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Report of the Task Force on

Health

Eastern Mediterranean and Middle East Climate Change Initiative

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Eastern Mediterranean and Middle East Climate Change Initiative

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Abbreviations

EMME	Eastern Mediterranean and Middle East
EMME-CCI	Eastern Mediterranean and Middle East Climate Change Initiative
MENA	Middle East and North Africa
PC-GDP	Per capita gross domestic product
PM	particulate matter
VBD	vector-borne disease
WHO	World Health Organization
WNV	West Nile Virus

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Executive summary

Climate change is predicted to affect many aspects of human life in complex and interconnected ways. The impacts of climate change on human health and wellbeing can be both direct (e.g., exposure to extreme and unusual temperatures, drought, and flooding) and indirect (e.g., changes in air quality, food and water availability/quality, and patterns of infectious disease transmission). These effects are further compounded by a variety of biological, ecological and socio-political factors.

An extensive body of research has identified several factors that can adversely affect the vulnerability of human health and wellbeing to climatic factors, including age, gender, geographic location, socio-economic status, occupation, health status and housing conditions, among other. Climate change is predicted to exacerbate these vulnerabilities, especially in the lower-income countries and resource-limited settings of the EMME region, which is also characterized by high rates of population growth, urbanization, political tension and migration.

In this report we summarize the current knowledge regarding the effects of climate change on the health of the people of the EMME region. We provide recommendations regarding research priorities and relevant policies, which can help increase the region's resilience to human health challenges set to be imposed by climate change.

Extreme heat

Exposure to extreme heat is associated with heat stroke, kidney injuries and myocardial infarction in adults, especially the elderly, as well as electrolyte imbalance, respiratory conditions and renal problems in children. Extreme heat has also been linked to mental health problems, sleep disturbances and increased suicide rates. Factors such as air pollution, elevated humidity and urban heat islands can further compound the negative effects of heat stress on human health.

A large share of the population of the EMME region is already acclimated to high ambient temperatures. However, future heatwaves in the region are predicted to be increasingly severe and disproportionally affect vulnerable population groups including the elderly, people living in poverty, those with disabilities or chronic health conditions and individuals that regularly work outdoors. Thus, areas of the EMME region with large susceptible populations, such as urban areas, will be particularly affected by future extreme heat events.

Water shortage

Human health is dependent on the availability of safe, reliable and accessible water supplies. The EMME region comprises some of the countries with the lowest water availability in the world, with nine out of 15 countries in the Middle East considered to experience absolute water scarcity.

The health consequences of freshwater scarcity can be both direct and indirect and include diarrheal and parasitic diseases, chronic health issues, increases in the incidence of vector-borne diseases and nutritional deficiencies, among other. Reduced agricultural productivity due to water scarcity is expected to cause drops in export revenues in many of the EMME countries that range in the billions of dollars, potentially impacting health services and infrastructure.

Several countries in the region have successfully implemented strategies that allow them to increase the productivity of their water resources and obtain usable water through nonconventional means such as desalination and wastewater re-use. Unfortunately, the high costs associated with some of these processes currently limit their widespread use.

Air pollution, dust events, and wildfires

In Europe and the Eastern Mediterranean, around 1 million people die prematurely each year due to air pollution. Increased particulate matter concentrations in ambient air from energy generation, industrial pollutants, traffic, domestic energy use and wildfires are implicated with increases in the incidence of respiratory and cardiovascular diseases, as well as higher mortality rates. These health problems are aggravated by the growing abundance of desert dust, especially in the EMME region. Vulnerable groups include the very young and elderly, as well as people with chronic cardiopulmonary diseases.

The strong urbanization trend in the EMME region is another direct effect of climate change and contributes significantly to the worsening of air pollution in urban areas. The byproducts of fossil fuel burning include greenhouse gases, particulate matter and various hazardous gases. Because heat facilitates the formation of some of these noxious reaction products, urban heat islands and heatwaves also contribute to the deterioration of air quality.

Vector-borne diseases

Infectious diseases transmitted by arthropod vectors, known as vector-borne diseases (VBDs), are particularly susceptible to climatic variability due to the complex structure of their natural cycles. The biology of mosquitoes, sandflies, ticks and other disease vectors is profoundly influenced by factors such as temperature, rainfall and humidity, creating a direct link between climate change and the epidemiology of VBDs.

Variation in climate and other environmental factors can also affect physiological parameters of vector-borne pathogens, altering their transmission patterns. Human interventions such as increased urbanization and the disruption of natural ecosystems can further enhance the potential for VBD transmission.

Ecological and socio-economic factors currently found in the EMME region create the appropriate conditions for the transmission of VBDs, including dengue and Chikungunya fever, leishmaniasis, West Nile fever, and malaria, among others. Future climatic change is expected to influence the epidemiological landscape of these diseases by altering the vector geographic distribution, seasonality, abundance and capacity to transmit disease.

Population displacement

In the past 50 years, the displacement of human populations in the EMME region increased significantly due to complex environmental, economic and socio-political issues. Climate change can stimulate population displacement in several ways, including increases in the intensity and frequency of extreme weather events, loss of land to sea-level rise, deterioration of lifesustaining ecosystems and aggravation of armed conflicts.

Several EMME countries are listed among those with the largest shares of migrants in the world. As of 2019, Syria and Iraq were among the 10 countries with the highest number of internationally displaced persons, while Turkey, Iran and Lebanon were hosts to some of the largest refugee populations.

The distinct sanitary conditions of refugees, often housed in densely packed, makeshift dwellings that lack appropriate access to basic resources such as running water and waste disposal, render this group extremely vulnerable to factors such as extreme temperatures, water scarcity, nutritional deficiencies, infectious diseases, maternal /neonatal morbidity and mortality and, importantly, mental health issues. The lack of resources and uncertain legal status associated with displacement can place the most vulnerable individuals (e.g. women and children) at an elevated risk of being the target of sexual violence and exploitation. Access to medical and psychological health care for refugees is limited, with some aspects (such as mental and reproductive health) being particularly difficult to address amid logistic and cultural challenges.

Research gaps

During the drafting of this report, we have identified several areas where additional research is required in order to either better understand or better address the health challenges posed by climate change. These include:

- **Empirical evidence on exposure-response functions involving climate change and specific health outcomes:** Our current understanding of the specific effects that climate exerts on several health conditions is relatively poor. Areas where further research is required include the impact of dust exposure on chronic health conditions, the development of tools to accurately evaluate the psychological effects associated with forced displacement, the effects of air pollution by wildfires on respiratory and neurologic health, and the effects of climate change on overall children's health, among others.
- **Assessment of the effects of climate change on ecological determinants of human health:** There is a dearth of empirical data about the influence of changing climate on ecological factors that can ultimately affect human health. This situation is particularly relevant in the field of vector-borne diseases due to the complex nature of their natural cycles. The generation of a larger body of empirical biological and/or ecological data could help improve the accuracy of predictive mathematical models, which are key components of climate-related health action plans.
- **Effects of long term exposure to climate change:** Currently available information related to the influence of climate change on human health is mostly based on the effects of severe weather events, which typically have a relatively short duration. Little information is available, however, on the effects of long-term exposure to smaller variations in climatic factors.
- **Evaluation of the interactions between adaptation and mitigation strategies:** The interactions between adaptation and mitigation strategies can be complex, and sometimes conflicting. These complexities are rooted in the inherent differences between these strategies (e.g., while adaptation often focuses on achieving short-term goals at the local level, mitigation focuses on long-term goals at the regional or global level). We propose that research in this area should characterize the cross-linking and trade-offs between mitigation and adaptation efforts.

Policy suggestions

Because most climate-related factors expected to impact human health (e.g., heat waves, air pollution, infectious disease transmission, etc.) are not contained by national boundaries, any effective adaptation and/or mitigation policies must be regional in nature and the result of collaborative efforts among EMME nations. Relevant policies suggested by our Task Force include:

- **Move decisively towards de-carbonization:** Achieving a significant reduction on the emission of greenhouse gasses is a key component of any plan aimed at protecting human health from climate change. Although phasing out fossil fuels is one of the most important steps to protect human health, our current rate of fossil fuel consumption is deeply rooted in complex and often outdated political and societal practices. Achieving meaningful, sustainable changes will require profound commitments on the side of consumers, institutions and policy makers alike. Therefore, only strong political determination at the national and regional levels can drive a concerted and efficient effort towards de-carbonization.

- **Integration of environmentally driven morbidity and mortality data throughout the region:** The EMME region would greatly benefit from the development of an integrated system that facilitates the tracking of morbidity and mortality data attributable to climatic factors. The development of such system would not only make it possible to establish clearer correlations between regional variations in climatic parameters and the incidence of specific health issues, but could also be instrumental in measuring the efficiency of mitigation or adaptation policies adopted in the region.

- **Advancing the development and widespread use of cheaper technologies for the production and management of drinking water by non-traditional means:** Water scarcity is a common threat for the future of most EMME countries. Therefore, efforts should be made to optimize the efficiency of water distribution systems, as well as to stimulate rational consumption by users. EMME countries should prioritize investments in research aimed at optimizing and reducing the cost of alternative technologies for the generation of drinking water, and to mitigate any ecological costs associated with these technologies.

- **Comprehensive regional strategies for the improvement of the health status of displaced populations:** Policies related to the health of migrant populations need to consider aspects such as the inherent inequalities in healthcare access of the displaced vs. local populations, as well as the cultural, ethnical and religious complexities of refugee settlements. EMME countries hosting groups of displaced individuals should implement comprehensive health policies that include access to healthy food and water, mental health services, maternal and reproductive health and infant vaccination, among other.

- **Fostering regional networks to monitor and control the spread of infectious diseases and disease vectors:** Due to the inter-connected nature of our modern societies, infectious diseases can spread rapidly across national boundaries. Among infectious diseases, those transmitted by vectors can be particularly hard to track and control, as their spread is driven by the movement of vector and reservoir species, as well as human hosts. For this reason, efforts at the national level are often insufficient to adequately monitor and control the dissemination of infectious diseases, whereas regional efforts can be more efficient at producing large-scale epidemiological data, identifying dissemination routes and facilitating control strategies.

1. Scope

Climate change affects every aspect of human life in complex and inter-connected ways. The impacts of climate change on health can be either direct (*e.g.*, exposure to extreme and unusual temperatures, drought and flooding) or indirect (*e.g.*, through changes in infectious disease epidemiology, and variations in the availability and/or quality of food, water and air). These effects are further compounded by a variety of biological (age, gender), ecological (pollution, disease-causing microbes, food and water contamination) and socio-political (socio-economic status, acclimation, occupation, health infrastructure, housing conditions) factors. For countries in the Eastern Mediterranean and Middle East (EMME) region, vulnerability to climate change is heightened by factors such as high rates of population growth and urbanization, an ageing population, political and military conflicts, mass population displacement and, in some cases, struggling economies.

In this report, we summarise current knowledge regarding the effects of climate change on the health of the people living in the EMME region, with particular focus on exposure to extreme temperatures, water shortage and food security, air pollution, VBDs and the health of displaced populations. We identify gaps in knowledge and research infrastructures that, when addressed, will help us better understand and monitor the impacts of climate change on human health. Finally, we offer policy suggestions which can help ameliorate some of these effects especially among vulnerable individuals including pregnant women, the young, the elderly, people with chronic or pre-existing medical conditions and socially marginalised populations including the poor, malnourished and displaced, and those lacking basic resources and sanitation.

2. Geographical setting

The geographical focus of this report is the region comprised by the Eastern Mediterranean and the Middle East (EMME). The countries included in this region (Figure 1) are Bahrain, Cyprus, Egypt, Greece, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Palestine, Qatar, Saudi Arabia, Syria, Turkey and the United Arab Emirates (UAE).

Climate can be very variable among the different sub-regions of the EMME. In the north, climate is rather temperate with hot, dry summers and relatively mild winters. In the south, on the other hand, prevailing conditions are those normally associated with desertic areas: arid, hot, and mostly devoid of precipitation and vegetation [1].

It is estimated that this region is home to approximately 459 million inhabitants (estimate for 2020) [2], with three countries (Egypt, Iran and Turkey) accounting for over 58% of the total human population. Strong inequalities in economic development are prevalent among the countries of this region; for example, per capita gross domestic product (PC-GDP) in 2019 ranged from less than $1,500 in Syria to over $62,000 in Qatar [3]. In fact, economic data reported for the same year (2019) show that the combined per-capita wealth (as measured by PC-GDP) of the region's five wealthiest countries (Qatar, Israel, UAE, Kuwait and Cyprus) was roughly 12.5 times higher than that of the five poorest countries (Syria, Egypt, Iran, Palestine and Jordan) combined [3].

FIGURE 1. Geographical setting

Note: Countries included in the definition of the 'Eastern Mediterranean and Middle East' (EMME) region are labelled.

3. Review of the effects of climate change on human health

3.1. Extreme heat

The ability to regulate body temperature is part of the basic physiological characteristics that have allowed humans to survive and function in a diverse range of environments across the globe [4]. Normally, the human body regulates its core temperature to stay between ~36.8°C and 40°C[1] [4], [5]. The body's ability to stay within these functional limits is intricately linked to the temperature of the direct surroundings, with higher environmental temperatures making it more difficult to dissipate the heat produced by metabolic processes, especially when it is combined with high humidity, which in turn can lead to various acute and chronic health issues.

When the body's core temperature rises above 40.5°C, there is an elevated risk of heat stroke [6]. It has been postulated that the thermal regulation capacity of humans reaches its sustainable limit when environmental "wet bulb" temperature (a measure of combined temperature and humidity) exceeds 35°C [7]; this temperature is considered to represent the limit for human survival. However, health problems related to increased environmental temperatures can also arise from exposure to temperatures well below this limit, especially if the exposure is maintained for extended periods of time.

Rising average environmental temperatures, as well as the increased frequency, intensity and duration of heatwaves,[2] are one of the most evident and most direct threats to human health caused by climate change. The main health conditions associated with heat exposure include heat stress, heat stroke, acute and chronic kidney injury and myocardial infarction in adults [8], [9], as well as electrolyte imbalance, fever, respiratory disease and renal problems in children [9]. Additionally, heatwaves have been associated with increased rates of mental and behavioural issues such as sleep disturbances, cognitive deficits, aggressive and criminal behaviour, collective violence, assault, homicide and suicide [9]–[11] (Figure 2).

1. Most people regulate body temperature to stay around 37°C. However, under particular circumstances (such as during high-performance athletic training), the body temperature of normal individuals can temporarily rise above this limit without permanent negative consequences [4].
2. Although there is no standardized definition for the concept of heatwaves, they are generally described as periods of "consecutive days where conditions are excessively hotter than normal" [243].

It has been reported that on a global scale, one in three heat-related deaths recorded between 1990 and 2018 are attributable to man-made global warming [12]. This estimate is believed to be much higher for Middle Eastern countries, where up to two in three deaths from heat are attributable to man-made global warming (e.g. 63% in Iran and 68% in Kuwait) [12].

Vulnerable populations

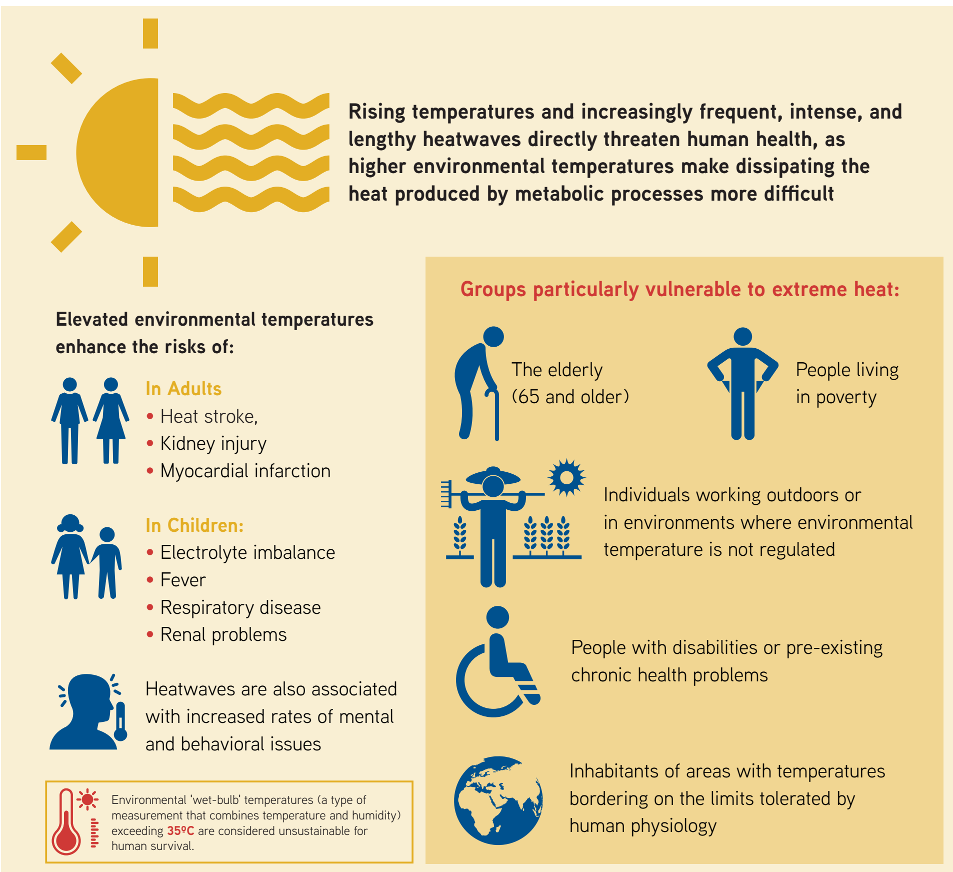
The elderly (*i.e.*, persons aged 65 years and older) are among the groups most vulnerable to extreme heat exposure [13], [14]. Other susceptible populations include people living in poverty, people with disabilities or pre-existing chronic health problems, individuals working outdoors or in environments where the ambient temperature is not regulated and the inhabitants of certain regions of the planet where temperatures already border the limits tolerated by human physiology [14] (Figure 2). Furthermore, the effects of heat on human health are also modulated by urban characteristics (such as population density and air pollution levels) and socio-economic factors (*i.e.*, gross domestic product and income inequality). It has been reported that both an abundance of green spaces and a high prevalence of air-conditioning units represent effective adaptation strategies to mitigate the negative health effects of heat [15], [16].

Because of the interaction between age and susceptibility to rising environmental temperatures, ongoing global demographic shifts are particularly relevant: in 2018, the global proportion of people over 65 years became larger than the proportion of those under 5 years [17] for the first time in history, and is expected to reach 16% of the world's population by 2050 [18]. Older individuals are particularly susceptible to environmental threats due to factors such as the reduction of their social support networks, increased prevalence of chronic health problems, reduced cognitive capabilities and the physiological decline normally associated with ageing (which importantly includes a significant reduction in mobility and thermoregulatory capacity) [6], [14], [16][18]. In this context, several studies have also identified gender as a risk factor for heat-related mortality in elderly individuals, with women showing greater susceptibility than men [21]. Furthermore, extreme heat exposure has been reported to cause severe negative effects in pregnant women and unborn children [22]. Therefore, women of child-bearing age can also be considered a group particularly susceptible to extreme heat exposure.

Chronic conditions that increase susceptibility to environmental heat include diabetes and other endocrine disorders, cardiovascular disease, mental and neurological disorders (such as Alzheimer's, dementia, schizophrenia and Parkinson's), obesity, cystic fibrosis, renal disease and respiratory disease [23], [24]. In addition to the physiological, cognitive and/or behavioural problems normally associated with these conditions (which directly impair the affected individuals' ability to successfully cope with increased temperatures), the medicines required to manage them can also interfere with the body's thermoregulatory processes, further increasing vulnerability in those afflicted by chronic health issues [23], [25].

In a study looking at the relation between increasing environmental temperature and daily mortality, Vicedo-Cabrera *et al*. [26] have shown that the mortality caused by increased heat has declined over the past decades in many countries. However, this trend is not uniform across the globe, or even across regions relatively homogeneous in their social and economic structures, such as continental Europe. De'Donato *et al*. [27] found that the reduction of mortality due to heat in the past 20 years has been mostly observed in Europe's warmer regions close to the Mediterranean, but not in Northern Europe, where in fact mortality associated to heat exposure has risen [27], [28]. Therefore, it seems that the reduction in heat-related mortality can be attributed, at least in part, to the fact that

FIGURE 2. The effects of increasing environmental temperatures on human health



people living in warmer regions have developed an increased awareness of the health risks posed by increasingly warmer weather, leading them to adopt protective practices and behaviours such as the implementation of "heat health action plans", early warning and response systems, air conditioning, building designs that maintain cool temperatures in indoor spaces and medical services that efficiently prevent and/or treat heat-related health issues [28], [29]. These protective factors might not be as prevalent in more temperate regions, increasing their inhabitants' vulnerability to extreme heatwaves [27]. In this context, Ramis and Amengual [30] conclude that vulnerability is temporally and spatially variable, with steeper increases commonly observed in regions where extreme temperatures are rare.

Heat-related morbidity and mortality

In Europe and the Eastern Mediterranean, a combination of an ageing population, high prevalence of chronic diseases and intense urbanization renders these regions highly vulnerable to heat exposure [9], [31]. This enhanced vulnerability has become evident in recent years, as heatwaves have broken temperature records and caused tens of thousands of deaths across Western and Central Europe (heatwave of 2003) [32] as well as Eastern Europe (heatwave of 2010) [33]. More recently, excess mortality attributable to increased environmental temperatures has been recorded in several cities in the region, including Athens, Crete and Istanbul [31][34].

Countries in the EMME region have also reported increased health concerns related to warming temperatures. Studies in both Cyprus and Kuwait have found an increase in relative mortality risk due to cardiovascular disease associated with increased average daily temperatures [38], [39]. In Iran, Mohammadi *et al*. [40] reported increased rates of acute myocardial infarctions due to elevated environmental temperatures, particularly in males and the elderly. In a report about the interaction between temperature and mortality in Cyprus, Heaviside *et al*. [41] projected that with a 1°C increase in the daily maximum temperature, heat-related mortality would double; and with a 5°C increment, mortality could increase almost 8-fold. The risk of heat-related mortality in Nicosia (Cyprus's capital) is reportedly higher in urban areas due to the urban heat island effect[3] [42]–[44]. In Egypt, it has been estimated that under a business-as-usual scenario (Representative Concentration Pathway 8.5) approximately 80% of the days in the last decade of the 21st century (2090-2100) will be hotter than 90% of the days of the 20062015 period [45].

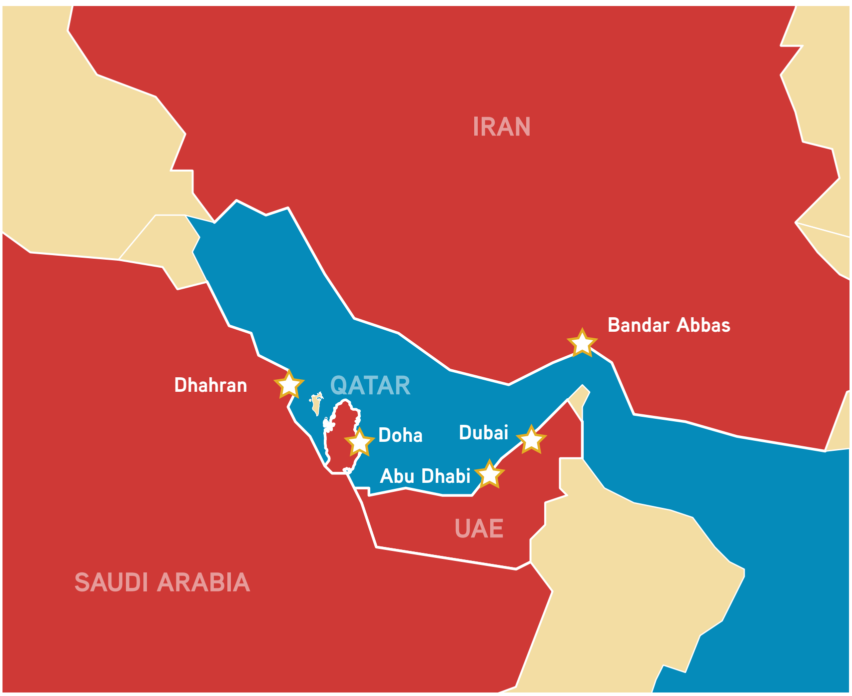
The epidemiology of some infectious diseases has been linked to variations in temperature and humidity due to climate change. Saad-Hussein *et al*. [46] found that the incidence of

3. It has been documented that environmental temperature in cities is generally higher than in the surrounding rural areas [43]. This is known as the "urban heat island" effect.

fungal keratitis in the greater Cairo area increased significantly with rises in minimum temperature and maximum atmospheric humidity during 19972007. Predicted increases in the incidence of this disease up to the year 2030 correspond to expected increases in surface temperature and greenhouse gas emissions in the region [46].

In the future, under a business-as-usual greenhouse gas concentration scenario, the death toll caused by heatwaves in Europe is predicted to account for 99% of all weather-related disaster fatalities by the end of the century [47]. Parts of the EMME region are predicted to reach maximum daytime temperatures of around 50°C [48], and could in exceptional cases exceed 60°C [7]. The effect of this marked increase in environmental temperature could be further amplified in densely populated areas due to the urban heat island effect [44]. As a result, by the end of the century cities around the Persian Gulf, including Abu Dhabi and Dubai (United Arab Emirates), Doha (Qatar), Dhahran (Saudi Arabia) and Bandar Abbas (Iran) could experience periods of such intense heat that they might surpass the thermal limits suitable for human survival [7] (Figure 3).

FIGURE 3. Cities where future environmental temperatures could surpass the limits for human survival



Source: Data from Pal *et al.* 2016 [7].

Note: By the year 2100, five cities (represented with stars) located in four EMME countries (Iran, Qatar, Saudi Arabia and the United Arab Emirates) could reach environmental "wet bulb" temperatures above 35°C, surpassing the threshold for the human body's physiological adaptability. UAE: United Arab Emirates.

3.2. Water stress

Water availability

The Middle East and North Africa (MENA) is among regions with the lowest water availability in the world, with only approximately 1 100 cubic metres (m^3) of natural renewable water resources (NRWR) per capita per year [49], [50]. In comparison, water-rich regions such as Australia and Latin America count over 34 000 m^3 NRWR per capita per year, and Western Europe has over 5 000 m^3 NRWR [50]. The most widely accepted measure of water availability, known as the "Falkenmark indicator" or "water stress index", establishes 1 700 m^3 NRWR per capita per year as the minimum threshold to sustain a population's basic needs. Countries that fall below this figure are considered to experience *water stress*. Countries with less than 1 000 m^3 are considered to suffer from *water scarcity*, and countries with less than 500 m^3 are considered to suffer from *absolute water scarcity* [51], [52].

While in several of the EMME countries water supply is based on desalination projects, 9 out of 15 countries in the Middle East are considered to experience absolute water scarcity, with one country (Kuwait) possessing practically no internal NRWR [49], [53]. Overall, >60% of the region's population is estimated to live under either "high" or "very high" water stress conditions [49]. Projections suggest that under a business-as-usual scenario, all countries in the region could deplete their groundwater reserves by the year 2050 [49]. Chenoweth *et al*. [54] have forecasted that "If the internal water footprint of the region declines in line with precipitation but the total water footprint of the region increases in line with population, then by mid-century, as much as half the total water needs of the region may need to be provided through desalination and imported in the form of virtual water".

In the Southeast Mediterranean region, water availability is similarly constrained with an estimated 180 million inhabitants experiencing water scarcity conditions, and about 80 million people living under absolute water scarcity [55]. This scenario is further complicated by the region's quickly growing population, increasing rural-to-urban migration and heavy dependence on water-intensive farming, which is the main source of income for up to 79% of its rural population [56]. Additionally, the renowned appeal of the Mediterranean coasts as tourist destinations often creates a large seasonal increase in the demand for potable water. This effect can be exemplified by the case of Cyprus, a country with less than 900 000 inhabitants that attracted somewhere between 3.1 and 3.9 million tourists per year between 2016 and 2019 [57]. It has been estimated that water demands associated with tourism account for 4.7% of the total water consumption in Cyprus [58].

Links between safe water supply and health

Direct links

Freshwater is vital to life, and the health of human populations is heavily dependent on the availability of a "safe, reliable, affordable and easily accessible" water supply [59]. The lack of access to safe water affects human health in a variety of ways. Perhaps most important, exposure to water contaminated with viruses or bacteria is the leading cause of diarrhoeal diseases, one of the top five contributors to the global disease burden [59], [60]. Children are particularly susceptible to the effect of water-borne infections, with diarrhoeal diseases ranking as the third-most important cause of diseases among children aged nine or younger, surpassed only by neonatal disorders and lower respiratory infections [60]. In 2016 alone, the lack of access to safe water and sanitation caused nearly 1.2 million deaths worldwide, including 300 000 children aged five years or less who died of diarrhoea [61].

Although several countries in the MENA have substantial death rates caused by diarrhoea in young children, Syria is currently by far the country with the worst outlook, with approximately 15% of its infant mortality attributable to this cause (a value well above the world's average, which is 9%) [53]. When comparing countries of similar gross domestic product, those with better access to improved water services display significantly lower infant mortality rates [59]. It is also worth mentioning that outbreaks of water-borne diseases are not exclusive to developing nations, as disease outbreaks linked to either drinking or recreational water are reported every year in developed countries [62]. Furthermore, it has been suggested that about one-third of all diarrhoea cases are linked to the consumption of poor-quality water from systems supposedly compliant with robust safety standards [62], [63].

Besides diarrhoeal diseases, sub-optimal water access can affect health in several other ways. Ingestion of water contaminated with parasites can cause debilitating diseases such as dracunculiasis, amoebiasis and giardiasis, among others [64], [65]. Acute or chronic exposure to water contaminated with chemicals (including arsenic, copper, fluoride, lead, nitrate, phenol, pesticides and endocrine-disrupting compounds) has been linked to disorders ranging from nausea and skin rashes to serious and life-threatening conditions such as renal failure, cancer, gangrene and foetal abnormalities [59], [62], [66], [67]. Furthermore, an inconsistent water supply forces people to collect and store water where important disease vectors, such as mosquitoes responsible for the transmission of dengue fever, chikungunya, Zika and yellow fever, can easily breed [64], enhancing the likelihood of VBD transmission in water-deprived areas (Figure 4).

Indirect links

A deficient water supply can indirectly affect the health of a region's population by reducing local food production, thereby interfering with people's ability to obtain a healthy and nutritious diet from local sources. In this context, several studies have shown that improving irrigation of local farming lands resulted in significantly better nutrition, particularly among children [59], [68], [69]. Ferald *et al*. [70] have proposed that undernourishment in children can cause elevated cortisol levels, which in turn can reduce their cognitive capabilities, decrease their functional immunity and increase their risk of cardiovascular disease later in life (Figure 4).

In water-scarce settings, water sources are often located away from homes, and people need to transport water for daily consumption from the source to their dwellings. This

FIGURE 4. Direct and indirect impacts of freshwater scarcity on human health

Access to fresh water is crucial to human life. A lack of access has direct and indirect negative impacts on human health.

Direct Impacts

- Exposure to water contaminated with viruses or bacteria is the leading cause of diarrheal disease—and children are particularly susceptible.
- Water contaminated with parasites can cause debilitating diseases such as dracunculiasis, amoebiasis and giardiasis.
- Water contaminated with chemicals such as arsenic, copper, fluoride, lead, nitrate, phenol, pesticides and endocrine-disrupting compounds is linked to renal failure, cancer, gangrene and fetal abnormalities.
- Vector-borne diseases such as dengue fever, chikungunya, Zika and yellow fever are more likely to exist in areas deprived of fresh, running water, where people must collect and store water in places where mosquitoes can easily breed.

Indirect Impacts

- Water scarcity reduces the capacity for local food production, which is vital to a healthy diet.
- In water-deprived areas, women and children usually transport water needed for daily consumption, often leading to fractures, lacerations, contusions and alterations to bone structure.
- The time required for water-collection can interfere with the ability of children to attend school and of women to engage in income-earning activities.
- Women and children who collect water are at an elevated risk of being exposed to parasites that can enter the body through the skin.

In 2016, lack of access to safe water and sanitation caused nearly **1.2 million deaths** around the globe, **including 300,000 children.***

*Source: World Health Organization [61].

task, often assigned to women and children, can impose heavy workloads on those transporting the water, and can lead to injuries (such as bone fractures, lacerations and contusions) and alterations to normal bone structure due to the repeated transport of heavy weight [64], [71], [72] but also exposure to extreme heat conditions. The time required for these journeys can also interfere with other important daily activities, such as children school attendance (stymying their educational process) and adult engagement in business endeavours which could contribute to financial instability of households [64], [71]. Furthermore, water collection practices increase the likelihood of exposure to water contaminated with certain parasites, like those belonging to the genus *Schistosoma*, which can enter the body through the skin, putting those responsible for these activities at an elevated risk of acquiring parasitic diseases.

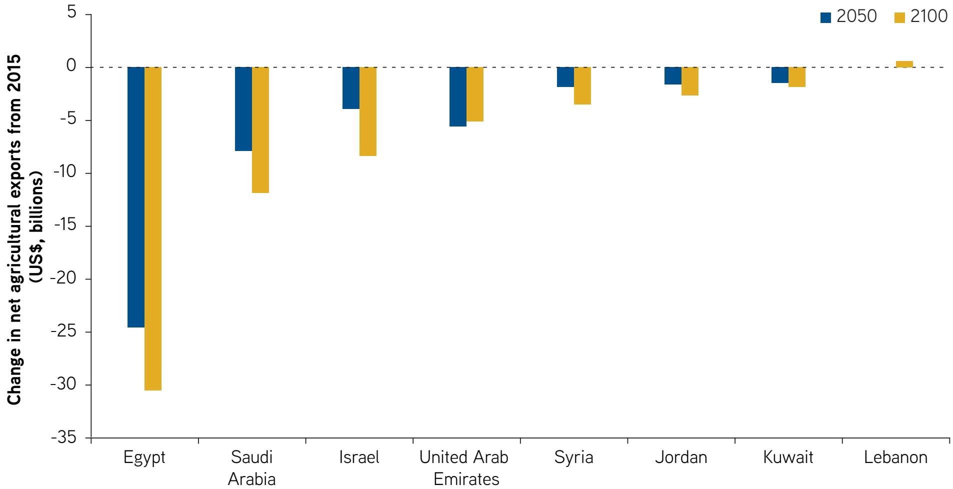
3.2.1. Water stress, economy and food security nexus

Water availability is necessary for virtually all economic activities, and therefore its scarcity represents a threat not only to a region's public health, but also to its economy. Food production requires large quantities of water and, often, expensive investments are required in order to obtain, purify and transport the required water resources from their source to the end users [49].

Agricultural activity is responsible for approximately 70% of global water consumption. However, the very arid climatic conditions and dry soils of the Middle East increase the water requirements of its agricultural sector to approximately 80% of all water withdrawals, with certain countries (such as Syria, Oman, Saudi Arabia, Iran and Yemen) using as much as 90% of water withdrawals for agricultural practices [53]. Additionally, countries in this part of the world have some of the highest rates of freshwater resource losses per capita within their food supply chain, with certain countries wasting as much as 177 m^3 freshwater per capita per year during production, processing and distribution of food [73].

The expected scarcity of water resources in the Middle East might cause certain countries in the area to lose up to 60% of their agricultural productivity by the year 2050 [74]. In addition to directly affecting the availability of food for the local population, this reduction in agricultural output would also cause a massive drop in the gross domestic product of these countries (estimated between 6% and 14%) and negatively affect the livelihoods of almost one-third of the region's population who work in agriculture-related businesses [49], [74]. Furthermore, reduced agricultural productivity is expected to cause drops in agricultural export revenues in the range of billions of dollars, with countries such as Egypt, Saudi Arabia, Israel, Yemen and the United Arab Emirates being the most affected by this phenomenon [74] (Figure 5).

FIGURE 5. Expected changes in revenue from agricultural exports in selected EMME countries



Source: Figure modified from Borgomeo *et al.* (2018) [74].

On a positive note, several countries in the region have successfully implemented strategies that allow them to increase the productivity of their water resources, as well as to obtain usable water through non-conventional means such as desalination and wastewater re-use [53]. In Israel, for example, water generated by the aforementioned non-conventional processes accounts for approximately 25% of that nation's total water supply, and provides about half of the water used for agricultural purposes [75]. However, the high financial and energy costs associated with some of these processes (particularly desalination) currently limit their widespread use [76].

In summary, the projected reduction in water availability in the EMME region will greatly affect crucial aspects of life in the region, including the health, education and economic status of the population. To quote a North Atlantic Treaty Organization (NATO, 2019) report on the topic, in this region "water scarcity has the potential to deeply undermine the structure of society" [49].

3.3. Dust events, wildfires and air pollution

3.3.1. Dust events

The Sahara, the Arabian Peninsula, the Arabian deserts (i.e. Iraq, Syria and Jordan's arid lands) and the Sistan region are the four major sources of airborne dust in the EMME region, strongly affecting the concentration and deposition of dust particles across and beyond the region [77], [78] (Figure 6). Saharan dust plumes have been detected in several countries, including the United States, Spain, Italy, Greece, Cyprus, Israel and Lebanon [79], [80], [81], and dust storms from the western Middle East (i.e. the Arabian Peninsula and Arabian deserts) have been shown to reach Iran [82], [83] and India [84]. Ahmady-Birgani *et al*. concluded that the Persian Gulf States, Syria and Iraq are the main sources of dust affecting western Iran [85]. Additionally, the Sistan region between Iran and Afghanistan is now the main source of dust events in the eastern Middle East, affecting Iran, Afghanistan, Pakistan and India [86]–[88]

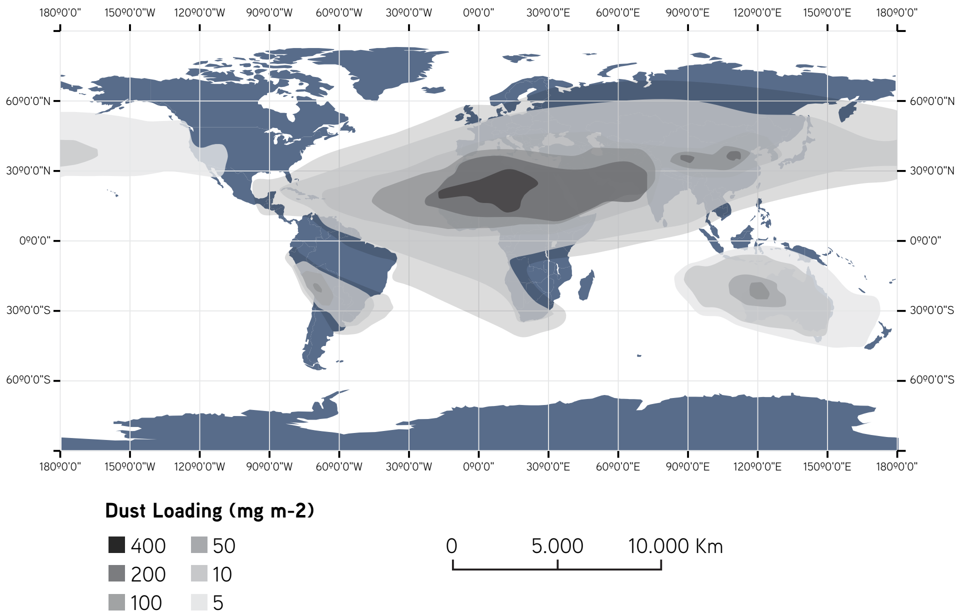
Any review of dust events across the EMME region should consider changes in air pressure, temperature, wind speed, soil moisture and geomorphological settings. It is projected that the temperature in this region will rise by 39°C by the year 2100 [89], which would lead to changes in air pressure across large sections of the EMME region. For example, the Sistan region is affected by higher pressures coming from the Caspian Sea and lower pressures coming from India and Pakistan, resulting in an intensification of the phenomenon known as the "120-day winds" (also known as the Levar winds) [90].

Global drying and warming trends are strong drivers of the increase in the frequency and intensity of dust storms [91] [92], while water shortages, poor water management, land surface erosion, high evaporation, high wind erosion, desertification and deforestation may create new drylands and sources of dust [93] [94] [95], [96]. Although the exact nature of the interaction between climate change and dust events remains unclear, some studies have emphasised the fact that these phenomena are inter-connected. For example, Klingmüller *et al*. have postulated that increases in temperature and reductions in relative humidity associated with climate change during the past decade have increased dust emissions in the Middle East [97], and Naderi-Beni *et al*. have reported that dust events throughout the Persian Gulf are directly related to drought and water scarcity attributable to climate change [98].

In Iran, Baghbanan *et al*. reported that different phenomena associated to climate change (including rising temperatures, low surface moisture, vegetation loss, wetland drying, high-speed winds and successive droughts) have increased the frequency of dust storms [99]. Furthermore, it has also been shown that wind erosion is prevalent in many Iranian provinces, and susceptibility to drought is expected to increase considerably in the near future [94] [95].

Meanwhile, studies in Israel reported an increase in concentrations of PM with a diameter below 10 µm (PM_{10}) due to dust storms between 2001 and 2015, and detected more extreme dust events, with higher daily and hourly levels since 2009, which was attributed to climate change [100] [92] [28].

FIGURE 6. Distribution of atmospheric dust loads around the world



Source: Figure modified from World Bank (2019) [101].

The impacts of dust exposure on chronic health conditions and mortality have not been sufficiently characterised in contrast to the impacts of air pollution [102]. However, available data point towards increased risks of hospitalization and mortality due to circulatory and respiratory diseases resulting from dust events in the EMME region [28][103][104][105]. Research performed in Greece has revealed associations between exposure to airborne PM (including desert dust) and increased hospital admissions due to asthma in Athens [106], as well as increased admissions due to chronic obstructive pulmonary disease in Crete [107]. And in Iran, it has been reported that the presence of PM in the environment is associated with an increase in daily mortality in the city of Ahvaz [108],[109]. Also in Iran, Bonyadi *et al*. concluded that atmospheric PM and sulphur dioxide have negatively affected the health of the people in the city of Shiraz by increasing the incidence of cardiovascular disorders (including acute myocardial infarction) as well as respiratory diseases [110].

Many microorganisms, including human pathogens, have been detected in dust plumes transported over long distances [111]–[113]. The nature of transported microorganisms may depend on their origin, and their abundance and diversity could be enhanced due to climate change causing the appearance of new sources, as well as the spread of microbial species previously not subjected to transportation and deposition [92].

Although the viability and pathogenicity of these bio-agents is unclear, chronic and episodic exposure to high dust levels has been associated with allergies, silicosis, lung disease, chronic respiratory diseases and infections such as granulomatous, sarcoidosis and meningococcal meningitis [77], [114]. As with exposure to extreme heat, groups that are particularly vulnerable to the exposure of high dust concentrations include very young and elderly people (due to underdeveloped or deteriorating immunity, respectively), as well as people with chronic cardiopulmonary diseases. Studies in Iran have reported a link between temperature, humidity, atmospheric dust and peaks of shigellosis cases in summer months [115]. Furthermore, research performed in the city of Ilam (western Iran) revealed that the concentration of bio-aerosols in the environment is elevated during dust storms [116].

Airborne dust originating from agricultural areas could potentially facilitate the spread of antibiotic resistance genes, a growing global health problem [92]. Traces of pesticides and herbicides, as well as microbial and heavy metal contaminants of anthropogenic origin (including those generated by military conflict), could coincide with dust storms and increase their risk to public health in the region [92], [94], [95],[112], [113], [117]–[119]. Atmospheric dust has also been associated with the incidence of food-borne disease in the region [95].

3.3.2. Wildfires

Reduced precipitation and relative humidity and higher temperatures are expected to increase the risk of forest fires and associated air pollution [120] [1]. In the latest report of the Lancet Countdown, the largest increase in the risk of wildfires between 2001 and 2019 was observed in Lebanon along with Kenya and South Africa [14]. In Turkey, storms, floods, droughts and forest fires are among the most frequent natural disasters, and an increasing trend has been reported especially in the past two decades [120].

In addition to their direct health impacts, wildfires increase the number of patients checking into emergency departments, and are implicated with an increase in acute and chronic respiratory diseases [120]. Furthermore, a recent review and meta-analysis by Karanasiou *et al*. [121] established that exposure to the emissions of biomass burning (including wildfires) is positively associated with mortality, including deaths caused by cardiovascular problems.

Early warning systems and the protection and improvement of forest ecosystems are major factors contributing to the decrease in the area damaged by wildfires [122].

3.3.3. Air pollution

Outdoor air pollution in the form of fine PM with a diameter of 2.5 μm or less ($PM_{2.5}$) is implicated in up to 9 million premature deaths per year globally [123], [124]. In 2018 alone, air pollution was responsible for approximately 8.7 million deaths around the world – approximately 20% of that year's total global mortality [125].

The largest epidemiological study conducted to date on the short-term health effects of air pollution with PM_{10} and $PM_{2.5}$ showed a concentration-response function with a consistent increase in daily mortality as PM concentrations increased, with no discernible thresholds [126]. This finding is particularly worrisome for megacities in the EMME region. Similar concentration-response functions with no discernible thresholds have recently been reported for carbon monoxide and nitrogen dioxide [127], [128].

In Europe and the Eastern Mediterranean, around 1 million people die prematurely each year due to air pollution [129]. High concentrations of $PM_{2.5}$ and ozone in outdoor air are associated with adverse health impacts, including chronic obstructive pulmonary disease, acute lower respiratory illness, cerebrovascular disease, ischaemic heart disease and lung cancer [130][102].

Increased PM concentrations in ambient air from energy generation, industrial pollutants, agriculture, traffic, domestic energy use and increasingly frequent wildfires are implicated with respiratory and cardiovascular diseases, potentially aggravated by the growing abundance of desert dust in outdoor air. Egypt, Turkey and Iran were among the top 15 countries with the highest premature mortality attributable to air pollution in 2010 [1].

The strong urbanization trend in the region, in combination with the increase in human-induced emissions, are both major contributors to air pollution, causing air quality degradation in several megacities, such as Cairo, Istanbul and Tehran [1]. Excess morbidity and mortality associated with ground-level ozone and air pollution (caused by fine PM) are predicted in the region [1].

In the EMME region, especially in the Persian Gulf States, fossil fuels dominate the energy supply. The by-products of fossil fuel burning include greenhouse gases, PM and hazardous gases such as ground-level ozone, nitrogen dioxide and volatile organic compounds. Because heat and sunlight facilitate the formation of some of these noxious compounds, urban heat islands, heatwaves and the high intensity of sunlight contribute to the deterioration of air quality in the densely populated environments of the EMME region.

A modelling study performed by Lelieveld *et al*. in 2012 suggested that the expected warming and increased frequency and intensity of heatwaves will strongly increase the demand for air conditioning in the region [1]. The increasing energy demand for industry, traffic, air conditioning and desalination due to water shortage will exacerbate air pollution and greenhouse gases, which in turn will feed into environmental and climate change.

3.4. Vector-borne diseases

Arthropods capable of transmitting human pathogens, also known as "disease vectors", are unable to self-regulate their body temperatures by physiological means, and must therefore rely on external sources of heat to maintain their temperature within functional limits. Consequently, environmental conditions are major determinants in the development, physiology, behaviour and ecology of disease vectors, and can also influence important biological processes in the life cycle of pathogens [131]–[133]. Therefore, the epidemiological landscape of VBDs is heavily influenced by climate change [134]–[136].

Environmental factors that can influence the transmission rate of VBDs include temperature, precipitation, relative humidity, wind and duration of daylight [134], [137]. Among these, temperature and precipitation play particularly determinant roles in the geographic distribution, seasonality and ecology of VBDs [138]–[140].

The interaction between temperature and VBD transmission is complex, often non-linear, and variable among different vector/pathogen combinations [141], [142]. In some instances, it has been proposed that global warming will cause changes to the geographic distribution and seasonality of disease vector species, allowing them to survive in areas and/or seasons currently deemed unsuitable due to their low temperatures, therefore enhancing the potential for transmission of VBDs [143]. However, it has also been proposed that in other regions, global warming could cause environmental temperatures to rise above the maximum tolerable levels for certain vector/pathogen systems, resulting in a reduction of current geographic ranges, alterations to seasonal transmission patters or shifts in the relevance of different VBDs for specific geographic settings [142], [144], [145].

Besides climate, the epidemiology of VBDs is also influenced by socio-economic factors such as population density, access to running water; housing quality; and local knowledge, attitudes and practices, among others [146]–[150]. Presently, a combination of ecological and socio-economic factors found in the EMME region creates appropriate conditions for the local transmission of several VBDs, including malaria, dengue, leishmaniasis and West Nile fever, among others [137], [151] (Table 1).

It has been proposed that warming climatic trends observed for the region will cause the incidence of these infections to rise [14], [28], [152], [153]. Below, we address several VBDs of particular concern in the region, and describe the expected effects of climate change on their regional epidemiology.

TABLE 1. Principal vector-borne diseases affected by climate change in the EMME region

	West Nile Fever	Malaria	Leishmaniasis	*Aedes*-borne arboviral infections
Causative agent	• West Nile Virus.	• Various species of *Plasmodium* parasites.	• Various species of *Leishmania* parasites.	• Dengue virus, Zika virus, chikungunya virus, among others.
Common vectors	• Various species of *Culex* mosquitoes.	• Various species of *Anopheles* mosquitoes.	• Various species of Psychodidae sandflies.	• Various species of *Aedes* mosquitoes.
Symptoms	• Ranging from mild and flu-like to encephalitis and death.	• Intermittent periods of high fever with a feeling of intense cold. • Nausea, headaches, and myalgia. • In severe cases, blood vessel blockage, organ failure and death.	• Varying from non-healing skin lesions (which can lead to disfigurement and disability) to internal organ enlargement, anemia and death.	• Large proportion of cases can be asymptomatic. • When present, symptoms vary from mild and flu-like to severe and potentially fatal, including haemorrhagic syndrome, polyarthralgia and neurological complications.
Relevant environmental influences	• High temperatures (particularly during the summer). • High precipitation in late winter/early spring, coupled with particularly dry summers. • Presence of migratory bird species.	• Rainfall, temperature, humidity, vegetation, hydrogeology and wind speed. • In areas where this disease has been eradicated, the presence of endemic competent vector species increases the risk of re-emergence.	• Precipitation, temperature, altitude, land use, water development projects and presence of potential reservoir species.	• Temperature, precipitation and host/reservoir availability. • Temperature is a major determinant of several important parameters, including habitat suitability for vectors, vector capacity and virus mutation rates.

3.4.1. West Nile Fever

West Nile Fever is caused by the West Nile Virus (WNV), a member of the Flaviviridae family of viruses. During its natural (i.e. enzootic) transmission cycle, WNV is normally transmitted between birds by mosquitoes (Diptera: Culicidae) belonging to the *Culex* genus. A few mosquito species that feed on both birds and mammals can act as "bridge vectors", transmitting the virus to a broad diversity of mammalian hosts, including humans and horses. Mammalian hosts usually do not develop high enough viremias to infect blood-feeding mosquitoes, and are therefore considered to be dead-end hosts.

Infection with WNV in humans is generally sub-clinical. However, symptomatic cases might range from mild and flu like to paralysis, full-blown encephalitis and even death

[154]. Fatality rates vary depending on age and co-morbidities, reaching up to 29% in people aged 70 years and over. Moreover, among clinical cases that recover, up to 50% can still present consequences lasting for a year or longer post infection [155].

Originally endemic to Africa, WNV has spread throughout the world, and at present is considered the most widespread of all flaviviruses, as it is found around Africa, Eurasia and the Americas. In countries of the EMME region such as Greece, Israel and Turkey, a clear correlation has been established between WNV outbreaks in humans and the unusually warm summers between 2010 and 2014 [137], [156]–[158]. In Greece, Stilianakis *et al*. found that increased soil and air temperatures were correlated with an incremental increase in the incidence of WNV cases in humans, and proposed that higher temperatures might contribute to the spread of the disease by favouring mosquito larval development and reducing generation times [158].

Studies in the Mediterranean region have also demonstrated the importance of water bodies and precipitation for WNV epidemiology: One study showed that areas with positive anomalies of the Modified Normalized Difference Water Index during the month of June are at a higher risk of transmission [157]. Another study proposed that high precipitation in late winter/early spring, coupled with particularly dry summers, are good predictors of WNV outbreaks [159]. On the other hand, it was found in other regions that drought conditions can be as much a risk factor for WNV outbreaks [160]. A recent study in Italy found that WNV outbreaks are associated with the local pool of mosquitoes infected in previous years [161]. When combined with an increasing mosquito abundance and the number of WNV cases in recent years, the association between the risk of WNV outbreaks and climate change is strengthened [162]. Furthermore, because of the role of birds as reservoirs of WNV, the epidemiology of this pathogen is also dependent on variables such as bird migration pathways over the area, which are in turn affected by climate change [158], [163].

3.4.2. Malaria

Malaria is a mosquito-borne disease caused by infection with one of several species of protozoans from the *Plasmodium* genus. Human *Plasmodium* species are transmitted by mosquitoes (Diptera: Culicidae) belonging to the *Anopheles* genus. The co-evolution of the ancestors of humans and *Plasmodium* parasites is ancient, stretching millions of years before the appearance of modern human beings [164].

Infection with *Plasmodium* sp. in humans generally causes periods of high fever during which the affected person can experience a feeling of intense cold and shivering. Other symptoms might include nausea, headaches and myalgia. Severe cases can lead to severe anaemia, blood vessel blockage, organ failure, brain swelling, seizures, coma and death.

Pregnant women, children under five years of age and the elderly present a higher risk of malaria-related complications and mortality [165]. According to the World Health Organization (WHO), in the last two decades the global average number of malaria cases per year is 236 million (ranging from 217 to 248 million). Over the same period, the number of yearly deaths due to malaria decreased from 738 000 (average for the 200004 period) to 425 000 (average for the 201519 period) [166].

There have been several successful efforts to control the spread of malaria at the national and regional levels across the globe. The current geographic spread of this disease responds in part to these control efforts, as well as climatic factors [134], [138]. For example, although malaria was historically endemic to Europe, intense and well co-ordinated control efforts led to its eradication from the entire continent by the late 1970s [134], [167]. However, local transmission of malaria resumed in Europe during the late 1990s, and has occurred sporadically in several countries of the region during the past decade, including in Greece and Cyprus [167], [168]. On the other hand, the WHO's most recent World Malaria Report highlights several countries in the EMME region for their achievements in reducing malaria incidence. For instance, Iran reported progressively decreasing malaria cases throughout the past decade, and zero cases in 2018 and 2019. Saudi Arabia reported only 38 indigenous cases in 2019, and Iraq, Oman and Syria have not reported indigenous cases since 2009, 2011 and 2004, respectively [166].

A systematic review of the literature describing the associations between climate change and health in the Eastern Mediterranean countries found that rainfall, temperature, humidity, vegetation index, hydrogeology and wind speed were among the reported environmental determinants of malaria transmission [169]. Furthermore, it has been proposed that due to the existence of competent vector species in the region, future climate change could create conditions that facilitate the reappearance of malaria in countries where the disease is currently considered to be eradicated [137].

3.4.3. Leishmaniasis

Leishmaniasis is a parasitic disease caused by infection with one of several species of parasites from the genus *Leishmania*. In addition to humans, these parasites can infect a diversity of vertebrate hosts, which act as reservoirs. *Leishmania* parasites are transmitted by over 90 species of sandflies (Diptera: Psychodidae) belonging to the phlebotominae sub-family [170]. In the EMME region, leishmaniasis vectors belong to the *Phlebotomus* genus [171].

According to the WHO [172], this disease has three main forms:

1) *Visceral leishmaniasis*, also known as kala-azar, is characterised by the enlargement of the spleen and liver, fever, anaemia and weight loss. If not treated, its fatality rate is >95%. Most cases of this kind of leishmaniasis occur in Brazil, East Africa and India. However, Iraq (part of the EMME region) has reported a high incidence of this disease in the recent past.
2) *Cutaneous leishmaniasis* is characterised by non-healing skin lesions which can cause serious scarring and disability. This is the most common form of leishmaniasis, with up to 1 million new cases occurring each year, and is particularly prevalent in the Americas, the Mediterranean region, the Middle East and Central Asia. In fact, countries within the WHO's Eastern Mediterranean region account for ~70% of the cutaneous leishmaniasis cases reported worldwide. Countries in the EMME region reporting high incidence of this form of leishmaniasis in the recent past include Iran, Iraq and Syria.
3) *Mucocutaneous leishmaniasis* is characterised by the destruction of mucous membranes in the upper respiratory tract (nose, mouth and throat), often leading to dramatic scarring and disfigurement. Most cases of this form of the disease occur in Bolivia, Brazil, Ethiopia and Peru.

In the Eastern Mediterranean region, significant correlations between leishmaniasis incidence and climate have been shown, with a positive correlation between incidence and precipitation, and a negative correlation between incidence and temperature [169]. Furthermore, a study in Israel showed that much of the variance in sandfly spatio-temporal activity and population growth is determined by early night temperatures, and that the effect of rising temperatures on sandfly populations is more marked at lower elevations [173]. Other factors associated with the incidence of leishmaniasis in the region include elevation, land use, presence of potential reservoirs and water development projects [169], [174].

Ecological niche modelling predicts that future climate change will alter the geographic distribution of the existing *Phlebotomus* species within the EMME region. On the one hand, it is expected that these changes will allow sandflies to spread towards areas currently not suitable for their survival (eventually reaching Western and Central Europe), while on the other hand some sandfly populations are expected to disappear from currently suitable areas [175].

3.4.4. Arboviral diseases transmitted by *Aedes* mosquitoes

Mosquitoes (Diptera: Culicidae) belonging to the *Aedes* (*Ae.*) genus, particularly *Ae. aegypti* and *Ae. albopictus*, are the main vectors for several arboviruses of major medical relevance, including the dengue, chikungunya and Zika viruses. All three viruses contain ribonucleic acid as their genetic material, and cause infections that present a wide range of symptoms, from mild and flu-like, to severe and potentially life threatening. Furthermore, a large proportion of infections with these viruses are asymptomatic [176].

Ae. aegypti, a species of African origin, is a highly synanthropic mosquito that thrives in urban environments, is capable of breeding in man-made containers (such as discarded plastic, tires, etc.) and feeds almost exclusively on humans [177]. *Ae. albopictus*, on the other hand, is a species of Asian origin and has a more flexible ecology, being able to adapt to urban, rural and agricultural habitats, and breed in either natural or man-made containers as well as feed on a wider range of vertebrate hosts, including birds and mammals. Because of its catholic host preferences, *Ae. albopictus* has the potential to act as an important vector of zoonotic viruses [178]. An additional important difference between *Ae. aegypti* and *Ae. albopictus* is their thermal tolerance: while *Ae. aegypti* is generally unable to thrive in temperatures below 10°C, *Ae. albopictus* is able to adapt to below-freezing temperatures by undergoing diapause. This characteristic allows *Ae. albopictus* to colonise a broader latitudinal gradient than *Ae. aegypti* [177], [179], [180]. On the other hand, *Ae. albopictus* is less tolerant to very high temperatures than *Ae. aegypti*, limiting the capability of *Ae. albopictus* to survive in extremely hot zones [145].

Temperature is not only a major determinant of habitat suitability for vectors but can also affect important biological parameters related to disease transmission. For example:

- Because female mosquitoes feed on blood to provide the nutrients required for egg development, warmer temperatures increase the biting rate of female mosquitoes by reducing the time period required for egg maturation (gonotrophic cycle) [145]. Since the transmission of mosquito-borne viruses happens during blood feeding, higher biting rates mean higher disease incidence. Therefore, increases in environmental temperature will intensify epidemics by decreasing the time between successive infections in humans [181].
- In the case of dengue, it has been proposed that the number of secondary infections will increase with environmental temperature until reaching an optimal temperature of approximately 33°C, after which it will start decreasing [181].
- Due to the high mutation rates and short generation times characteristic of arboviruses, the increased numbers of infections caused by rising temperatures might promote faster evolution rates in these pathogens. The increased genetic variability generated by this process could result in the emergence of novel virus strains and/or serotypes, with different properties regarding virulence and/or transmissibility [182].

It is often the case that an increase in environmental temperature leads to an increase in arbovirus transmission rates, although this trend does not apply to all arboviruses [140]. The interactions between temperature and disease transmission are complex and not always linear, with factors such as spatiotemporal temperature variations and the effects of rearing temperature on adult vector biology playing important roles [140], [183].

Besides temperature, other environmental factors such as precipitation and host availability have been shown to be major determinants of an area's suitability for *Aedes* vectors [184], [185]. Furthermore, in currently endemic areas, factors such as population growth can deeply influence the epidemiology of *Aedes*-borne diseases; as an example, it has been estimated that between 2015 and 2080, the number of people at risk of contracting dengue will increase by 2.25 billion, reaching a global total of over 6.1 billion (equivalent to 60% of the planet's population). This increase will be largely due to growing population sizes in endemic areas [186].

The global geographic distribution of both *Ae. aegypti* and *Ae. albopictus* is expected to shift as a result of climate change, potentially resulting in enhanced disease transmission [187]. Both *Ae. aegypti* and *Ae. albopictus* are currently present in several countries of the EMME region (Figure 7), and it has been shown that all countries in the Eastern Mediterranean

FIGURE 7. Current distribution of *Aedes aegypti* and *Aedes albopictus* in the EMME region

Source: Data from Ducheyne *et al.* (2018) [184] and European Centre for Disease Prevention and Control (2021) [189], [190].

region have at least some areas with suitable conditions for the establishment of both species, making it possible for the expansion of their geographic ranges to regions which they have either never before colonised, or where they have been successfully eradicated in the past [145], [184]. Furthermore, future climate change is expected to render additional areas suitable for the survival of these mosquito species, including regions within the MENA region and continental Europe [177], [188].

3.5. Population displacement

3.5.1. Climate change and human displacement

Climate change has been intimately linked to the geographic displacement of human populations throughout the history of our species, and might have played an important role in shaping early societies [191]. In recent history, climate change has been associated with such notable events as the mass migrations resulting from the Little Ice Age in 17th century Europe, and the population displacement resulting from the 19th century Irish Potato Famine, among many others [192], [193].

During the past 50 years, the displacement of human groups has surged significantly due to complex environmental, economic and socio-political issues. Currently, it is estimated that approximately 13% of the world's population (~1 billion people) do not live in their place of birth, and approximately 3.5% of the world's population (~270 million people) have moved between countries [194]. The United Nations Refugee Agency reported that by 2019 the global number of forcibly displaced persons had reached 79.5 million, 40% of which were children [195].

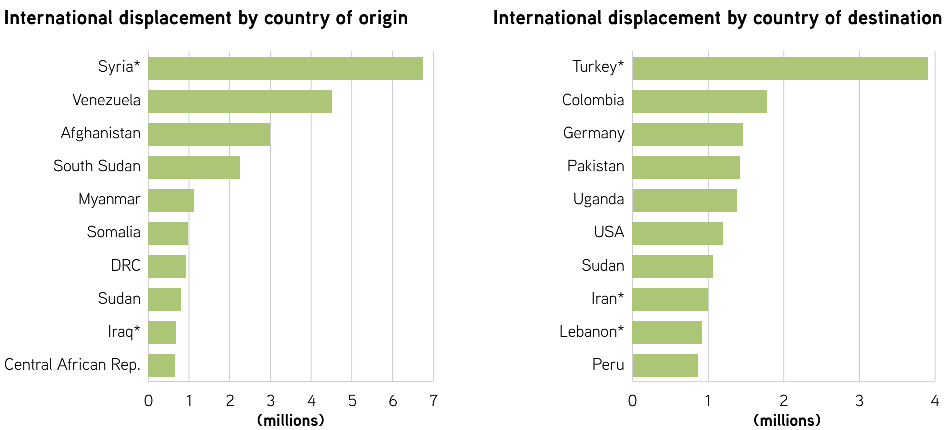
Climate change can stimulate population displacement in several ways, including increases in the intensity and frequency of extreme weather events, loss of land to sea-level rise and the deterioration of life-sustaining ecosystems, among others [196], [197]. Furthermore, it has been proposed that the negative effects of environmental events might influence people's reaction to pre-existing socio-political problems, sometimes leading to turmoil and violence, which in turn force people to move out of their lands. Bowles *et al.* [198] state that:

"Decreased availability of essential resources could directly increase the probability of violence. Diminished arable land or available water could lead to conflict between ethnic groups or between nations. Somewhat less directly, countries may respond to water shortages by building dams or contravening water treaties, which may provoke conflict, including through attacks on water infrastructure by downstream countries".

The recent civil war in Syria can be viewed as a key example of the interaction between environmental change, social conflict and population displacement: Kelley *et al*. [199] propose that the severe drought that affected the greater Fertile Crescent region between 2007 and 2010 caused a devastating loss of crops and livestock, forcing as many as 1.5 million Syrians to migrate from rural areas towards urban centres in search of better livelihoods. In the authors' opinion, the intense pressure this migration exerted on urban areas, together with pre-existing problems such as overcrowding, unemployment, corruption and poverty, triggered the civil unrest that started in 2011 [199]. However, other authors argue that the uprising responded to decades of socio-political problems, and would have happened even in the absence of extreme drought conditions [200]. Although it is often impossible to know with certainty whether environmental factors are direct triggers of conflict, a widely accepted notion is to understand climatic events as "risk multipliers" – that is, elements that exacerbate pre-existing tensions and increase the likelihood of violent confrontations being triggered by economic, social or political factors [198], [200]. Furthermore, it has been proposed that in regions experiencing active turmoil, climatic events can also act as "peace inhibitors" by creating conditions that undermine conflict resolution efforts [198], [201].

Countries in the MENA region have some of the largest shares of migrants anywhere in the world [202] (Figure 8). The reasons behind this massive movement of people can be traced to failing economies, climate change, natural disasters or violent conflicts [200], [203]. Protracted conflicts in many of the region's countries have caused the displacement

FIGURE 8. International population displacement by country of origin and destination, 2019



Source: Figure modified from UNHCR (2020) [195].

Note: Figure shows the 10 countries either generating (left panel) or receiving (right panel) the largest internationally displaced populations in the world. *EMME countries. DRC: Democratic Republic of the Congo. USA: United States of America.

of millions of people – as of 2019, Syria is the country with the highest number of displaced people in the world (13.2 million, 6.7 million of which are internationally displaced). Iraq, another country of the EMME region, ranks ninth in the global list of countries with the highest number of displaced persons – 0.6 million [195]. Furthermore, several EMME countries serve as hosts to very large displaced populations: Turkey alone has received approximately 3.9 million people, becoming the world's largest host of internationally displaced populations. Iran and Lebanon are also home to large international refugee populations, receiving approximately 1 million displaced people each [195].

3.5.2. Health impacts on displaced populations

Direct effects

The displacement of human populations can have detrimental health effects at various levels. Direct effects can include bodily injuries and psychological trauma (in cases of displacement caused by violence), as well as the problems caused by rough conditions prevalent either during the displaced person's journey, or at the temporary dwellings where displaced populations are usually housed [198], [200], [204]. The main health problems associated with refugees' poor living conditions include respiratory, gastrointestinal and skin conditions, as well as dehydration, hypothermia, burns and malnutrition [198], [204], [205]. Additionally, the sub-optimal nature of the housing usually available to refugees tends to render them particularly vulnerable to climatic phenomena such as extreme temperatures, flooding or air pollution (Figure 9).

Indirect effects

Infectious diseases

The displacement of people across borders has important epidemiological consequences for infectious disease transmission: on the one hand, migrating individuals coming into new geographic areas can be exposed to infections which they have not faced before, and against which they lack both immunity and protective practices. On the other hand, migrants themselves can act as carriers of pathogens to the areas through which they journey, or where they settle [196]. Displaced populations are often sheltered under sub-optimal conditions where overcrowding, poor ventilation and lack of access to basic sanitation are common, creating an environment where diarrhoeal diseases (including cholera), measles, meningitis, acute respiratory infections, scabies and tuberculosis are easily transmitted [196], [206]–[208]. Importantly, in areas where vector-borne pathogens are endemic, these sub-optimal living conditions create ideal environments for the transmission of diseases such as malaria, dengue, leishmaniasis, epidemic typhus, relapsing fever and trench fever, making them particularly serious threats to displaced populations [192], [207], [209], [210]. A clear example of this are the outbreaks of cutaneous leishmaniasis observed among Syrian refugees sheltered in Lebanon and Jordan [211], [212]. Furthermore, the epidemiology of parasitic diseases can also be affected by climate change: Ahmed *et al*. [213] have suggested that increases in the incidence of bladder cancer due to schistosomiasis in the Red Sea area of Egypt are linked to the internal migration of farmers from Delta governorates, who had lost their lands to sea-level rise.

Reporting on refugees (originating mostly from the Middle East) seeking shelter in Greece during 2016, Shortall *et al*. [205] found that more than half of the cases reported by volunteer physicians could be attributed to infectious diseases, highlighting the threat that pathogens pose to displaced populations in the EMME region. This issue is further compounded by the fact that vaccination rates tend to be much lower among displaced children than in the general population, increasing the risk of infection even more in this vulnerable group. As an example, Mowafi *et al*. [203] report that while overall vaccination rates for children in Iraq are up to 78%, only 48% of displaced Iraqi children have completed their basic vaccination courses against diphtheria, pertussis, tetanus, polio and measles.

Infection with the human immunodeficiency virus (HIV) is a concern for displaced populations, as turmoil and displacement increase the probability of its transmission [203], [214]. Although the overall prevalence of HIV in the MENA region is still one of the lowest in the world, with an estimated 0.1% [215], it is possible that official numbers underreport the actual prevalence of this disease, particularly among certain high-risk groups [203]. Adding to this complexity is the fact that new HIV infections in this part of the world have increased at alarming rates during the past two decades [215]. For refugees hosted in certain countries of the region, being diagnosed as HIV+ implies not only a devastating social stigma, but also the possibility of being forcibly deported to their country of origin (a practice known as "*refoulement*") [203], [216]. Such dramatic consequences create important barriers for testing and reporting HIV in displaced populations.

Non-communicable diseases

Globally, non-communicable diseases (NCDs) such as diabetes, cardiovascular disease, cancer and chronic respiratory disease are the leading cause of death, causing 63% of all reported fatalities [217], [218]. EMME countries are no exception to this trend: in 2018, NCDs were reportedly responsible for 84% of deaths in Lebanon, 76% in Jordan and 78% in Saudi Arabia. In Syria, NCDs were responsible for 77% of deaths prior to the recent civil war [219]. The high prevalence of these diseases represents an additional risk to displaced individuals, as the harsh conditions of their journeys and temporary settlements usually curtail the access to medicines and health-care facilities required to manage NCDs [204]. For internationally displaced individuals, language, cultural differences and legal status might represent additional barriers to obtaining access to health care. The WHO reports that "being undocumented can be considered a risk factor for poor health among migrants in Europe" [220]. Furthermore, the high prevalence of NCDs, together with the high burden these diseases place on public health systems, can represent significant economic and logistic problems for countries hosting large displaced populations [203].

Unhealthy behaviours, such as tobacco and alcohol use, physical inactivity and poor diet greatly increase the severity of NCDs. Unfortunately, the stressors associated with forced displacement can significantly enhance the likelihood of individuals engaging in such behaviours, further complicating their health status [218], [220].

Sexual and reproductive health
Population displacement can place the most vulnerable individuals (i.e. women and children) at an elevated risk of being the target of sexual violence and exploitation. In some instances, the lack of resources and uncertain legal status associated with displacement can push individuals to engage in sex work in order to support themselves and their families. In other instances, displaced persons can be kidnapped, raped or otherwise sexually exploited [214], [221]. In all these scenarios, the victims of sexual violence and exploitation are at an elevated risk of sexually transmitted infections and unwanted pregnancies. Unfortunately, social customs in several countries of the region can make it very difficult for victims to access reproductive health services, or even basic family planning options [203], [216].

Displacement can be particularly risky for pregnant women due to the lack of appropriate hygiene, nutrition and antenatal/postnatal care. In this group, problems such as reproductive tract infections and malnourishment, as well as the lack of access to medical services, enhance the risk for maternal morbidity and mortality, pre-term birth, miscarriage, stillbirth and other forms of perinatal and neonatal morbidity [222].

Mental health
Mental health problems are reportedly among the most important and yet most neglected issues faced by displaced populations [200]. People fleeing areas of armed conflict are at an elevated risk of experiencing issues such as post-traumatic stress disorder, depression, anxiety and suicide [200], [223]. The study of mental health issues in displaced populations is greatly complicated by the lack of appropriate psychological assessment tools to evaluate the effects of extreme forms of trauma often endured during armed conflict, such as kidnappings, assassinations, torture, genocide and mass rape [197], [214].

Even in cases when displacement is not caused by armed conflict, the displaced individuals invariably experience profound psychological distress triggered by the separation from their usual material and social environments. Not only do they leave behind their home, land, crops, vehicles and animals, but also their community affiliations, social network, social status and civic roles. Importantly, their occupational identity can be drastically altered, as any skills that were used to provide livelihood might not be useful following resettlement, creating enormous obstacles in the pursuit of financial stability [197].

Mental health issues are highly prevalent among displaced populations. The WHO estimates that following a humanitarian emergency, 1520% of adults will suffer mild to moderate mental disorders, while 34% will suffer severe mental problems [224]. Other studies suggest that at least 50% of refugees experience some form of psychological disorder, and often multiple disorders simultaneously. Children are particularly susceptible to psychological trauma during armed conflict, when it is likely they will witness acts of violence being committed, often against their loved ones [204], [214]. Accordingly, physicians working with refugees from the EMME region have reported high rates of psychosocial distress in displaced populations, including increased suicide attempts [225] (Figure 9).

An important complicating factor for refugees in the EMME region is the scarcity of psychological support. In many countries of the region, access to psychological counselling can be scarce even for the local population. As an example, the estimated number of psychiatrists working in the Middle East is in the order of 1 per 100 000 to 200 000 inhabitants [200], [203]. Various authors have highlighted this fact as a major obstacle for the well-being of displaced populations in the area [200], [203], [204], [225].

It is important to highlight that psychological trauma differs from physical trauma in that it often has very long-lasting effects, which can even be passed on from one generation to the next [226]. For this reason, author Wakel Al-Delaimy states that "…poor mental health is going to be a major health impact of climate change in the MENA region among displaced populations, whether resulting from climate impacts on the environment and livelihood of populations in the region or from ongoing civil unrest and violence" [200].

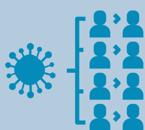
FIGURE 9. Direct and indirect effects of population displacement on human health

Heath effects of population displacement

Direct effects

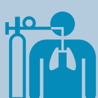
- Bodily injuries and psychological trauma
- Respiratory, gastrointestinal and skin conditions
- Dehydration
- Hypothermia
- Burns
- Malnutrition
- High vulnerability to climatic phenomena

Indirect effects



Infectious diseases

- Diarrheal disease, measles, meningitis, acute respiratory infections, scabies, tuberculosis and vector-borne diseases
- Exposure to "new" infections (lack of immunity)
- Poor housing conditions increase transmission risk
- Low vaccination rates



Non-communicable diseases (NCDs)

- High prevalence of NCDs (including diabetes, cardiovascular disease, cancer and chronic respiratory disease) in the EMME's population
- Obtaining required medicines can be difficult for the displaced
- High prevalence
- Can impose a significant burden for hosting countries

Sexual and reproductive health

- Displaced individuals can be particularly susceptible to sexual violence and exploitation
- Elevated risk of sexually transmitted diseases, unwanted pregnancies
- Increased risk of maternal, neonatal and perinatal morbidity and mortality

Mental health

- Among the most important and neglected issues for displaced populations
- Highly prevalent in displaced populations (15 to 50% of displaced people)
- Children are highly susceptible
- Scarcity of psychological support services in the EMME
- Effects are long-lasting, often trans-generational

4. Research gaps and proposed policy initiatives

The data available in the scientific literature show that climate change will have profound impacts on the health of those living in the EMME region. It is therefore imperative to devise strategies aimed at reducing the burden of these adverse effects.

In order to attain an effective level of resilience, all adaptation and mitigation policies need to factor in the risks that climate change pose to human health [227]. Because heat waves, air pollution and the spread of infectious diseases, among other adverse effects, are in no way contained by national boundaries, corresponding adaptation and mitigation measures need to have a regional scope and should be borne out of collaboration among the EMME nations.

In the following sections, we identify several areas affected by knowledge or policy vacuums. We also suggest measures that can improve resilience and preparedness in the EMME region in the face of future climate change events.

4.1. Research and knowledge gaps

4.1.1. Empirical evidence on exposure-response functions involving climate change and health outcomes

Our capacity to predict the effects of climate change on human health is largely based on our understanding of the exposure-response functions[4] of human beings. However, the empirical evidence available to evaluate these functions does not cover all health aspects potentially influenced by climatic factors [228]. More research is required, for example, on the effects of dust exposure on chronic health conditions [102], the effects of air pollution caused by wildfires on respiratory and neurologic health, and the effects of climate change on children's overall health [228], [229]. Furthermore, we need to develop better tools to evaluate the psychological effects of human displacement, particularly for children and women [214].

4. Exposure-response functions are defined as the potential associations between climate-sensitive environmental hazards and health outcomes [244].

4.1.2. Assessment of the effects of climate change on ecological determinants of human health

In addition to the aforementioned scarcity of data linking climate change and certain health outcomes, there is also a dearth of empirical data about the influence of changing climate on ecological factors that ultimately affect human health. This situation is particularly relevant in the field of vector-borne diseases due to the complex nature of their natural cycles, which involve pathogens, vectors and reservoirs in addition to human beings.

Several recent studies have sought to estimate the effects of altered environmental temperatures on the vectorial capacity of some of the main species of disease vectors [141], [230], [231]. However, these studies are based on predictive models which often rely on generalizations about biological and physiological parameters, and rarely incorporate variables such as the genetic variability of pathogens and vectors. Furthermore, it is difficult (and often impossible) for modelling studies to account for complex aspects such as progressive adaptive changes in the biology, physiology and/or behavior of the many species involved in the transmission cycles of infectious diseases.

More and better empirical data could in turn be used to produce and refine predictive models. Priorities for study include (a) the effects of environmental variables on vector physiology, longevity, fertility, behavior, morphology and competence; (b) effects of climate change on the biology, abundance and distribution of reservoirs, and (c) the effects of climate change on the genetic variability and pathogenicity of vector-borne microbes.

4.1.3. Effects of long-term exposure to climate change

Most of our current understanding about the influence of climate change on human health is based on the effects of severe weather events (such as heat waves), which are typically short-lived. Little information is available, however, on the effects of long-term exposure to persistent climatic change, such as the gradual increase in average temperatures or low-level increases in the concentration of air pollutants [228], [232], [233]. In addition, data on long-term exposure to climatic change is often focused on mortality instead of disease incidence [232].

One important consequence of the current focus on the human health effects of severe, short-term weather events is that without data on long-term exposure to low-level environmental change, it is not possible to properly assess a population's adaptation responses, whether autonomous (e.g. changes in local attitudes and practices) or planned (e.g. development of early warning systems and response strategies) [228].

4.1.4. Evaluation of the interactions between adaptation and mitigation strategies

Although it is generally accepted that strategies aimed at either mitigating climate change or adapting to it are beneficial for human health [234], [235], literature reporting on the complex, and sometimes conflicting, interactions between mitigation and adaptation strategies is rather scarce. An example is outlined by Madrigano *et al*. [228]:

> "the most effective adaptation strategy for preventing heat-related morbidity and mortality is to increase access to air conditioning [...]. However, without sufficient renewable electricity generation, such a strategy will result in an increase in greenhouse gas emissions, directly conflicting with mitigation goals."

The complexity of these interactions is rooted in the inherent differences of the two types of strategies. While both adaptation and mitigation seek to address climate change, they usually work at different temporal and geographic scales, with adaptation strategies aiming to achieve local changes in the short and medium terms, while mitigation strategies generally seek global changes over the long term. Furthermore, there are also important differences in the relative relevance of these two types of strategies to different sectors, with mitigation strategies being mainly relevant to the energy and finance sectors, while adaptation strategies are generally more applicable to the health, water management, farming and tourism sectors, among others [236].

Therefore, research in this area should focus on establishing the cross-linking and trade-offs between mitigation and adaptation efforts (i.e. how global mitigation efforts impact options for adaptation in specific regions, and how adaptation practices can alter greenhouse gas emissions). Ultimately, researchers and policy makers should strive to devise strategic plans that commingle adaptation and mitigation tools, ensuring their acceptability across social, economic and environmental perspectives [237].

4.2. Policy suggestions

4.2.1. Move decisively towards de-carbonization

Achieving meaningful reductions in greenhouse gas emissions is a key component of any plan aimed at protecting human health from future climate change. Lelieveld *et al*. [238] have estimated that burning fossil fuels causes an excess mortality rate of approximately 3.61 million people per year, globally. Although phasing out fossil fuels is one of the most important steps to protect human health from climate change, our current rate of fossil fuel consumption is deeply rooted in complex and often outdated political and societal practices. Thus, achieving meaningful and sustainable changes will require profound commitments on the side of consumers, institutions and policy makers alike.

Several technologies with the potential to reduce greenhouse gas emissions (including improvements in energy efficiency, carbon sequestration and renewable energies, among other advances) have existed for decades, so the current barriers to de-carbonization are not necessarily technical or even economic [239]. Therefore, only strong political determination at the national and regional levels can drive a concerted and efficient de-carbonization movement. As clearly stated in a recent editorial by Atwoli *et al.*, endorsed by over 200 scientific journals:

> "The current strategy of encouraging markets to swap dirty for cleaner technologies is not enough. Governments must intervene to support the redesign of transport systems, cities, production and distribution of food, markets for financial investments, health systems, and much more."[240]

4.2.2. Integration of environmentally driven morbidity and mortality data throughout the EMME

After a careful revision of scientific and medical data available to date, it has become apparent that the EMME region would greatly benefit from the development of a system that facilitates the tracking of morbidity and mortality data attributable to climatic factors.

Such a system would allow us not only to establish clearer correlations between regional variations in climatic parameters and the incidence of specific health issues, but also to measure the efficiency of policies designed to prevent or mitigate the effects of climate change at the national or regional levels.

To develop a system of this nature, the EMME nations need to take several important steps. Namely:

- Reach a scientific consensus regarding which health conditions are directly and indirectly influenced by climatic factors
- Homogenize reporting criteria for the aforementioned health conditions throughout EMME countries
- Create a regional data repository where researchers and policy makers can openly access up-to-date clinical and epidemiological information
- Archive validated data –both historical and current- on climate and pollution in the air, fresh water, oceans, etc.
- Establish environmental health funds to finance region-wide research on climate change and its effects on health.

4.2.3. Advancing the development and widespread use of cheaper technologies for the production and management of drinking water by non-traditional means

Water scarcity is a common threat for the future of most EMME countries. It is therefore vitally important to develop region-wide policies aimed at either managing or generating water for human consumption.

Efforts should be made to optimize the efficiency of water distribution systems as well as to stimulate rational consumption. To this end, the implementation of smart-metering systems might improve cost recovery and reduce waste on the users' side by increasing awareness of consumption [53].

Although recent advances in desalination and membrane technology have decreased the costs associated with the production of drinking water by alternative means, the price tag of these technologies remains high enough as to become prohibitive for many countries in the region. Therefore, EMME countries should prioritize investments in research aimed at optimizing (and therefore reducing the cost of) alternative technologies for the generation of drinking water. Furthermore, it is also necessary to develop technologies that mitigate the ecological costs of these technologies (for example, the safe disposal of the highly concentrated brine generated by seawater desalination processes).

Potential mechanisms to achieve the required improvements include the creation of funding schemes for academic groups working in this research field, as well as policies that foster startup companies focused on developing relevant novel technologies.

4.2.4. Comprehensive regional strategies for improving the health status of displaced populations

The particular circumstances surrounding displaced populations require special healthcare considerations. Mazhin and collaborators (2020) have stated that "Public health responses and policies related to health risks associated with migration from climate change must be consistent with the nature of the migration and the demographic characteristics of those who migrate" [241]. In this context, policies related to the health of migrant populations need to consider aspects such as the inherent inequalities in healthcare access of the displaced population vs. the local populations, as well as the cultural complexities of refugee settlements, which often intermix populations with an array of cultural, ethnic and religious backgrounds.

We recommend that EMME countries hosting settlements of displaced individuals implement comprehensive health policies that offer access to:

- Healthy food and water
- Mental health services and crisis help lines
- Maternal and reproductive health resources
- Medicines to control chronic health conditions
- Infant vaccination
- Diagnosis and treatment of infectious diseases
- Control of disease vectors

In order to plan and implement such comprehensive health policies, national governments should coordinate efforts with nongovernmental organizations (e.g. the International Organization for Migration, the United Nations High Commission for Refugees, The Red Cross, Médecins Sans Frontières, among other), private institutions, local authorities and the displaced communities themselves.

4.2.5. Fostering regional networks to monitor and control the spread of infectious diseases and disease vectors

As starkly evidenced by the ongoing COVID-19 pandemic, infectious diseases spread easily across national boundaries. Vector-borne diseases can be particularly hard to track and control, as their spread is driven by the movement of vector and reservoir species, as well as human hosts.

For this reason, efforts at the national level are often insufficient to monitor and control the spread of infectious diseases. By way of contrast, coordinated regional efforts can be much more efficient at producing epidemiological data, identifying dissemination routes and facilitating control strategies, as has been the case with regional initiatives that successfully reduced the disease burden of malaria in certain parts of Africa, and Chagas disease in South America [137].

In the EMME region, several initiatives have attempted to create regional networks for the monitoring and control of infectious diseases. These include the EpiSouth project, which in its initial stages sought to connect infectious disease experts from southern Europe, the Mediterranean and the Balkans [137], and the Middle East Consortium on Infectious Disease Surveillance (MECIDS), an initiative that facilitates communication and coordination among the ministries of health in Jordan, Palestine and Israel [242]. Ideally, these incipient initiatives could be expanded, or they could serve as models for novel, more comprehensive regional networks that facilitate collaboration among infectious disease experts from EMME countries despite regional differences in language, culture and resource availability.

5. Summary and recommendations

Human health is linked to climatic factors in intricate ways, and therefore climate change has profound direct and indirect health impacts. Susceptibility to climate change is also modulated by biological, ecological and socio-political factors such as age, gender, geographic location, socio-economic status, occupation, health status and housing conditions, among other features.

In the EMME region, climatic factors known to affect public health include extreme heat, water shortages and air pollution (caused by fossil fuel use, dust events and wildfires, among other). Furthermore, the epidemiology of vector-borne diseases and the health consequences of population displacement are also linked to climatic change in the region.

We recommend the following research priorities for the EMME region:

- Generating more empirical evidence on exposure-response functions involving climate change and specific health outcomes, such as the impact of dust exposure on chronic health conditions.
- Developing tools to evaluate the psychological effects associated with forced displacement, the effects of air pollution by wildfires on respiratory and neurologic health, and the effects of climate change on children's overall health.
- Determining how climate change alters the ecological determinants of human health, particularly in the transmission of vector-borne diseases.
- Improving our understanding of the effects of long-term exposure to climate change.
- Evaluating the interactions between adaptation and mitigation strategies, as they can sometimes come into conflict owing to their different temporal and geographic scopes.

Because national boundaries cannot contain most climate-related factors expected to impact human health, we propose that any effective adaptation/mitigation policies must have a regional scope, and must therefore be the result of collaborative efforts among EMME nations. Relevant policies suggested by our Task Force include:

- A decisive region-wide movement towards de-carbonization.
- Integration of environmentally driven morbidity and mortality data throughout the region.

- Advancing the development and widespread use of cheaper technologies for the production and management of drinking water by non-traditional means.
- Comprehensive regional strategies to improve the health status of displaced populations.
- Fostering regional networks to monitor and control the spread of infectious diseases and disease vectors.

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