Chapter 5

Global Climate Change and its Impact on Mosquito Borne Diseases: A Complex Scenario

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Abstract

Climate change is one of the most critical global challenge affecting all aspects of our life and is believed to be the result of increase in the emission of green house gases causing global warming. Recent events such as excessive rain fall, droughts, heat wave, cyclones and hurricanes emphatically demonstrated our vulnerability to climate change. The increase in temperature, melting glaciers, rising sea level, retreating ice caps, and abrupt weather pattern are the consequences of the changing climate, the impact of which may range from affecting agriculture, accelerated erosion of coastal zones, species extinction and the spread of infectious and vector borne diseases due to natural disasters to food scarcity and malnutrition. The impact may differ from one place to another and from developed countries to resource poor developing countries. As mosquitoes are highly sensitive to temperature, humidity and rainfall any shift in temperature may have profound effect on disease transmission in highland areas and variation in rainfall and drought conditions may affect the transmission potential in the low land areas. Countries with sound health care delivery and having an early warning system may be able to reduce the impact to significant level. However, it is believed that dynamics of vector borne diseases is highly complex and factors other than the climate such as land use change, drug and insecticide resistance and people behavior also plays an important role, hence a comprehensive approach with increased awareness is needed to overcome the onslaught of the climate change.

Key words: Climate; Green house gases; Global warming; Mosquitoes; Malaria; Dengue

1. Introduction

From devastating floods in many parts of the world to cloudbursts and landslides in Leh and Uttaranchal in India and massive heat waves in Europe and Russia to extended rain fall and downpour in north India the altered climatic conditions have become a regular phenomenon in recent past blamed to be the consequences of abrupt weather pattern due to global warming affecting all aspects of the life including health and socioeconomic conditions of the society. Last few decades have witnessed more severe catastrophic climatic events like tsunami in Indian ocean to cyclones and hurricanes like Katrina, Wilma, Nargis, Laila, Aila and Irma in US and south-east Asia and from heavy rainfall in cities like Mumbai, Gujarat and arid areas of Rajasthan in India to severe drought and heat waves and forest fires in others displacing many people and causing untold miseries. The rise in malaria in some areas to increasing incidence of dengue in others the nation has constantly been reeling under the impact of climate sensitive mosquito borne diseases likely to have some weather connection. The climate pattern is changing fast and furiously affecting our lives particularly our health. Global climate change is considered to be one of the most serious threats to the global environment and has been at the centre of scientific and political debate in recent years.

2. The Climate and its Impact of Global Warming

It is highly believed that man-made activities are altering the world's climate as we are increasing the atmospheric concentration of energy trapping gases thereby amplifying the natural greenhouse effect that makes the earth inhabitable. Green House Gases mainly comprise of carbon dioxide (mostly from fossil fuels combustion and forest burning), methane (from irrigated agriculture, animal husbandry and oil extraction), nitrous oxide and various human made hydrocarbons [1]. The level of these gases has increased considerably in recent past which is making our planet more warm and altering the weather pattern. The emission of CO_2 the main culprit in this complex scenario has increased 12 fold from 534 million to 6.59 billion metric tons in the 20th century [2]. The resultant meltdown of arctic snow caps, rise in sea level, changes in cloud formation and rain fall pattern etc are consequences of global warming. The adverse effects are also observed on natural resources, food supply, human health and national economy.

In 1896, the Swedish Scientist SavanteArrhenius suggested that human activity could substantially warm the earth by adding CO_2 to the atmosphere [3]. His predictions were subsequently independently confirmed by Thomos Chamberlin. The establishment of United Nations Intergovernmental Panel on Climate Change (IPCC) in 1988 was a pivotal move by the world community to address this issue. The IPCC predicts a 1.4 to 5.8^{0}C rise in temperature by 2100 and sea level rise is also expected in the range of 15-89 cm. IPCC posits that most climatic change since 1950 is human induced and will have far reaching environmental and health effects [4] (**Figure 1 & Figure 2**).

3. Kyoto Protocol and Beyond

In an attempt to halt climate change, international efforts to reduce emission have already been put in place. Since 1990, international efforts have created the climate change regime, the centre piece of which is the UNFCCC and its instrument, the Kyoto protocol [l5]. The Kyoto protocol has now been ratified by 187 nations (not US) and went in to effect in 2005. The purpose of the meeting held in Copenhagen (COP15) in December, 2009 was to establish a framework for tackling climate change beyond 2012. However, in the end no binding solution was passed [6].

The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change, which commits its Parties by setting internationally binding emission reduction targets. The Kyoto Protocol was adopted in Kyoto, Japan, on 11 December 1997 and entered into force on 16 February 2005. Its first commitment period started in 2008 and ended in 2012. In Doha, Qatar, on 8 December 2012, the "Doha Amendment to the Kyoto Protocol" was adopted. During the first commitment period, 37 industrialized countries and the European Community committed to reduce Green House Gas (GHG) emissions to an average of five percent against 1990 levels. During the second commitment period, parties committed to reduce GHG emissions by at least 18 percent below 1990 levels in the eight-year period from 2013 to 2020. Under the Protocol, countries must meet their targets primarily through national measures. The Kyoto Protocol, like the Convention, is also designed to assist countries in adapting to the adverse effects of climate change. It facilitates the development and deployment of technologies that can help increase resilience to the impacts of climate change. The Kyoto Protocol is seen as an important first step towards a truly global emission reduction regime that will stabilize GHG emissions, and can provide the architecture for the future international agreement on climate change. (*http://www.unfccc.int/kyoto_protocol/items/2830.php*).

4. Impact of Climate on Human Health

Climate is a key determinant of human health and climate constraints the range of infectious diseases while weather affects the timing and intensity of outbreaks. The concept that weather and climate are linked to incidence of infectious diseases in humans has been recognized since the time of Hippocrates. According to IPCC (2007) warming of the earth climate is unequivocal. Global changes already documented includes increased global surface temperature, rising sea level, decreased arctic and alpine snow & ice and evidence of plant and animal responding to these changes by moving to higher elevations or closer to the poles. Precipitation has increased in some parts of the world while decreasing in others. Climate change is predicted to have a variety of impact on human health, many of which have been extensively reviewed [4].

Climate change will be the root cause of many public health nightmares. The World Health Organization (WHO) has documented more than 39 new and re-emerging diseases since 1960s that are linked to global warming. In addition there has been resurgence of old diseases like malaria and cholera in some areas. Though this change in some diseases may be due to deterioration of public health system but diseases that involve two or more species such as malaria reflect changing ecological and climatic conditions as well as social changes. Temperature increase over the past century have led to an estimated 5.5 million DALY (Disability Adjusted Life Years) and at least 1,50,000 lives annually [5,7]. According to the Centre for Disease Control & Prevention, there were 8015 heat related deaths in United States between 1979 & 1999. In addition, the heat wave that affected Europe during the summer of 2003 led to 22,000 to 45,000 excess deaths [8]. Mosquito populations are expanding across the globe and bringing nasty diseases like West Nile virus (WNV), malaria and yellow fever. Dengue and Chikungunya have also re-emerged as a significant public health problem. Hotter temperature also enhance smog formation and influence the disease conditions such as asthma and lung cancer. The impact of climate change on human health is likely to be two fold.

1. Direct Effects : Physiological effect of Heat and Cold

2. Indirect Effect : Spread of vector-borne pathogens in to areas where diseases does not exists currently or was eradicated and enhancement of transmission in others. However, in certain situations in countries having robust health infrastructure the impact may not be so prominent. Since the vector binomics is complex and local climatic and socio-econmic factors also play an important role, they will also need to be studied.

Climate change creates fertile conditions and alters the geographic range of disease vectors and carriers such as mosquitoes, ticks and rodents bringing them in to greater contact with human populations naïve to the diseases they carry. Malaria for example, is expected to move to higher altitude and dengue to move further north. A difference of 1^0C in the global mean average temperature increase could be the difference between a 10% and a 40% reduction in crop yields, between 16% and a 23% increase in malaria exposure in Africa or between 1 billion and 4 billion additional individual experiencing severe water shortage. Water quality and quantity are also likely to change in future as precipitation pattern change and warmer conditions adversely affect the potential levels of aquatic borne pathogens and water pollution [9,10] (**Table 1**).

Although the casual relationship between climate change and particular disaster is difficult to establish, the heat wave in Europe (2003), the flooding in Mumbai (2005), and Hurricane Katrina and Irma in the United States (2005, 2017) are indicative of events likely to occur more often in future [9].

5. Impact of Climate on Mosquitoes and Mosquito Borne Diseases

The existence of mosquitoes on this planet is known from time immemorial and they are found throughout the globe except in places that are permanently frozen. There are around 3500 species of mosquitoes of which nearly three quarters are native to humid tropics and subtropics and they transmit many dreaded diseases (**Figure 3**). The burden of major mosquito borne diseases in India is shown in **Table 2**. The temperature, humidity and rainfall are major detrimental factor for survival, proliferation and propagation of each and every species of mosquitoes. Hence climate and weather variability will have profound effect on mosquito immature as well as adult survival [11]. Vector mosquitoes are highly sensitive to weather conditions and their vectorial capacity is governed by the existing climatic conditions. Changing trend in average temperature and precipitation are anticipated to have an astounding impact on vector borne diseases and their distribution. It is expected that there is real risk of re-introduction of malaria in to non-malarial areas including parts of Australia, US and South Europe (IPCC estimates that potential malaria transmission area may increase to 60% as compared to 45% at present; *http://www.gcrio.org/ipcc/qa/10.html*).

Temperature and humidity are most important factors affecting mosquito development and longevity and consequently disease transmission. Extrinsic incubation period (EIP) of the parasite shorten dramatically at higher temperature, so mosquitoes becomes infectious sooner. It is also noticed that if water temperature rise, larvae take shorter time to mature, capacity to produce more off springs during transmission period. In warmer climate, adult female digest blood faster and feed more frequently thus increasing transmission intensity. With the increase in temperature epidemic potential is also increased. Climate change represents 1-3% increase in total population at risk (**Figure 4**).

6. Area Specific Impacts

Impact of global warming may be different in different areas for example in low land areas rain fall quantity and continuity will have important role in water logging, creation of more breeding places for mosquitoes or flushing of mosquitoes in severe rainy days. In riverine areas rivers may be subjected to flooding due to glacier melting or excessive rain fall and flush away the mosquito immature while in drought conditions subjected to formation of pools, provide breeding of mosquito vectors. As well as migration of population with their cattle to newer areas may enhance the man vector contact. Whereas, in highland areas temperature will play a crucial role as a slight increase in temperature may increase the survival of mosquitoes and extend the transmission period of the diseases they cause by creating more conducive environmental conditions.

6.1. Malaria

Malaria continues to remain the oldest scourge to humankind and a serious public health problem affecting around 40% of the world population in 100 endemic countries. According to the World Malaria Report 2017 around 216 million people around the world get crippled by this disease and more than 0.44 million lose their life with maximum damage occuring in Africa [12]. Malaria is highly sensitive to climate and excessive rain fall or drought may severely affect its transmission. Models of climate change indicate that increase in temperature will expand the geographic range of malaria to higher altitude and latitude and expand its area of prevalence from 40 to 60%. If global temperature increase by 2 to 3^0C as expected, it is estimated that population at risk for malaria will increase by 3 to 5%.Thermodynamic malaria development model clarifies that temperature fluctuation can substantially alter the incubation period of the parasite.

Although excessive heat kills mosquitoes but warmer average temperature within their survival limit increase their survival range, accelerate reproduction, biting and the rate that pathogens matures with in them including malaria parasite Plasmodium. P. *falciparum* and *P*. *vivax* require temperature of 18^0C and 15^0C for development respectively. At least 20^0C is needed to initiate a malaria epidemic. The IPCC predicted 1.4 to 5.8^0C in global temperature would increase the proportion of land areas experiencing temperature of 20^0C or higher. Warmer temperature will permit *P*. *falciparum* to mature faster and increase its epidemiological outcome [13,14].

The last few decades have seen a marked resurgence of malaria in the East African highlands. The reasons for this seasonal malaria are not fully resolved but factor that has been widely debated is the possible influence of regional warming due to climate change. Among the studies supporting a climate driven response, Pascual *et al* [15] used a temperature dependent population dynamics model to demonstrate that a small change in mean ambient air temperature of just 0.5^0C could translate in to 30-100% increase in mosquito abundance in other words biological amplification of temperature effect. In Africa and elsewhere such biological response may be especially significant in determining the risk of malaria. Predictions are common that in coming decades more cases will occur in regions where disease is already present and that vector and pathogens will move to higher latitudes and altitudes [16].

It is expected that due to rise in temperature there is every possibility of introduction of malaria in new areas or in areas from where it has already been eradicated. Rising temperature also pose problem for highland areas with the rising trend of malaria in the highlands of Kenya has already been discussed. In Kurseong, Drjeeling district in eastern part of India, Annual Parasite Incidence (API) rose from 2 to 7.8 between 2000 and 2004. Two foothill areas with forest and slow moving streams accounted for 88% of cases in 2004 [17]

Transmission windows for malaria in India are predicted to increase with climate change. For most vectors of malaria, the temperature range of 20^0C-30^0C is optimal for development and transmission. A relative humidity higher than 55% is optimal for vector longevity, enabling the successful completion of sporogony. Analysis of average temperature, humidity, precipitation and incidences indicate that maximum incidence occurs in the months of June, July and August, when the RH is in the range of >60 and <80 and temperature ranging between 25^0C to 30^0C. This window shift from state to state depending upon arrival of the monsoon. Study carried out by the National Institute of Malaria Research, New Delhi revealed that northern states such as Jammu and Kashmir, Himachal Pradesh, Panjab, Haryana, Uttarakhand and north-eastern states are more vulnerable to climate change and transmission windows are likely to extend temporarily by 2-3 months, while south eastern states such as Karnataka, Kerala and Andhra Pradesh are less vulnerable to climate change as the climatic conditions are already suitable for malaria transmission almost through out the year, however, there may be reduction in transmission windows in Orissa, and Tamil Nadu [18].

It has been reported that impact of climate change on malaria will vary in stable and unstable malaria situations. In stable malaria regions where the principal malaria vector is anthropophillic and in the situation of high survival rates the disease is hard to control because transmission is efficient and transmission rates are so high that most people experience many infective bites per year and climate change may not make large difference in already existing difficult situation but in unstable malaria situations where anophelines are zoophillic and their survival rates are low with epidemics separated by many years with low immunity in the populations the disease may appear suddenly. Thus behaviour and ecology of vector and host are the dominant factor in malaria transmission along with the climate [19].

6.2. Dengue

Dengue is another important arboviral disease occurring in tropical and sub-tropical regions particularly in urban settings and affecting about 100 million people worldwide with incidence increasing 30 fold in the past 50 years. Dengue fever has increased dramatically in Malaysia from less than 1000 cases in 1973 to about 46000 cases in 2007 [20]. In India since 1960 more than 50 outbreaks have been reported or investigated by National Institute of Communicable Diseases (renamed as National Centre for Disease Control). The 1996 epidemic in Delhi was the worst of its kind which affected 16,517 persons and killed 545 [21]. In much of south-east Asia region dengue is spreading not only geographically but in serious outbreaks. It has been reported in the mountainous countries of Bhutan and Nepal since 2002 [7]. WHO states that it is most rapidly spreading mosquito borne disease and experts estimates that 50 million dengue infections are occurring annually and 2.5 billion live in dengue endemic countries. In India dengue have shown rising trends from 5534 cases in 2007 to 1,29,166 cases in 2016 with 245 deaths [22].

Dengue fever is sensitive to climate. Studies have shown that an increase in 1-2^{0}C result in quicker and higher replication of viruses. Global warming resulting in drought may lead to increase of cases due to house hold storing of water particularly in urban/semi-urban areas which provide ideal habitats for *Ae. Aegpyti* the vector mosquito to breed, while in rural areas *Ae. albopictus* breed prolifically. The climate change is expected to increase the number of regions affected by arbovirus, such as Australia and New Zealand. Heavy rainfall and a rise in temperature increase the rate of infection. It is expected that by 2080, about 6 billion people will be at the risk contracting dengue fever as a consequence of climate change. Already, during 1988 heat wave in Mexicco, *Ae. aegypti* carried dengue fever from 1000 to 1700 m altitude [14]. Sometimes ENSO event affects dengue occurrence by causing changes in household water storage practices and surface water pooling. Between 1970 and 1995 the annual number of dengue epidemics in south Pacific was positively co-related with La-Nina conditions. In India it has been shown that immature of *Ae. aegypti* in Darjeeling are expanding geographical limits.

Along-with the impact of climate change on dengue prevalence the increase in population, rapid urbanization, escalation in construction activities also encourage the increase in the water storage containers such as Over Head Tanks, Cisterns, earthen pots, tyres, drums, Desert Coolers *etc* which support the breeding of *Ae. aegypti* and due to changed climatic conditions and extension of favourable period for mosquitoes to survive coupled with rapid travel and transport accelerate the problem of dengue.

6.3. Chikungunya

Chikungunya is another mosquito borne viral disease spread by the *Ae aegypti*, that is spreading fast in Asia region. In recent past outbreak of chikungunya has been witnessed in many parts of India and it has re-emerged as a serious public health challenge. It is expected that along with dengue it will also pose serious problem in climate change scenario. The emergence and resurgence of chikungunya fever and its association with global warming has been studied by Epstein [23].

6.4. Leishmaniasis

It is a climate sensitive disease affecting development of sand fly vectors in alluvial soil with high sub-soil water table. Temperature ranging from 7^{0}C to 37^{0}C and Relative Humidity (RH) more than 70% in India are suitable conditions for risk areas. The life cycle of sand flies is influenced by RH & temperature resulting in fluctuations in density. In north-eastern Colombia, it was found that during El-nino, cases of leishmaniasis increased whereas, during La-nina, leishmaniasis cases decreased [24].

The other mosquito borne diseases such as filariasis, Japanese encephalitis *etc* also needs to be studied with reference to changing climate and it is expected that vector borne diseases of local distribution such as chagas disease, lyme disease, west nile virus, rift valley fever, eastern equine encephalitis, western equine encephalitis, St louis encephalitis, *etc* are also likely to be effected in climate change scenario.

7. **Abrupt weather, Ocean Circulation and El-Nino Southern Oscillation (ENSO): A Tool for Epidemic Forecasting**

Climatically important thermohaline circulation (THC) is a conveyer like circulation in the Atlantic ocean and transport heat throughout the planet where near surface current bring warm, saline water from the subtropics to higher northern latitude. This is important as it affect the weather. Rapid change in ocean circulation is associated with abrupt weather.

El-Nino Southern Oscillation (ENSO) is a climatic phenomenon and comprises changes in Pacific Ocean, which occurs every 2-7 years. The cycle of warming (El-Nino or warm water) and cooling (La-Nina or cold event) of sea surface temperature (SST) in the eastern pacific results from changes in the ocean circulation. ENSO creates rainfall and temperature fluctuations in certain geographic areas world wide, which on average has less rain fall (drought) during warm event (El-Nino) and more rain fall during cold phase (La-Nina). Malaria epidemics have been associated with excess rain fall in arid areas and drought in humid climate, where rivers can be transformed in to pools and becomes conducive for mosquito breeding. Climate change is expected to increase the intensity and frequency of ENSO events and thereby affecting mosquito borne diseases. The ENSO pattern has become more pronounced since 1970s.

El-Nino associated drought appears to affect malaria transmission in the following year. Reduction in transmission during a dry year is likely to reduce population immunity and hence increase the size of vulnerable population in the following season. ENSO has been suggested as predictive tool for vector borne diseases and in epidemic forecasting as well as targeting scarce resources. Major focus of research is the ability to predict El-Nino events several months in advance.

Bouma *et al* [25] have shown that rainfall in west Rajasthan in the year after El-Nino event was 40% higher than in the El-Nino year and 50% higher in the La-Nina year. Strong co-relation was seen between rainfall and malaria incidence and also with number of rainy days in Jodhpur district [26]. In Venezuela malaria morbidity and mortality increased by an average 36.5% in years following recognized El-Nino events [27]. Kilian *et al* [28] in Uganda attributed increased Pf infection to increased and prolonged rainfall caused by ENSO. Many malaria epidemics every 5-8 years have been associated with ENSO cycle e.g.Former British Panjab, Pakistan, Sri Lanka, Highlands of Uganda, Columbia, Peru, Bolivia, Ecuador, Rwanda etc. In Dehradun (Uttarakhand), India, higher co-relation between parasitic incidence and climatic variables was found, the highest being between rainfall and malaria incidence [29].

8. Other View Point

Chris Dye and Reiter [30] reported that a rise in temperature spreads the development of parasite but if there is no water for mosquito to breed and limited control with human, high temperature would not matter much. In an other study carried out by Hay *et al* [31] , no evidence was found with warming in highland locations in East Africa and it was suggested that the cause of resurgence of malaria was due to change in land use, human demography, resistance to anti-malarials, *etc*. Pattern of rainfall and malaria in MP was studied by Singh and Sharma [32] and no clear relationship was observed though it was stated that a major water resource might have masked any significant association. Lindsay *et al* [33] found more rain fall after strongest recorded El-Nino in Tanzania but strikingly less malaria was noticed in preceding years. Hence, in certain situation non-climatic factors may play an important role.

9. Early Warning System

Epidemics/outbreaks of mosquito borne diseases are serious public health emergencies. Typically they occur with little or no warning in areas where health system is unprepared to deal with the emerging problem. Early identification of an infectious diseases outbreak is an important first step towards implementing effective diseases intervention and reducing resulting mortality and morbidity. The impact of epidemics can be minimized by prediction and improved prevention through vector control and deployment of appropriate drugs. WHO advocates the development of integrated malaria early warning system based on vulnerability assessment, seasonal climate forecast, weather and environmental monitoring and case surveillance.

9.1. Historical Early Warning System

The use of climate data for predicting outbreak of infectious diseases dates back to work of Gill and others in India [34]. Gill (1923) [35] developed an Early Warning System (EWS) for malaria based on rainfall, prevalence of enlarged spleen, economic conditions and epidemic potential. Recently a study has been conducted on the development of Epidemic Early warning in Eritrea using the parameters of vulnerability assessment, surveillance data and seasonal climate forecast based on NDVI and SSTs [36] .

9.2. Climate Models

Most of the mosquito borne diseases including malaria are dependent on rain fall, temperature, humidity, wind, land cover-use, topography and other local conditions. Accurate seasonal prediction of rainfall, temperature and other hydro-meteorological variables and land cover-use are very useful for early warning of malaria risk, mapping disease distribution and decision making about prevention.

9.3. Predictor of Malaria Early Warning System (MEWS)

By combining information through satellites, weather statistics and health centre data, researchers have developed statistical models to help predict malaria transmission. MEWS use 4 main groups of indicators to predict the timing and severity of malaria epidemics:

1. Vulnerability indicators (e.g. immune status, drug resistance)

2. Transmission risk indicators (unusual increase in rain fall higher than the average seasonal rain fall, seasonal climate forecast, 1-6 month in advance, weather monitoing)

3. Early case detection indicator (case surveillance)

4. Monitoring vector population

Kenya Medical Research Institute (KEMRI), Kenya, Kenya Meteorological Department and International Centre for Insect Physiology and Ecology have launched a new tool that calculate data based on environmental factors (weather, geography) and mosquitoes mating schedule successfully(with 86-100%) and predict a malaria epidemic 90 days before [37]. The disease prediction tool should help policy makers and health officials prepare in time to deal looming outbreaks with regards to when and where to spray.

9.4. Disease Surveillance

Monitoring of malaria cases can be used for early case detection of an epidemic if collection and notification are timely (*i.e.*weekly). Disease surveillance for early detection of malaria epidemics has been used in Thailand [38], where deviation from seasonal averages were used to detect outbreaks (*i.e.* where monthly cases exceed the long term mean plus 2 SD). This approach detected 228 out of 237 epidemics in 114 district from 1973-1980. Parasitological data for the years 1973-81 were examined to determine the years of acceptable or normal transmission of malaria for every district of northern Thailand. The monthly mean number of cases plus 2 Standard Deviation (SD) were calculated for the selected years and plotted on log-linear graph paper and distributed to Malaria Sector Officers. If the observed incidence in their Sector was more than 2 SD greater than the normal mean for that month, the Zone and Regional Malaria Officers were informed. Retrospective analysis of data of the districts where outbreaks reported indicated that the method provided an effective warning of impending epidemics.

9.5. Land cover and vegetation index (NDVI)

Land cover and Land use has a significant impact on malaria transmission. A biological indication of rainfall *i.e.* the normalized difference vegetation index (NDVI) derived from satellite data is a measure of the amount of photo-synthetically active vegetation and is thus proxy for land cover, it has been found useful in prediction of malaria incidence. Many studies have shown a positive correlation between NDVI and malaria incidence. Temporal changes in the vegetation index (NDVI) have been shown to be a good indicator of the malaria season in The Gambia, Niger [39] and Kenya [40].

9.6. Land use change and enhanced incidence of malaria

Agricultural and land use practices in developing and rapidly industrializing countries have been found to affect vector borne diseases [41]. Deforestation was found to affect the ecological succession of vector mosquitoes in Nainital District, in Uttarakhand, India. *An. minimus* was the principal vector in 1930s and deforestation resulted in the succession of *An. fluviatilis* and further colonization of terai and irrigation introduced *An. culicifacies* which is now the vector of malaria [42]. The indiscriminate digging of borrow pits, rice paddy cultivation, use of pesticides in agriculture resulting in evolution of resistance in disease vector, malaria diffusion through population movement and inaccessibility of villages in the hinterland are some of the factors that would maintain the transmission.

In many areas, major ecological changes have occurred and vectors were uprooted and eliminated but soon these niches were filled by new vectors. Classical examples as mentioned above is the succession of *An. minimus* by *An culicifacies* in UP terai and a similar succession of *An. sundaicus* by *An. culicifacies* in Chilka lake area in Orissa. In Orissa, *An. culicifacies* has established itself all over the state even in areas where it was not recorded previously and now it is playing the role of primary vector [43-44]. In Malnad foothill areas in Karnatka dams were built in the valley resulting to deforestation and elimination of streams, the breeding places of *An. fluviatilis* the major malaria vector in the area and thus eliminated the malaria from the area [45,46].

Agronomic practices have also contributed to technical obstacles in malaria control. Use of insecticides in agricultural crops *e.g.* in Andhra Pradesh and Orissa has precipitated malathion resistance in *An. culicifacies* [43]. Malaria began to appear at higher altitude of Kenya after clearance of forests for development of tea estates and importation of labour [19]. Construction of Roads and railways create innumerable flooded borrow pits due to depression left by excavation and contribute to mosquito breeding. In highland of Madagascar, following extensive development of rice irrigation, diseases became endemic [47].

Changes in land use might also be responsible for recent emergent foci of Crimean-congo hamorrhagic fever virus in many countries. Evidence is presented to show that an expansion of brackish water bodies in coastal zones can increase the densities of salinity tolerant mosquitoes like *An. sundaicus* and *Cx. sitiens* and lead to adoption of fresh water mosquito vector *An. culicifacies*, *An. stephensi*, *Ae aegypti* and *Ae. albopictus* [48].

10. Geographical Information System/Remote Sensing

Geographical Information System (GIS) and Remote Sensing (RS) technologies can be utilized properly for mapping of mosquito breeding places and planning better control strategies. GIS is an information technology to input, store, update, retrieve, analyze & output geo-referenced data. It has the potential to develop thematic maps of the input data with overlaying and integration of the maps and has a strong statistical component to visualize, interpret complex real situation to provide effective solutions. GIS analysis helps to identify factors which will indicate disease threats and would also help in planning rationale and suitable control strategies and early preparedness in preventing outbreaks/epidemics. Remote Sensing is the technology of collecting images of the earth surface from satellite platforms and transforming the images in to maps. Remote sensing can generate data on land use features, soil type, water bodies, vegetation, forest cover, human habitation etc, which can be used as databases in GIS for vector borne disease analysis. The combined use of GIS & RS in addition to stratifying areas, identify risk factors can also help in identifying the priority areas for control and in construction of spatial decision support system for planning disease control strategies. This may also be useful for rapid Geographical Reconnaissance at village level with coverage of large and inaccessible areas and may be useful for ecological change detection for micro stratification and help in early warning of malaria (short and long range).

11. Cold Cloud Duration

Clouds with the coldest top surface produce heaviest rainfall. It is possible to derive estimates of rainfall by measuring the cloud top temperature using half hourly infrared images obtained from Metostat channel (satellite).

12. ENSO and Sea Surface Temperature (SST)

As global warming increases, there is an expected rise in the frequency of irregular climate fluctuations, including phenomenon known as ENSO, which causes characteristic changes in atmospheric conditions. Mosquito borne diseases are sensitive to changes in temperature and precipitation. Any increase in frequency of ENSO event could bolster epidemic. SST is an early indicator of ENSO event in some parts of the world, where SST in the Pacific are important predictions of climate events. Significant co-relation between malaria incidence anomalies and SST has been observed. Both rainfall and annual malaria incidence anomalies were significantly related to SST in eastern Pacific suggesting that they may be predictable months in advance using seasonal climate forecasting methodologies [49]. Thomson *et al* [50] showed that in Botswana indices of El-Nino related climate variability can serve as the basis of malaria risk prediction and early warning.

13. Comprehensive plan may include:

- Development of an integrated early warning system
- Emergency response plan
- Refugee management plan
- Increase capacity to provide shelter, drinking water, sanitation and sustainable agricultural products to most vulnerable population
- Partnership with both Govt and non-Govt sector will also be necessary
- Regional climate models must be integrated with health data
- Satellite and geospatial technology may provide new insights regarding the geographic distribution of risk and diseases
- Integration of social, demographic and land cover data with health data will aid in describing a holistic health scenario
- Data on land use and land cover may provide additional information on relevant environmental factors that influence risk and vulnerability.

14. Conclusion

The epidemiology of vector borne diseases is highly complex and is the function of many abiotic and biotic factors including temperature, humidity, rainfall and insecticide and drug resistance to poor health care delivery systems to individual immunity. Deforestation, agronomic practices and land use changes are also detrimental factor in disease transmission. The understanding the role of climate is rather more complex. As certain situations favour or encourage the breeding of mosquito vectors but if proper health care management is there the impact of such climate catastrophes can be minimized. An early warning system can predict the genesis of epidemic in advance and help in making the better control and prevention strategies. Availability of key intervention tools for mosquito control, drugs and effective surveillance can also play a positive role. Though it is essential to cut down the emission of greenhouse gases and reduce the magnitude of the problem but on the other hand there is also need to equip yourself to face such challenges. Government of India is also taking positive steps in this direction and released its much awaited National Action Plan on Climate Change to mitigate and to adopt climate change on June 30, 2008.Awareness and strengthening of health care delivery system may produce positive results. This is the time to act and act in right direction with integrated approach.

15. Tables

Table 1: Impact of Climate Change on Human Health

Environmental Change	Climate Change	Ecological Change
Air Pollution	**Thermal Extremes**	**Food Availability**
Cough Asthma	Heat strokes	Malnutrition Growth Retardation Developmental Delay
UV Radiation Sunburn Malignant Melanoma Immunosuppression	**Weather Disasters** Drowning Dehydration Gastrointestinal illness Psychosocial Trauma	**Allergen/Mycotoxin** Allergies Cancer Birth defects
Sunburn		**Infectious Diseases Exposures**
		Malaria Dengue Encephalitis Lyme Diseases
		Emerging Infectious Diseases
		West Nile Virus Hantavirus Others

Source: based on Bunyavanich, Ambulatory Pediatrics, 2003; 3: 44-52

Table 2: Burden of Vector Borne Diseases in India

Sr No.	Diseases	Cases/annum	Death
1.	Malaria	1.09 million	331
2.	Filariasis	0.20% mf rate	Nil
3.	Kala-Azar	6245	Nil
4.	Dengue	1,29,166	245
5.	Chikungunya	64,057	Nil
6.	JE/AES	1676/11651	283/1301

Source: NVBDCP, Govt of India (nvbdcp.gov.in); cases in 2016

16. Figures

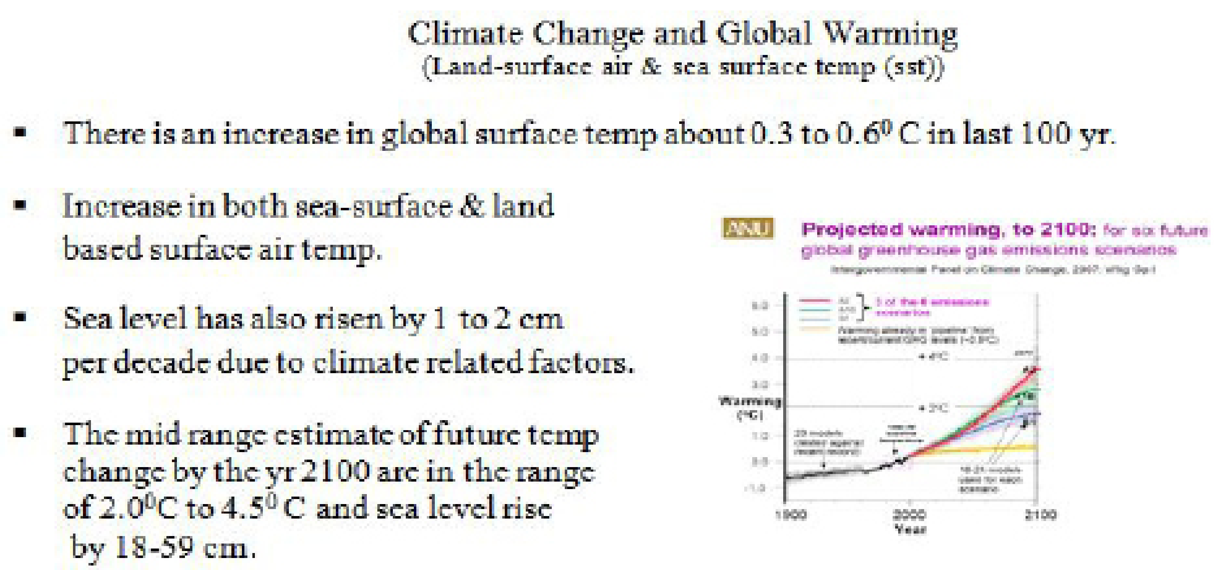

Figure 1: Global warming and its consequences on increase in temperature and sea level rise.

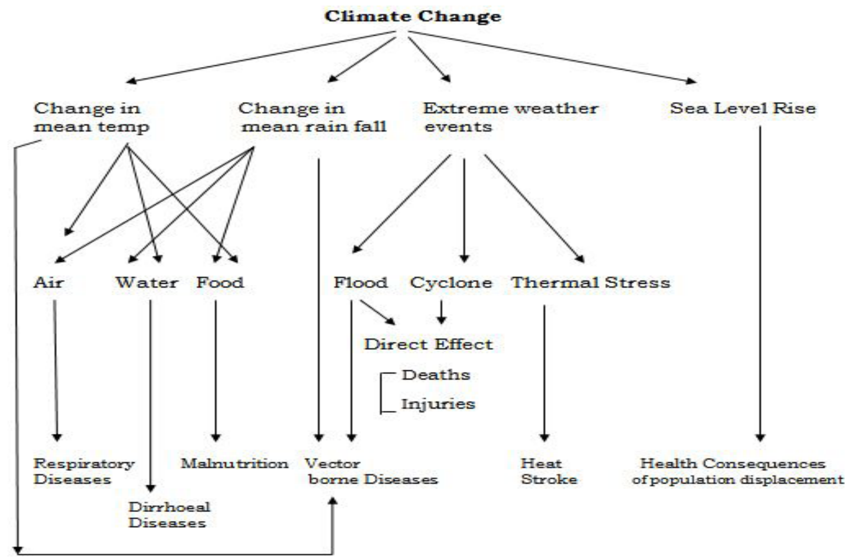

Figure 2: Impact of Climate Change on Human Health
(based on Climate Change and disease dynamics in India edited by Dogra N and Srivastava S, 2012, The Energy and Resource Institute: New Delhi.)

- Malaria
- Filariasis
- Dengue
- Yellow fever
- Japanese Encephalitis (JE)
- Eastern Equine Encephalitis
- St. Louis Encephalitis
- La-Crosse Encephalitis
- West Nile virus
- Chikungunya

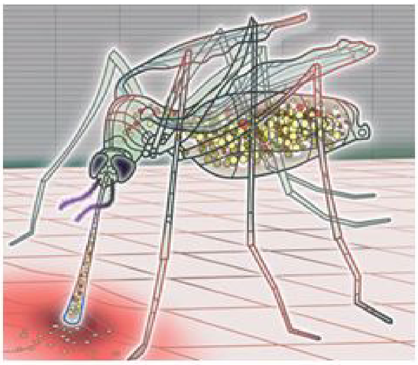

Figure 3: Major Mosquito-borne diseases

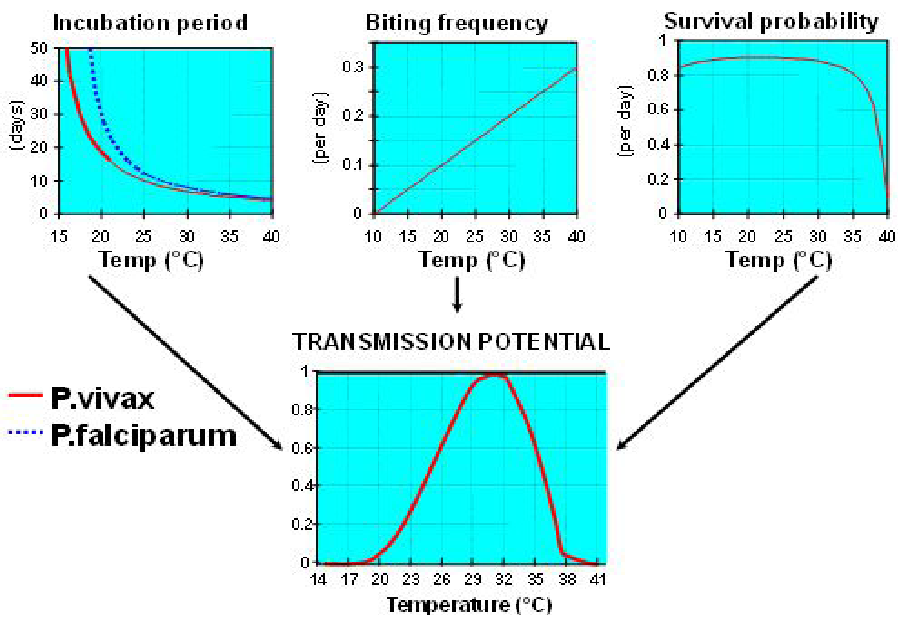

Figure 4: Impact of temperature on transmission potential of mosquito borne diseases

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