and longer heat waves, represent only a few of the effects of climate change. The increased risk of extreme climate events (e.g., cyclones, droughts and floods) is another serious public health issue. These adverse effects are enhanced in areas and countries not having the capacity to effectively deal with climate change.*

Study design. *We primarily aimed at summarizing the impacts of climate change on public health. A further aim was to identify the most concerning consequences of this phenomenon and the vulnerability factors that amplify the negative effects of climate change.*

Methods. *PubMed and other literature databases were used as literature sources for this narrative review based on the search terms 'climate change' and 'diseases categories' up to January 2024, in order to assess the most recent and relevant scientific evidence about the relation between climate change and public health, identify knowledge gaps and priorities for future research. We also screened the websites of major agencies devoted to human health protection and environmental health.*

Results and Conclusions. *Climate change appears to induce a broad spectrum of generally adverse effects on public health. It may increase the risk of infectious diseases, psychiatric disorders, cancer and other diseases. Currently, we are not effectively counteracting this phenomenon, since pollutant and greenhouse gas emissions have been increasing alongside temperatures. A host of measures are required in order to prevent and fight climate change and related health effects. These include the adoption of a holistic approach and the collaboration of different kinds of expertise in order to design more effective strategies. Special attention should be paid to those who live in disadvantaged countries, and those who are more vulnerable to the adverse health consequences of climate change.*

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Introduction

Climate change is an emerging public health threat due to an impact on both physical and mental health (1). Although widespread interest developed as a result of global warming and increasing pollutant emissions, several features and consequences linking climate change and human health should be considered. For example, climate change has been reported to increase flood and drought risk, causing poverty and hunger and damaging health as well as educational services (2, 3). The United Nations have set different goals to improve capacity to face climate-related risks across countries and integrate climate change measures into national policies, strategies and planning to prevent negative effects (4). At the 2015 Paris Conference of the Parties (COP), plans were agreed to limit global warming to <2°C, and preferably to 1.5°C, as compared to pre-industrial levels. The goal was to be achieved by decreasing greenhouse gas emissions and increasing clean energy production (5). The impact of climate change also endangers oceans and seas. Human activities have led to ocean acidification, caused by the absorption of CO_2 emissions, an increase in water temperatures and rising sea levels (3, 4).

We performed a narrative review to assess the main consequences of climate change on human health, updating the most relevant literature and highlighting the potentially effective public health measures. A narrative review allows to pursue an extensive description and interpretation of the state of science on a specific topic, being a flexible and rigorous approach to the critical assessment of the literature and the available evidence, the identification of knowledge gaps, and the highlighting of the most relevant and timely lines of research (6-8).

Methods

For the purpose of this review, we searched for available literature on online databases, including PubMed, Embase and Web of Science, about the relation between climate change and public health until January 4, 2024. We also used recent systematic and narrative reviews on the topic of health effects as a source of additional references for citation chasing. We also assessed the websites of the major agencies devoted to human health protection and environmental health, including the United Nations (UN), World Health Organization (WHO), Center for Disease Control and Prevention (CDC), and World Meteorological Organization (WMO).

Results and Discussion

Climate change and effects on the environment

International agencies have reported that atmosphere concentration of greenhouse gases continues to rise, as are ocean temperatures. As a consequence, CO_2 reacts with seawater lowering its pH, a process known as ocean acidification. Other pollutants are also substantially contributing to global warming, environmental pollution and climate change, due to an increased concentration of many contaminants, reactive gases such as ozone, and particulate matter (4, 9, 10). In particular, human activities are affecting the world's largest ecosystem: oceans and seas. The phenomenon of ocean acidification and the rise in ocean temperatures are serious issues threatening especially marine biodiversity. Between 2009 and 2018, the planet lost about 14% of its coral reefs, an extraordinary ecosystem rich in marine species. Oceans play a crucial role in climate mitigation, since they absorb around a quarter of global annual CO_2 emissions. However, the absorbed CO_2 is converted into acid products, and such ocean acidification limits the capacity to further absorb CO_2 from the atmosphere (4). In addition, rising sea levels has been reported. Satellite data indicate that the Global Mean Sea Level (GMSL) has risen by about 21-24 cm since 1880. In most recent years, GMSL has risen by about 3.4 mm/year (11). Glacial melting and ice sheet loss are now the main contributors to GMSL rise. Greenland and Antarctic ice melting are a worrying trend, with their ice sheet decreasing in mass by about 277 and 149 gigatons per year, respectively.

Extreme climate events and human health

Human activities have contributed to an increasing frequency of extreme events since the 1950s. Heatwave and drought frequency has risen on a global scale. Fire weather frequency has also increased in some regions, including southern Europe, the USA and Australia. The World Meteorological Organization reported an increase in the annual mean frequency of high tide flooding events, caused by rising GMSL (10). Extreme climate events, including warming and heatwaves, droughts, wildfires, hurricanes and floods, have been linked to several detrimental effects on humans (12-14). Besides climate change-related injuries and deaths, studies have also focused on effects in

terms of chronic diseases, especially in relation to increased risk and mortality for cardiovascular and respiratory diseases (15, 16). In particular, extreme temperature conditions like heatwaves have been associated with hospital admissions and emergency department visits (17-21). Children are considered at higher risk of climate change-related adverse effects. As a matter of fact, most recent studies on children's health have established a detrimental relation between climate events and respiratory health, including asthma and allergies (22-25), and cancer (26, 27). Finally, climate change can affect older people and plays a role in general population aging, for instance in terms cardiovascular diseases as already shown for the general population (28), with recent studies highlighting a detrimental effect on neurodegenerative diseases (29-32).

Climate change and infectious diseases

Climate change may influence the spread of certain pathogens due to several factors, leading to especially increased rates of infectious disease reproduction and incubation, including vector-borne diseases (33). In particular, heavy rainfall and drought periods can affect the spatial-temporal distribution of vectors. We are currently experiencing an era of global warming caused by human activities, which trigger climate change. Altered rainfall, flooding and an increased likelihood of extreme weather events are commonly observed: they contribute to the expansion of the geographic range and facilitate the replication of certain vectors. Such events are involved in the potential increase and spread of a range of arboviral threats (34). Current climate change is causing an increase in mosquito circulation. This encourages the wide spread of vector-borne viruses such as Dengue and Chikungunya, previously reported in tropical and sub-tropical countries (35-37). Similarly, the spread of the West Nile virus is increasing in many countries due to climate change, responsible for a favorable environment in previously non-permissible areas (38). Of the several meteorological factors, temperature can radically affect vector distribution, leading to the geographical expansion or shift of some diseases. This is the case because vectors that usually live in low-latitude regions may expand their distribution to mid- or high-latitude regions. As a consequence, several studies have demonstrated that the distribution of many vector-borne human infectious diseases such as malaria, African trypanosomiasis, Lyme disease, tick-borne encephalitis, yellow fever, the plague and Dengue has expanded due to climate change (39). Humidity also plays an important role in disease transmission: with mean humidity under 60%, for instance, the lifespan of malaria vector mosquito becomes too short to cause malaria transmission. Low humidity, especially if accompanied by high temperatures, creates unfavorable conditions for ticks and fleas, reducing transmission of the related diseases (39).

The most vulnerable areas are located near tropical and subtropical regions, where poverty is common, population growth rates are very high and health systems are underdeveloped (3, 40). Alterations to hydrological systems increase transmission of fecal-oral pathogens such as *Salmonella typhi*, a trend that is currently being documented in the increased incidence of salmonellosis in European countries such as England, Holland and Spain, given the involvement of rising temperatures in 35% of the cases of salmonellosis that occur (41). Floods, droughts and an increase in temperatures can also heighten the risk of schistosomiasis, acquired through skin penetration by cercariae. Malaria has also expanded to higher altitudes due to rising temperatures (42, 43).

Finally, the recent COVID-19 pandemic helped single out climate and meteorological factors as likely to affect disease susceptibility. Some previous reports had already suggested a relation between meteorological factors – especially seasonal rainfall and temperature variations – and airborne infectious diseases (44, 45). In the wake of SARS-CoV-2, several studies demonstrated how environmental factors, especially outdoor air pollution, temperature, humidity and UV radiation affect virus spread and disease mortality (46-52).

The impact of climate change on water and food security

The severity and frequency of extreme conditions such as droughts and floods can both impact the quantity of available water resources and their microbial and physicochemical quality. Climate change influences microbial community composition and interactions (53). Global warming and the consequent extreme events may lead to a higher number and broader range of waterborne pathogens responsible for human infections. In turn, this is likely to lead to a higher incidence of water-borne and food-borne diseases. Indeed, extreme temperatures and precipitations can increase gastrointestinal disease risk due to the presence of fecal-oral pathogens (53-55). Several studies have highlighted an increase in infection risk due to the presence of microorganisms associated

with seasonality, daily maximum temperatures and precipitation, such as *Escherichia coli, Campylobacter, Salmonella, Shigella*, norovirus, hepatitis A virus and protozoa *Cryptosporidium* and *Giardia* (38, 53, 56-58). For instance, as many as 900,000 cases and 900 deaths due to waterborne diseases associated with both droughts and flooding have been estimated to occur on a yearly basis in the United States in the most recent period, and these figures are expected to increase in the upcoming years (53). The consequences of climate change in terms of gastrointestinal diseases will probably be even more severe in Asia and Africa (59).

Climate conditions such as rising rainfalls, temperature and/or humidity may facilitate the proliferation of microorganisms ubiquitous to water, such as nontuberculous mycobacteria (NTM) and *Legionella* in natural water resources, leading to an increase in the contamination of artificial water systems (53, 60, 61). There is for instance evidence that increased median rainfall higher than 0.42 increases the risk to have Legionnaires' disease, suggesting that rainfall facilitates the onset of this sporadic form of disease, and in addition relative humidity of 65% has been shown to facilitate survival of airborne *Legionella* compared with 30% of humidity (53). The role of warm weather and rain is obviously complex and specifically a sequence of warm weather followed by heavy rainfall results in a higher relative humidity (Rh), the most favourable condition for community-acquired Legionnaires' disease (62). Thus, rainfall which would increase the general Rh of the environment during periods of warmer weather may lead to increased numbers of Legionnaires' disease. A recent study has reported a positive correlation between the average load of *Legionella* and average air temperatures (63). *Legionella* is an opportunistic pathogen sensitive to warmer temperatures, an ideal condition for its proliferation. Legionnaires' disease shows a seasonal pattern, with a peak during the warm summer months due to an increase in seasonal temperatures causing the proliferation of *Legionella* and, consequently, greater disease risk (64). In the Netherlands, a study reported a summer increase in Legionnaires' disease incidence related to a long period of warm weather followed by intense rainfall (62). This could be explained by the increased growth of *Legionella* in the environment during the warm weeks, and bacterium dissemination during the wet weeks. In particular, this Dutch study documented that disease incidence was 2.2 times higher after a 4-week period of warm weather as compared with a colder period (i.e., 4-week mean temperatures <10.5°C), and in addition it suggested that long-lasting and intense rainfall could further contribute to an increased incidence (62).

Water should be used more efficiently, while technologies should be implemented in order to assess the safety of available water. The application of 16S amplicon sequencing could be an innovative approach to characterize the water microbial community over time and evaluate its stability (65, 66). This could introduce an early-warning system in order to reduce population health risks through timely implementation of actions along the water treatment chain. In addition, climate change clearly has a deleterious effect on drinking water quality as far as its contaminant content is concerned, particularly in relation to arsenic, nitrates, cadmium and fluoride (all present in the WHO list of the ten chemicals of public health concern), as well as microplastics (67-69). Such increases may have adverse effects on a number of outcomes, as is the case with cadmium for metabolic and cardiovascular diseases (70, 71), breast and prostate cancer (72, 73). At the same time, adverse effects have been suggested for fluoride on some endpoints, when exposure exceeds the amount recommended for caries prevention, particularly for drinking water concentration above 1.5-2 mg/L (74-79).

Moreover, the increased frequency of droughts and floods can also compromise food safety (41, 80). Extreme temperatures and extreme precipitations can be serious issues for farmers, by damaging crops. High temperatures can make the soil drier, hindering crop growth. In this case, the soil needs better irrigation. While, however, that can be possible in some places, reduced water supplies could threaten the agrifood system elsewhere (81). Many weeds, pests and fungi thrive under warmer temperatures and increased CO_2 air concentration. The weed and pest distribution is expected to increase due to climate change (82). Moreover, CO_2 concentration increase in atmosphere can enhance plant growth, but reduce the nutritional value of most crops (83). For example, it reduces protein and mineral concentration in most plant species. A further problem is related to the effect of pesticides. More specifically, the wider spread of pests could increase pesticide use, leading to higher pesticide concentration in food and a negative impact on human health.

Climate change can have direct and indirect effects on animals. More precisely, heatwaves could stress livestock, making animals more susceptible to diseases and reducing fertility and milk production. Temperature rises can also increase infectious disease

risk for livestock, and damage feed supplies. In fact, droughts can dramatically reduce feed availability. Moreover, the increased infectious risk could lead to an excessive use of antiparasitic agents and other animal health treatments, increasing risk of pesticide resistance and food chain contamination (84). Finally, climate change can trigger a vicious circle where infectious diseases contribute to the spread of hunger, which in turn increases infectious disease risk for the affected populations (85).

Impact of climate change on mental health

Climate change can affect mental health through four different pathways: a direct impact, gradual changes, indirect effects and effects related to climate change perception (86). Firstly, climate change leads to an increased risk of floods, droughts, wildfires and storms. It is estimated that about 20% of people experiencing an extreme weather event have developed a mental health problem. In particular, exposure to environmental disasters is associated with increased prevalence of post-traumatic stress disorder and depression, a prevalence that for the former condition may be as high as 76.9% in the recently reviewed 20 papers published in 2018 and reporting estimates for both outcomes (87).

Climate change leads to more gradual and less immediate disruptive changes than hurricanes or storms, which can nevertheless alter the psychological and physical well-being of humans. Global warming has also been linked to increased rates of aggression, both hetero-directed and self-directed (88, 89), suicide rates (43, 90) and hospitalizations related to mental issues (91, 92).

Indirect effects of climate change can result in food and economic insecurity and can be a source of stress for families. Moreover, global warming could increase migratory phenomena, because some areas could become less habitable or even inhospitable (93). Involuntary migrations are associated with impaired mental health, because people have to cope with loss of habitation, the need to adapt to new cultures and potential hostility from residents of the territories where they moved (94).

In relation to the increasing interest for climate issues, a new phenomenon has been examined. This is "climate anxiety", which denotes anxiety linked with perceptions about global warming. Climate anxiety has been diagnosed even among individuals who experienced no direct consequences of climate change (95). The term "eco-anxiety" refers to low mood, sleep disorders, panic attacks, and feelings of anger, guilt or helplessness, typically observed in young people (96). A feeling of existential dread linked with an overwhelming sense of responsibility has been reported by people experiencing climate anxiety. Discussion with young people should be encouraged and their feelings should be acknowledged and validated. Nevertheless, experts suggest that laying too much emphasis on climate catastrophe is unhelpful, unless this is accompanied by the implementation of possible solutions. From this perspective, even suggesting lifestyle changes, such as eating less red meat, could provide individuals with a purpose to redouble their efforts in fighting climate change.

Other adverse effects of climate change

There is increasing evidence that environmental pollution and climate change are associated with a number of other adverse effects. Among these are oral health issues, particularly (though not only) in children. First of all, limited food availability and increasing socioeconomic difficulties may prevent people from having an adequate and healthy diet, leading to malnutrition, unhealthy lifestyles, intake of potentially toxic elements and diet rich in processed or sugary food (97-100). Poor dietary habits and malnutrition are associated with an increased risk of dental caries, enamel defects and dental development abnormalities in children, along with periodontal disease and ulcerative diseases of the oral mucosa (101-103). Higher seasonal temperatures can easily lead to dehydration, especially in hot climates, causing changes to salivary gland function, altered saliva composition and reduced flow (104). Dry mouth impairs the maintenance of proper homeostasis of the oral environment and is a risk factor for a number of oral conditions, including dental caries (102).

Additionally, increased heat and humidity may promote the proliferation of noxious oral micro-organisms such as cariogenic bacteria, periodontal pathogens, fungi and viruses (105). An increased rate of common oral ulcerative lesions sustained by viral and immune-mediated mechanisms has also been associated with the transition to higher temperatures and more humid climates (106, 107). Poor air quality and pollution due to climate change have been linked to an increased prevalence of respiratory diseases such as asthma and chronic bronchitis. In this context, medications used to treat such respiratory conditions are often sugar-based and may also cause dry mouth (101, 102). Both factors have a detrimental effect on oral health, causing increased caries risk and predisposing to oral infections and poor trophism of the oral mucosa.

Furthermore, ozone layer depletion due to rising temperatures and pollution causes increased exposure to ultraviolet (UV) radiation. This is a major risk factor for oral cancer, especially of the lips, and skin cancer of the face, head and neck (102, 105). Oral cancer is a public health concern, with over 300,000 new cases annually in the US (108). Finally, the presence of higher levels of contaminants and pollutants in air, water and food, such as lead and microplastics, has been linked to the development of early childhood caries and enamel hypomineralization defects (109, 110).

Conclusions

In this review, we encompassed several different health-related issues linked to climate change, suggesting that such potential or established consequences of climate should not be underestimated and must be counteracted as much as possible. Rising temperatures, sea level changes and the increase in greenhouse gas concentration in the atmosphere will undoubtedly and seriously impact human health in the short term and for the next decades. An increased risk of extreme weather events, climate-related migrations and the impact on the distribution of disease-carrying vectors, effects on mental health, higher environmental pollution and its effect on chronic conditions across children and adults are only a few of the adverse consequences of climate change on human health.

The Paris Agreement allowed for many important points to be reiterated. These include the necessity of limiting temperature rises to well below 2°C compared with pre-industrial levels, and the importance of helping developing countries and reducing emissions. Nonetheless, these goals will not be easily achieved and may even not be enough. As already mentioned, CO_2 emissions are currently increasing and the average global temperature in 2022 was about 1.15°C above pre-industrial levels. This implies we are getting ever closer to the limit set by the Paris Agreement (111). For these reasons during the last COP28 Conference in Dubai, countries delivered the "UAE Consensus" including as key component the Global Stocktake to assess progress since Paris and put forward a plan to close implementation gaps to 2030, setting out the ambitious actions needed to keep 1.5°C within reach and enable the world to reach a zero net emission by 2050 (112).

Emissions resulting from human activities should be reduced, with a special focus on the 'agrifood system' considered to be responsible for one-third of these emissions (113). The influence of climate change on migration flows and mental health should not be neglected, either. Its consequences could be severe, especially in developing countries that are incapable of dealing with them effectively. Stress related to migration and the strong psychological (and physical) impact of climate disasters are only a few of the aspects highlighting the vital importance of fighting climate change.

The fight against climate change should be conducted through a multidimensional approach, since different kinds of expertise within the health system are required to devise effective strategies to resolve climate change-related problems. In particular, primary care, and the health system more generally are currently undergoing marked organizational changes and renovation in countries like Italy (114, 115). However, they both have a key role in raising awareness of adverse health effects of climate change as well as the prevention and early detection of such effects also through involvement of multiple stakeholders and educational systems (116-119), as also highlighted in the COP28 Conference (112, 117). In addition, a wider transnational approach may be required to effectively counteract climate change and environmental pollution (120). Overall, the climate change problem should effectively involve a range of different approaches: improvements to the agrifood system, a reduction in industrial emissions and environmental pollution, and investments in sustainable energy sources instead of fossil fuels. At the same time, it should be remembered that the health of humans, animals and ecosystems is strongly embedded within the holistic approach of the One Health perspective.

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Riassunto

Effetti sulla salute del cambiamento climatico: un aggiornamento

Introduzione. Il mondo sta attualmente affrontando un processo di cambiamento climatico che potrebbe avere un impatto negativo

sulla salute umana in molti modi diversi. La sicurezza di acqua, alimenti e degli ambienti urbani è messa in pericolo dalle conseguenze del cambiamento climatico. Il livello del mare e l'aumento della temperatura, insieme a ondate di caldo più frequenti e più lunghe, rappresentano solo alcuni degli effetti del cambiamento climatico. 'aumento del rischio di eventi climatici estremi (ad esempio cicloni, siccità ed inondazioni) rappresentano un'altra rilevante criticità per la sanità pubblica. Questi effetti negativi sono accentuati nelle aree e nei paesi che non hanno la capacità di affrontare efficacemente il cambiamento climatico.

Disegno dello studio. L'obiettivo principale di tale rassegna è quello di riassumere gli impatti dei cambiamenti climatici sulla sanità pubblica. Un ulteriore obiettivo è l'identificazione delle conseguenze più rilevanti di questo fenomeno e i fattori di vulnerabilità che amplificano gli effetti negativi del cambiamento climatico.

Metodi. PubMed e altre banche dati sono state utilizzate come fonti di letteratura per tale rassegna narrativa usando termini di ricerca quali '*climate change'* e '*diseases categories'* aggiornata fino a gennaio 2024 al fine di analizzare la letteratura più recente e rilevante sulla relazione tra cambiamento climatico e sanità pubblica, identificando inoltre le lacune conoscitive e le priorità per la ricerca futura.

Risultati e Conclusioni. Il cambiamento climatico sembra esercitare un ampio spettro di effetti generalmente avversi sulla sanità pubblica. Può aumentare il rischio di malattie infettive, disturbi psichiatrici, cancro e altre malattie. Attualmente non stiamo contrastando efficacemente questo fenomeno, poiché le emissioni di sostanze inquinanti e di gas serra sono aumentate insieme alle temperature. Sono necessarie numerose misure per prevenire e combattere il cambiamento climatico e i relativi effetti sulla salute. Questi includono l'adozione di un approccio olistico e la collaborazione di diversi tipi di competenze al fine di progettare strategie più efficaci. Un'attenzione particolare dovrebbe essere prestata a coloro che vivono in paesi svantaggiati, che sono più vulnerabili alle conseguenze negative sulla salute dei cambiamenti climatici.

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