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Research Article

Climate Change Projections and its Impacts on Potential Malaria Transmission Dynamics in Uttarakhand

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A B S T R A C T

Introduction: Mountainous regions in India are prone to malaria disease but with low intensity. In this context, Uttarakhand state, a hilly region situated in the northern parts of India and located in the central Himalayan region is also prone to malaria disease and malaria is present in four out of its 13 districts which are mainly plain stations.

Method: A numerical dynamical malaria model, VECTRI is used in this study based on various climatic and non-climatic parameters such as surface mean temperature, rainfall, population density etc. to predict the future malaria transmission dynamics in Uttarakhand state. VECTRI model is simulated with the inputs obtained from the CCSM4 global climate model for the baseline period (1975-2005) and for the near future projection period 2006-2035 (hereafter referred to as 2030s). Rainfall, surface mean temperature, mosquito vector density and entomological inoculation rate (EIR) during the Indian monsoon season (June-Sept) are being investigated from the outputs of VECTRI model simulations to predict the future malaria transmission dynamics in the Uttarakhand region with respect to the future climate change under RCP 8.5 emission scenario.

Results: Results indicate an overall increase in EIR values (increase is around 30%), indicating an increase in future malaria transmission in Uttarakhand state as a whole with a maximum increase in the central parts of the state which are plain areas with a warming temperature of 1°C and with an increase in rainfall of 15% by 2030s with respect to the baseline period.

Conclusion: Future warming and increase in the rainfall intensity during the summer monsoon season (June-September) over Uttarakhand state could potentially increase the spatial and temporal distribution of malaria transmission over the regionin future under RCP8.5 scenarios.

Keywords: Climate Change, Global Climate Model, Malaria Transmission, VECTRI Model

Introduction

As per the World Health Organization reports,[31] globally, the most important and deadly tropical mosquito-borne parasitic disease is malaria. It kills around 1 million people and troubles as many as 1 billion people in 109 countries throughout Africa, Asia, and Latin America. However, in India, malaria is still a serious public health problem. According to the National Vector Borne Disease control programme reports, approximately one million malaria cases are reported annually in India.[21] In South East Asia, Indian regions are the second most malaria-affected regions in the globe after the African region. In this context, a few mountainous regions in India are also prone to malaria disease but with low intensity. As per the report,[21] active reported malaria cases of mosquito-borne diseases in Uttarakhand are eventually lower than rest of the states in India. Further, the report indicates that malaria is present in only four out of 13 districts in the state, which are in the plains. Climatic diversity is one of the utmost reasons for the persistence of malaria in India. The factors that cause concerns for malaria disease in India are the changes in temperature and rainfall patterns owing to climate change. In past, it has been investigated extensively by using various climate modelling studies that there is an indication of widespread future warming and increasing heavy rainfall events in most parts of the Indian region during the monsoon seasons. (Sandeep et al. 2018).[1,4,6,14,19,27] Therefore, future climate change projections for this region are essential on a temporal and spatial scale to address this issue. India has a rich diversity of malaria vectors adapted to its equally rich ecological diversity. The intensity of malaria transmission is highly affected by major climatic variables like temperature and rainfall. (Pascual et al. 2006).[3,8,15,17,22,23] These climatic variables contribute considerably to changes in the mosquitoes and the parasite development life cycle.[2,13,24] Optimal conditions for malaria transmission occur when the temperature is between 18°C and 27°C. The water temperatures regulate the period of the aquatic breeding cycle of the mosquito vector.[7] In many parts of the globe, such kinds of studies have been carried out so far to derive the impact of climate change on malaria transmission.[18,25,34] Dynamics of malaria transmission in different parts of the world are being investigated using different dynamical malaria models such as MIASMA,[30] LMM(Jones, 2007), MARA,[3] and VECTRI[29] etc. Particularly in India, a few such studies have been carried out so far by using VECTRI model simulations by using various climate model outputs.[26] Further, in Uttarakhand state, it is found that changes in climate have a direct impact on the plain areas of the state which are vulnerable to various vector-borne diseases like malaria[9] but there are no malaria studies found so far that focus on the future malaria transmission dynamics in Uttarakhand state with respect to the climate change studies. As malaria transmission frequently occurs during the monsoon and post-monsoon seasons due to the increase in the number of mosquito breeding sites, this study is concentrated mainly on investigating the link between monsoonal climate and its impact on malaria transmission dynamics in the state of Uttarakhand, India. Malaria transmission is seasonal, with the highest peak occurring during the monsoon season and post-monsoon season in most of India.[10] In this study, we have used VECTRI malaria model to predict the future transmission dynamics of malaria in the study region. The VECTRI model associated with various climatic and non-climatic input parameters such as temperature, rainfall, population density etc.weremodified during the model run based on the available literatureon the Anopheles Culicifacies malariaspecies for the study region. The temperature and rainfall variations in a region have a huge impact on the malaria vector development cycles as well as on the presence of malaria parasite,[16] and VECTRI model considers this effect while predicting the malaria transmission for a region. Again, human population density is one of the main parameters considered by the VECTRI model to evaluate the mosquito-biting rate which helps in predicting the malaria transmission rate. In this context, VECTRI malaria model is considered one of those models that incorporates a good representation of transportation of the malaria parasites through human migration to different regions that leads to malaria transmission. Additional details of the VECTRI malaria model structure, model runs, and experimental setup are given in the methodology section.

Study Area

Being situated in the mountainous region and with the forest ecosystem (64.7% supports forest area from the total area), Uttarakhand state is highly vulnerable to climate change.Itis a hilly state in India, which is situated in the central Himalayan region between 28º to 31.5ºN and 77.5º to 81.4ºE. The topography of the study region is shown in Figure 1. Uttarakhand receives maximum rainfall (80% of annual rainfall) during the Indian summer monsoon season (June to September, JJAS) and sometimes it receives rainfall due to the eastward movement of western disturbances. The maximum temperatures generally range between 25 to 27 °C with higher warming during the JJAS season and the lowest minimum temperatures ranged between 10 to 12 °C.[35,36,37] Further, 60% of the population isseen over the southern parts of the state including the districts Dehradun, Haridwar, Udham Singh Nagar, and Nainital. Out of the 13 districts of the State, there are only 4 districts which are in plain stations and the remaining are in hill stations.

Further, the elevation of the state ranges from 175 meters (from the sea level) in the plain stations to 7400 metersinthe northern hilly regions.

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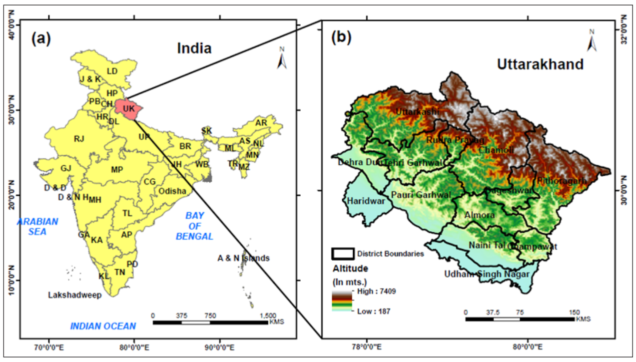

Figure 1.Study Area of Uttarakhand State in India focussing on all 13 Districts

Materials and Method

We have used VECTRI malaria model in this study to simulate malaria transmission dynamics in the Uttarakhand state for both the present and future period. VECTRI model, used in this study is based on the life cycle of the malaria vector Anopheles culicifacies and the Plasmodium falciparum malaria parasite.[29] The model is simulated in the study region by considering a few important parameters such as population density, surface temperature, rainfall etc. which account for malaria transmission for the parasite. The parameters are set by considering the changes in the biology of the species in the focused region and changes in the climatic factors that influence the survival of the species in the region. For this simulation, Aphrodite observed data is used for daily mean surface air temperature and rainfall at 0.25° resolution for the historical period of 1975 to 2005.[32,33] The major focus of this investigation is to predict the future malaria transmission dynamics in Uttarakhand state with the help of observed Aphrodite data of 0.25° x 0.25° resolution for the historical period of 1975 to 2005 and future projection scenarios of the Global Climate Models (CCSM4 model) output. Our results are shown for one future projection period of 2030s. CCSM4 is one of the best performing global climate models from the CMIP5 set of simulations while simulating the monsoonal rainfall in the Indian region. Therefore, we chose this model for historical validation and climate change projections in the focused study region. This model outputs are made freely available and are being used for a variety of policy-making applications.[20,27](Sandeep et al. 2018) For the future projection period, we used the population density data (0.01° x 0.01°) in Uttarakhand provided by the Socioeconomic Data and Applications Centre (SEDAC) of the National Aeronautics and Space Administration (NASA).[11,12] The outputs from the VECTRI simulations have been used to quantify the temperature, rainfall, vector density and malaria transmission intensity in the state of Uttarakhand for the present as well as for the future period. In particular, EIR (Entomological Inoculation Rate) is used to explore the possible changes in the intensity of malaria transmission in the changing climate scenario. In this context, we have analysed only on few outputs from the VECTRI model simulations in this study such as rainfall (mm day^{-1}), mean temperature (°C), adult mosquito density or vector density (per square meter) and EIR (number of infective bites/person/day).

Results and Discussion

Figure 2 shows the VECTRI model performances while simulating the surface temperature, rainfall, vector density, and EIR both from observed Aphrodite data and CCSM4 data during the JJAS period of 1975 to 2005. Results indicate that VECTRI model forced with CCSM4 rainfall is well simulated spatially over most parts of Uttarakhand. Few of the regions show a dry bias of 0 to 1 mm/day in the CCSM4 model when compared with the model results forced with Aphrodite datasets. Similarly, in the case of surface temperature, the model underestimates about 0 to 0.6 °C with respect to the observation in most parts of the state. From the spatial correlation results, it is found that both the observed and model data are in good agreement in most of the regions in Uttarakhand (correlation values are showing between the range of 0.3 to 0.5).

Again, values of vector density and EIR from VECTRI model simulations forced with CCSM4 model data are underestimated in the southern parts of Uttarakhand than their values from VECTRI model simulations forced with observation. In a few of the northern parts of the state, vector density and EIR values are very negligible due to the mountainous regions. From the spatial correlation results, it is found that the vector density and EIR simulations from the model in the central and southern parts are highly correlated to the observation (correlation values are between 0.3 and 0.5).

Figure 3 shows the monthly temperature, rainfall, vector density, and EIR projections for the whole of Uttarakhand during the 2030s. Results indicate an average increase in temperature, rainfall, vector density, and EIR during the SW monsoon (June–September) as projected for 2030s with reference to the baseline period (1975 to 2005). The intensity of monsoon rainfall is projected to increase by 15% with a change of 1 °C in surface temperature in Uttarakhand as a whole during the peak monsoon season, especially during the August month, the rainfall increase is showing nearly 25% when compared with the baseline period. Further, a maximum increase of EIR is seen during the months of September and October indicating a higher malaria transmission during this period.

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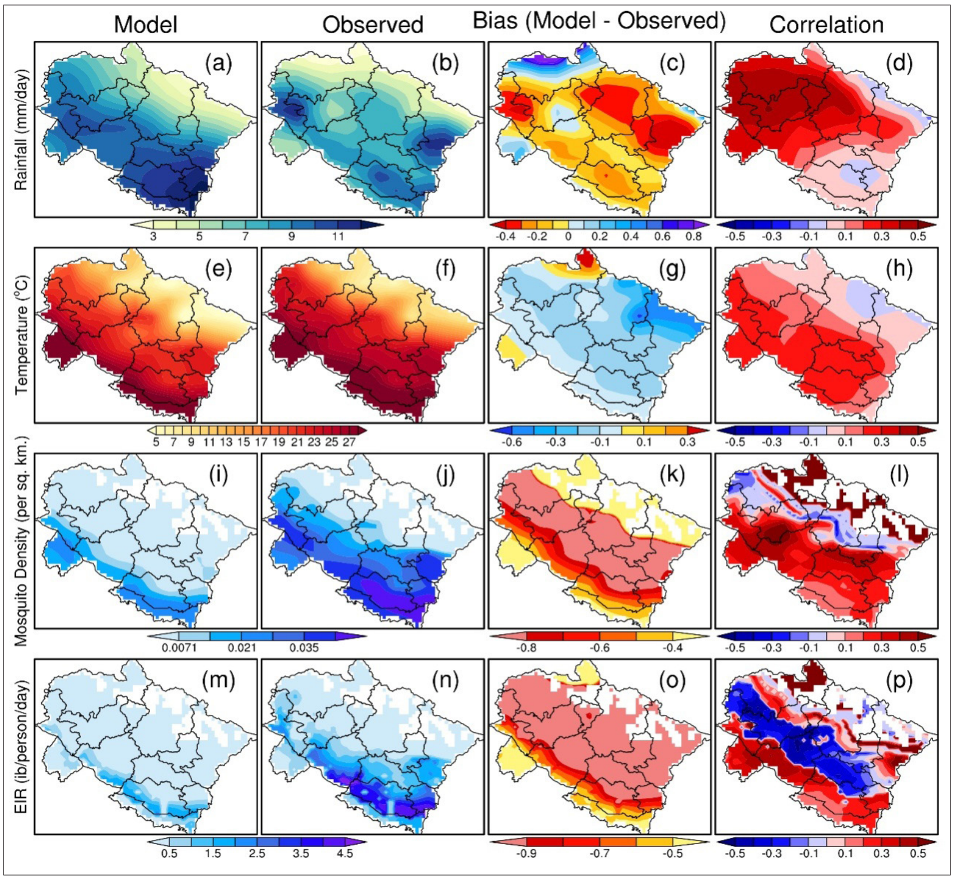

Figure 2.CCSM4 Model Evaluation with respect to the Aphrodite Observation during the Baseline Period of 1975-2005.

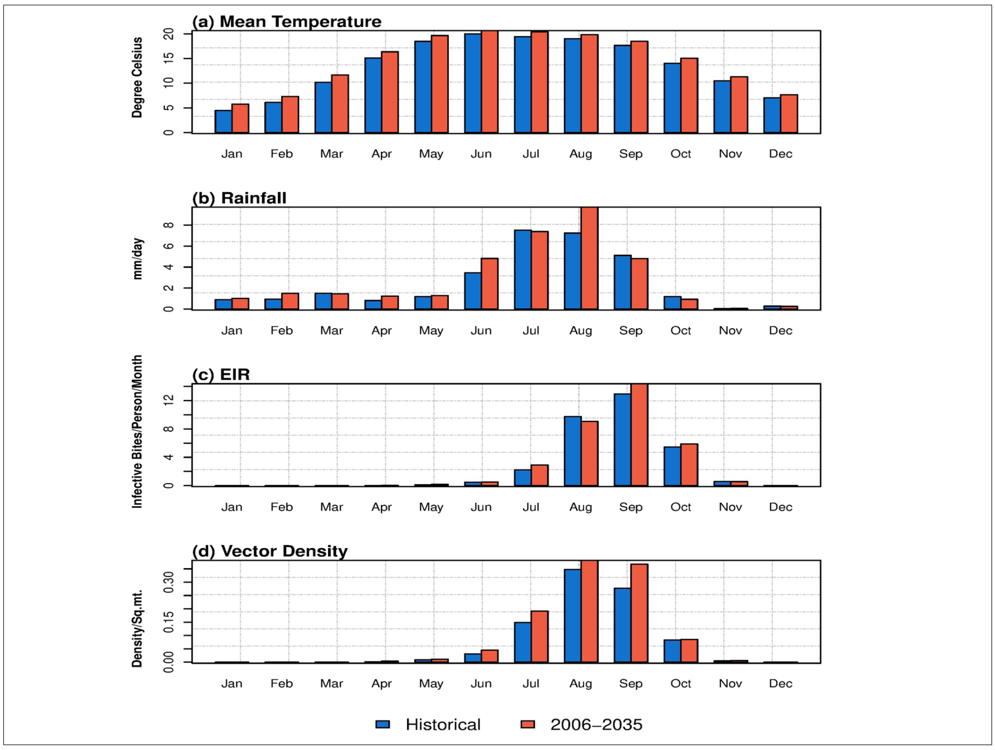

Figure 3.Monthly Mean Values of Simulated Parameters in the whole Uttarakhand State corresponding to the Two-time Slices (Historical and 2006-2035, referred to as 2030s)

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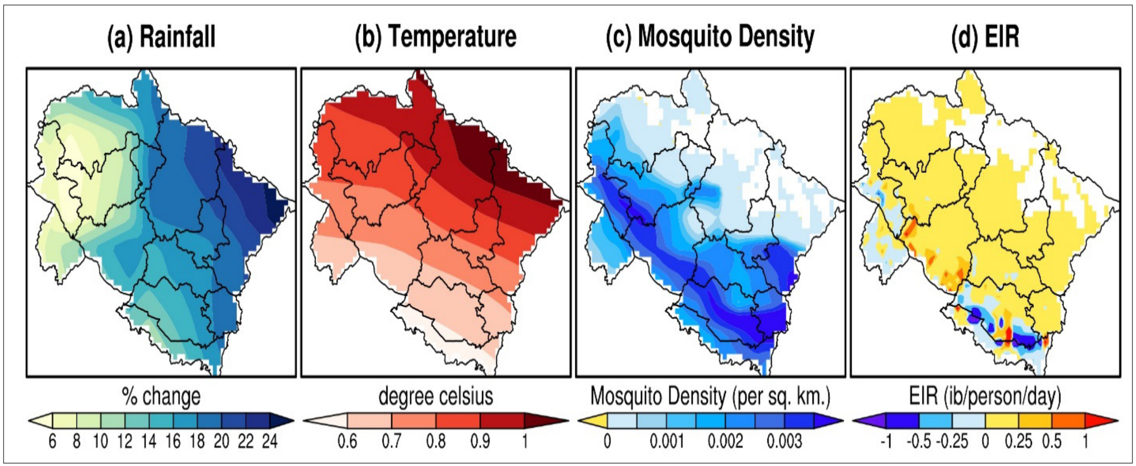

Figure 4.Projections of the VECTRI Simulated Four Parameters (Changes are shown for the Temperature in °C and % Changes are shown for Rainfall, Mosquito Density, and EIR) for 2030s during Summer Monsoon Season (JJAS) with respect to the Baseline Period (1975-2005)

Figure 4 shows the future projections of temperature, rainfall, vector density, and EIR in Uttarakhand for 2030s with respect to the baseline period. Our analysis indicates that a few of the northern districts of Uttarakhand may experience a maximum change in surface temperature of 0.8 to 1 °C by 2030s and with a maximum increase in rainfall of 20 to 25% in the north-eastern districts. Further, changes in vector density in the state show a maximum increase over the central and southern districts. Also, changes in EIR show an increase in most parts of the state except in a few southern districts. Again, no changes are seen in a few northern districts of the state. This can be linked with the mountainous region with less population. The maximum increase in mosquito density and EIR are seen in central parts of the state during the study period and most of these districts are plain areas. It can also be linked with the increase in rainfall of 10 to 18% in these areas which creates favourable conditions for the breeding of mosquitoes with higher malaria transmission.

Conclusion

In this study, we have used VECTRI dynamical model to assess the future malaria transmission dynamics in Uttarakhand state with the changing climate. Results from the global climate model CCSM4 indicate that most parts of Uttarakhand state may experience a maximum rise in surface temperature of 1°C by 2030s with a maximum increase in rainfall of 15% during this period with respect to the historical period (1975-2005). Our results indicate that future warming and an increase in the rainfall intensity during the summer monsoon season (June-September) in Uttarakhand state could potentially increase the spatial and temporal distribution of malaria transmission over the region, and especially during the September month, mosquito density and EIR may increase in future (2030s) under RCP8.5 scenarios. Further central regions of Uttarakhand are seen to be maximum prone to malaria transmission when compared to the other regions. In this study, we have used the historical period of 1975 to 2005 which is very commonly used by the recent climate change research community and this period is considered the present climatology of Uttarakhand state. Although this study presents a preliminary result from one model output and for the near future period (2030s), our next study will focus on the malaria transmission study in Uttarakhand for the far future period i.e. by the end of the century (2080s), using outputs from multi-models and with recent CMIP6 SSPs scenarios.

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Conflict of Interest: None

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References

1. Bal PK, Ramachandran A, Palanivelu K, Thirumurugan P, Geetha R, Bhaskaran B. Climate change projections over India by a downscaling approach using PRECIS. Asia-Pac J Atmos Sci. 2016 Aug;52(4):353-69. [Google Scholar]
2. Blanford JI, Blanford S, Crane RG, Mann ME, Paaijmans KP, Schreiber KV, Thomas MB. Implications of temperature variation for malaria parasite development across Africa. Sci Rep. 2013 Feb;3(1):1. [PubMed] [Google Scholar]

3. Craig MH, Snow RW, le Sueur D. A climate-based distribution model of malaria transmission in sub-Saharan Africa. Parasitol Today. 1999 Mar;15(3):105-11. [PubMed] [Google Scholar]
4. Chaturvedi RK, Joshi J, Jayaraman M, Bala G, Ravindranath NH. Multi-model climate change projections for India under representative concentration pathways. Curr Sci. 2012 Oct:791-802. [Google Scholar]
5. Dhiman RC, Singh P, Yadav Y, Saraswat S, Kumar G, Singh RK, Ojha VP, Joshi BC, Singh P. Preparedness for malaria elimination in the wake of climate change in the State of Uttarakhand (India). J Vector Borne Dis. 2019 Jan;56(1):46. [PubMed] [Google Scholar]
6. Goswami BN, Venugopal V, Sengupta D, Madhusoodanan MS, Xavier PK. Increasing trend of extreme rain events over India in a warming environment. Science. 2006 Dec;314(5804):1442-5. [PubMed] [Google Scholar]
7. Shidrawi GR, Gillies MT. Anopheles paltrinierii, n. sp. (Culicidae: Diptera) from the Sultanate of Oman. Mosq Syst (USA). 1987;19(3):201-11. [Google Scholar]
8. Goklany IM. Climate change and malaria. Science. 2004 Oct;306(5693):55-7. [PubMed] [Google Scholar]
9. Goswami R, Sharma R, Sreenivas V, Gupta N, Ganapathy A, Das S. Prevalence and progression of basal ganglia calcification and its pathogenic mechanism in patients with idiopathic hypoparathyroidism. Clin Endocrinol (Oxf). 2012 Aug;77(2):200-6. [PubMed] [Google Scholar]
10. Gómez-Amores L, Mate A, Miguel-Carrasco JL, Jiménez L, Jos A, Cameán AM, Revilla E, Santa-María C, Vázquez CM. L-carnitine attenuates oxidative stress in hypertensive rats. J Nutr Biochem. 2007 Aug;18(8):533-40. [PubMed] [Google Scholar]
11. Gao J. Global 1-km downscaled population base year and projection grids based on the shared socioeconomic pathways, revision 01. NASA Socioeconomic Data and Applications Center (SEDAC); 2020.
12. Gao J. Downscaling global spatial population projections from 1/8-degree to 1-km grid cells. National Center for Atmospheric Research, Boulder, CO, USA. 2017;1105. [Google Scholar]
13. Koenraadt CJ, Githeko AK, Takken W. The effects of rainfall and evapotranspiration on the temporal dynamics of Anopheles gambiae ss and Anopheles arabiensis in a Kenyan village. Acta Trop. 2004 Apr;90(2):141-53. [PubMed] [Google Scholar]
14. Kumar KK, Kamala K, Rajagopalan B, Hoerling MP, Eischeid JK, Patwardhan SK, Srinivasan G, Goswami BN, Nemani R. The once and future pulse of Indian monsoonal climate. Clim Dyn. 2011 Jun;36(11):2159-70. [Google Scholar]
15. Lindsay SW, Bødker R, Malima R, Msangeni HA, Kisinza W. Effect of 1997–98 EI Niño on highland malaria in Tanzania. Lancet. 2000 Mar;355(9208):989-90. [Google Scholar]
16. Leedale J, Tompkins AM, Caminade C, Jones AE, Nikulin G, Morse AP. Projecting malaria hazard from climate change in eastern Africa using large ensembles to estimate uncertainty. Geospat Health. 2016;11:102-14. [PubMed] [Google Scholar]
17. Martens P, Kovats RS, Nijhof S, De Vries P, Livermore MT, Bradley DJ, Cox J, McMichael AJ. Climate change and future populations at risk of malaria. Glob Environ Change. 1999 Oct;9:S89-107. [Google Scholar]
18. Martens WJ, Niessen LW, Rotmans J, Jetten TH, McMichael AJ. Potential impact of global climate change on malaria risk. Environ Health Perspect. 1995 May;103(5):458-64. [PubMed] [Google Scholar]
19. Mishra SK, Sahany S, Salunke P. CMIP5 vs. CORDEX over the Indian region: how much do we benefit from dynamical downscaling? Theor Appl Climatol. 2018 Aug;133(3):1133-41. [Google Scholar]
20. Mishra SK, Sahany S, Salunke P, Kang IS, Jain S. Fidelity of CMIP5 multi-model mean in assessing Indian monsoon simulations. NPJ Clim Atmos Sci. 2018 Oct;1(1):1-8. [Google Scholar]
21. NVBDCP. National Vector Borne Disease Control Programme Report. 2015; 2017.
22. Omumbo JA, Lyon B, Waweru SM, Connor SJ, Thomson MC. Raised temperatures over the Kericho tea estates: revisiting the climate in the East African highlands malaria debate. Malaria J. 2011 Dec;10(1):1-6. [PubMed] [Google Scholar]
23. Patz JA, Olson SH. Malaria risk and temperature: influences from global climate change and local land use practices. Proc Natl Acad Sci USA. 2006 Apr;103(15):5635-6. [PubMed] [Google Scholar]
24. Paaijmans KP, Wandago MO, Githeko AK, Takken W. Unexpected high losses of Anopheles gambiae larvae due to rainfall. PLoS One. 2007;2(11):e1146. [PubMed] [Google Scholar]
25. Paaijmans KP, Read AF, Thomas MB. Understanding the link between malaria risk and climate. Proc Natl Acad Sci USA. 2009 Aug;106(33):13844-9. [PubMed] [Google Scholar]
26. Singh Parihar R, Bal PK, Kumar V, Mishra SK, Sahany S, Salunke P, Dash SK, Dhiman RC. Numerical modeling of the dynamics of malaria transmission in a highly endemic region of India. Sci Rep. 2019 Aug;9(1):1-9. [PubMed] [Google Scholar]
27. Sahany S, Mishra SK, Salunke P. Historical simulations and climate change projections over India by NCAR CCSM4: CMIP5 vs. NEX-GDDP. Theor Appl Climatol. 2019 Feb;135(3):1423-33. [Google Scholar]
28. Temu EA, Minjas JN, Coetzee M, Hunt RH, Shiff CJ. The role of four anopheline species (Diptera: Culicidae)

ISSN: 0019-5138
DOI: https://doi.org/10.24321/0019.5138.202249

in malaria transmission in coastal Tanzania. Trans R Soc Trop Med Hyg. 1998 Mar;92(2):152-8. [PubMed] [Google Scholar]
29. Tompkins AM, Ermert V. A regional-scale, high resolution dynamical malaria model that accounts for population density, climate and surface hydrology. Malaria J. 2013 Dec;12(1):1-24. [PubMed] [Google Scholar]
30. Van Lieshout M, Kovats RS, Livermore MT, Martens P. Climate change and malaria: analysis of the SRES climate and socio-economic scenarios. Glob Environ Change. 2004 Apr;14(1):87-99. [Google Scholar]
31. WHO. World Malaria Report. UNICEF; 2005.
32. Yasutomi N, Hamada A, Yatagai A. Development of a long-term daily gridded temperature dataset and its application to rain/snow discrimination of daily precipitation. Glob Environ Res. 2011;15(2):165-72. [Google Scholar]
33. Yatagai A, Kamiguchi K, Arakawa O, Hamada A, Yasutomi N, Kitoh A. APHRODITE: constructing a long-term daily gridded precipitation dataset for Asia based on a dense network of rain gauges. Bull Am Meteorol Soc. 2012 Sep;93(9):1401-15. [Google Scholar]
34. Zhang Y, Jordan JM. Epidemiology of osteoarthritis. Clin Geriatr Med. 2010 Aug;26(3):355-69. [PubMed] [Google Scholar]
35. Sharma A, SinghOP, Saklani MM. Climate of Dehradun report.Indian Meteorological Department Government of India, Ministry of Earth Sciences; 2012.
36. BanerjeeA, DimriAP, KumarK. Temperature over the Himalayan foothill state of Uttarakhand: present and future. J Earth Syst Sci. 2021;130:33. [Google Scholar]
37. Raj S, Shukla R,Trigo RM, Merz B, Rathinasamy M, Ramos AM, Agarwal A. Ranking and characterization of precipitation extremes for the past 113 years for Indian western Himalayas.Inter J Clim. 2021;41(15):6602-15. [Google Scholar]

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