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## REVIEW

# Climate change and epidemiology of human parasitosis in Egypt: A review



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## ABSTRACT

Climate change is an emerging global issue. It is expected to have significant impacts both in Egypt and around the world. Thus, the country is in need for taking action to prepare for the unavoidable effects of climate change, including the increase in water stress, the rise in sea level, and the rapidly increasing gap between the limited water availability and the escalating demand for water in the country. Also, weather and climate play a significant role in people's health. Direct impacts of climate change on the Egyptians public health may include also increased prevalence of human parasitic diseases. Climate could strongly influence parasitic diseases transmitted through intermediate hosts. The present work reviews the future of such parasitic diseases in the view of the current available evidence and scenarios for climate change in the Egypt.

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**Introduction**

Climate change is now widely accepted as a fact. Evidence of such change includes the instrumental temperature record, rising sea levels, and decreased snow cover in the Northern Hemisphere. Scientists projected future changes in air and

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sea surface temperatures, as well as changes in precipitation, sea level, and ocean salinity and circulation patterns. These environmental changes are likely to have an impact on all the natural ecosystems and socioeconomic systems [1,2].

In 2000, the Intergovernmental Panel on Climate Change (IPCC) issued a Special Report on Emission Scenarios (SRES) that presented more than 40 scenarios based on different visions of how the world may develop in the 21st century, the sources of energy it will use, and how the communities will solve their problems. Based on the SRES, an array of serious threats is apparent to develop in Egypt with the climate change [3].

Egypt is generally an arid country that depends on the Nile River as its main and almost exclusive source of fresh water. At present, it is the largest consumer of the Nile water. It is one of the African countries that could be vulnerable to water stress under climate change [3]. The river is very sensitive to temperature and precipitation changes mainly because of its low runoff/rainfall ratio which is 4% [4]. Because of being at the bottom end of the river, Egypt is affected by the climate change impacts, not only within its borders, but also within the whole basin, which it shares with ten other countries. Egypt will be likely to experience an increase in water stress with a projected decline in precipitation [5]. At present, there is a rapidly increasing gap between the limited water availability and the escalating demand for water in the country. The rate of water utilization has already reached its maximum for Egypt, and climate change will exacerbate this vulnerability. The quantity of water used in 2000 was estimated at about 70 km<sup>3</sup> which is already far in excess of the available resources [6]. Temperature rise is expected

to reduce the productivity of major crops and increase their water requirements, thereby directly decreasing crop water-use efficiency [7,8]. This situation may be complicated by a general increase in irrigation demand [9]. The ongoing expansion of irrigated areas will reduce the capacity of Egypt to cope with future fluctuation in flow [10].

In addition, climate change is likely to cause rise in sea level as a consequence of global warming. This could affect the Nile Delta and other coastal areas [11]. Coastal cities such as Alexandria (Egypt's second city) will probably be impacted and could be completely lost [12].

Direct impacts of climate change on Egypt may include also increased prevalence of many parasitic diseases, physiological disorders, skin cancer, eye cataracts, respiratory ailments, heat strokes, and heat related illnesses. The indirect impacts involve factors such as demographic dislocations and socioeconomic disruptions. However, comprehensive studies that contain detailed estimations and correlations between climate change and human health are still lacking for Egypt [13]. For the interest of the public health in the country, it becomes crucial to review how human parasites may respond to the climatic change expected in next decades, according to results obtained with forecasting climatic models.

#### Impacts of climate change on human parasitosis in Egypt

Climate change could strongly affect diseases transmitted through insects, snails, and other cold blooded animals

**Table 1** Potential range of effects of climate on disease transmitted to man through other hosts. Adapted from McMichael and his coauthors in 2001 [19].

Climate Factor	Intermediate host	Pathogen	Vertebrate host and rodents
Increases in temperature	<ul style="list-style-type: none"> <li>– Decreased survival (e.g., <i>Culex tarsalis</i>)</li> <li>– Change in susceptibility to some pathogens; seasonal effects</li> <li>– Increased population growth</li> <li>– Increased feeding rate to combat dehydration, therefore increased vector-human contact</li> <li>– Expanded distribution seasonally and spatially</li> </ul>	<ul style="list-style-type: none"> <li>– Increased rates of extrinsic incubation in vector</li> <li>– Extended transmission season</li> <li>– Expanded distribution</li> </ul>	<ul style="list-style-type: none"> <li>– Warmer winters favor rodent survival</li> </ul>
Decreases in precipitation	<ul style="list-style-type: none"> <li>– Increase in container-breeding mosquitoes because of increased water storage</li> <li>– Increased abundance for vectors that breed in dried-up river beds</li> <li>– Prolonged droughts could reduce or eliminate snail populations</li> </ul>	<ul style="list-style-type: none"> <li>– No effect</li> </ul>	<ul style="list-style-type: none"> <li>– Decreased food availability can reduce populations</li> <li>– Rodents may be more likely to move into housing areas, increasing human contact</li> </ul>
Increases in precipitation	<ul style="list-style-type: none"> <li>– Increased rain increases quality and quantity of larval habitat and vector population size</li> <li>– Excess rain can eliminate habitat by flooding</li> <li>– Increased humidity increases vector survival</li> <li>– Persistent flooding may increase potential snail habitats downstream</li> </ul>	<ul style="list-style-type: none"> <li>– Little evidence of direct effects</li> <li>– Some data on humidity effect on malarial parasite development in anopheline mosquito host</li> </ul>	<ul style="list-style-type: none"> <li>– Increased food availability and population size</li> </ul>
Increase in precipitation extremes	<ul style="list-style-type: none"> <li>– Heavy rainfall events can synchronize vector host-seeking and virus transmission</li> </ul>	<ul style="list-style-type: none"> <li>– No effect</li> </ul>	<ul style="list-style-type: none"> <li>– Risk of contamination of flood waters/runoff with pathogens from rodents or their excrement (e.g., <i>Leptospira</i> from rat urine)</li> </ul>
Sea-level rise	<ul style="list-style-type: none"> <li>– Coastal flooding affects vector abundance for mosquitoes that breed in brackish water (e.g., <i>Anopheles subpictus</i> and <i>Anopheles sudaicus</i> malaria vectors in Asia)</li> </ul>	<ul style="list-style-type: none"> <li>– No effect</li> </ul>	<ul style="list-style-type: none"> <li>– No effect</li> </ul>

(Table 1). Intermediate hosts of human infections are sensitive to subtle temperature, precipitation, and humidity changes. However, diseases that require intermediate hosts are also dependent on many other interacting factors. Although there has been a resurgence of infectious diseases in recent years, it is unclear that climate change has played a significant role. Other factors such as the movement of human and animal populations, the breakdown of public health infrastructure, changes in land use, and the emergence of drug resistance have been contributory [14].

The capacity of climatic conditions to modulate the distribution and intensity of human parasitosis is well documented [15]. Climatic conditions especially global warming strongly affect the survival and distribution of the intermediate hosts (insects, snails, and other cold blooded animals) and also directly influence the development and reproduction of parasites carried by them [16]. In addition, climate change may also expand the current limits of agricultural activities, increasing the chance of contact between species that have not normally interacted in that area. Animal livestock may be infected with microorganisms which have zoonotic potential and can be transmitted to humans [17]. Also, global warming is expected to enhance the northern spread of diseases. As northern countries warm, disease-carrying intermediate hosts will migrate north, carrying pathogens with them. Concerning the southern borders of Egypt, many arthropod-borne parasitic diseases were reported in sub-Saharan Africa and Sudan. These are malignant malaria, African trypanosomiasis, (*Trypanosoma b. gambiense* and possibly *T. b. rhodesiense*), loiasis (infection with the nematode species *Loa loa*), and onchocerciasis (infection with *Onchocerca volvulus*) [18].

## Mosquito-borne diseases

### Malaria

Malaria is the world's most important vector-borne disease. Of all infectious diseases, malaria continues to be one of the biggest contributors to the global disease burden in terms of death and suffering. It is caused by parasites of the genus *Plasmodium*. The infection is transmitted to humans through the bites of female mosquitoes of the genus *Anopheles*. Four species of *Plasmodium* are pathogenic to humans: *P. falciparum*, *P. malariae*, *P. vivax*, and *P. ovale*. *Plasmodium falciparum* is the most common species in tropical areas and the most dangerous clinically. *Plasmodium malariae* is much less apparent, with low parasitemia, and found mainly in tropical Africa. *Plasmodium vivax* has the most extensive geographic range and is present in many temperate zones as well as the tropics and subtropics. *Plasmodium ovale* resembles *P. vivax* and replaces it in West Africa [20,21].

In Africa, distribution of the disease is greatly limited by climate, except at the southern limit [20]. Using the climate change scenarios, modeling experiments suggest a 5–7% potential increase in malaria distribution in Africa by 2100, primarily expanding malaria's altitudinal reach rather than latitudinal. An overall increase in person-months of exposure risk to malaria will be 16–28%, largely because of a prolonged transmission season [22]. Generally speaking, this topic is of intense controversy, and our understanding will continue to evolve as new research data are generated.

Evidence for human malaria infection in Egypt dates back to the Pharaonic times [23]. Since the 15th century, documented cases of malaria have been periodically reported in different parts of Egypt. In 1900, one third of the population of the Suez Canal area was reported to be infected with malaria. In 1942, an outbreak of malaria occurred in Nubia as a result of an invasion of the efficient vector, *Anopheles gambiae*, from Sudan. This epidemic lasted for almost four years where several hundreds of cases and deaths were recorded. Periodically, every few years, semi-epidemics occur in different parts of the country. This is probably related to special climatological and hydrological changes that cause the flourishing of a high density of the vector species. Historically, the three species of malaria were reported from Egypt: *P. vivax*, *P. falciparum*, and *P. malariae* [24]. Among all the anophelines present in Egypt, only four species are known to be efficient vectors of malaria; *A. pharoensis*, *A. sergentii*, *A. stephensi*, and *A. superpictus*. *Anopheles pharoensis* was found to be distributed all over Egypt, especially in the Delta. *Anopheles sergentii* proved to be the number one vector in the Oases of the Western Desert and Fayoum. *Anopheles stephensi* (in the Red Sea Coast) and *A. superpictus* (in Sinai) are known to be malaria vectors in other countries; however, they were not caught infected in Egypt [24].

*Anopheles sergentii* may be of a particular interest in projection of the future trends of the disease in Egypt. This species is known as the “oasis vector” or the “desert malaria vector” due to its distribution within oases across the Saharan belt in northern Africa and its ability to cope with the extreme climate across this region [25]. As mentioned above, in Egypt, it was found in the Oases of the Western Desert, Fayoum, and as south as Aswan and Toshka which represent the southernmost distribution in northern Africa [18,25,26]. *Anopheles sergentii* is highly zoophilic, and it is an indiscriminate biter of both humans and animals, both indoors and outdoors [27]. The key factor that limits oasis malaria transmission in Egypt is the zoophilic feeding behavior of *A. sergentii* [28]. As mentioned above, Egypt could be vulnerable to water stress and reduction crop productivity due to the climate change. To overcome this problem, the Egyptian government started to use the huge underground water reserves in the Western Desert in irrigation/agricultural projects. The new settlements may help in emergence of malaria due to the presence of the zoophilic *A. sergentii* the vector of the disease there.

The main vector species of malaria in Africa are the *A. gambiae* complex. They are the most efficient vectors in the world and are a major factor in the high burden of disease in the continent. In 1943, a major malaria epidemic occurred in Egypt associated with the spread of *A. arabiensis* (a member of the *A. gambiae* species complex) from Sudan along the Nile Valley [29,30]. This anopheline invasion was associated with greatly increased traffic into Egypt from Sudan, due to wartime difficulties of shipping in the Mediterranean. The *gambiae*-transmitted malaria struck as far north as Assiut, some 320 km from Cairo. It produced some 130,000 deaths within a two-year period until successful control measures were implemented in late 1944 [29]. In 2010, Menegon and his colleagues reported that malignant malaria is common in Sudan with antimalarial drug resistance mainly in *P. falciparum* [31]. With global warming and the continuous increase in tempera-

ture, it is possible that *A. gambiae* expands its range of distribution to Egypt. This situation may be further complicated by the presence of *A. sergentii* in Aswan and Toshka [18,26]. Also, Toshka and other irrigation/agricultural projects in the south of Egypt and north of Sudan may further facilitate the anopheline expansion north.

Climate change may contribute to the resurgence of malaria in areas where the public health infrastructure is insufficient (e.g., in rural areas). Human infections with *P. falciparum* were reported in Egyptian patients who were recruited from Peacekeeping Mission Forces in Sudan [32]. Such imported cases may initiate spread of the disease to new rural foci. In regions where malaria has been locally eliminated but the vectors persist, there is a theoretical but small risk of localized outbreaks that could increase under climate change. Although malaria has been successfully eradicated from most foci in Egypt, the vectors are still present, and there is probability of emergence/re-emergence of the disease. Very few sporadic cases of malaria are still diagnosed in Egypt [32]. The most obvious example is Fayoum which was categorized as a high risk area for malignant malaria during the last two decades [33,34].

#### Lymphatic filariasis

Lymphatic filariasis (elephantiasis) affects an estimated 120 million people in tropical areas of the world. Endemic foci are found in sub-Saharan Africa, Egypt, southern Asia, the western Pacific Islands, the north-eastern coast of Brazil, Guyana, Haiti, and the Dominican Republic. Since most infections are asymptomatic, many go unrecognized. The disease is known to be endemic in rural areas of Egypt. It is an infection with the nematode *Wuchereria bancrofti* and transmitted by *Culex pipiens* mosquitoes. The disease has a focal distribution, and it is estimated that currently over 2.5 million people are at risk of acquiring filariasis. It is considered one of the most important vector-borne diseases in Egypt, posing a major public health problem in six governorates in the Nile Delta (Qalyoubia, Menoufia, Sharkia, Kafr El-Sheikh, Dakahlia, and Gharbia) and the governorates of Giza and Assiut in Upper Egypt [35].

In 1997, the World Health Assembly passed a resolution calling for “the elimination of lymphatic filariasis as a public health problem”. Accordingly, the World Health Organization (WHO) developed a new strategy and initiated a global program for the elimination of lymphatic filariasis as a public health problem by the year 2020 [36]. Egypt was among the first countries to join the WHO global program. In 2000, a national program for elimination of lymphatic filariasis was initiated. In the years of the focalized control campaign, Egypt had made substantial progress in decreasing microfilaria prevalence [35].

In 2012, Slater and Michael used ecological niche modeling to map the current potential distribution of lymphatic filariasis in Africa and to estimate how future changes in climate and population could affect its spread and burden across the continent. They estimated that populations at risk to lymphatic filariasis may range from 543 to 804 million and that this could rise to between 1.65 and 1.86 billion in 2050 depending on the climate scenario [37].

## Fly-borne diseases

### Leishmaniasis

Sandflies are important vectors of leishmaniasis, a vector-borne zoonotic disease which is endemic in 88 countries throughout Africa, Asia, Europe, and North and South America. The insect vectors are over 50 species of the genus *Phlebotomus* in the Old World and genus *Lutzomyia* in the New World. Rodents, dogs, wild cats, jackals, foxes, sloths, hyraxes, and other carnivores are the main animal reservoirs in nature. The disease manifests mainly in three forms: visceral, cutaneous, and mucocutaneous [38,39]. Sandflies of the genus *Phlebotomus* (Family: Psychodidae) are widely distributed across the Middle East, from Morocco to Egypt, and the Arabian Peninsula to Jordan, Turkey, and Iran [40]. Nine species of *Phlebotomus* were reported in Egypt [41]. Two forms of leishmaniasis have been reported in Egypt, cutaneous leishmaniasis in Sinai [42] and visceral leishmaniasis in the northern coastal margins [43]. Three species of *Leishmania* are known to be endemic in Egypt: *L. infantum* which causes zoonotic visceral leishmaniasis, *L. major* which causes zoonotic cutaneous leishmaniasis, and *L. tropica* which causes cutaneous leishmaniasis [40,42,43]. *Leishmania donovani* DNA was detected in samples taken from ancient Egyptian and Nubian mummies that originate from around 4000 B.C. [44]. Since 1904, rare cases of visceral leishmaniasis have been reported in Egypt; some were imported, others were probably autochthonous. A focus of visceral leishmaniasis was discovered in El-Agamy area, 25 km west of Alexandria in 1982 [45]. The last case in El-Agamy area was reported in 2005, and only one more case of visceral leishmaniasis was reported in the Suez region in 2008. It should be noted here that due to a lack of awareness among medical practitioners, visceral leishmaniasis is suspected to be underreported [46]. Cutaneous leishmaniasis has been an increasing problem in Egypt [47]. Known foci are among nomads in North Sinai with 471 reported cases in 2008 [48].

Sudan is one of the highly endemic countries for visceral leishmaniasis or kala-azar, which is thought to have originated in country and later spread to the Indian subcontinent and the New World [49]. Since the early 1900s, visceral leishmaniasis has been among the most important health problems in Sudan, especially in the eastern and central regions. Several major epidemics have been reported; the most recent was in 1988 and occurred in Western Upper Nile province in southern Sudan. The disease spread to other areas that were previously not known to be endemic. Epidemiological and entomological studies confirmed *Phlebotomus orientalis* as the vector in several parts of the country. Infection rates with *Leishmania* were high, but subject to seasonal variation, as were the numbers of sand flies. Parasites isolated from humans and sand flies were identified as *L. donovani* [50].

Global warming is increasingly being implicated in species' range shifts throughout the world, including those of important vector and reservoir species for infectious diseases [51]. In North America, leishmaniasis is autochthonous in Mexico and Texas and has begun to expand its range northward. Ecological niche models of vector and reservoir species predict that climate change will exacerbate the ecological risk of human exposure to leishmaniasis in areas outside its present range

in the United States and, possibly, in parts of southern Canada [52]. A similar scenario for expansion of visceral leishmaniasis from its range in Sudan to southern areas in Egypt is expected. The effect of climate change on the present foci of the disease in Northern areas of the country requires further studies. To the best of our knowledge, cutaneous leishmaniasis has been an increasing problem in Egypt [47]. Thorough epidemiological studies are required to pinpoint the factors responsible for such increase.

#### *Mechanically transmitted parasites*

The housefly (*Musca domestica*) can serve as mechanical carrier of pathogens including many parasites. Protozoal cysts and helminth eggs can be carried on wings, legs, and body hairs of the fly and transmitted to human food and drinks. Climate change is also predicted to have major effects on flies of public health significance in domestic premises; thus, climate change models have predicted that housefly population could increase substantially, with increases of up to 244% by 2080. In light of this predicted increase in numbers, the role of houseflies as vectors of parasites and other pathogenic organisms is likely to take on greater importance [53].

#### **Snail-borne parasitic infections**

Freshwater snails that transmit parasitic digeneans generally prefer stagnant or slow moving water [54]. The increase in water stress expected to accompany climate change in Egypt may result in reduction in water currents in irrigation and drainage canals. In addition, construction of dams and irrigation projects reduce the speed of freshwater currents. These two factors may help the freshwater population to flare up in the future.

#### *Schistosomiasis (Bilharzia)*

In Egypt, schistosomiasis is caused by the two species *Schistosoma mansoni* and *S. haematobium*. The snail intermediate host of *S. mansoni* is *Biomphalaria alexandrina*, while the snail host of *S. haematobium* is *Bulinus truncatus* [55]. The schistosome larvae must infect the snail before escaping into water, seeking a human host. The abundance of the parasite is in direct proportion to that of the snail population. Abundance of snails is dependent on the type of vegetation in the habitat, seasonal rain variation, and changes in water temperature and flow [14]. In the Nile Delta and Valley in Egypt, the prevalence of schistosomiasis parallels the construction of new irrigation projects. With the construction of Aswan Dams in Egypt, year-round irrigation became possible, and the snail populations dramatically increased [55]. As mentioned above, Egypt could be vulnerable to water stress and reduction in crop productivity due to the climate change. To overcome this problem, the Egyptian government may construct new irrigation/agricultural projects which will increase schistosomiasis prevalence and disease spread to new foci.

#### *Fascioliasis*

*Fasciola hepatica* and *F. gigantica* are the causing agents of fascioliasis in humans and animals. Both species are endemic

in Egypt [56]. At present, fascioliasis is emerging/re-emerging disease in many regions of Latin America, Africa, Europe, and Asia, both at animal and human levels. Most human cases are known in Andean countries (Bolivia, Peru, Chile, Ecuador), the Caribbean area (Cuba), northern Africa (Egypt), western Europe (Portugal, France and Spain), and the Caspian area (Iran and neighboring countries) [57]. The incidence of fascioliasis in humans and animals has been related to air temperature, rainfall and/or potential evapotranspiration. These factors affect the intermediate snail host population dynamics and the parasite population at the level of both the free living larval stages of egg and metacercaria and the intramolluscan parasitic larval stages of sporocysts, rediae, and cercariae [58]. The strong dependence of fascioliasis on weather factors indicates that climate change may have a marked influence on the future evolution of this disease. The effect of climate changes may dramatically affect the prevalence of the disease in Egypt.

#### **Research gaps on climate change and parasitic diseases in Egypt**

Changes in transmission patterns of parasitic diseases are a likely major consequence of climate change. More information about the underlying complex causal relationships is needed. Also, it is crucial to apply such information to the prediction of future impacts, using more complete, better validated, integrated models. There are three main types of models, used to forecast future climatic influences on infectious diseases, that include statistical, process-based mathematical, and landscape-based models. These types of model address somewhat different questions. Statistical models require the derivation of an empirical statistical relationship between the current geographic distribution of the disease and the current location-specific climatic conditions. This describes the climatic influence on the actual distribution of the disease, given prevailing levels of human intervention (disease control, environmental management, etc.). By then, applying this statistical equation to future climate scenarios, the actual distribution of the disease in future is estimated, assuming unchanged levels of human intervention within any particular climatic zone. Process-based mathematical models use equations that express the scientifically documented relationship between climatic variables and biological parameters, e.g., vector breeding, survival and biting rates, and parasite incubation rates. In their simplest form, such models express, via a set of equations, how a given configuration of climate variables would affect vector and parasite biology and, therefore, disease transmission. Such models address the question: "If climatic conditions alone change, how would this change the potential transmission of the disease?" Using more complex "horizontal integration," the conditioning effects of human interventions and social contexts can also be incorporated. The landscape-based modeling entails combining the climate-based models described above with the rapidly-developing use of spatial analytical methods, to study the effects of both climatic and other environmental factors, e.g., different vegetation types often measured, in the model development stage, by ground-based or remote sensors [59,60]. Unfortunately, comprehensive studies that contain detailed estimations and correlations between climate change and human health are still lacking for Egypt [13].

## Conclusions

Climate change poses an immediate and growing threat to many countries of the world including Egypt. The country is in need for taking action to prepare for the unavoidable impacts of climate change, including the increase in water stress, the rise in sea level, and the rapidly increasing gap between the limited water availability and the escalating demand for water in the country. Also, weather and climate play a significant role in people's health. Direct impacts of climate change on Egypt may include also increased prevalence of human parasitic diseases. Climate could strongly influence parasitic diseases transmitted through intermediate hosts. Climatic conditions especially global warming strongly affect the survival and distribution of the intermediate hosts and also directly influence the development and reproduction of parasites carried by them. The present work reviews the effect of the expected climate change in Egypt on the spread and prevalence of mosquito-borne diseases (malaria and lymphatic filariasis), fly-borne diseases (leishmaniasis and mechanically transmitted parasites), and snail-borne parasitic infections (schistosomiasis and fascioliasis). Comprehensive studies that contain detailed estimations and correlations between climate change and human health are still lacking for Egypt. With the current available evidence and scenarios for climate change in the Egypt, it would appear that the public health effects of climate change especially on human parasitic infections is an emerging issue that needs to be intensively studied.

## Conflict of interest

*The author has declared no conflict of interest.*

## Compliance with Ethics Requirements

*This article does not contain any studies with human or animal subjects.*

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