Current Environmental Health Reports (2022) 9:315–323
https://doi.org/10.1007/s40572-022-00339-7

The Prospective Effects of Climate Change on Neglected Tropical Diseases in the Eastern Mediterranean Region: a Review

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Accepted: 27 January 2022 / Published online: 14 March 2022

Abstract

An increase in the annual daily temperature is documented and predicted to occur in the coming decades. Climate change has a direct effect and adverse impact on human health, as well as on multiple ecosystems and their species. The purpose of this paper is to review the effect of climate change on neglected tropical diseases including leishmaniasis, schistosomiasis, and lymphatic filariasis in the Eastern Mediterranean Region (EMR). A list of engine web searches was done; 280 full-text records were assessed for eligibility. Only 48 original records were included within the final selection for the review study. Most research results show an alteration of neglected diseases related to climate change influencing specifically the Eastern Mediterranean Region, in addition to the expectation of more effects at the level of vectors and reservoir whether its vector transmission route or its egg hatching and replication or even the survival of adult worms in the coming years. At the same time, not all articles related to the region interpret the direct or indirect effect of climate variations on these specific diseases. Although few studies were found describing some of climate change effects on neglected tropical diseases in the region, still, the region lacks research funding, technical, and mathematical model expertise regarding the direct effect of climate change on the ecosystems of these neglected tropical diseases.

Keywords Climate change · Neglected tropical diseases · Eastern Mediterranean Region

Introduction

The global climate has warmed by approximately 0.85 °C since the mid of eighteenth century [1]. By the end of the twenty-first century, the annual daily temperature is predicted to increase by 2 to 5 °C [2]. The change in the global climate is affected by trapped heat in the lower atmosphere due to the burning of fuels that release different pollutant gasses such as carbon dioxide and chlorofluorocarbons [3]. It is well established that rain, air, and temperature variations such as hurricanes, air pollution, and sea-level rise have a direct impact on health [4]. A review of European human and domestic animal pathogens proposes that two-thirds of these pathogens are climate-sensitive [5]. Low-income countries with low resources and infrastructure are at the greatest risk of the adverse effects of climate variations on human health [6-9]. For instance, in Africa, climate change will contribute to the spread of waterborne diseases, floods, decreased food production, and substantial changes in the ecosystem. The lack of rain and dryness has already begun in large parts of Africa. For example, in Niger and Senegal, rain has declined by 50% according to the 2001 Third Assessment Report of the WMO/UNEP Intergovernmental Panel on Climate Change (IPCC) [10]. In addition to the direct adverse effect on human health, climate change has also an effect on multiple ecosystems and their species [11]. Living organisms can be influenced by environmental factors such as climate and air pollution produced by human activities [12•]. Climate change can have a major impact on infectious diseases, especially for neglected tropical diseases (NTDs) because the vector transmission route or its egg hatching and replication or even the survival of adult worms can be facilitated with the upcoming changes. For example, the emergence of different vector-borne

This article is part of the Topical Collection on *Climate Change and Health*

This article is part of the Topical Collection on *Global Environmental Health and Sustainability*

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diseases, such as leishmaniasis, worms, and soil-transmitted diseases (STDs), already ongoing in different locations is also an indication of the influence on climate change [13]. In the EMR, which includes more than 20 countries, several vector-borne diseases are endemic in one or more countries, such as lymphatic filariasis, schistosomiasis, soil-transmitted helminths (STHs) (*Ascaris*, hookworm, and whipworm). For instance, in Iran, Sudan, and Iraq, leishmaniasis of both types (cutaneous and visceral) is endemic. While in Yemen, schistosomiasis is still a public health problem [14]. At the same time, in Morocco, there is a high prevalence rate of trichuriasis [15].

Several studies have shown there is an association between seasonal variation and epidemiological trends in NTDs including increasing infection, reinfection, and prevalence rates with rainy seasons and higher temperature variations. For example, in several rural areas in Sri Lanka, there was an obvious relation between rainy and moist days and higher infection and reinfection levels of ascariasis [16-20]. Vectors and reservoirs of different infectious diseases including NTDs are influenced by climate change. It was found that the reproduction and livelihood of insects and snails (intermediate hosts) that spread infectious diseases were highly affected by climate variations [21]; for example, *Ascaris* eggs and larva are influenced by temperature variations [22] where high temperature increases egg development rate, while low temperature slows down the development of *Ascaris* eggs and their survival [23]. Although malaria parasitic infection is not included within the group of NTDs, there is potential that *Anopheles gambiae* species of mosquitoes broaden its geographical distribution to Egypt due to the increase of temperature globally [24]. NTDs with high incidence in Yemen and Egypt include schistosomiasis, leprosy, filarial infections, and soil-transmitted infections, while cutaneous leishmaniasis, is endemic in Iran and Iraq. Meanwhile, trachoma is present in Morocco, Algeria, Saudi Arabia, and Tunisia [25]. The purpose of this review is to search for studies that evaluate changes in the ecosystem, transmission, and reproduction among selected NTDs (leishmaniasis, schistosomiasis, *Wuchereria bancrofti*, and lymphatic filariasis) diseases in the EMR due to climate change.

Methods

Data sources and searches: we searched PubMed®, Scopus database, Ovid Medline, Science Direct, and Iraqi academic scientific journals through March and April 2021 for all NTDs recognized by the WHO to be selected for reports on NTDs and climate change in the EMR. A manual search was also performed using Google scholar and CDC for articles published related to NTDs. The search used the key words climate change, humidity, global warming, temperature, rainfall, environment effect on NDTDs, and specific names of NTDs such as ascariasis for example. The review included countries from the Eastern Mediterranean Region that are endemic with NTD infections in the EMR.

Results of Literature Search

The review included the effect of environmental factors (humidity, temperature, wet (rainy) weather) on the development, survival, and egg production of NTD parasites in EMR countries included in this review. A total of 280 full-text records were assessed and screened for eligibility according to titles and abstracts and NTD infections related to the EM region. Only 48 original and relevant records were included within the final selection for the review study, and 19 articles met the inclusion criteria of our review search.

Endemic Diseases in the EMR

Cutaneous leishmaniasis in the Eastern Mediterranean Region represents 80% of the cases worldwide. (Fig. 1). Visceral leishmaniasis is also highly endemic in Sudan, Somalia, and Iraq [26] (Fig. 2). Schistosomiasis is endemic in the EMR and is still an important public health problem in Yemen, Somalia, and Sudan. According to the WHO, in 2018 alone, 20 million people in the region were provided with chemotherapy as a preventive measure against schistosomiasis. At the same time, other countries in the region have low endemicity of schistosomiasis, including Iraq, Oman, Libya, Saudi Arabia, and Syria (Fig. 3). Schistosomiasis has been eliminated in Lebanon, Morocco, Tunisia, and Iran [27•]. However, with continuous conflicts in Iraq, Lebanon, Syria, and other countries in the region, floods in Oman and Saudi Arabia, dust storms in the Arabian peninsula, poor or no surveillance program and follow-up for reemerging neglected diseases, decline or postponement of preventive and control measures due to financial conditions, lack of studies on the effect of climate on these tropical diseases in some countries, and lack of updated prevalence of each neglected infectious disease all suggest concern is present for the increase of prevalence or reemerging of schistosomiasis or other neglected tropical diseases in countries where they announced its elimination or low endemicity.

Leishmaniasis in Iraq

A study in Iraq shows that more than 50% of cutaneous leishmaniasis case distributions were found during January and February winter seasons. At the same time, the high prevalence was reported in provinces of Iraq that are low-lying lands with an elevation of 51 m or less above

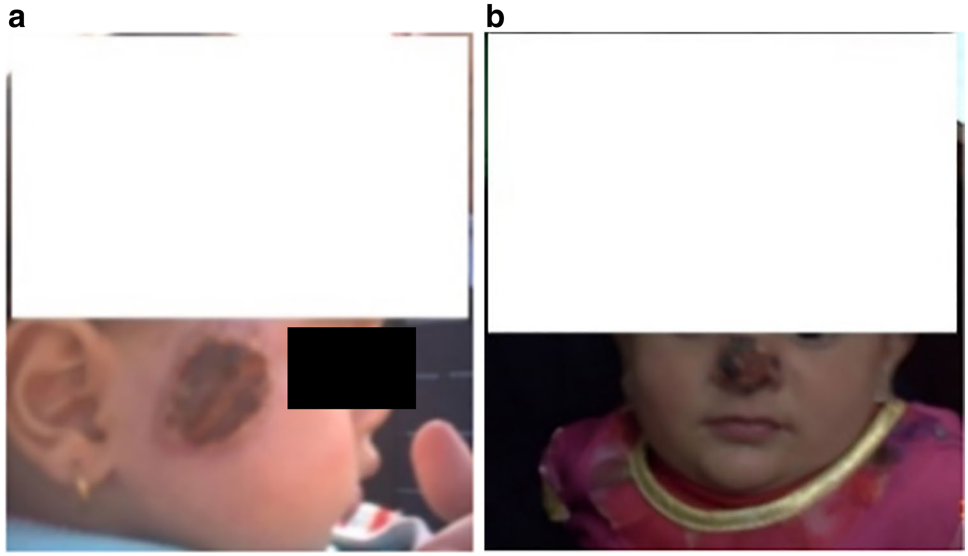

Fig. 1 Cutaneous leishmaniasis (**a** face and **b** nose) in Anbar Province, Iraq (field survey). The pictures were taken by the author. (Informed consent to start the study and to take the questionnaire and verbal permission for the picture both were **taken** from parents)

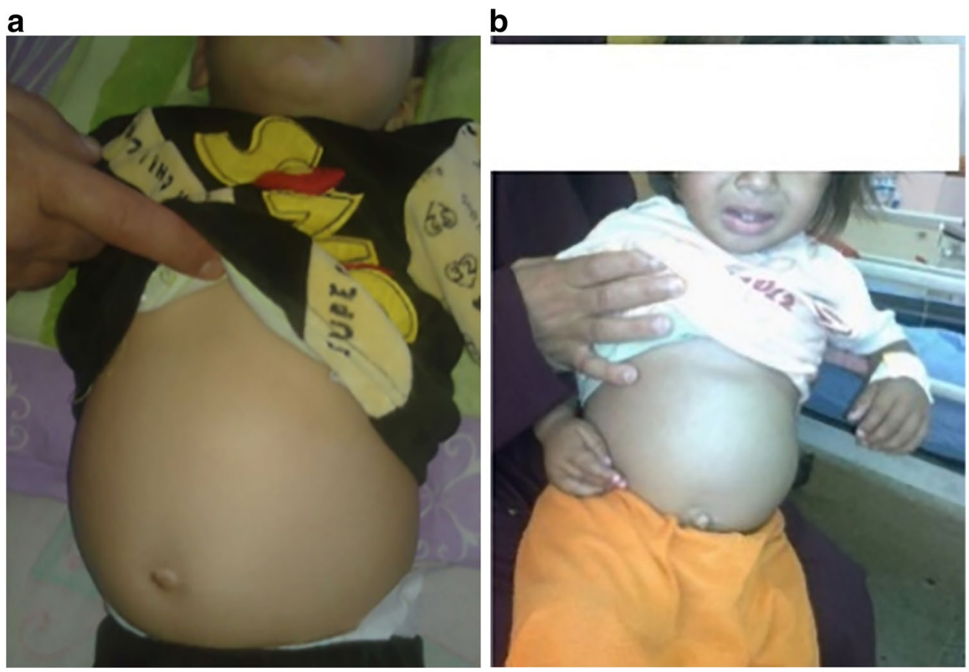

Fig. 2 Visceral leishmaniasis cases admitted at Children's Central Teaching Hospital in Baghdad, Iraq. (**a**, **b** Abdominal distention-hepatosplenomegaly). The pictures were taken by the author. (Informed consent to start the study and to take the questionnaire and verbal permission for the picture both were taken from parents)

sea level. Half of the cases of cutaneous leishmaniasis were reported in provinces with annual rainfall above 190 mm [28]. In addition, during the hot, dry summer in Iraq, a type of soil fissure called earth crack is common there that allows various species of sand fly vectors present in these regions to grow in these fissures leading to a high incidence of leishmaniasis from June to August (where temperatures range from 70 to 75 °F (21–23 °C) to 100 to 110 °F (37–43 °C), and humidity ranges from 10 to 30% [29]. Another field study in Iraq shows that the distribution of the vector of leishmaniasis (sand fly insect species) is highly affected by environmental factors (such as temperature and humidity) and physical factors (such as habitat availability) [30]. In summary, the disease leishmaniasis in Iraq with its both types, the cutaneous and visceral, are influenced by seasonal variations whether summer or winter and temperature variations, and rain or dryness. And the different climate changes mentioned could have an impact on the parasite or the vector's life cycle itself.

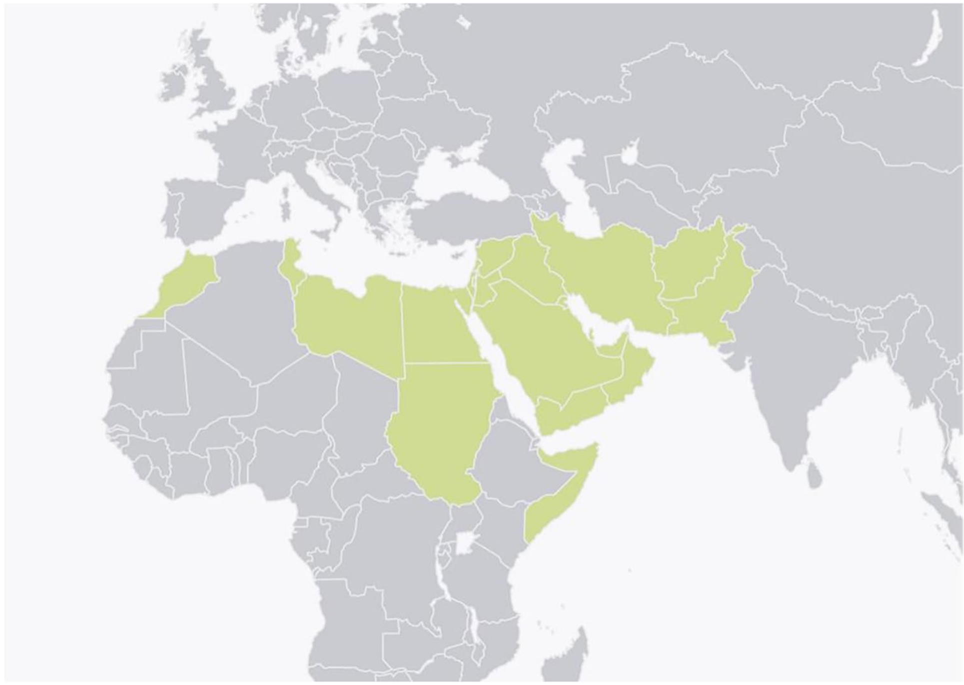

Fig. 3 WHO-EMRO region countries in the EMR (dark-green zone only). Source: https://extranet.who.int/countryplanningcycles/region/eastern-mediterranean

Leishmaniasis in Iran

In a study in Iran, eight species of sandflies were identified, three-quarters of them were phlebotomus (*Phlebotomus papatasi*) was among the highest predominant species outdoor), and the rest were *Sergentomyia* (*Sergentomyia sintoni* was the highest predominant species indoor) [31]. Another study shows that there was a significant relationship between cutaneous leishmaniasis disease incidence and all environmental and climate factors including humidity, temperature variations, and slope of the land [32]. Charrahy Z et al. predict in their study through modeling that by 2050, there will be new foci of both reservoirs and vectors of cutaneous leishmaniasis disease in the northwest of the country in the near future due to climate change. To prevent such new incidence cases of the disease, a follow-up at these areas through field study for early detection was recommended [33].

Leishmaniasis in Sudan

Leishmaniasis, especially the visceral type, is considered one of the endemic diseases in Sudan, and it is thought that it originated in the country in 1904 [34] and later on was spread to other areas, therefore Sudan was considered one of the main sources for the spread of that type of leishmaniasis throughout the world [35, 36]. The disease has been spreading outside the endemic areas and increasing in low incidence areas in Sudan such as the western part of Sudan and the capital city [36, 37]. Multiple field studies in Sudan show that the prevalence rate of visceral leishmaniasis and its vector *Phlebotomus orientalis* are high in different parts of the country and are influenced by climate change [37].

Leishmaniasis in Somalia

Visceral leishmaniasis in Somalia is endemic, affecting people's health in the south-central peripheral rural areas with low socioeconomic status [38]. Cracks in black clay soil and termite mounds in this region are associated with the presence of sand fly vectors [39]. Access to health care and application of health measures is poor due to country insecurity and conflict for years and the lack of a national control program, resulting in uncertainty regarding the true picture of visceral leishmaniasis in this country [40, 41]. Somalia has two seasonal rainfalls with usually dry and semidry climates. Meanwhile, its southern part has a productive agricultural soil area with hills where leishmaniasis sand fly increases after rainy weather [42]. Conflict areas in the region including Somalia are present, and this has its effects on neglected diseases including leishmaniasis, therefore taking no action (absence of a national control program) by the local government and neglecting such significant public health problem in Somalia is considered unfair and unjust, and both local and global communities should take responsibility and intervene to help, especially given climate change will negatively impact the control of these neglected diseases [43].

Another parasitic neglected tropical disease (also called bilharziasis) is mainly caused by three different species of blood fluke worms of the genus *Schistosoma*, namely *Schistosoma haematobium* (causes urinary schistosomiasis), *S.*

mansoni, and *S. japonicum* (both cause intestinal schistosomiasis [44].

Schistosomiasis in Egypt

The disease is endemic in Egypt; the snail intermediate host for both types of schistosomia found in this area are *Biomphalaria alexandrina* for *Schistosoma mansoni* and *Bulinus* truncates for *Schistosoma haematobium* [45]. Changes in seasonal rain, water temperature variation, construction of dams, and type of vegetation all have an impact on the number of snails [46]. Therefore, Egypt could be exposed to a lack of plant moisture, water stress, and a reduction in water currents in irrigation and drainage canals [45].

Schistosomiasis in Yemen

Schistosomiasis remains a major public health concern in Yemen [47]. Hani et al. found in their study that some provinces in Yemen located at the west-south side of the country with water streams were more infected with snails compared to the capital city location (Sana'a) where dams and water pools are found. The study mentioned that Yemen is under serious lack of water, which in turn forces people to find other sources of water to drink such as tanks, wells, and uncovered pools. In addition, the government is constructing dams for irrigation; all these environmental changes led to the finding of overlap distribution of two species (i.e., *S. mansoni* and *S. haematobium*) among children in the study [47]. In Yemen, a study showed that in different provinces in the country with different feet above sea level, the prevalence of snails and cases is affected by the high altitude. The higher the feet altitude above sea level places, the more snails and cases are found [48].

Lymphatic Filariasis (LF)

The WHO classifies LF (commonly known as elephantiasis) as an NTD that causes permanent disability [49, 50]. Over 120 million people are affected by this parasitic disease throughout the tropics and subtropics of Asia, Africa, the Western Pacific, and parts of the Caribbean and South America [51]. In Egypt, it is transmitted by the mosquito named *Culex pipiens*, and it was a major public health problem especially in rural areas, being one of the most concerning vector-borne diseases in Egypt until recently [52]. In 2017, the WHO announced that Egypt is the first country in the Eastern Mediterranean Region to achieve the goal and the success of eliminating the disease [53•]. Through the National Lymphatic Filariasis Elimination Program (NLFEP), Egypt succeeded in controlling and eliminating the disease through the MDA program and the follow-up surveillance, and although LF is considered one of the vector-borne diseases, and climate variation in the land has a direct effect on the vector, still, for the time being, there is no evidence that the disease is reemerging in Egypt [54-56]. However, it is not unlikely that it will remerge again because of weather pattern changes from climate change.

Discussion

In our electronic search and review, not all reports in the EMR were sufficiently providing information about the effect of climate change on specific species of neglected tropical diseases and endemic diseases in the region. Some countries in the region committed and implemented a national control health program to eliminate or reduce the prevalence of specific NTDs they suffer from; while in other countries, these diseases are still endemic due to conflicts, climate change, and financial resources.

In Africa and Asia, the image differs. Reports are clarifying the effect of climate and environmental factors on specific NTDs. In Africa, for example in Zimbabwe (a country that is not included within the EMR region), both biological model and regional climate model were done by a national survey to predict snail habitat under the effect of climate factors after involving the prevalence of schistosomiasis in this country. Results showed high temperatures and dry seasons could have a direct effect on snails (the intermediate host) in schistosomiasis infection through decreasing snails' prevalence at these territories, which in turn decreased the prevalence of schistosomiasis disease and may have a positive effect toward decreasing disease trends in Zimbabwe [57, 58]. Pullan and Brooker have found that the prevalence and transmission of *Trichurs trichiura* and *Ascaris lumbricoides* infection was statistically lower in rural areas compared to urban regions, and this evidence was referred to the dry land regions and variations in surface temperatures. Researchers indicate there is uncertainty regarding the reasons behind the decrease of *Ascaris* egg development in the hot temperature of Asia, while hookworm parasite development and larva proliferation increase in hot soil temperature of 40 °C or higher and rarely found in regions where land surface temperature (LST) is below 10 °C [59-61]. With the global climate warming and increasing temperatures annually [2], the above two selective worms (*Trichuris* and *Ascaris* can give us an indication that they can increase in productivity and infectivity and have the chance to spread to other wider range regions in the EMR region protecting their life cycle, feeding, and development from the direct effect of environmental factors [36]. In an animal laboratory experimental study of STH worms in European rabbits, parasite growth period, egg hatching, period of infective stages, and larva survival all were influenced by climate

Table 1 Climatic factors that influence disease transmission in some of the countries in the EMR region

NTDS	EMRO country	Environmental factors	Pathogen specified	Vector specified	Intermediate host	Reservoir host	References
Leishmeniasis (cutanenous)	Iraq	Increase temperature and increase earth cracks which, in turn increase sand fly activity and increase cases	Leishmania parasite (*L. tropica*, *L. major*)	*Phlebotomus papatasi*	———	Gerbils, rat	[28, 29]
Leishmeniasis (cutanenous	Iran	Increase incidence with climate factors changes	*Leishmania major*	*Phlebotomus papatasi* (outdoor) *Sergentomyia sintoni* (indoor)	———-	Gerbils, rat	[31, 32]
Visceral leishmeniaisis	Sudan	The disease has been spread outside the usual endemic areas	*Leishmania donovani*	*Phlebotomus orientalis*	———	Domestic dog	[36, 37]
Lymphatic filariasis	Egypt Yemen		*Wuchereria bancrofti*	*Culex pipiens* mosquitoes	———-	———	[52, 53•, 54] Elimination in Egypt in 2017 and in Yemen in 2019
Schisosomiasis	Egypt	Change climate variation, construction of dams, and type of vegetation all affect the number of snails	*Schistosoma haematobium Schistosoma mansoni*		Snail host of *S. mansoni* is *Biomphalaria alexandrina*, while of *S. haematobium* is *Bulinus truncatus*		[45, 46]
Schisosomiasis	Yemen	Environmental changes led to the finding of overlap distribution of its species	*Schistosoma haematobium Schistosoma mansoni*	*Culex* mosquito	*Bulinus beccarii*, *B. truncatus*, and *B. wrighti*		[47]
Visceral leishmeniasis	Somalia		*Leishmania donovani* complex	*Phlebotomus orientalis*		Dogs, Nile rat, mice, gerbils, servals	[38, 71]

change including daily temperature and seasonal changes [62]. The prevalence of soil-transmitted helminths can be influenced by changes in climate indirectly for example variations in agriculture practices and directly by changing the trends and abundance of the parasite in some locations [63]. This is true with schistosomiasis, particularly in Yemen and Egypt. In Yemen, a review paper done by Sallam and Wright describes three different provinces located in different regions to follow the effect of high altitude (feet above sea level) and temperature on snails. In the Hodeidah governorate, which lies on the Red Sea coast 2500 ft above sea level, snails were not found, and there was a low rate of infection among the population. In contrast, in Sana'a (the capital city of Yemen, 7200 ft above sea level) and Taiz (southwestern of Yemen, 4600 ft above sea level), in both governorates, there was a high percentage of snails, and people were heavily infected with *Schistosoma mansoni* [48]. Patz et al. also described the increase in the number of snails (intermediate host of *Schistosoma* blood flukes) that can be associated directly with climate change variations, whether rain and/or the temperature of water [46], where snails are presently completing the life cycle of this parasitic trematode worms *Schistosoma*.

In leishmaniasis disease, which is endemic in Sudan and Somalia (particularly visceral leishmaniasis type) and Iraq and Iran (both types of leishmaniasis visceral and cutaneous), a survey in Iran also used regression models and maps to determine the effect of climate changes and environmental factors on cutaneous leishmaniasis; results showed a significant relationship between the prevalence of the disease and predictive high-risk areas and regions (high prevalence was found along with the Iraqi borders), climate factors such as rainfall, temperature, and type of soil and land and others [64].

Concerning lymphatic filariasis, it was announced officially by the WHO that in 2017, Egypt was the first country in the EMR region to succeed in the elimination of LF disease, and Yemen followed in 2019 [52, 53•, 54, 55]. Egypt is considered a role model for other countries in the EMR region. However, Blum and Hotez discussed the uncertainty if the elimination of LF worldwide could be established through a mass drug administration program, and that climate variations could play an important role on mosquito wide range distribution [65]. Findings from Nepal indicate a shift of LF transmission from regions under the MDA program to high-altitude regions [66]. In addition, Slater and Michael predict that in Africa alone, the LF disease could put more populations at risk of infection due to climate change [67]. The same with LF infection in the EM region, although Egypt and Yemen announced officially the elimination of LF disease, still, the transmission of LF infection can be shifted to other countries in the region due to climate change. Nevertheless, climate variations and global warming, civil war, conflicts, and refugee camps in Yemen and other countries in the region, population growth, deforestation, dam construction, and irrigated agriculture (in schistosomiasis) [68, 69], rural to urban migration, and urbanization [70], each should be given a weight and consideration while starting the elimination program and/or studying the rate of transmission, the ecosystem of the parasite, and the prevalence of these NTDs in the EMR region.

Conclusion

This paper describes how conflicts and other important environmental factors affect NTD infection and species transmission (Table 1). Climate change and variations have a direct and indirect impact on the Eastern Mediterranean Region and countries. Lack of abundant reports related directly to the effect of climate change on specific NTDs are found. Few countries in the region did a regression model predicting the climate change effect on specific NTDs. In addition to the continued surveillance, the MDA program and ongoing follow-up of NTD diseases, mathematic regression modeling through geographical information systems (GIS), and remote sensing (RS) surveys are needed and should begin urgently in the EM region to gain more information and understanding about the ecology and epidemiology of the parasite, otherwise reemerging of diseases that have been eliminated in some countries could occur.

Declarations

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

Conflict of Interest The author declares no competing interests.

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Papers of particular interest, published recently, have been highlighted as: • Of importance

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