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IDENTIFICATION OF POTENTIAL RISK AREAS OF MALARIA PARASITES IN PAKISTAN USING CLIMATE DATA AND GIS

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ABSTRACT

Malaria, one of the major infectious diseases in Pakistan, affects thousands of people every year. Its pathogens are highly dependent on the environmental conditions and have their own climatic niche. Mosquitos are poikilotherms which can survive only in a particular range of temperature. Also, the extrinsic incubation period for malaria parasites is temperature influenced. This paper aims to find the areas that allow easy transmission of parasites into human population under current climatic conditions, which shows that *Plasmodium vivax* has a greater area coverage than *Plasmodium falciparum.*

Keywords: malaria, risk areas, Temperature transmission windows

INTRODUCTION

Mosquitoes are very efficient vectors of microorganisms. They account highest among all the vector-borne infectious diseases and can carry parasites, myiasis, and viruses (Peter *et al*., 2005). Diseases they can transmit include malaria, dengue, filariasis, West Nile virus, Chikungunya, yellow fever, Japanese encephalitis, Saint Louis encephalitis, Western equine encephalitis, Eastern equine encephalitis, Venezuelan equine encephalitis, La Crosse encephalitis and Zika fever, which contract about 700 million people (Caraballo and King, 2014). Over one million people die from mosquito-borne diseases every year, and those who are bitten by the mosquito torment for days (Oxitec, 2018).

With an unequivocal rise in temperature due to climate change, the dynamics of mosquito-borne diseases is feared to be changed. This is because mosquitoes are poikilotherms, organisms having a body temperature that varies with the temperature of their surroundings, and are, therefore, directly affected by environmental temperatures (Yang *et al*. 2009; Alto and Bettinardi, 2013). Climate Change is a crucial phenomenon and with the rise in temperature, it also encompasses changes in every aspect of the environment and ecology. This change appears to alter the dynamics of the mosquito-parasite relationship. Therefore, the effect of climate change on mosquito-borne infectious diseases may be both direct and indirect.

Public health researchers know that climate and weather both affect mosquitoes in different ways: the distribution of mosquitoes depends upon climate, while weather affects the timing and intensity of outbreaks. And since climate affects weather, therefore, the change in climate would affect both the distribution and intensity of outbreaks of mosquitoes. There are three ways in which mosquitoes respond to climate change (Davis *et al.*, 2005).

1. Migrate from a region of unsuitable climatic conditions to a region of more affordable conditions;
2. Adapt to the changing climatic conditions in the same region without changing their genes by means of phenotypic plasticity, the ability of an organism to change their certain features to some degrees by the environment; and
3. Change their genes and adapting to the changing climatic conditions (Gienapp *et al.*, 2008).

The ability of a mosquito to acquire, maintain and transmit the pathogen after imbibing a blood meal is called vector competence. Another term, **Vectorial Capacity** is used which is a quantitative measure of an efficiency of the mosquito to transmit disease. Vectorial Capacity depends upon several factors that are both extrinsic and intrinsic in nature. Extrinsic factors include the environmental and ecological factors as well as the density of mosquitoes and humans. Intrinsic factors include the genetic and physiological makeup of the mosquitoes. Both intrinsic factors and extrinsic factors are affected by environmental temperatures to a certain extent and thus increases the vector competence of mosquitoes (Gunay *et al.*, 2011). For example, increased temperature has helped in increasing the spread and intensity of the West – Nile virus through Culex by $T^{4;}$ also, the warmer temperature has helped the invasion of the new genome of West-Nile virus (WNV02) (Kilpatrick, *et al.*, 2008).

Objectives of the study

The aims of the paper are to a) review past studies and literature, how temperature is effecting mosquito-pathogen relationship b) find a potential extent of proliferation of endemic and emerging diseases vectored by mosquitos due for the current climatic conditions in Pakistan.

Malaria and temperature conditions

Temperature affects all four stages of mosquitoes, especially eggs and larva and poses an upper limit on the mosquito age and size. It also affects the feeding behaviour and gonotrophic cycle. Thus temperature can help in the proliferation of mosquitoes and parasites. The holistic approach is necessary in order to fully comprehend the effects of change in temperature on mosquito-borne diseases in humans due to climate change. There are approximately 3500 species of mosquitoes grouped into 41 genera by Centers for Disease Control and Prevention (CDC, 2015); but only three genera, *Anopheles, Aedes*, and *Culex*, bear the primary responsibility of carrying diseases to humans. The study discusses the parasites' and viruses' relation with the three genera of mosquitoes.

In the initial part of this review, we discussed the effect of constant temperature on the whole life-cycle of Anopheles, Culex and Aedes mosquitoes and their behaviour. Then the effects of DTR (diurnal temperature range) on these three mosquitoes are taken into account. Temperature's effect on biting rate and their size is also discussed and finally the effect on the extrinsic incubation period (EIP). Aforementioned points were also discussed with respect to climate change. Finally, we have also discussed factors that are impediments to establishing a relationship between the rise in temperature due to climate change and mosquito-borne diseases.

Study Area

Pakistan is a subtropical country with a large population of 20 million people. With low literacy rate and poor HDI, the country is under severe threat of climate change. Several international organizations have put the country under the 10 most vulnerable country in the world. Pakistan has a diverse geography and climate. Culturally, people live in a combined family system where maintenance of hygiene remains a problem and a general sense of hygiene is low. Also, there is a large diaspora who frequently travels to the country, any disease brought by an individual from any country has a potential to become epidemics. Climate Change with its many downsides has a potential to alter the dynamics of infectious diseases. This exacerbates the problem in Pakistan, which had recently reported epidemics of previously non-existent mosquito-borne diseases like dengue and chikungunya.

Significant of the study

Malaria has consistently been on the rise in Pakistan. The current study helps in the advancing the research of climate change on the infectious diseases in Pakistan, which is an imminent threat in near future.

Climatic Profile of Pakistan

Pakistan is a vast country and with its unique terrain, it has a diverse set of climates. The country has mostly arid to semi-arid climate along with desert areas and in North, it has one of the tallest mountains of the world like K2, Nanga Parbat etc. Using the Koppen-Geiger classification system, the twelve classifications of Pakistan are shown below:

Literature Review

Effect of Temperature on Malaria Mosquitoes and Parasites:

Malaria parasites, *Plasmodium vivax*, and *Plasmodium falciparum* are carried by Anopheles mosquitoes. These mosquitoes are present in the wide range of environments and climatic conditions. All stages of Anopheles mosquitoes are temperature dependent, but this dependency is not the same among the stages resulting in a nonlinear relationship of the mosquito population at different stages with the temperature. Several experiments have shown this difference and consequently many biological models have been developed to show this change. A multiple laboratories' parameterized model results show that temperature has a strong correlation with nearly every stage of the mosquito life. This could mean that changes in temperature due to climate-change phenomena could result in either proliferation or a reduction in mosquitoes and consequently the diseases they carry; that obviously depends upon how much and where the temperature has changed in the region and the type of mosquito species thriving there. If, say, some regions experience long durations of 40^0- 42^0C temperature, then adult Anopheles mosquitoes would not survive (Craig *et al.*, 1999). This could mean that regions where the mean temperature lies in the range that accelerates Gonotrophic Cycle, Juvenile development rate and decreases Juvenile mortality rate, mosquitoes would thrive and increases the likelihood to carry microorganisms. Places where the temperature is unbearable to mosquitoes, they may try to find places where they can survive, like Aedes (Hales *et al.*, 2002). An increase in half-degree centigrade temperature increases 30 to 100 percent increase in mosquito population (Pascual *et al.*, 2006). Also, due to the survival pressure, they might imbibe more blood and produce offspring faster so the rate of infections increases (Focks *et al.*, 1995). In Anopheles, biting rate is also temperature dependent and increases as the temperature increases because as the temperature increases digestion increases (Detinova, 1962).

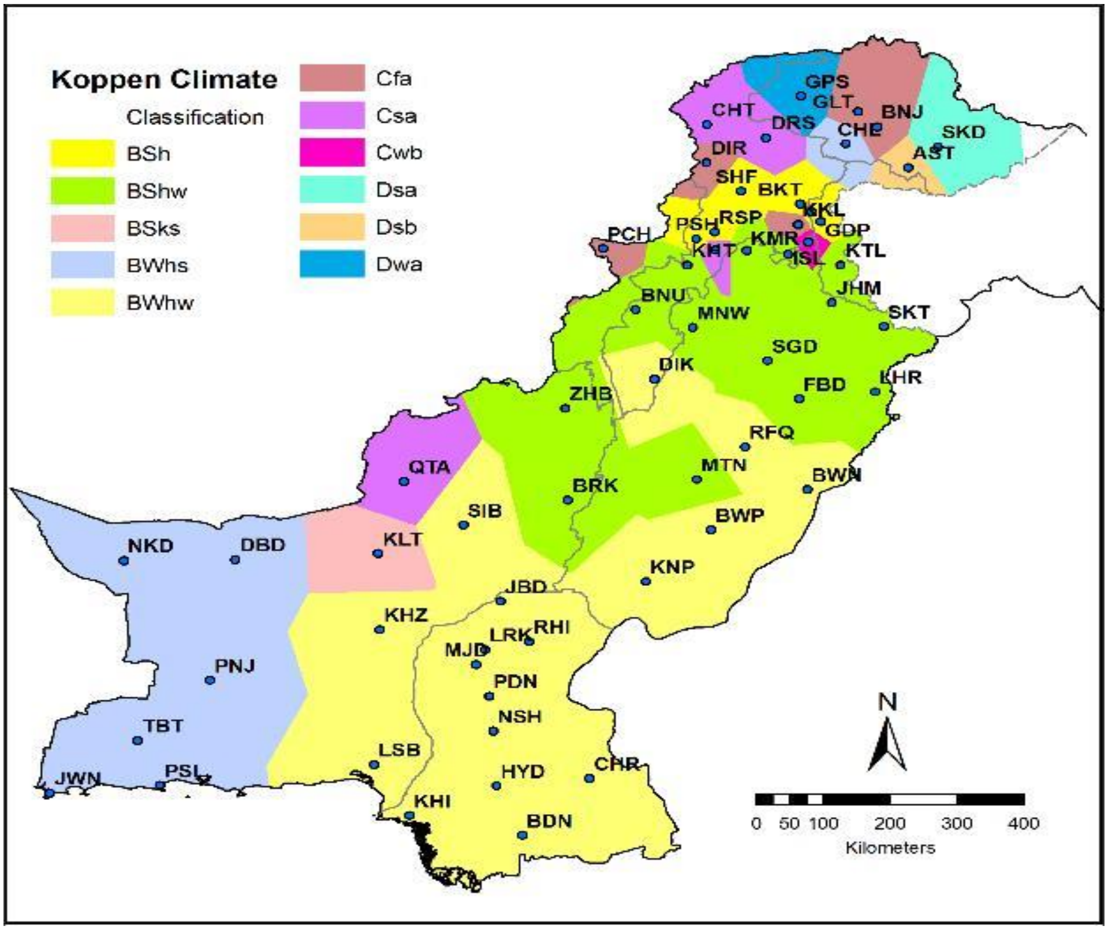

Fig. 1. Koppen Climate Classification of Pakistan Source (Sarfaraz *et al*., 2014).

Effect of temperature on the extrinsic incubation period

Extrinsic Incubation Period is the time taken for the microorganism to develop within the mosquito. Mosquitoes are hosts of protozoa and viruses. EIP for viruses is temperature dependent (Watts *et al.*, 1987). It is found that as the temperature increases the extrinsic incubation period decreases and this relationship is strictly true with any kind of virus as shown in the figure below. The same observation is true for the protozoa, Plasmodium, within Anopheles.

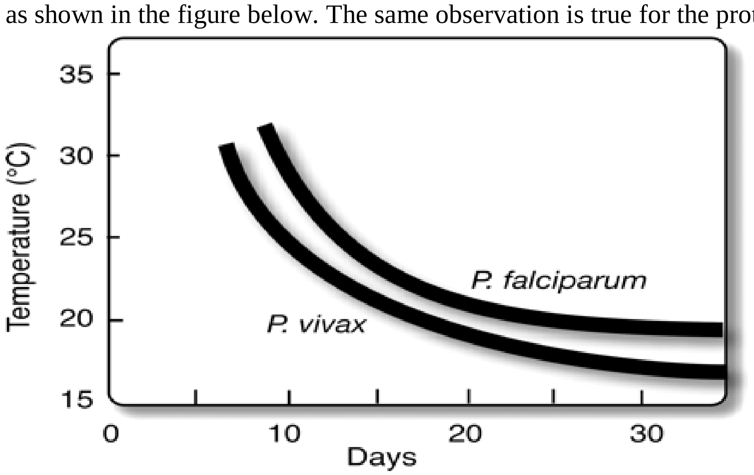

Fig. 2. Extrinsic Incubation Period (EIP) of parasites inside mosquitoes. Source: (Patz and Olson, 2006).

Figure 2 shows that for both *Plasmodium vivax* and *Plasmodium falciparum*, as temperature increases days to incubation decreases. As mosquitoes in the field could not live to longer, therefore, longer EIP makes them redundant.

Materials and Methods

We reviewed the literature to find out the effects of temperatures on mosquitoes and the pathogens they carry. These climatic temperatures provide windows to optimally transmit parasites into humans. We took the overall average temperature of different regions of Pakistan. Then we sorted out areas that fall in the transmission window and predict the possible affected areas using ArcGIS (Girvetz *et al.* , 2009).

RESULTS AND DISCUSSION

Climatic Suitability Window and Risk Area

Based on Table 1, Fig. 2, it appears that malaria parasites are able to thrive and have temperature window for their transmission. It can be seen clearly that in the Northern regions of Pakistan and a small portion of Baluchistan, marked in yellow, are areas which are not suitable for the transmission of malaria parasites. However, *Plasmodium Vivax* has the largest spread based on its temperature niche. Entire Sindh, Punjab and most of Baluchistan and Khyber Pakhtunkhwa (KPK) it is widespread. On the other hand, *Plasmodium falciparum* has less suitable areas for its transmission as can be seen in the legend in Fig. 2. Above study helps in the formulation of the effects of climate change on malaria parasites.

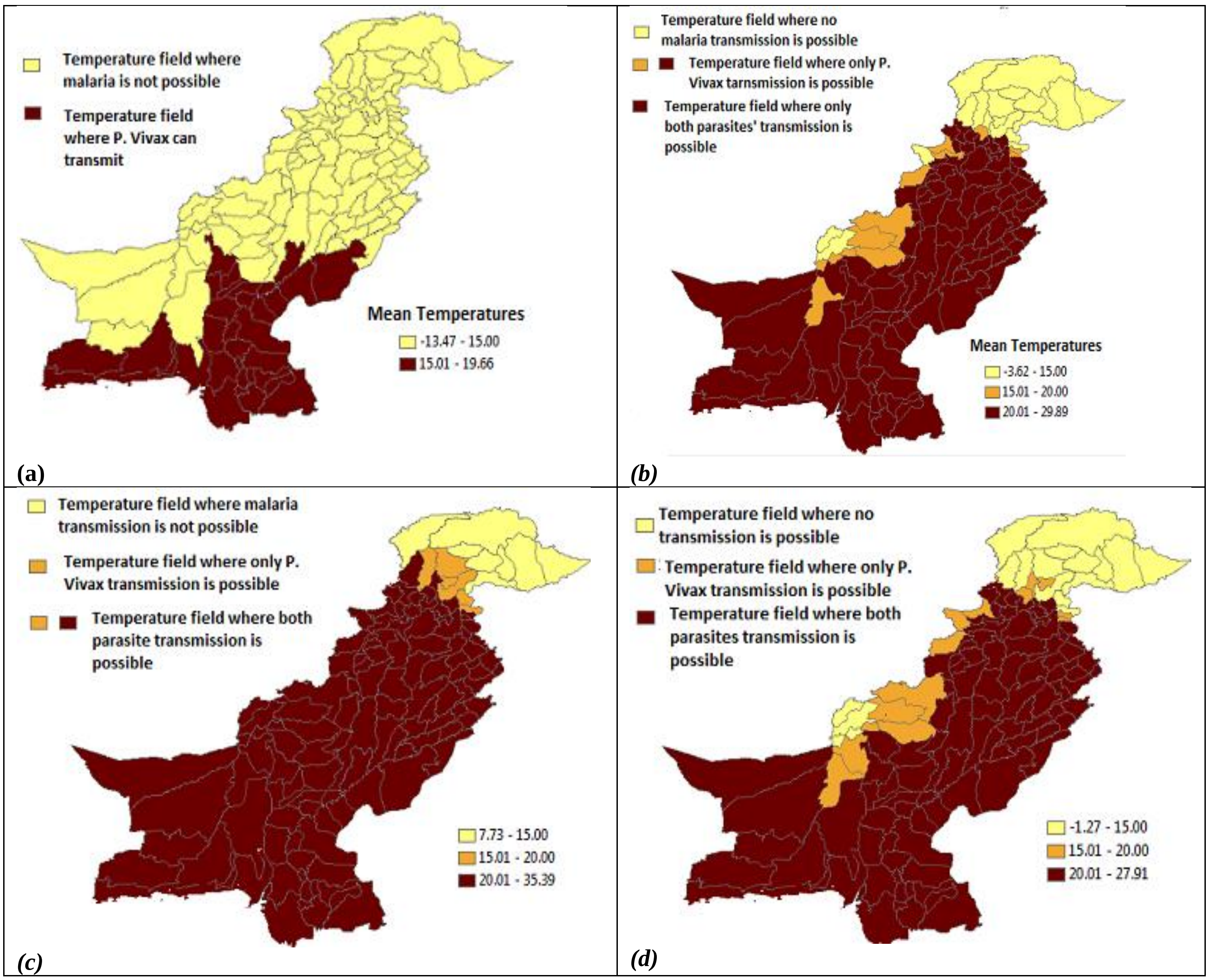

Fig. 3. Seasonal Mean Temperatures and Possible Risk Areas. **(a)** Dec-Feb **(b)** March-May **(c)** June-August **(d)** Sept-Nov.

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Table 1. Suitable transmission temperatures (Bhattacharya *et al*., 2006; Eisen, *et al*., 2014).

	Pathogen	**Vector and their optimal development temperatures (^{0}C)**	**Suitable Temperatures (^{0}C) for transmission**
1	*Plasmodium Vivax*	Anopheles (15-35)	15-30
2	*Plasmodium Falciparum*	Anopheles (15-35)	20-35

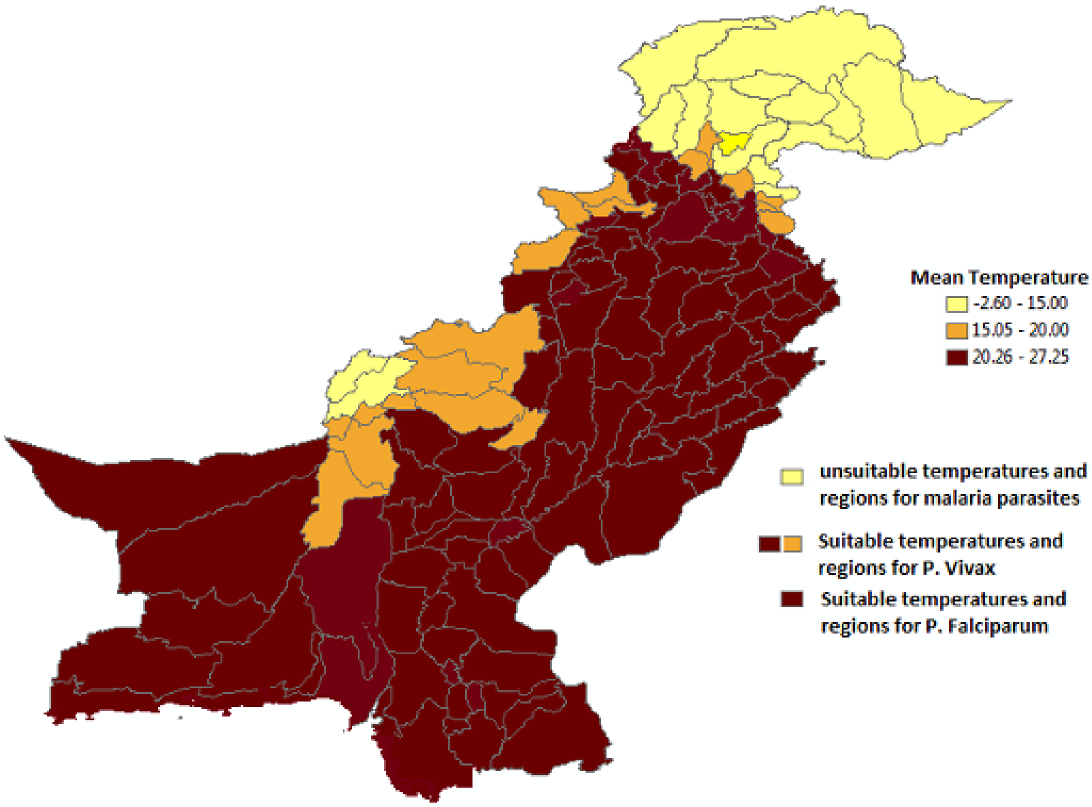

Fig. 4. Potential risk areas of malaria parasites in Pakistan.

Fig. 4 shows areas that are potentially vulnerable to the transmission of malaria parasites. Yellow districts are not at all vulnerable to any malaria parasites while districts in orange are only vulnerable to *Plasmodium vivax* and dark brown district which covers most of Punjab, Sindh, Baluchistan and most parts of KPK have high transmission potential of both parasites of malaria.

Limitation of the study

Malaria and other mosquito-borne diseases depend on many factors including temperature, humidity, Rainfall pattern and amount, vegetation and socioeconomic conditions. In this study, we mainly discuss overall seasonal and annual temperature conditions.

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