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Impact of climate variability on occurrence and distribution of vector and vector-borne parasitic diseases

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Abstract

Climate change is a reality which may explain the increase in density of arthropod vectors, but also of their hosts, changes in periods of activity and variations in geographical distribution. Climate change and ecological disturbances have exerted a marked influence on the emergence and proliferation of parasitic diseases. Each environmental change, whether occurring as a natural phenomenon or through human intervention, changes the ecological balance and context within which disease hosts or vectors and parasites breed, develop and transmit disease. Vector-borne diseases are among the major microbial causes of morbidity and mortality in the world today affecting nearly half of the world's population. Much of the impact of climate on vector-borne diseases can be explained by the fact that the arthropod vectors of these diseases are vector- borne which are unable to regulate their own internal temperature and therefore highly dependent on climate for survival and development. Temperature, precipitation, humidity and other climatic factors are known to affect the reproduction, development, behaviour and population dynamics of the arthropod vectors of these diseases. Adapting to the effects of global climate change will require the development of adequate response plans, enhancement of surveillance systems and development of effective appropriate strategies to reduce the climate- related vector and vector–borne parasitic diseases. This paper aims to discuss the impact of climate variability on occurrence and distribution of vector and vector-borne parasitic diseases.

Keywords: Climate change, vector, vector borne diseases, adaptation strategies

Introduction

The fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC) observes that the global temperatures have risen due to increasing concentrations of heat-trapping greenhouse gases in the atmosphere, resulting in the reduction in the amount of snow and ice and a rise in sea level [1]. The increased amount of greenhouse gases in the atmosphere, which is intimately linked to human development, is among the man-made causes of climate change [2]. Carbon dioxide, methane, nitrous oxide and fluorinated gases are considered to be the major greenhouse gases that are continuously increasing in concentration since 1978 [3]. The livestock sector is thought to play an important role in greenhouse gases emissions as it accounts for about 7–18% of the emissions globally [4]. IPCC [5] reports predict that by around 2100 it is estimated that global temperatures will have risen by between 1.0 and 3.5 °C, increasing the likelihood of many vector-borne diseases in new areas and in the course of the present century, sea levels will rise by between 18 and 59 centimetres. Climate change due to natural factors includes continental drift, volcanoes, changes in the sun's intensity, slow changes in the earth's orbit around the sun and human activities through the burning of fossil fuels, the land surface changes like deforestation, urbanization and desertification are also contributing to climate change. Changes in the climate provide a favourable environment for parasite reproduction. There are chances of emergence and re-emergence of new strains and inter species infection in the animal and human population. Vector-borne diseases (VBDs) are among the most well studied of the diseases associated with climate change, owing to their large disease burden, widespread occurrence and high sensitivity to climatic factors. The simplest connections are through temperature, affecting the biting, survival and reproductive rates of the vectors and the survival and development rates of the pathogens that they carry.

Vector-borne Disease Dynamics
The vector-borne pathogens, which include viruses, rickettsia, bacteria, protozoa and worm parasites, spend part of their life cycle in a cold-blooded arthropod vector and thus are influenced by environmental changes. VBDs results from infections transmitted to animals and humans by blood-feeding arthropods, such as mosquitoes, ticks and fleas. VBDs are the major causes of morbidity and mortality in the world today affecting nearly half of the world's population. VBDs are especially susceptible to changing environment conditions due to the impact of temperature, humidity and demographics of vectors. The occurrence of vector-borne diseases extends from the tropics and subtropics to the temperate climate zones. With a few exceptions, VBD do not occur in the colder climatic regions of the world. The transmission patterns of these diseases may, therefore, be affected by ambient temperature [6]. There are three crucial elements which must co-exist for the occurrence of VBD:
a) The susceptible population
b) The vector (most often arthropods)
c) The disease pathogen (e.g., bacteria, virus, parasite)

In areas where VBD most frequently occurs, conditions must be suitable for vectors, host, pathogen survival and reproduction/replication. Global climate change is likely to affect all three of these components both directly and indirectly. Some vector- borne diseases which cause huge morbidity and mortality including malaria, dengue, Schistosomiasis, leishmaniosis, Chagas disease and African trypanosomosis. In addition to deaths, many vector-borne diseases, such as lymphatic filariosis and onchocercosis cause significant debilitation and suffering, contributing to a much larger overall burden of disease [7]. The effect of climate change on these disease transmissions will depend on biological processes and socio-economic factors which influence communities' vulnerability to diseases.

Direct Effects of Climate Change on Vector and Vector-Borne Diseases
Effects of Temperature: Climate change has the potential to increase range or abundance of animal reservoirs and/or arthropod vectors (e.g., Malaria, Schistosomiasis). Survival of the vector can decrease or increases depending on species, some vectors have higher survival at higher latitudes and altitudes with higher temperatures. It affects biology and physiology of vector thus changes in the susceptibility of vectors to some pathogens, also altered the rate of vector population growth and feeding rate. At temperatures above 30◦C, cattle, sheep, goats, pigs and chickens would reduce their feed intake by 3–5% for each unit increase in temperature [8]. Changes in temperature also trigger the secretion of stress hormones (including cortisol) which suppress immunological responses including the functioning of the white blood cells. A rise in temperature increases replication rates of pathogens in the vector, therefore shortening their extrinsic incubation period. This suggests that within the limits when the vector survival is ideal, higher temperatures should result in shorter development interval of the pathogen in the vector, and hence greater chances of the vector living longer to transmit the infection [9].

Effect of changes in precipitation: Rainfall intensity is considered a key determinant of the transport of parasites. Rain provides the breeding sites for arthropods and prolongs the life of vectors but excess rain or snowpack can eliminate habitat by flooding, decreasing vector population and low rainfall can create habitat by causing rivers to dry into pools (dry season malaria). The distribution of intermediate host and their parasite species are also sensitive to the amount of rainfall and length of the dry season.

Indirect Effects of Climate Change on Vector and Vector Borne Diseases
Indirect effects include changes in vegetation and agricultural practices which would mainly be caused by temperature changes and trends in rainfall patterns. These changes either promote or inhibit disease transmission by their association with increased or decreased vector density. Irrigated land (such as paddy fields) provides a suitable breeding ground for a number of vectors like snail and mosquitoes thus favouring Schistosomiasis and filariosis. The changing scenarios of major vector-borne diseases (e.g., malaria, leishmaniosis and Chagas disease) have been linked to several factors, including urbanization and deforestation, changing demographics in both developing and developed countries, economic crisis, increased global movement of people and animals and climate change [10]. Hydrological changes leads to formation of more brackish water lagoon thus extending the breeding species in that area, also affect the *tse-tse* fly and tick distribution and spread the tick borne diseases in wider areas. Desertification, drought and natural calamities produce the scarcity of drinking water and increase the chances of guinea worm transmission and also the distribution of rodent reservoir. IPCC [5] estimated that 20–30% of the world's vertebrate species are likely to be at increasing risk of extinction from climate change impacts within this century if the change in global mean temperature exceeds 1.5–2.5°C due to the fact that temperature changes affect species ecological niches and landscape productivity.

Influence of Global Climate Change on Tick & Tick-borne Parasitic Diseases
By altering the global environment, climate change has a significant potential to intensify certain diseases, particularly those transmitted by vectors. Indeed, global climate change will affect disease vector behaviour, which may alter the current patterns of vector-borne diseases [11]. The development rates of ticks (through pre-oviposition, pre-eclosion, larval and nymphal stages) are governed by temperature while the survival of the free living stages as well as hatching and moulting depend on humidity. Ticks generally have a longer maturation rates in cold environments. East Africa and South Africa are considered as the most vulnerable regions to climate-induced changes in tick distribution and incidence of tick-borne diseases (TBDs) [12].
Climate change may influence tick distribution and density, as well as the risk of tick-borne pathogen transmission to animals. Recently, long-term studies have demonstrated changes in the distribution of the castor bean tick *Ixodes ricinus* which transmits tick-borne encephalitis and Lyme disease (borreliosis) in different parts of its range. For instance, data from a 30-year study conducted in Sweden indicated a clear expansion of the distribution range of this tick towards northern latitudes [13]. A retrospective study suggests that hotter summers will change the dynamics and pattern of seasonal activity, resulting in the bulk of the tick population becoming active in the later part of the year. The effect of climate change (particularly of increased temperatures) in tropical zones may be deleterious to some

species, adversely affecting habitat suitability and forcing certain tick species to colonize new areas. In South Africa, for example, it has been predicted that increasing the temperature by 2 °C will decrease habitat suitability for four tick species (*i.e*. the African blue tick *Rhipicephalus decoloratus*, the South African bont tick *Amblyomma hebraeum*, the brown ear tick *Rhipicephalus appendiculatus* and the small smooth bont-legged tick *Hyalomma truncatum*) as reported by Estrada Peña [14].

Recent studies strongly suggest that *Dermacentor reticulatus* has expanded its range within the last three decades particularly in the eastern and southwestern parts of Germany. Further evidence for the changing distribution of *D. reticulatus* is provided by the occurrence of canine babesiosis in new areas of Germany, Hungary, Switzerland and the Netherlands [15]. *D. reticulatus* is a vector of canine babesiosis, tularemia, Q-fever, zoonotic rickettsiosis and has vector competence for *Anaplasma marginale*. *Rhipicephalus sanguineus* is the primary vector of Mediterranean-spotted fever (a rickettsial zoonosis caused by *Rickettsia conorii*) also *Ehrlichia canis* and *Babesia canis vogeli*. However, *R. sanguineus* is an endophilous tick so may potentially cause temporary infestations in heated accommodation anywhere in the world [16]. Another study suggested that the progressive increase in temperatures seems to be forcing the dispersion of tropical bont tick *Amblyomma variegatum* towards areas outside of zones that have a prolonged dry period in Zimbabwe [17]. The issues of global changes, climate change and tick-borne diseases are becoming the order of the day [18].

Influence of Climate Change on Mosquito & Mosquito-borne Parasitic Diseases

The ecology, development, behaviour, survival of mosquitoes and the transmission dynamics of the diseases they transmit are strongly influenced by climatic factors. High temperatures generally increase the metabolic rates of arthropod vectors leading to an increase in: (i) the rate at which they feed, (ii) the frequency with which they deposit their eggs or larvae, and (iii) maturation rates of immature stages [19]. In East Africa, the warm phase of ENSO is associated with outbreaks of many mosquito-borne diseases. Mosquito-borne disease transmission is climate sensitive for several reasons; mosquitoes require standing water to breed, and a warm ambient temperature is critical to adult feeding behaviour and mortality, the rate of larval development, and speed of pathogen replication. High temperatures should increase the likelihood of transmission because they reduce the extrinsic incubation period. However, activities such as biting and egg lying are also likely to be accelerated. These are high-risk activities, so survival rate, and thus transmission rate, may also be affected. If the climate is too cold, pathogen development is slow and mosquitoes are unlikely to survive long enough to become infectious. Between certain limits, longevity of a mosquito decreases with rising temperature and increases with increasing relative humidity. Mosquitoes prefer humidity above 60%, and optimum temperature for mosquito survival is in the range of 20-25 °C. An excessive temperature increases the mortality, and there is a threshold temperature above which death ensues. Rainfall plays a crucial role in malaria epidemiology because it provides the medium for the aquatic stages of the mosquito life cycle. The length of rain may prove beneficial to mosquito breeding if moderate, but if excessive it may flush out the mosquito larvae. Rainfall also increase the relative humidity and hence the longevity of the adult mosquito. Although a suitable climate is necessary for disease transmission, other factors are needed for an epidemic to take place, including a source of infection, vector populations, and a susceptible human population [20].

Malaria and its climatic influences

Malaria is caused by genus *Plasmodium* and transmitted by mosquito of the genus *Anopheles* in human beings**.** Approximately, 40% of the world's population lives in areas at risk for malaria. Every year about 500 million people become severely ill from malaria. IPCC predicts that the global population at risk for malaria will increase by 220-400 million in the next century. According to a report of National Vector Borne Disease Control Programme, the prevalence of malaria was highest in Orissa followed by Jharkhand and Chhattisgarh (Fig. 1).

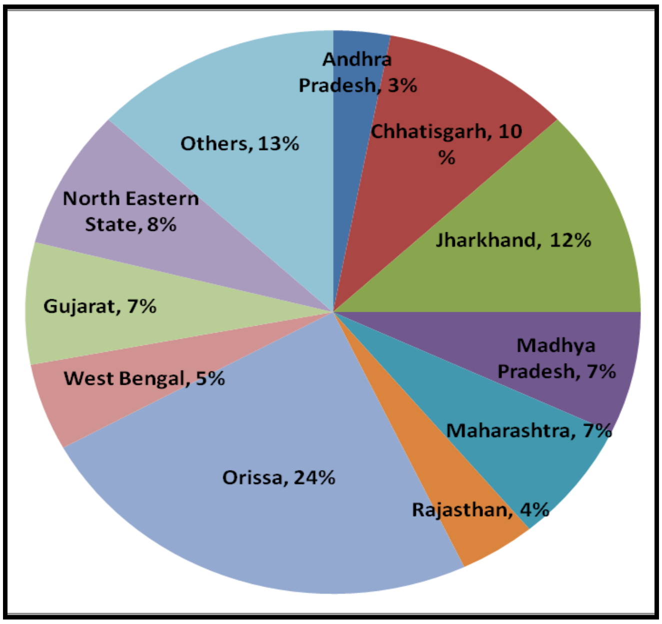

Fig. 1: State wise distribution of Malaria in India [21]

Malaria is an extremely climate sensitive disease. High temperature should increase the likelihood of transmission because they reduce the extrinsic incubation period of parasite inside mosquitoes and thus mosquitoes become infectious sooner. Transmission cannot occur below 16 °C or above 33 °C as sporogony cannot take place. Vectorial capacity of mosquitoes increases as temperature increases, mosquito lifespan and female blood meal frequency increases at higher temperatures. Aquatic life cycle of mosquitoes reduced from 20 to 7 days. *Plasmodium* species grow faster at higher temperatures. Thus, climate change provides the best conditions of 20–30 °C with 60% relative humidity for development of the malaria parasite [22]. Rainfall can promote transmission by creating ground pools and other breeding sites, but heavy rains can have a flushing effect, cleansing such sites of their mosquitoes. Humidity also reduced survival rate when hot weather is accompanied by low humidity, but in areas where such conditions are normal, local species have adapted to cope with them.

Leishmaniosis and its climatic influences

Visceral Leishmaniosis (VL) is a vector- borne anthroponotic disease, caused by protozoan *Leishmania donovani* and is transmitted by an insect vector sand fly (*Phlebotomus argentipes*) that lives in warmer places where humidity and temperature both are present at regular intervals in a day. It is endemic in warmer part of the world covering almost 88 countries around the globe; more than 90 per cent cases are reported from India, Bangladesh, southern Sudan, Nepal and northeast Brazil [23]. Sand fly can survive cold temperatures in diapauses (overwintering), which are initiated by a combination of low temperature, reduced daylight and can last 4 to 8 months depending on location. The worldwide distribution of sand flies is considered to be confined to areas that have at least one month with a mean temperature of 20 °C. Sand flies are sensitive to sudden temperature changes and usually prefer those regions where maximum and minimum temperatures are slightly differ. Poroton stone buildings provide favourable condition for sand fly growth because they store humidity during night and evaporate during day [24]. The rise in temperature in day time and humidity level during night time have greatly influenced the growth of flies and the distribution of leishmaniosis but in the cold climatic countries the prevalence is limited because the growth of fly is limited and they are not able to suck the blood in night. High level of precipitation has also played very important role in the spread of disease, flooding may spread the vector of disease and the larvae of fly to distant and non infected areas. In some parts of Latin America, deforestation has led to an increase in leishmaniosis, the former forest has been replaced by areas of farmland, interspersed with patches of forest. With growth of the fox population, an excellent reservoir host of visceral leishmaniosis, Kala-azar has increased and the sylvatic leishmaniosis vector sand flies have become peridomestic. Recent studies have highlighted the spreading of the leishmaniosis, as they accompany the movement of the phlebotomine vectors into previously free areas as suggested for the spread of canine leishmaniosis from southern to northern Italy and from northern to southern Brazil [25]. Global warming could prompt the establishment of canine leishmaniosis in areas such as the United Kingdom, where the vectors are currently absent, but where *Leishmania infantum* infected dogs that had travelled to endemic areas are present [26].

Dirofilariosis and its climatic influences

Dirofilariosis are vector-borne parasitic infections mainly of dogs and cats and they are caused by *D. immitis* and *D. repens*. It is considered to be a great hazard in tropical, subtropical and in some temperate countries. The transmission of *Dirofilaria* occurs by mosquito of the genera *Anopheles*, *Aedes* and *Culex*. Both *Dirofilaria* species are zoonotic and the human infections caused by *D. repens* are increasing in Europe [27]. *A. albopictus* considered mainly a problem of serious biting nuisance for humans (which is active and able to bite also during the day) at the beginning of its introduction in Italy. Transmission of *Dirofilaria* infections are dependent upon the presence of sufficient numbers of infected, microfilaraemic dogs, susceptible mosquitoes and a suitable climate to permit extrinsic incubation of *Dirofilaria* in the mosquito intermediate host [28].

Dirofilariosis is a mosquito borne parasitic diseases therefore climate suitable for breeding of mosquito is the time of occurrence of this type of parasitic diseases. The mosquitoes are abundant in the warmer climate therefore new cases become available during this period. Temperature, precipitation and relative humidity are the three main factors that determine the abundance of mosquitoes and the prevalence of mosquito-borne *Dirofilaria* infection. The global warming projected by the IPCC suggested that warm summer is suitable for *Dirofilaria* transmission and that will be the rule in the further decades and if the actual trend of temperature increase continues, filarial infection should spread into previous infection free area.

African Trypanosomosis and its climatic influences

Trypanosomosis, spread by tsetse flies, imposes a huge burden on African people and livestock. Many aspects of the vectors' life cycles are sensitive to climate. A study conducted by McDermott *et al* [29] demonstrated that the risk of animal trypanosomosis transmitted by tsetse flies in most places in eastern Africa will generally contract with climate change and increase in human population. Tsetse oviposits larvae into the soils but high temperatures increase larvae mortality rates. Significant shift in tsetse distribution is therefore expected across Africa, with a reduction in the overall tsetse population by about 7% [30].

The length of the *Glossina* pupal development period decreases with increasing temperature, whereas larval production decreases above a certain threshold and both pupal and adult mortality increase with temperature. When there is deforestation, these effects are exacerbated if the forest is replaced by tall crops such as cocoa, coffee, oil palms and mangoes, which provide comfortable habitats for tsetse colonization. Human populations, who work on the land and tend the herds, are vulnerable to infection. As the tsetse fly requires the protection of vegetation or forests, in the African Sahel zone they inhabit the river banks, moving into drier areas during the rainy seasons and returning to the forests during dry seasons.

Adaptation Strategies

Mitigation and adaptation measures for climate change need to be aligned with livestock development objectives for them to be implemented sustainably. Three ways of reducing Green House gases (GHG) emissions from livestock have been proposed by Gerber *et al* [4] and these includes: i) Increase forage digestibility to reduce GHG production from fermentation in the gut as well as from stored manure ii) Better management of manure to ensure that time for storage, aeration and stacking is reduced and solids and liquids are separated efficiently iii) Improve animal husbandry through improving animal genetics, proper nutrition and herd health management. This is considered to be the most effective of the three options. Strategies to be adopted for reducing the climate sensitive vector and vector–borne parasitic diseases include [31].

i) Capacity building: Need to develop capacity among livestock owners and market actors on disease recognition and allow early detection, prompt response and management of cases whenever they occur.
ii) Breeding for disease resistance: Innate resistance to parasitic diseases such as trypanosmosis and helminthosis etc. has allowed farmers to raise animals in harsh environmental conditions, reduce our dependence on antimicrobial products, therefore improving the sustainability of livestock production systems.
iii) Surveillance and Monitoring: Enhance vector surveillance and control programs and monitor disease occurrence
iv) Environmental controls: Mosquito control programs (e.g., with insecticides or predator fish species), Community elimination of aquatic breeding sites, Window screens, air conditioning and other personal protective measures
v) Research and development: New technologies are being developed to be used for detection, response and management of infectious diseases include:

- Develop vaccines for vector and other vector-borne diseases
- Pharmaceutical and pesticide development
- Develop more rapid diagnostic tests
- Using satellite data and geographical information systems to feed into surveillance systems.

vi) Coordination: Pests and disease impacts are not constrained within national boundaries, and response strategies should take this into consideration and develop approaches to coordinate at the regional and continental scales in response to these challenges. All countries should make polices for serious attempts to mitigate global warming.

Conclusion
Climate change will increase the impact of vector-borne diseases on human and animal health around the world. It also affects the distribution and incidence of VBDs globally and current evidence suggests impacts on some already occurring diseases. Impacts may include unanticipated emergence of new pathogen. To prepare for these risks, we need to predict the potential impacts of climate change, vector and the pathogens they transmit using remote-sensing and geographic information system (GIS) methodologies. It is clear that improved integrated vector control is needed as a key part of the public and animal health toolbox. The regions which are presently free from disease need priority as they do not have any knowledge of disease occurrence, preventive methods and personal protection etc. Veterinarians combined with good coordination of public health services will play an important role in responding and mitigating the effects of climate change.

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