



Climate change impacts on infectious diseases in the Eastern Mediterranean and the Middle East (EMME)—risks and recommendations

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Abstract

The Eastern Mediterranean and Middle East (EMME) region has rapid population growth, large differences in socio-economic levels between developed and developing countries, migration, increased water demand, and ecosystems degradation. The region is experiencing a significant warming trend with longer and warmer summers, increased frequency and severity of heat waves, and a drier climate. While climate change plays an important role in contributing to political instability in the region through displacement of people, food insecurity, and increased violence, it also increases the risks of vector-, water-, and food-borne diseases. Poorer and less educated people, young children and the elderly, migrants, and those with long-term health problems are at highest risk. A result of the inequalities among EMME countries is an inconsistency in the availability of reliable evidence about the impacts on infectious diseases. To help address this gap, a search of the literature was conducted as a basis for related recommended responses and suggested actions for preparedness and prevention. Since climate change already impacts the health of vulnerable populations in the EMME and will have a greater impact in future years, risk assessment and timely design and implementation of health preparedness and adaptation strategies are essential. Joint national and cross-border infectious diseases management systems for more effective preparedness and prevention are needed, supported by interventions that improve the environment. Without such cooperation and effective interventions, climate change will lead to an increasing morbidity and mortality in the EMME from infectious diseases, with a higher risk for the most vulnerable populations.

Keywords Eastern Mediterranean · Middle East · Climate change · Infectious diseases

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1 Introduction

The Eastern Mediterranean and Middle East (EMME) region is comprised of 16 countries, including Bahrain, Cyprus, Egypt, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Palestine, Qatar, Saudi Arabia, Syria, Turkey, United Arab Emirates (UAE), and Yemen. It is characterized by rapid population growth and large differences in socio-economic levels between countries. For example, while the GDP per capita in the UAE and Qatar is 43,103 US\$ and 50,805 US\$, respectively, it is 3548 US\$ in Egypt and only 824 US\$ in Yemen (Table 1). Other major challenges in the EMME are migration, increased water demands, and ecosystem degradation (The World Bank 2020). Populations in the least developed countries suffer from inadequate basic conditions such as inappropriate housing or contaminated water as well as inadequate healthcare facilities. The recent spread of COVID-19 in the EMME region highlights the unpreparedness of some EMME countries and the region as whole for large-scale epidemics.

While several rich countries (mainly the Gulf states) are the source of much of the carbon-driven climate change, as Qatar, Kuwait, and the UAE, with CO₂ emission levels of 32.4, 21.6, and 20.8 metric tons per capita, respectively (see “CO₂ emissions” per country, Table 1), the whole region is experiencing a significant warming trend as a part of the global change, with longer and warmer summers, increased frequency and severity of heat waves, and a drier climate (Zittis et al. 2016). Given the socio-political conflicts in parts of the EMME along with food insecurity and lack of adaptive capacity, severe drought and water shortages intensified by climate change may aggravate regional disputes (Gleick 2014). Indeed, studies on the Syrian war show that a combination of the most severe recorded drought related to climate change (Kelley et al. 2015), persistent multi-year crop failures, and the related economic deterioration, all played an important role in contributing to political instability through the displacement of people, food insecurity, higher unemployment, and increased violence (Gleick 2014; Kelley et al. 2015). In 2018, the Regional Refugee and Resilience Plan of the UN Refugee Agency (UNHCR) intended to support 5.3 million Syrian refugees, who increasingly vulnerable and face extremely high rates of poverty (UNHCR 2018–2019). In Lebanon, one in five people is a refugee, while Turkey hosts the largest number of refugees in the world. Currently, several EMME countries host a very large number of refugees (Table 1)—Turkey with more than 3.6 million refugees, Jordan with more than 3 million as well as the West Bank and Gaza and Lebanon, with more than 2.3 and 1.3 million refugees, respectively (UNHCR 2021; World Bank 2021).

It is known that climate change has direct and indirect effects on population movement and also on health, while migration is itself also a risk factor for health (Matlin et al. 2018). The diverse factors are all connected together in complex ways, which may increase the direct and indirect risks for infectious disease epidemics (Bowles et al. 2015).

Furthermore, many of the most common infectious disease are highly sensitive to climate variability (Hess et al. 2020) since a warmer climate and changing rainfall pattern may create hospitable environments for both vectors and pathogens (Crowley 2016). Vector-, food-, and water-borne diseases largely arise due to exposure in vulnerable areas such as the developing countries of the EMME. This may contribute to increasing density of infectious agents and reduced disease control (WHO 2018), as illustrated by the spread of COVID-19 in Yemen (MedGlobal 2020).

Table 1 Socio-economic and health indicators of the EIMME countries (latest data)

Country	Population (total, thousands), 2019	Refugee population, 2020	GDP per capita (current US\$), 2020	CO2 emissions (metric tons per capita), 2018	Improved drinking water source (total, % of population), 2017 est.	Population using at least basic sanitation services (%), latest data	Average of 13 International Health Regulations core capacity scores*, 2019	Current health expenditure (%), 2018	Physicians density/1000 population, latest data	Hospital beds (per 1000 people), latest data
Turkey	84,339.07	3,652,362	8538.2	5.0	98.9	97.3	77	4.1	1.85	2.9
Cyprus	1207.36	14,037	26623.8	6.1	100	99.15	74	6.8	1.95	3.4
Syrian Arab Republic	17,500.66	584,059	2032.6	1.6	99.4	91.22	48	n.d.	1.29	1.4
Lebanon	6825.44	1,349,955	4891.0	4.0	100	98.48	73	8.4	2.10	2.7
Israel	9216.90	1898	43610.5	7.0	100	100	87	7.5	4.63	3.0
West Bank and Gaza	4803.27	2,348,243	3239.7	n.d.	96.8	n.d.	n.d.	n.d.	1.45	1.2
Jordan	10,203.14	3,009,517	4282.8	2.5	98.9	97.34	43	7.8	2.32	1.5
Egypt	102,334.40	272,856	3547.9	2.5	100	94.19	83	5.0	0.45	1.4
Iraq	40,222.50	270,392	4157.5	4.9	97.9	94.12	58	4.1	0.71	1.3
Kuwait	4270.56	737	32373.3	21.6	100	100	76	5.0	2.65	2.0
Saudi Arabia	34,813.87	340	20110.3	15.3	100	100	75	6.4	2.61	2.2
Bahrain	1701.58	256	23,443.4	19.6	100	100	80	4.1	0.93	1.7
Qatar	2881.06	201	50,805.5	32.4	100	100	96	2.5	2.49	1.3
United Arab Emirates	9890.40	1330	43103.3	20.8	100	98.59	96	4.2	2.53	1.4
Oman	5106.62	308	15343	15.2	100	100	86	4.1	2.00	1.5
Yemen	29,825.97	166,936	824.1	0.3	92	59.05	52	5.6	0.53	0.7
Source	World Bank	World Bank	World Bank	World Bank	CIA	WHOa	WHOb	CIA	CIA	World Bank

References:

-CIA The World FactBook, <https://www.cia.gov/the-world-factbook/countries/>
 -The World Bank Indicators, <https://data.worldbank.org/indicator>
 -WHOa, The Global Health Observatory, <https://www.who.int/data/gho/data/countries>
 -WHOb, Average of 13 International Health Regulations core capacity scores, SPAR version (percentage of attributes of 13 core capacities that have been attained at a specific point in time), <https://www.who.int/data/gho/data/indicators/indicator-details/GHO/-average-of-13-international-health-regulations-core-capacity-scores-spar-version>

2 Current impacts of climate change on infectious diseases in the EMME

A direct result of the inequalities among EMME countries is an inconsistency in the availability of reliable data (WHO-EMRO 2021) and deficiencies of scientific knowledge about the impacts of climate change on infectious diseases transmission. This inconsistency is a result of differences among the countries including their socioeconomic development, quality of health services (see details on physician density and hospital beds per 1000 people in Table 1), and availability of scientific resources. Consequently, while for some countries there are solid findings (for instance regarding the role of high temperatures in West Nile virus transmission in Israel (e.g., Paz et al. 2013; Anis et al. 2014; Lourenço et al. 2020)), for others, scientific insights are very limited (only one study refers to the linkage between the changing climate and the cholera crisis in Yemen (Paz 2019a)). Additionally, quantitative measurements of how infectious diseases respond to climate change in the EMME region are limited as well, and available only for part of the infectious diseases in part of the countries of the study area. Indeed, recent mapping of the global scientific literature on climate and health using machine learning and systematic approaches demonstrates significant geographical gaps in the evidence, which apply to several regions (e.g., Central Asia, Central, and North Africa) including significant part of the EMME, mainly from the low-income countries that suffer most from the health consequences of climate change (Berrang-Ford et al. 2021).

In order to help address this knowledge gap, a search of the available peer-reviewed literature was conducted (using Google Scholar, PubMed, and Web of Science; based on the following search terms: infectious diseases, vector-, water-, food-borne diseases, climate change, global warming, temperature, heat wave, precipitation, eastern Mediterranean, Middle East, and country name) with a focus on recent, English language publications from the last years (since 2017) that examined the association between climate change and disease transmission in the EMME. This is to create a focused overview of the current and predicted situation in the region which is characterized by unique challenges, as a basis for related recommended responses and suggested actions for more effective preparedness and prevention.

In the EMME, several vector-borne diseases, sensitive to climatic variations, are common, while others are potential threat (Waldock et al. 2013). West Nile fever (WNF) is caused by the West Nile virus (WNV), a member of the *Flaviviridae* family of viruses. Its transmission cycle involves both rural ecosystems and urban areas, where the virus circulates between birds and ornithophilic mosquitoes, particularly members of the genus *Culex*. Under suitable environmental conditions, it spreads to human settlements where it infects humans and equines often causing regional outbreaks. Although most people (8 out of 10) infected with WNV do not develop any symptoms, infections can be serious, mainly among the elderly. About 1 in 150 people who are infected develop a severe illness affecting the central nervous system such as encephalitis or meningitis (CDC 2018). Originally endemic to Africa, WNV has spread globally as it appears currently in Africa, Southern Europe, Eurasia, and the Americas. Today, it is the most widespread of all flaviviruses (Paz 2015; Stilianakis et al. 2016). During the last decade, outbreaks of WNF erupted in several eastern Mediterranean countries including Turkey, Cyprus, and Israel, following heat conditions which had significant impacts on the mosquito vector populations and on the establishment of the virus in new areas (Paz 2015, ECDC 2021). A transmission suitability index was employed to WNV in Israel, based on prior knowledge on bird reservoir

and *Culex* species, using local time series of temperature and humidity as inputs. The index was found to be highly associated with WNV cases with correlation coefficients between 0.68 and 0.91 per different years (Lourenço et al. 2020).

WNV transmission is maintained in an enzootic cycle involving migratory birds, local avian population, and mosquito vectors, from where it occasionally jumps to humans and other mammals (Anis et al. 2014). Since birds are the principal hosts for WNV, increased temperatures might have an indirect effect on the virus spreading and transmission through impacts on bird populations and migratory routes which may be affected by climate change. This issue is crucial for the eastern Mediterranean which is a crossroads for over half a billion birds that migrate each spring and fall between Africa and Eurasia (Leshem et al. 2005). While warmer than normal winter temperatures may affect bird migration, hatching, or avian community composition (Hahn et al. 2015), observations indicate an earlier migration of birds to their breeding sites as a consequence of early rise of the mean spring temperatures (Tomotani et al. 2018). Such changes may influence the appearance timing of the disease in locations near or along migration routes (Paz 2019b) as was demonstrated for Eurasia and the Mediterranean (Paz et al. 2013).

Rift Valley fever (RVF) is another mosquito-borne disease that causes acute viral hemorrhagic fever most commonly seen in domesticated animals. While most human RVF cases present either no symptoms or a mild illness, 8–10% of them develop much more severe symptoms, including ocular disease, encephalitis, and hemorrhagic fever (CDC 2020a). While RVF is closely associated with high-rainfall conditions (e.g., after prolonged excessive rainfall in sub-Saharan Africa), large outbreaks have also occurred in dry and low-rainfall areas of the EMME such as Egypt and the Arabian Peninsula (Linthicum et al. 2016).

Dengue, chikungunya, and Zika are also mosquito-borne arboviral diseases of interest to the EMME. While a large proportion of infections with these viruses are asymptomatic, they may cause infections that present a wide range of symptoms, from mild and flu-like, to severe and potentially life-threatening (Paixão et al. 2018). The viruses are transmitted by *Aedes aegypti* and *Ae. albopictus* mosquitoes (Diptera: Culicidae) that exhibit widespread distribution throughout tropical, sub-tropical, and temperate zones, mostly in urban and suburban areas, respectively. *Ae. aegypti* is a highly competent vector for dengue, chikungunya, and Zika. It is restricted to warm, urban environments where it breeds around houses and in man-made containers. Although *Ae. albopictus* is a less competent vector of these pathogens, it is far more ecologically flexible, able to adapt to below-freezing temperatures by undergoing diapause, and can be found in suburban, rural, residential, and agricultural habitats. This characteristic allows *Ae. albopictus* to colonize a broader latitudinal gradient than *Ae. aegypti* (Lounibos et al. 2003; Paupy et al. 2009; Brady et al. 2014; Ryan et al. 2019). As a consequence, the recent establishment and rapid spread of *Ae. albopictus* in almost all countries of the EMME region (e.g., Turkey, Syria, Lebanon, Israel, Palestine, Jordan) is a cause of major concern (Proestos et al. 2015), in parallel with the potential risks of diseases transmission by *Ae. Aegypti* which currently exists in Turkey, Israel, Egypt, Saudi Arabia, and Oman (Ducheyne et al. 2018).

Since temperature is a crucial factor impacting the distribution of both vectors, climate change is likely to impact their range. Other important variable are precipitation patterns, the altitude, and human impacts as urbanization and population density (Ducheyne et al. 2018; Reinhold et al. 2018). In response to past and projected climate changes globally, Iwamura et al. (2020) found that during 1950–2000, the world became ~1.5% more suitable per decade for *Ae. aegypti*, while this trend is predicted to accelerate to 3.2–4.4% per decade by 2050. The model predicts climatic suitability increasing in the future in regions

where *Ae. aegypti* has already been observed to be widespread, including in the eastern Mediterranean.

Liu et al. (2020) explored the variation in the epidemiologic potential of outbreaks among different climatic zones and arboviruses including dengue, Zika, and chikungunya. The results show that the R_0 (basic reproduction number with values greater than 1 corresponding to epidemic growth) of an arboviral outbreak is highest for the sub-tropical zones. Indeed, in the EMME region, dengue and chikungunya fever pose a major risk with frequent or continuous outbreaks currently reported in Yemen, Saudi Arabia, and sporadic occurrences in Oman and Egypt (Altassa et al. 2019; CDC 2020b), while changes in temperature and precipitation patterns directly affect the size of vector populations, parallel with indirect factors such as urbanization, armed conflicts, economic crisis, and inter-regional migration. For example, floods in Yemen possibly maintained local transmission of chikungunya a decade ago, while intense human activities and continuous population movement between the districts helped its spread (Malik et al. 2014). A study in Jeddah, the second largest city in Saudi Arabia, found a significant association between seasonality of dengue and increase in temperature within the range of ~ 25 to ~ 33 °C but not with extremely hot temperatures, as well as with decrease in relative humidity with highest peaks between 45 and 65% (Hashem et al. 2018).

Malaria is another serious and sometimes fatal mosquito-borne disease caused by infection with protozoan parasites of the genus *Plasmodium*. Human malaria parasites are transmitted by mosquitoes (Diptera: Culicidae) of the genus *Anopheles*. Infection with *Plasmodium* sp. in humans generally causes periods of high fever while 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 anemia, blood vessel blockage, organ failure, brain swelling, seizures, coma, and death (CDC 2021). In 2019, an estimated 229 million cases of malaria occurred worldwide and 409,000 people died, mostly children in sub-Saharan Africa (CDC 2021).

In a systematic review, temperature, relative humidity, rainfall volume, vegetation index, hydrogeology, and wind speed have been shown to influence the propagation and survivorship of malaria vectors in the EMME (Khader et al. 2015). Local transmission of malaria has occurred sporadically during recent years in several countries of the EMME including Cyprus (ECDC 2017). While malaria is endemic in some places, for example in Saudi Arabia near the border with Yemen (CDC 2019a), the recent World Malaria Report highlights several EMME countries for their achievements in reducing malaria incidence. For example, Saudi Arabia reported only 38 indigenous cases in 2019, while Syria, Iraq, and Oman have not reported indigenous cases since 2004, 2009, and 2011, respectively (WHO 2020).

Although most countries in the EMME are considered malaria-free, the increasing influx of immigrant workers from endemic regions can be an important source of disease outbreaks due to the continued presence of the responsible vectors. As shifting climate patterns change the geographical range and intensity of transmission of malaria vector mosquitoes, the ability of the EMME countries to confront malaria will determine the burden caused by climate change-induced malaria on healthcare systems (Salimi and Al-Ghamdi 2020). A study in the Sistan and Baluchestan provinces of Iran found that temperature and humidity over 60% show a significant positive impact on the incidence of malaria. In the towns Nikshahr and Sarbaz, an increase in 1°C of minimum temperature in a specific month caused a significant increase of 25% and 15% in malaria incidence in the next month, respectively. The increase in maximum temperature was associated with increased incidence between 13 and 35% per different locations. In the one-month lag time analysis,

each 1% increase in humidity was respectively associated with a 3–10% increase in malaria incidence (Mohammadkhani et al. 2019).

Leishmaniasis is a disease caused by infection with one of several species of parasites of the genus *Leishmania*. While *Leishmania* parasites are transmitted by over 90 species of sandflies (Diptera: Psychodidae), in the EMME region, all known leishmaniasis vectors belong to the genus *Phlebotomus*. Two types of Cutaneous Leishmaniasis (CL), caused by *Leishmania major* and *L. tropica*, respectively, are common in the region. CL is characterized 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 while countries within the WHO Eastern Mediterranean region account for ~70% of the cases reported worldwide. Countries in the EMME region reporting high incidence of this form of leishmaniasis in the recent past include Iraq and Syria (WHO 2021a).

The optimal temperature for the development of sand flies and *Leishmania* parasites is ~25°C (Killick-Kendrick and Killick-Kendrick 1987). Higher temperatures increase the vector biting rate and number of human exposures, and reduce the incubation time of the infective agent within its vector (Bates 2008). Indeed, in the Mediterranean region, there is evidence that the geographical range of phlebotomine sand flies incriminated in leishmaniasis transmission has changed in response to climate change (Chalghaf et al. 2018).

Since the late 1990s, rapid unexpected outbreaks have occurred in new urban and rural foci in Jordan, Israel, and the Palestinian Authority (Waitz et al. 2018). In early 2013, an alarming increase by tens of thousands of CL cases was reported in Syria, in places that are not historical hotspots of CL, a change that might be attributed to the massive human displacement within Syria. Additionally, CL has begun to emerge in neighboring countries (Turkey, Lebanon, and Jordan) where displaced Syrians and disease reservoirs coexist, in parallel with ecologic disruption of sandfly habitats (Al-Salem et al. 2016). An investigation into the temperature effects on sandfly vectors of *L. tropica* in Israel found that the high ambient temperatures of early night explained the high proportion of the variance in the spatiotemporal sandfly activity patterns. This indicates the contribution of high temperatures to faster development and thus shorter life cycles of sandfly populations (Waitz et al. 2018). Another vector population dynamics model using surveillance datasets from Turkey, Cyprus, and Greece indicated that in addition to temperature, changes in breeding habitats, land cover, and land use have a large impact on sandfly abundance (Erguler et al. 2019).

Parallel with the impacts of climate change, the contribution of land use changes and their impact on leishmaniasis spreading should be considered. In the north-eastern Galilee (Israel), rapid human population growth, coupled with intensive land-use changes and the creation of artificial rock-piles, which created potential habitats for both vectors (sand-flies) and hosts (rock hyrax, the main reservoir host in the region) in many settlements, have increased the prevalence of *L. tropica* among the human population in the region (Waitz et al. 2019).

Water-related diseases such as cholera, an acute diarrheal infection caused by ingestion of food or water contaminated with the bacterium *Vibrio cholera* (WHO 2021b), which is associated with poverty, water contamination, and high temperatures, already affect part of the region. Since *V. cholerae* is autochthonous to the aquatic environment, an increased sea surface temperature could lead to prolonged seasonal abundance of *V. cholerae*, with profound public health implications (Ceccarelli and Colwell 2014). An increase in SST seems to be a critical factor not only for *Vibrio* persistence but also for the emergence of new *Vibrio* spp. habitats (Christaki et al. 2020). While about 2.86 million (1.3–4.0 m) cholera cases occur annually in endemic countries with 95,000 (21,000–143,000) deaths per year

(Ali et al. 2015), the largest documented cholera epidemic of modern times started in 2016 in Yemen, the least developed country in the EMME region. By the end of January 2018, the number of suspected cases in Yemen had risen to over one million (WHO-EMRO 2018). This epidemic was driven by ongoing armed conflict, which led to destruction of water and wastewater facilities, devastated infrastructure, and the collapse of the health system. Consequently, millions of people were cut off from clean water, and waste collection has stopped in major cities (Al-Gheethi et al. 2018). The unique climatic conditions over Africa as a result of the strong El Niño of 2015–2016 followed by regional winds over the Gulf of Aden throughout the summer of 2016 may have played a role in cholera transmission through dissemination of cholera-contaminated flying insects (chironomids) from the Horn of Africa to Yemen (Paz 2019a).

Leptospirosis is a bacterial disease, caused by bacteria of the genus *Leptospira*, that affects humans and animals worldwide, but is most common in temperate or tropical climates. It is a hazard for people who work outdoors or with animals but is also associated with outdoor sports as swimming or rafting in contaminated lakes and rivers (CDC 2019b). Strong influence of climate conditions on human leptospirosis incidence has also been found. In Israel, human leptospirosis is uncommon but an unusual outbreak in the north of the country in the summer of 2018 was linked to contaminated water bodies, resulting from low water levels following years of severe drought (Dadon et al. 2018).

Climate change increases the risks of food-borne diseases. For example, the survival and multiplication of salmonellosis in the environment and in food is influenced by temperature (Milazzo et al. 2016). In the EMME region, non-typhoidal *Salmonella* cases were reported in Lebanon, Saudi Arabia, Bahrain, Iraq, and Kuwait (Al-Rifai et al. 2019). Although the knowledge on campylobacteriosis in the Middle East is limited, *Campylobacter* species are a major and increasing cause of gastroenteritis in this region (Kaakoush et al. 2015). The incidence of campylobacteriosis varies seasonally and geographically and is highest during the summer months. A recent retrospective study in the Eastern Mediterranean found that higher temperatures across seasons, before or around the time of food purchasing, played a significant role in human infection. A significant positive temperature-disease relationship was detected for the two prominent serotypes, *C. jejuni* and for *C. coli*, controlling for season, public holidays, and long-time trends. Beyond a threshold temperature of 27°C, a 1°C rise was found to correspond to a 16.1% increase of reported *C. jejuni* infection cases and 18.8% *C. coli* cases (Rosenberg et al. 2018).

A concluding summary of the key socioeconomic challenges, climate change impacts, and the main infectious diseases sensitive to climate change in the EMME region is shown in Table 2.

3 Predicted risks for the coming decades

In parallel with the projected continuing growth of the EMME population in the coming decades (Vollset et al. 2020) and the expected higher demand for water and land, different RCPs (representative concentration pathway) predict that the region will be warmer and drier while climate warming will be much stronger in the summer than in the winter; this is in a region where summers are already very hot and dry (Zittis et al. 2016). While the frequency, persistence, and severity of heat waves are projected to increase strongly, the Gulf region is likely to approach critical threshold for human adaptability. These trends will impact humans in different ways, for example through declining agricultural

Table 2 Key socioeconomic challenges, climate change impacts, and main infectious diseases sensitive to climate change in the EMME region

<p>Key socioeconomic challenges</p> <ul style="list-style-type: none"> • Rapid population growth • Large differences in socio-economic levels between countries • Migration • Increased water demand • Food insecurity • Ecosystems degradation • Regional conflicts • Political instability • Temperature increase • Longer and warmer summers • Increased frequency and severity of heat waves • Decrease in rainfall amounts, drought processes 			
<p>Climate change impacts</p>			
<p>Main infectious diseases sensitive to climate change</p>		<p>Main locations in the EMME countries</p> <p>Eastern Mediterranean (Turkey, Cyprus, Israel)</p> <p>Egypt, Arabian Peninsula</p> <p>Yemen, Saudi Arabia, sporadic occurrences in Oman and Egypt</p> <p>Turkey, Cyprus, Syria, Israel, Jordan, Palestinian Authority, Iraq</p> <p>Yemen</p> <p>Israel</p> <p>Lebanon, Saudi Arabia, Bahrain, Iraq, Kuwait</p> <p>Major and increasing cause of gastroenteritis in the Middle East (e.g., Egypt, Jordan, Cyprus, Israel)</p>	<p>References</p> <p>Paz et al. 2013; Anis et al. 2014; ECDC 2021</p> <p>Linthicum et al. 2016</p> <p>Altassa et al. 2019; CDC 2020b; WHO-EMRO 2021</p> <p>Waïtz et al. 2018; Al-Salem et al. 2016; Erguler et al. 2019; WHO 2021a</p> <p>WHO-EMRO 2021</p> <p>Dadon et al. 2018</p> <p>Al-Rifai et al. 2019</p> <p>Kaakoush et al. 2015; Rosenberg et al. 2018</p>
<p>Vector-borne diseases</p> <p>West Nile fever</p> <p>Rift Valley fever</p> <p>Dengue, chikungunya</p> <p>Leishmaniasis</p> <p>Cholera</p> <p>Water-related diseases</p> <p>Leptospirosis</p> <p>Food-borne diseases</p> <p>Salmonellosis</p> <p>Non-typhoidal Salmonella</p> <p>Campylobacteriosis</p>			

productivity that will continue to contribute to migration (Waha et al. 2017). Additionally, the predicted trends will impact health status in various ways, including increased risks of food- and water-borne diseases (such as gastroenteritis, including *Salmonella* spp.) that will be compounded in electricity power-cut events, due to peak electricity demand exceeding supply (e.g., during heat-waves), when, for example, refrigerators will stop working. For vector-borne diseases, the risks are more variable as warmer temperatures may result in some regions becoming too hot and/or too dry for some vectors during the summer months despite the increased probability of survival during the winter months.

A predictive tool which use environmental and climatic variables was used to indicate the areas and periods at major risk of WNV transmission. For the Eastern Mediterranean, during the period from May to June, the more likely affected areas are Egypt and the north of Cyprus (with a suitability level above 0.8), while the months of August through October see an increased presence along the Mediterranean coast of Africa and the Middle East (Conte et al. 2015).

A model applying the projected July temperatures, extracted for the A1B Scenario, was used to predict the probability of WNV infection in Europe and the Mediterranean basin in 2025 and 2050. The results showed high predicted probability in southern Turkey (0.06–0.5), Cyprus, the eastern Mediterranean coast, and higher in Egypt (≥ 0.5), and increased predicted probability in Turkey and western Syria in 2050 (≥ 0.5) (Semenza et al. 2017).

Another modeling study suggests that some areas currently climatically unfavorable for *Ae. aegypti*, including the Arabian Peninsula, will become more favorable (Khormi and Kumar 2014). In their study on the predicted global expansion of *Aedes*-borne viruses, Ryan et al. (2019) calculated the changing population at risk due to temperature suitability for *Ae. aegypti* virus transmission. While currently there are 455 million people at risk in North Africa and the Middle East, future projections for 2050 revealed net change from the current population of 10.6, 13.0, 12.9, and 14.2 million by 2050, based on the 2.6, 4.5, 6.0, and 8.5 RCPs, respectively. For 2080, the models predict an extension of 10.4, 13.5, 14.1, and 11.8 million for the same RCP scenarios.

The environmental suitability was predicted for seven malaria vectors in Iran according to three climate change scenarios (RCP2.6, RCP4.5, and RCP8.5) for the 2030s and 2050s. The model shows that while RCP8.5 would reduce the area at risk for several species (e.g., *An. culicifacies* s.l., *An. dthali*) in the 2050s compared to the 2030s, the reverse will be induced by RCP2.6 and RCP4.5 scenarios. The authors noted that although the total high-risk areas for almost all vectors are expected to decrease, the risky areas might change spatially to newly populated regions (Hanafi-Bojd et al. 2020).

A forecast of the geographical shifts of *Leishmania* species under future climate scenarios (A2a and B2a of the Canadian Centre for Climate Modeling and Analysis) revealed that the increase of temperature and humidity due to the global warming will affect the distribution of *Leishmania* vectors. While *Phlebotomine* sand flies are prospected to invade extra-Mediterranean regions, *Leishmania* vectors will lose areas for suitable conditions in North Africa and the Middle East. These changes in their geographical distribution are more intense under the A2a pessimistic scenario than the optimistic B2a scenario (Chalghaf et al. 2018).

These risks to health will not affect all sections of the population equally. Poorer and less educated people, young children and the elderly, and those with long-term health conditions such as diabetes and kidney disease will be at greatest risk from the health effects of climate change. Some impacts can be ameliorated by public health interventions (such as immunization and screening) and access to effective health care. Greater public health

impact though can be achieved through addressing the wider determinants of health—such as ending conflict, providing clean water and good sanitation, reducing poverty, and improving education levels.

4 Recommended response

Climate change already impacts the transmission of infectious diseases in the EMME and will have a greater impact in the future, in a region which is characterized by a significant inequality in the capability of the national health systems to deal with these challenges. While most of the population have access to improved drinking water sources and at least basic sanitation services (except in Yemen), there are gaps in the quality of the health-care systems of the EMME countries and their ability to deal with health challenges. Such differences between countries of the EMME are highlighted by comparing the average of 13 International Health Regulations core capacity scores (which include the following, according to the WHO: (1) National legislation, policy and financing; (2) Coordination and National Focal Point communications; (3) Surveillance; (4) Response; (5) Preparedness; (6) Risk communication; (7) Human resources; (8) Laboratory; (9) Points of entry; (10) Zoonotic events; (11) Food safety; (12) Chemical events; (13) Radio nuclear emergencies), when, for instance, the score for the UAE is 96, and for Jordan is 43. The density of physicians and hospital beds (both for 1000 population) also highlight these gaps. For example, in Israel, the density of physicians per 1000 people is 4.63 and hospital beds are 3.0 while in Egypt the corresponding values are 0.45 and 1.4, respectively (Table 1). Therefore, risk assessment and timely design and implementation of health preparedness and adaptation strategies are essential.

Several publications suggested general recommendations for a better preparedness at the global level such as systematic collection of data, efficient vector surveillance, collaboration between different disciplines, and social protection, among others. Here, the following proposed actions are aligned with the key challenges of the EMME region, including inequality between and within countries, increased water scarcity, internal and external conflicts, and migration.

The risk from vector-borne diseases in the EMME is influenced by onwards transmission in/from endemic areas or by viremic passengers arriving from endemic countries to regions where a competent vector is present (for example, immigrant workers from endemic regions may be a source of malaria outbreaks). In both scenarios, the function of the climatic suitability for transmission is crucial. While most studies from the EMME are based on data from urban areas (e.g., Hashem et al. 2018; Mohammadkhani et al. 2019), epidemiological data should be collected systematically not only in urban environments, but also in poorer and more remote areas. Reliable data is essential for targeting prevention measures—such as test, trace, and isolate policies, as in the current COVID-19 outbreak.

Depending upon the vector-borne disease of concern (Table 2), diverse factors related to different vector species have to be surveyed, including identifying dominant vector species (e.g., *Ae. albopictus*), its period of activity, biology, ecology, phenology, and diversity; determine the presence and distribution of vectors; and detect the presence of pathogens in the vectors. In addition, data on infected cases among the human population and domestic animals (for example in the case of WNV) is also crucial for effective surveillance, including total proportion of viremic cases, and infected case frequency, geographic location, and

spread. Data should be collected in high volume, and from multiple sources on a routine basis in the pre-disease stage and in real time during the disease stage, with a special attention to areas at risk (ECDC 2014; Tong and Ebi 2019).

Following epidemiological data collection, surveillance plans are a key element in highlighting the certain areas at risk, controlling emerging, and reemerging infectious diseases and in identifying disease thresholds. In areas at risk, mosquito breeding sites need to be eliminated to reduce mosquito density, parallel with seasonal surveillance that should be conducted for both mosquitoes and human health, to identify sentinel cases (Semenza and Paz 2021). Providing adequate information for efficient risk assessment can help decision-makers and guide appropriate interventions.

To determine weather conditions and environmental changes that have the potential to impact the transmission risk of the pathogen, an early warning system of atmospheric forecasts is crucial for the prediction of severe weather events, such as heat waves or floods that may contribute to vector-borne transmission (e.g., Linticum et al. 2016). Additionally, consistent monitoring in real time remotely of the sea surface temperature in marine waters around the Arabian Peninsula can predict the environmental suitability of pathogenic *Vibrio* infections in marine waters and serve as an alert for increased seasonal abundance of *V. cholerae* (Semenza et al. 2017). In that case, beach closures, alerts to the public, and notifications to health care providers can minimize the exposure of recreational water users to cholera infection risk (Semenza and Paz 2021).

As seen in the current COVID-19 pandemic, infectious diseases can spread rapidly across national boundaries. Those transmitted by vectors can be particularly hard to track and control, since their spread is driven by the movement of vector and reservoir species, as well as by human hosts. In the EMME region, especially in countries with limited resources for surveillance and intervention, the ability to track and control the disease spreading is harder. Since efforts at the national level are often insufficient to adequately monitor and control the dissemination of infectious diseases, and in order to reduce the spread of insect vectors of disease across borders of neighboring countries, coordinated regional efforts should be more efficient at producing epidemiological data, identifying dissemination routes in and between countries, and facilitating control strategies, as can be learned from the regional initiatives to reduce the disease burden of malaria in certain parts of Africa, and Chagas disease in South America (Dias et al. 2002; World Malaria Report 2014). Although conflicts in the EMME limit cross-border relationships, collaboration between countries should be a priority for national health agencies to address shared challenges of disease transmission, even for countries lacking diplomatic relations. Examples of such initiatives that exist, despite conflicts, are The Middle East Consortium on Infectious Disease Surveillance (MECIDS) frameworks that operates across Israel, Jordan, and the Palestinian Authority and the Cyprus government initiative for coordinating climate change actions in the EMME region (ECCI), spearheaded by the Cyprus Institute. Ideally, these incipient initiatives can be either expanded, or at least serve as models for the development of novel, more comprehensive regional networks that facilitate collaboration between infectious disease experts from EMME countries in spite of the unavoidable differences in culture and resource availability.

Efforts should be made to address the knowledge gaps in the region regarding infectious disease risks under climate change conditions, including quantitate measurement of the current situation as well as prediction for the near future.

Ensuring water and food safety (with special attention to meat, seafood, and dairy products) for all the people of the region to prevent contamination that increase the risk for infection (among other risks such as malnutrition), should include farm-level

interventions to prevent food contamination, as well as during production, processing, and distribution, parallel with public education campaigns for improved eating habits, safe food preparation, and storage in a warmer climate (Semenza and Paz 2021). Additionally, monitoring water quality in real time should be done on a regular basis with a special attention to changes resulted from severe climatic conditions as floods or prolonged drought. A study in Saudi Arabia on water scarcity caused by climate change indicated that desalination, wastewater recycling, and virtual water trade (outsourcing food supply) could be important adaptation measures to decrease the pressure on water resources (DeNicola et al. 2015).

In the developing countries (as Iraq or Yemen) in particular, access to public health interventions and health care is limited. This should be enhanced by national health authorities with a special attention to the vulnerable populations. Since the ability and resources are scarce, increased financing of such efforts is needed, perhaps undertaken mainly by the richer countries in the region which have the interest to reduce the regional health risks, with the support of other major global health funders. It is worth noting that after years in which the discipline of climate and health has been systematically deprived of funding for training, research, and other activities, recent years have seen some positive developments, including investments from the European Union and other international agencies or other funders such as the Wellcome Trust that have tentatively engaged climate and health program (Hess et al. 2020).

Special attention should be given to refugee camps, including provision of clean water and appropriate wastewater management, disease surveillance, and vaccination programs, as people in these camps are at very high risk of outbreaks of infectious diseases, such as cholera and COVID-19. Help may be obtained from groups working at the international level as The M8 Alliance that promote attention to the three inter-related issues of migration, health, and climate change (Matlin et al. 2018).

Strengthening the public awareness on recommended prevention of infectious diseases risks in the light of the changing climate conditions is of crucial importance. This can be achieved through various educational instruments and involve the local media and community leaders and health workers. For example, the risk of vector-borne disease outbreaks could be reduced through community-driven elimination of small breeding sites, using insect repellent, wearing long-sleeved shirts and pants, and taking steps to control mosquitoes indoors and outdoors.

5 Conclusions

Climate change has already impacted the health of the EMME population and its effects will increase in future years. Joint national and cross-border infectious diseases management systems for more effective preparedness and prevention are needed, supported by interventions that improve the environment and reduce the impact of climate change. Without such cooperation and effective interventions, parallel with mitigation actions to reduce greenhouse gas emission, climate change will lead to an increasing level of morbidity and mortality resulted from infectious diseases in the region, with a higher risk for the most vulnerable populations.

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Declarations

Conflict of interest The authors declare no competing interests.

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