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A REVIEW ON CLIMATE CHANGE AND IMPACT ON PARASITIC DISEASES INCIDENCE AND PREVALENCE

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Abstract:
Climate change has a significant influence on ecological interactions and processes, including parasitism. Parasites are critical for maintaining ecosystem balance as integral elements of ecological systems and potential drivers of outbreaks and disease-related mortality. Understanding their sensitivity to changing climatic conditions is therefore essential. This calls for a consolidated review of existing knowledge on the subject, along with the development of improved methods to predict how parasites will respond to these environmental shifts. In addition to directly affecting the parasites' dispersive phases in the environment, such as eggs and larvae, indirect effects of the changing climate may also affect the larvae, which mostly inhabit intermediate invertebrate hosts. Parasites, like all living things, have optimal temperature ranges for their essential processes, and these rates can be directly impacted by climate change. However, the immediate environment provided by the host offers some protection, partially shielding parasites from external environmental fluctuations. Yet, as environmental changes begin to alter the host's condition, competency, and availability, these shifts inevitably influence the parasites dependent on them.

Keywords: Parasitic diseases, Climate change, Ecosystem, Diseases, Vector-borne diseases.

Introduction

Climate is shaped by the connections between the different elements of the climate system, such as the atmosphere, oceans, sea ice, and landforms. Any alterations in these components, whether driven by internal dynamics or external influences, have the potential to induce climatic variations and changes (Washino and Wood, 1994). One of the main issues facing the world today is climate change, which has a significant impact on the environment and affect millions of human health worldwide (Cheng *et al,* 2023). In addition of being a worldwide risk, it poses a serious risk to public health and is among the biggest injustices nowadays (Field *et al,* 2014). Climate change directly affects health through a variety of factors, including long-term changes in temperature and precipitation patterns, as well as the extreme weather events such as heat waves, hurricanes, flash floods, deteriorating air quality, rising sea levels in low-lying coastal areas, besides complex effects on food production systems and water resources (Nesmith *et al,* 2021). Undoubtedly, human activities have greatly amplified alterations in atmospheric conditions, leading to an accelerated progression and the critical state posing significant threats to global health, and security, underscoring its urgent and far-reaching consequences (Stocker *et al,* 2013). Human actions, particularly fossil fuels consumption such as coal, oil, and gas, are the primary cause of climate change since the 19th Century, which releases greenhouse gases into the atmosphere, causing in a heat-trapping layer and higher worldwide temperatures. Industrial processes contributed greatly to these emissions, with the major sectors such as energy, construction, transportation, agriculture, and manufacturing playing dominant roles in releasing greenhouse gases (Wang *et al,* 2024).

WHO reported that climate change and global warming are two of humanity's most pressing issues in the twenty-first century, affecting practically globally. While the two terms are often interchangeable, they are not entirely synonymous (Ghazali *et al,* 2018). The term "global warming" implies the increase in average worldwide temperatures recorded in recent decades, in terms of frequency and intensity. It is a subset of climate change that encompasses broader environmental changes (Jimenez-Clavero, 2012). Greenhouse effect, produced by increased the CO_2 emissions from a growing reliance on fossil fuels, is the major cause of global warming, which is exacerbated by widespread deforestation. This warming trend has accelerated over time and is predicted to keep escalating in the next years, with projections estimating a temperature rise ranging from 1.6°C up to 6°C depending on model simulations (El-Sayed and Kamel, 2020). Climate change impacts parasitic diseases via complex mechanisms, reshaping interactions between parasites and their hosts, disrupting ecosystems, and amplifying health inequities. It is commonly acknowledged that people in low-income nations are disproportionately affected by climate change, led to a heightened diseases communities burden (WHO, 2012).

This review explores the relation between parasitosis and climate change, emphasizing its intensified effects on them, and vector-borne diseases, also emphasizing the crucial necessity for aggressive public health measures to stop these risky hazards.

Review, discussion and conclusion

Effect on Trematodes: Temperature plays a particularly clear and significant role in influencing the dynamics of diseases caused by flukes. It has a direct impact on critical phases of transmission throughout their life cycle. For example, the generation and release of their free-living infective stages, cercariae from first intermediate snail exhibit a strong positive correlation with rising temperatures, which influences infectivity to second intermediate hosts; invertebrates or fish or even man, depending on the parasite (Studer *et al*, 2010). Because cercariae or encysted metacercariae are critical phase and global warming led to significantly higher infection rates in hosts (Poulin and Mouritsen, 2006). Nonetheless, parasite-host relationships are determined not just by abiotic elements such as temperature, but also by intricate interactions among species with in ecosystem (Goedknegt *et al*, 2015).

Schistosomiasis: It is a severe intravascular illness transmitted by freshwater snails. It is caused by an infection with *Schistosoma* species inhabit human bloodstream (Gryseels *et al*, 2006). Schistosomiasis was defined as one of the most neglected tropical diseases (NTDs), with an estimated 732 million persons at risk of infection (WHO, 2014). The larvae reside within the snail, their intermediate host, for about one month before emerging into the water in search of a human host. The parasite's prevalence is closely linked to the intermediate snails' density that are regulated not merely by seasonal ranfalls and changes in water temperature and flow, but also by vegetation types' availability, and snail population (Patz *et al*, 2000).

Schistosomiasis prevalence is affected by environmental factors like water temperature and flow patterns. Warmer temperatures stimulate the growth and reproduction of intermediate host snails which release infective cercariae into the water. This raises the potential of illness for anyone who is exposed to these water sources. Southeastern Africa faces a heightened risk of rising schistosomiasis infection rates, with warming temperatures likely to render new regions endemic to the disease (McCreesh *et al*, 2015). In Senegal, *Biomphalaria pfeifferi* contributes to the transmission of *S. mansoni* during the rainy season, whereas *Buliunus globosus* facilitates *S. haematobium* transmission during dry season (Ernould *et al*, 1999). A modeling study in China predicted comparable patterns, indicating that temperature increases could lead to 8.1% expansion in the country's at-risk areas, spreading northward into regions that are currently non-endemic (Zhou *et al*, 2008). Also, flooding events may shift snail populations, enabling the disease to spread to areas that were previously unaffected. Besides, changes in river flow can lead to the concentration of snail populations in certain regions, potentially increasing transmission rates in those localized areas (Cheng *et al*, 2023). McCreesh *et al.* (2015) created a model to analyze how temperature affects the life cycle stages of *S. mansoni* and intermediate host snail. Using low, moderate, and high climate warming estimates for Eastern Africa, their analysis showed that, assuming other factors remain constant, infection risk could rise by up to 20% in most parts of the region within the next 20 to 50 years. Also, Mangal *et al.* (2008) reported that an increase in surrounding temperature from 20 to 30°C could result in more than a tenfold rise in the mean burden of *S. mansoni* infections in endemic areas. Human-driven ecolgical changes, such as irrigation development systems, dams for agriculture, and energy production increased snails contributed to the sustained of schistosomiasis transmission in many sub-Saharan African countries (Fenwick *et al*, 2009).

Fascioliasis: *Fasciola hepatica* and *F. gigantica* are the main parasites affecting edible animals, and man causing illness and economic losses (Mas-Coma *et al,* 2019). *Fasciola hepatica* is estimated to infect up to 17 million individuals as well as livestock such as sheep and cattle and even rabbits. The climate change effect, particularly global warming, has significantly contributed to enhanced survival of free-living cercariae and their snail vectors, facilitating the parasite's spread into new regions. Besides, extended grazing seasons have increased livestock's exposure to the parasite. As a result, the prevalence of fascioliasis has risen noticeably in endemic areas over the past decade (Beesley *et al*, 2018). Increased prevalence of zoonotic fascioliasis in Sub-Saharan Africa is mostly caused by factors such as rural-to-urban migration, proximity to farm animals, global warming, and inadequate access to clean water and/or food (Welburn *et al,* 2015). In Egypt, zoonotic fascioliasis infection was well documented **(**Hussieun *et al,* 2022).

Snails as intermediate hosts: Climate change is not the sole factor influencing changes in water velocity and temperature; human activities also play a significant role in boosting snail populations. Actions such as redirecting water for irrigation systems and constructing dams can lead to slower water flow, elevated water temperatures, and, ultimately, an increase in snail populations (Morgan *et al,* 2001). This rise in snail numbers has important repercussions for disease transmission; the changing climate appears to be favoring lymnaeid snails, the intermediate hosts of *F. hepatica*, particularly in regions farther from the equator. Their population levels are influenced by factors such as air and water temperatures, along with soil evapotranspiration rates (Van Dijk *et al,* 2010). Global warming has facilitated the expansion of snail habitats into new regions, which has led to a growing incidence of certain diseases in Europe (Kolarova, 2007). Major outbreaks of urogenital schistosomiasis were reported in Italy, France, and Germany (Boissier *et al,* 2015). *Schistosoma* snails were identified in Eastern Europe (Majoros *et al,* 2008). Other trematodes such as *Paragonimus*, *Opisthorchis*, *Clonorchis* showed similar spreading patterns correlated to the extended range of host species into new geographical territories (El-Sayed and Kamel, 2020). *Opisthorchis* and *Clonorchis* were introduced to Egypt with immigrants' workers back from Saudi Arabia (Morsy and Al-Mathal, 2011).

Effect on echinococcosis/hydatidosis: Two species *Echinococcus multilocularis* and *E. granulosus* infect man causing serious public health hazards that may be fatal. Carnivorous as dog are definitive host and herbivores are intermediate hosts, with man an accidental host (Battelli, 2009). Human echinococcosis/hydatidosis is a globally prevalent infectious disease affected 2-3 million persons worldwide, with about 200,000 annual new cases (McManus, 2010). The infective eggs can survive in resistant and latent forms supported by warm climates until a suitable host is available (Polley and Thompson, 2009). Climate change has an impact on echinococcosis spreading as both temperature and humidity on the eggs ability to survival in the environment (Burlet *et al,* 2011). In Egypt, human hepatic hydatidosis followed by pulmonary hydatidosis and other sites were reported (Ibrahim and Morsy, 2020), and as a silent health problem among children (Haridy *et al*, 2008).

Soil-transmitted helminthes (STH): Among the main species of soil-transmitted nematodes are *Ascaris lumbricoides*, *Trichuris trichiura*, *Necator americanus*, *Ancylostoma duodenale*, and *Strongyloides stercoralis* with an estimated 1.5 billion infected people or 24% of the world's population causing nutritionally and physically impaired with sever iron deficiency anemia (WHO, 2023).

To eliminate STHs as a public health concern, the WHO 2030 NTD Strategy sets the goal of eradicating the morbidity brought on by STHs. Reducing frequency of moderate-to-heavy-intensity infections to <2% was the benchmark for this (WHO, 2020). However, more than 1.5 billion individuals, equating to about 24% of the global population, are affected by STHs. The infections were widespread in tropical and subtropical climates, with the largest frequency in Sub-Saharan Africa, the Americas, China, and East Asia (WHO, 2022). Increasing temperatures might speed up the development of STHs larvae and maturation of eggs process within them thereby reducing the infectious. Also, a rise in humidity promotes higher larval survival in soil, particularly benefiting hookworm larvae, which are more vulnerable to desiccation compared to other STHs (Short *et al*, 2017). This was especially true with *A. lumbricoides* (Schüle *et al*, 2014), and in hookworms (Weaver *et al*, 2010). Okulewicz, (2017) reported that in nematodes, such as geohelminths and biohelminths, climate change allows them to more prevalence and incidence to new unaffected hosts, and change their life cycles. Meanwhile, climate changes not only have geographic distribution of STHs, but also have a marked impact on snails' intermediate hosts as well as insect-borne infectious diseases (Elwakil *et al*, 2021). In Egypt, all these STHs, with the exception of *N. americanus* were encountered in nearly all Egyptian Governorates (Curtale *et al*, 1998; El Shazly *et al*, 2008; Al Hoot, *et al*, 2024).

Tissue Nematodes: 1- Filariasis caused by *Wuchereria bancrofti* is transmitted by bites of *Culex*, *Anopheles*, and *Aedes* mosquitoes. Variations in soil moisture levels and/or stagnant water contaminated with animal waste create ideal mosquitoes breeding sites and filariasis (Rajagopalan *et al*, 1990). 2- Loiasis caused by *Loa loa* is transmitted by *Chrysops* species bites is prevalent in Central and West Africa where breeding grounds are typically found in forest swamps, and affected by climatic changes in spreading (Boussinesq, 2006). 3- Onchocerciasis is caused by *Onchocerca volvulus* and transmitted by *Simuliium* species, which vector activity increases and peaks during periods the rainy season (Cheke *et al*, 2013).

Climate changes and vector-transmitted diseases: The spread of infectious viruses, bacteria, and parasites from one host to another is significantly aided by mosquitoes, flies, lice, fleas, and ticks vectors, as well as rodents, bats and other wild and domestic animals serve as natural reservoirs to susceptible hosts (Cheng *et al*, 2020). Generally, arthropod vectors are significantly affected by climatic conditions and ecological factors because of their heightened sensitivity to temp erature variations (Tahir *et al*, 2019). Malaria, dengue fever, Chagas disease, leishmaniasis, trypanosomiasis, and yellow fever are among the vector-borne diseases transmitted by infectious vectors bites significantly increased the frequency of infectious illnesses globally (Ewing *et al*, 2021). Rising temperatures significantly increased vector activity and lifespan (Brady *et al*, 2013). Moreover, the geographic distribution and quantity of vectors are influenced by climate change, which also shapes the habitats suitable for them (Wilson *et al*, 2017). The vectorial capacity, or the disease's maximal daily reproducing rate, can be used to summarize entomological parameters impacted by temperature and rainfall (Dye, 1986). Most of serious tropical vector-borne diseases have vectorial capacities that are typically strongest at rather high temperatures (Lafferty and Mordecai, 2016). The ideal temperature range for disease transmission and progression differs based on the specific vector-pathogen pairing. Climate change's impact on habitats, which triggers shifts in ecosystems, coupled with increasing human pressures on the natural environment, is causing substantial harm to biodiversity. As a result, this amplifies the emergence and spread of infectious illnesses (Keesing *et al,* 2010).

Climate change indirectly affects human health by intensifying these impacts and threatening food safety, especially livestock, and grain production. Vector-borne diseases (VBDs) play a significant role in this dynamic, posing serious threats to the health of domestic animals and livestock via diseases like trypanosomiasis, Rift Valley Fever, and blue tongue (Baylis and Morse, 2012). Increasing temperatures create favorable conditions for agricultural pests, diseases, and vectors (McDermott *et al,* 2021). So, climate changes already contributed to enhanced transmission of infectious illnesses, such as Lyme disease, waterborne illnesses, and mosquito-borne disease as malaria and dengue fever (Diner *et al,* 2021). Fleas, and ticks tend to be more prevalent during hot season, with marked emergence and pathogens spreading (Gao *et al,* 2021).

Leishmaniasis: Leishmaniasis is caused by 20 *Leishmnia* species, transmitted by *Lutzomyia,* one of two genera of sub-family Phlebotominae to transmit *Leishmania* species in New World, with the other is *Phlebotomus* vector only in the Old World (Reithinger *et al,* 2006). Significant levels of morbidity and death resulted from the dissemination of leishmaniasis parasite to previously free areas due to increase in traveling and migration (Franco-Paredes *et al,* 2009).

Besides, rising temperatures increase vector capacity by improving biting rates (Bounoua *et al,* 2013). In risk areas, there was higher chance of leishmaniasis spread, and all year-round (Salomón *et al,* 2012). Moreover, regions with higher rainfall typically have more breeding grounds for vectors and other intermediate hosts, whereas regions with lower rainfall may have less appropriate breeding habitats (González *et al,* 2014). In Egypt, zoonotic cutaneous leishmaniasis is encountered in long ago (Morsy, 1983) and also, infantile visceral leishmaniasis and its vector *P. langeroni* were introduced into Alexandria from Libya (Kassem *et al,* 2017). Cutaneous leishmaniasis and to less extend visceral type spread nearly to other governorates with climatic and ecological changes (Morsy and Dahesh, 2023).

Malaria: is caused by five specific species of *Plasmodium* parasite: *Plasmodium falciparum, P. vivax, P. malariae, P. ovale,* & *P. knowlesi* (WHO, 2010). Malaria has been traced as far back as 4000 B.C.E. in Egypt, with genetic evidence of the disease was detected in King TUT and other ancient mummies WHO added Egypt is the third country to be awarded a malaria-free certification in the WHO Eastern Mediterranean Region following the UAE and Morocco, and the first since 2010. Globally, a total of 44 countries and 1 territory have reached this milestone (WHO, 2024). In Egypt, *Anopheles* species encountered in alphabetical order were *An. algeriensis, An. coustani, An. dthali, An. multicolor, An. pharoensis, An. rupicolus, An. sergentii, An. superpictus,* and *An. tenebrosus* (Morsy *et al,* 1995). Also, imported malaria mai- nly malignant one was reported among Egyptian Pilgrims (Zaher *et al,* 2007), Peace Keeping Mission Forces in Africa (El-Bahnasawy *et al.* (2010), and passive males who attended to Malaria Units on returning from Sudan (Dahesh and Mostafa (2015). El-Bahnasawy *et al.* (2011) in Toshka Project reported that climatic and ecological changes paved the way to three *Anopheles* species from Sudan where chloroquine resistant *P. falciparum* is endemic. Al-Agroudi *et al.* (2018) in Almaza Fever Hospital retrospective malaria situation study in the last 3 years of 100 patients found *P. falciparum* (83), *P. vivax*

(10), *P. ovale* (one), and mixed pplasmodia (six). Mahmoud *et al.* (2019) found that although in Aswan district no *Plasmodium* parasites were detected either in *Anopheles* or human blood films, yet, risk of subsequent malaria outbreaks existed due to presence local *Anopheles* species and imported cases. In sub-Saharan Africa, pregnancy reduces a woman's immunity to malaria, making her more susceptible to infection and at greater risk of illness, severe anemia and death. Maternal malaria also interferes with the growth of the fetus, increasing the risk of premature delivery and low birth weight a leading cause of child mortality (WHO, 2019). Temperature has an impact on malaria transmission, which follows a complex pattern and varies depending on the specific vector involved (Alonso *et al,* 2011). *Anopheles* relies on sufficient rainfall for stable breeding habitats that remain intact for 9-12 days without drying out or being washed away. For the malaria parasite to replicate within the mosquito, a minimum air temperature of 15-16°C is required for *P. vivax* but, *P. falciparum* needs 19-20°C (Fouque and Reeder, 2019). Precipitation contributes to form suitable breeding habitats for vectors, and the association between precipitation, temperature, and malaria transmission highly depend on the specific vector implicated making the general public more susceptible to outbreaks in most African countries (Kelly-Hope *et al,* 2009).

Cryptosporidium and *Giardia* are globally common zoonotic culprits behind gastrointestinal infections as waterborne pathogens resisting disinfectants (Savioli *et al,* 2006). Both were up to 2.87 & 2.61 times higher, respectively, during and after heavy rainfall (Young *et al,* 2015). *C. hominis* and/or *C. parvum* are zoonotic ones (Cacciò, 2005). But, nonhuman *C. canis, C. felis, C. meleagridis,* and *C. suis* infect immunocompromised and/or immunosuppressed persons (Xiao and Feng, 2008).

Amoebiasis: *Entamoeba histolytica* may be asymptomatic, but always presents with symptoms such as prolonged cramping, abdominal pain, watery or bloody diarrhea, and weight loss (Haque *et al,* 2003). Also, extraintestinal illnesses such as purulent pericarditis, pneumonia, cerebral amoebiasis and liver abscess occur (Petri and Haque, 2013). Thus, measures must be taken to avoid climate change-related factors (Lin *et al,* 2022).

Naegleria fowleri infections are often linked to polluted waters, with significant human cases, which were affected by the climate changes (Nichols *et al,* 2018**).**

Climate impacts on water-borne parasites: Waterborne infectious diseases are a leading cause of illness and death globally, claiming the lives of approximately 801,000 children each year due to diarrheal conditions. Globally, illnesses linked to food and water present serious global health issues. These outbreaks' frequency is directly related to climatic shifts and environmental disruptions (Kotloff, 2017). They tend to be more common during the summer months, with their prevalence rising alongside increases in temperature and humidity (Greer *et al,* 2008). Also, anticipated climate changes include a highest incidence of floods and heavy rainfall, driven by ocean warming and the amplified frequency and intensity of phenomena like El Niño and hurricanes corresponding rise in waterborne (Haines and Patz, 2004). The distribution and persistence of these infectious agents in nature are significantly impacted by the rising frequency of extreme weather events, such as extended rains, severe flooding, severe droughts, and increased precipitation (Thomas *et al,* 2006).

Conclusions

Climate changes influence on parasitic diseases spreading, with direct and indirect human risks. Collaborative efforts are essential to develop comprehensive risk assessments and effective strategies for mitigation and adaptation. Proactive measures will not only manage current risks but also help prevent future outbreaks.

Undoubtedly, a routine regular surveys for insect-borne diseases and snail of medical and/or veterinary importance is a must at least at the Egyptian borders

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