An Exploratory Analysis of Malaria and Climatic Factors in India

Sachin Yadav Bodke[1][a] and Usha Ananthakumar[2][b]
[1]*Industrial Engineering and Operations Research, IIT Bombay, India*
[2]*Shailesh J. Mehta School of Management, IIT Bombay, India*

Keywords: India, Malaria Transmission, Seasonality, Rainfall, Temperature.

Abstract: Malaria remains a significant health challenge in India, prompting a thorough analysis of cases in recent years from 2020 to 2022. This study focuses on understanding the spread of malaria over time and across different states, specifically emphasizing the impact of climatic factors such as rainfall and temperature. India's diverse climatic conditions, ranging from hot summers to cold winters, contribute to the complexity of malaria dynamics. Variations in malaria prevalence were observed with changes in rainfall and temperature, particularly during the months of July to October. Our findings reveal a notable increase in malaria cases during a period characterized by significant rainfall and temperature. The study identifies a significant prevalence of malaria cases in India's West, East, and North East regions with peak transmission occurring in the rainy season months. Considering the intricate interplay between climatic factors and disease transmission, this study contributes valuable insights for tailored malaria control strategies during heightened transmission periods.

1 INTRODUCTION

Malaria, a life-threatening vector-borne disease transmitted by infected Anopheles mosquitoes, remains a significant cause of morbidity and mortality worldwide, particularly in tropical and subtropical regions. This study focuses on the spatio-temporal analysis of malaria in India, a country characterized by diverse climates and a large population.

In 2021, nearly half of the global population was at risk of malaria, with an estimated 247 million cases reported worldwide, slightly higher than the 245 million cases in 2020. The majority of cases in 2021 (95 percent) were concentrated in the WHO African region, while the WHO South-East Asia Region and the WHO Eastern Mediterranean Region accounted for 2 percent and 3 percent, respectively. The COVID-19 pandemic led to disruptions in essential malaria services including reporting of Malaria deaths, thus witnessing a decline from 625000 in 2020 to 619000 in 2021. The percentage of total malaria deaths in children under 5 years decreased from 87% in 2000 to 76% in 2015, with no significant change since then (WHO, 2022). The WHO South-East Asia Region, with nine malaria-endemic countries in 2021, accounted for 5.4 million cases and 9,000 deaths, contributing 2% to the global burden of malaria cases. Over the past two decades, the region has witnessed a 76% reduction in malaria cases, from 22.8 million in 2000 to 5.4 million in 2021, and an 82% decline in incidence, from 17.9 to 3.2 per 1000 population at risk. India, in particular, represented 79% of all malaria cases in the region in 2021, with about 40% attributed to the P. vivax strain. Certain Indian states, including Jharkhand, West Bengal, Uttar Pradesh, Chhattisgarh, Odisha, Gujarat, and Madhya Pradesh, consistently reported high malaria cases (WHO, 2022).

Approximately 95% of India's population resides in malaria-endemic areas, with the majority of cases (80%) originating from tribal, hilly, and inaccessible regions where about 20% of the population lives. Notably, from 2020 to 2022, there were 506,764 reported malaria cases and 262 reported deaths due to malaria in India (NVBDCP, 2022). The continued prevalence of malaria in specific geographic and demographic areas underscores the importance of targeted interventions and sustained efforts to control and eliminate the disease.

1.1 GIS in Malaria Research

Geographic Information System (GIS) plays a pivotal role in malaria research and control, offering a versatile tool for various applications. GIS has

[a] https://orcid.org/0009-0000-8947-455X
[b] https://orcid.org/0000-0003-1983-2168

Bodke, S. and Ananthakumar, U.
An Exploratory Analysis of Malaria and Climatic Factors in India.
DOI: 10.5220/0012817400003756

In *Proceedings of the 13th International Conference on Data Science, Technology and Applications (DATA 2024)*, pages 159-168
ISBN: 978-989-758-707-8; ISSN: 2184-285X

proven effective in the creation of base maps, spot maps, and different maps. It excels in mapping vector breeding habitats, delineating malaria risk zones, and analyzing regions with high disease prevalence. By utilizing GIS, researchers can generate insightful maps that aid in understanding past and present disease trends. By mapping malaria incidence and risk, decision-makers can identify priority areas for intervention, optimizing resource allocation and response strategies. This targeted approach enhances the efficiency of disease control efforts. Moreover, GIS-based mapping has proven invaluable in monitoring and evaluating malaria control activities on a broader scale. This technology facilitates the visual representation of control measures' impact over time, enabling authorities to assess the effectiveness of implemented strategies. This, in turn, contributes to the refinement and improvement of ongoing malaria control initiatives.

Noteworthy examples of GIS application in malaria research and control extend globally. Several countries, including various African nations, Brazil, Sri Lanka, Thailand, the Republic of Korea, Indonesia, and Malaysia, have harnessed GIS to enhance their understanding of malaria dynamics and optimize control measures (Saxena et al., 2009). In the context of India, GIS-based studies have been conducted in specific districts. Notably, in 2007, GIS was first incorporated into the national control program for tribal malaria in Madhya Pradesh (Srivastava et al., 2009). This integration marked a significant stride in leveraging GIS for targeted interventions and data-driven decision-making in the fight against malaria.

1.2 Climatic Factors and Malaria

Climatic conditions significantly influence the mosquito's life cycle and the malaria parasite's development. Numerous studies have established a correlation between malaria incidence and various climatic factors, including rainfall, relative humidity, and temperature. Investigating the relationship between malaria incidence and these climatic variables is imperative to provide the health system with early warning signals. Such insights are crucial for the timely implementation of effective vector control activities. Understanding the interplay between climatic conditions and malaria incidence allows for the identification of potential risk periods. Early detection of trends in malaria incidence based on climatic factors enables the health system to implement preventive measures and targeted interventions proactively. This proactive approach is instrumental in curbing the spread of malaria and minimizing its impact on public health.

In essence, the association between climatic conditions and malaria incidence serves as a valuable tool for developing predictive models and early warning systems. By leveraging this knowledge, health authorities can enhance their preparedness and response strategies, ensuring a more efficient and timely control of malaria outbreaks.

1.3 Motivation for this Study

The justification for conducting this study lies in the need to comprehensively understand the geospatial distribution and spatiotemporal clustering of reported malaria cases over a three-year period spanning recent years. This investigation aims to provide valuable insights that can inform targeted malaria interventions and resource allocation, particularly in regions with high malaria endemicity at the state level. Given the current context of climate change, examining the correlation between malaria incidence and climatic factors becomes crucial. This study seeks to contribute to malaria surveillance efforts by predicting disease outbreaks in advance. The analysis of such associations can enhance early warning systems, allowing for proactive measures to be implemented in regions susceptible to increased malaria transmission. Furthermore, the evaluation of the existing malaria surveillance system in India is an essential component of this study. By identifying areas of improvement and refining the surveillance process, this study aims to contribute to the overall effectiveness of malaria control measures in India

2 LITERATURE SURVEY

2.1 Background of Malaria

Malaria is a vector-borne disease caused by Plasmodium parasite transmitted through the bites of infected female Anopheles mosquitoes, which are active between dusk and dawn. These mosquitoes serve as vectors, living organisms capable of transmitting infectious agents between humans or from animals to humans. Of the five Plasmodium species causing Malaria in humans, P. falciparum and P. vivax pose the greatest threat, with P. falciparum being the most lethal. Globally, in 2021, there were approximately 247 million reported malaria cases and 619,000 malaria-related deaths. Alarmingly, children under the age of five accounted for 67 percent of these global malaria deaths in 2018 (WHO, 2022)(NVBDCP, 2022). The incubation period for most malaria cases typically ranges from seven to thirty days, representing the time between the bite of an infected Anopheles mosquito and the onset of initial symptoms. Malaria symptoms can vary from mild or nonexistent to severe and life-threatening. Common symptoms include fever, chills, sweating, headaches, body aches, nausea, vomiting, and general malaise. Preventing and reducing malaria transmission primarily rely on two forms of vector control: insecticide-treated mosquito nets and indoor residual spraying. Additionally, antimalarial medications play a crucial role in preventing Malaria. Suspected cases are confirmed through parasite-based diagnostic testing, which may involve microscopy or a rapid diagnostic test. Early diagnosis and treatment are imperative to reduce transmission and prevent fatalities (CDCP, 2020b).

Several risk factors contribute to the prevalence of Malaria, including climatic and environmental factors, genetic factors, and population density. Socioeconomic and behavioral risk factors, such as a lack of knowledge about Malaria and its control, cultural adherence to traditional and ineffective treatments, and entering endemic regions without preventive measures due to poverty or ignorance, also play a role. Human activities that create mosquito breeding sites, as well as night-time exposure of farmers to mosquito bites during agricultural work, contribute to the risk. Additionally, health system-related factors, such as shortages in human and financial resources, drugs, and equipment, impact the control and management of Malaria (CDCP, 2020a). Numerous research studies have unequivocally established a significant link between vector-borne diseases and environmental factors, offering a key to predicting disease outbreaks and implementing effective control measures. Coldblooded arthropod vectors, crucial agents in these diseases, undergo profound impacts due to temperature fluctuations, influencing their development, behavior, reproduction, and overall population dynamics. Moreover, the interplay of temperature with humidity affects pathogen development within vectors. The significance of rainfall and seasonality in creating breeding grounds for disease vectors cannot be understated, further emphasizing the diverse environmental risk factors, including altitude, slope, soil type, vegetation, and land use/land cover (Gage et al., 2008).

2.2 Climatic Factors and Malaria Transmission

The triad of temperature, relative humidity, and precipitation emerges as pivotal in the context of malaria transmission, orchestrating spatiotemporal changes in malaria vectors. Rainfall, humidity, climate seasonality, and temperature collectively contribute to 70%-90% of the malaria risk. The transmission of Plasmodium falciparum, the causative parasite, is intricately tied to temperature thresholds, with limitations below 16°C – 19°C and above 33°C – 39°C. Relative humidity plays a multifaceted role, impacting vector breeding, parasite development, and the spatial diffusion of malaria transmission. Areas with high vegetation in close proximity to human habitation become hotspots for malaria transmission, particularly when the distance from mosquito breeding sites is less than 2.5 km (Palaniyandi et al., 2017).

2.3 Forests as Malaria Hotspots

Forests emerge as fertile grounds for malaria transmission due to conducive conditions— vegetation cover, temperature, rainfall, and humidity—favoring the distribution and survival of malaria vectors. Tribal populations dwelling in forested areas rely predominantly on indigenous treatments due to factors like illiteracy, adherence to age-old traditions, and a deep-seated fear of the external world. The challenges are compounded by poor communication infrastructure, particularly during the rainy season, when mosquito dispersal dynamics are affected by even slight changes in distances from bodies of water (Kar et al., 2014).

2.4 Recent Studies and Geographical Variations

Over the past decade, numerous studies have delved into the association between malaria incidence and climatic factors, presenting a nuanced understanding of the temporal dynamics. Investigations in China, South Africa, Iran, Thailand, Uganda, Burkina Faso, and India have provided valuable insights into the complex relationships involving meteorological factors. The temporal lagged association between weekly malaria incidence and meteorological factors in 30 counties in southwest China from 2004 to 2009 is shown in (Zhao et al., 2014). Also, an investigation of the effect of monthly rainfall variations on malaria transmission in five districts of Limpopo Province of South Africa for the period 1998 to 2017 is presented in (Adeola et al., 2019). Furthermore, the association of monthly malaria incidence with climatic factors from 2000 to 2012 was studied in Sistan and Baluchestan, Iran (Mohammadkhani et al., 2019). The association of weekly malaria incidence with climatic data throughout the country from 2012 to 2017 in Thailand is presented in (Kotepui et al., 2018). Temporal relationships between environmental factors of weekly rainfall, temperature, and enhanced vegetation index series and malaria morbidity over the period January 2010–May 2013 in Uganda were studied using cross-correlation (Kigozi et al., 2016). Case studies from Bhutan and Odisha, India, reveal distinct geographical nuances. Bhutan experiences a rise in P falciparum cases with rainfall, and the seasonal peak aligns with the monsoon. The P falciparum cases increased by 0.7% for a one mm rainfall, while climatic factors (Temperature, Rainfall) were not associated with P vivax (Wangdi et al., 2020). Odisha reported 26.9% of the total malaria cases (2005-2010) in India, contributing significantly to India's malaria burden, relying on numerical simulations using the VECTRI model, showing the peak of transmission associated with specific temperature and rainfall ranges (Singh Parihar et al., 2019).

3 METHODOLOGY

3.1 Research Objectives

1. To analyze the geospatial distribution of reported malaria cases in India. 2. To explore spatiotemporal clustering of reported malaria cases in India. 3. To study the association of spatiotemporal clustering of reported malaria cases, if any, and potential climatic factors in India.

3.2 Study Area

India, spanning an expansive area of approximately 3.29 million square kilometers, stands as a vast and diverse subcontinent. There are 28 states in India. The geographical features include the towering Himalayan mountain range in the north, the fertile Gangetic plains, the arid Thar Desert in the west, and the extensive coastline along the Arabian Sea and the Bay of Bengal. The extensive coastline stretches for 7,517 km, and the holiest river, the Ganga or Ganges, flows for a remarkable 2,510 km. This diverse topography contributes to a wide range of climates and ecosystems across the country. Geographically, India can be broadly categorized into four regions: the plains, mountains, southern peninsula, and the desert. The eastern and central regions are characterized by the fertile Indo-Gangetic plains, while the arid Thar Desert graces the northwest in Rajasthan. Southern India predominantly features the Deccan plateau, bordered by the Western Ghats and Eastern Ghats mountain ranges along the coastal areas. Additionally, the Aravallis and Vindhyachal are prominent mountain ranges in India. India is the first-most populous country globally, with a population of approximately 1.42 billion people.

India's environmental landscape is characterized by a tropical climate, creating distinct wet and dry seasons. The maximum temperature is 40°C to 47.3°C, and the minimum temperature is -4°C to -1°C . The average annual rainfall is 1635 mm. Monsoon rains, typically from June to September, bring heavy precipitation and contribute significantly to the country's water resources. The tropical conditions, with warm temperatures and high humidity, provide an ideal environment for the proliferation of disease vectors, particularly mosquitoes. Vegetation ranges from dense forests in the Western Ghats to arid landscapes in Rajasthan, contributing to the biodiversity of the subcontinent. The tropical climate of India, with its pronounced wet season during the monsoons, creates favorable conditions for the transmission of vector-borne diseases. Malaria, in particular, thrives in areas with abundant rainfall and warm temperatures. Environmental factors, including temperature, humidity, and vegetation cover, significantly influence the breeding and survival of disease vectors, such as mosquitoes.

3.3 Data Collection

Malaria case data for the period of the specified timeframe was procured from the records of the "National Center for Vector-Borne Diseases Control." These records serve as a comprehensive source for understanding the distribution of malaria cases over the specified timeframe and over all states of India. Additional datasets were acquired to enhance the contextual understanding of the malaria data. Demographic information, providing insights into the population structure and distribution, was sourced from IndiaStat, a reputable data repository. IndiaStat serves as a valuable resource for climatic data, contributing to a holistic analysis of the correlation between malaria cases and climatic factors.

Furthermore, climate records were obtained from the India Meteorological Department, Pune, a crucial element in comprehending the environmental factors influencing malaria transmission. IndiaStat, serving as a reference for climate records, emphasizes the reliability and accuracy of the data, ensuring a robust foundation for assessing the climatic conditions during the specified period. The collaborative nature of data availability on IndiaStat, in association with the India Meteorological Department, Pune, adds credibility to the climate data used in the study. Moreover, the public facilities (i.e., number of hospitals and beds) and the number of beds records state-wise were obtained from the Ministry of Health and Family Welfare.

This multifaceted approach ensures a comprehensive dataset that encompasses the health-related aspects of malaria and demographic and climatic dimensions crucial for a nuanced analysis of the interplay between climatic factors and malaria transmission.

3.4 Data Cleaning and Software Use

Data download was done in Microsoft Office 2019 Excel. All data cleaning and data analysis were done using the Python software version Google Colab. QGIS software desktop version 3.34 was used to extract the India map shapefile. Data cleaning involves the conversion of raw data into a coherent and reliable format suitable for analysis. Ensuring a consistent and reproducible approach to data cleaning is essential. Python software provides an effective platform for performing reproducible data-cleaning tasks. Following tidy data principles ensures that each variable occupies its designated column, each observation aligns with a specific row, and every value is appropriately situated. Adhering to these rules facilitates a more efficient and organized workflow within the Python environment, enhancing the overall data analysis process.

Secondary data files of annual state-wise and monthly malaria case data for the years 2020 to 2022 were read in Python software for their data cleaning. Only relevant columns were kept, and the columns were given proper variable names to be used during analysis. Then, all datasets for 2020 to 2022 were merged into a single dataset. All variables were checked for missing values and imputation was carried out. Data on the temperature are in degrees Celsius (°C) and rainfall in mm. The malaria situation in India from 2020 to 2022 was analyzed using the number of monthly malaria cases and the population. The geospatial distribution of reported malaria cases in India from 2020 to 2022 was analyzed by creating choropleth maps at the state level. Pearson correlation analysis was done to study the association between monthly state-wise malaria cases, monthly statewise rainfall, and temperature values.

4 DATA ANALYSIS AND RESULTS

In our comprehensive study against malaria in India over the years 2020 to 2022, a multifaceted analytical

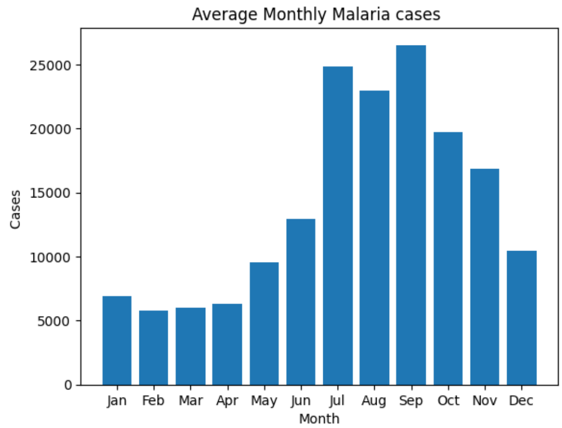

Figure 1: Monthly Average Malaria Cases for 2020-2022.

strategy was applied to gain nuanced insights into the temporal trends, seasonal patterns, and geospatial distribution of malaria cases. Section 4.1 provides results on the first objective, that is, to analyze the geospatial distribution of reported malaria cases in India by the creation of choropleth maps at state levels. Section 4.2 presents results related to the second objective: to explore the spatiotemporal clustering of reported malaria cases in India. The results of the third objective (to study the association of spatiotemporal clustering of malaria cases with potential climatic factors) is presented in section 4.3.

4.1 Epidemiological Situation of Malaria in India During 2020-2022

The epidemiological situation of malaria in India during 2020-2022 was analyzed in terms of population, blood samples examined, total malaria cases, percentage of PF malaria cases, and deaths. The average monthly malaria cases are shown in Figure 1, and data from NVBDCP is summarized in Table 1.

The number of blood samples examined has increased from 2020 to 2022. The total number of malaria cases decreased in 2021 but increased again in 2022. Also, Pf cases and deaths have decreased over the period of study. The histogram shows India's monthly average malaria cases from 2020 to 2022. Here, we can see malaria at its peak from July to November. Temporal analysis has provided a nuanced understanding of malaria cases' seasonality and temporal trends. The identification of peak periods and variations over the study period contributes to a more comprehensive grasp of the disease dynamics.

India is divided into different regions; the North-East region (Arunachal Pradesh, Assam, Meghalaya, Manipur, Nagaland, Mizoram, Tripura), East region

Table 1: Epidemiological situation of malaria in India during 2020-2022.

Year	2020	2021	2022
Population	1396387127	1407563842	1417173173
BSE	97177024	114391977	152083001
Total Cases	186532	161753	176522
Pf Cases	119088	101566	101068
Deaths	93	90	83

BSE: Blood Sampled Examined, Pf: Plasmodium falciparum

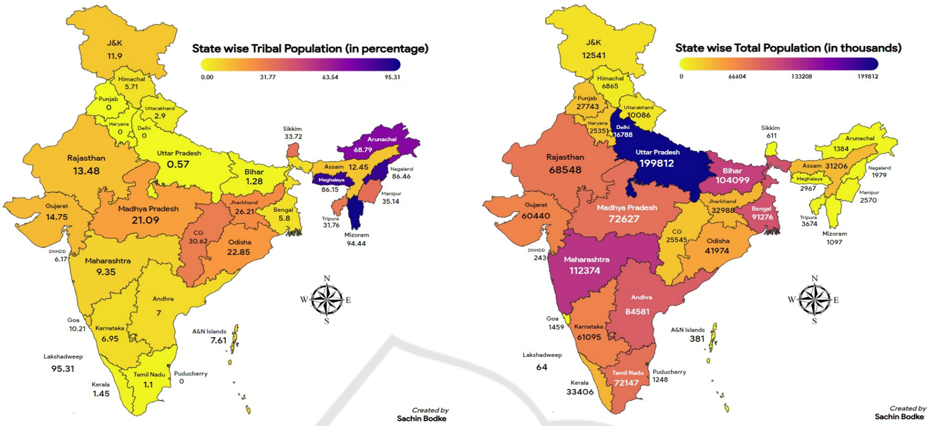

Figure 2: State-wise total population density and tribal population in India based on census 2011.

(Odisha, Chhattisgarh, Jharkhand, and West Bengal), East-South region (Telangana, Andhra Pradesh), South region (Kerla, Tamil-Nadu), South-west region (Karnataka, Goa), West region (Maharashtra, Gujrat), Central region (Madhya Pradesh), Middle-West region (Rajastan), North region (Haryana, Punjab, Delhi, Himachal Pradesh, Uttarakhand, Jammu Kashmir, Ladakh).

Figure 2 shows how population density and tribal population were distributed geographically in India in the year 2011 based on 2011 census data. Mostly, the states on the eastern and northeastern sides are characterized by low population density and a high proportion of the tribal population, and states on the western and middle western sides are characterized by higher population density and a lower proportion of the tribal population.

4.2 Geospatial Distribution of Malaria Cases at the State Level

In order to analyze the geospatial distribution of reported malaria cases at the state level, choropleth maps showing the geospatial distribution of the proportion of malaria cases among states were created. Figure 3 shows choropleth maps depicting the geospatial distribution of Malaria cases among states in India from the year 2020 to 2022. Overall, malaria cases in the states increased in 2021 and again decreased in 2022. Some of the states in the eastern region of India had higher cases than those in the non-eastern region. Odisha, Chhattisgarh, Jharkhand, West Bengal, Maharashtra, and Uttar Pradesh had the highest malaria cases in this three-year period. Figure 4 shows choropleth maps depicting the geospatial distribution of Malaria cases/Population ratio among all states in India from the year 2020 to 2022. Overall, the ratio in India has increased. Mizoram, Tripura, Odisha, Chhattisgarh, Uttarakhand, and Jharkhand have the highest ratio values.

4.3 Association of Spatiotemporal Clustering of Malaria Cases with Climatic Factors

To study the association of spatiotemporal clustering of reported malaria cases with climatic factors, we have considered monthly malaria cases and climatic variables, namely monthly rainfall (in mm) and temperature (in °C) for various states of India. Rainy season in India is usually from June to October. It was observed that there was a peak in malaria cases in July, August, and September, and most of the malaria cases were reported from July to October each year from 2020 to 2022. Thus, malaria cases in India follow seasonal patterns. Figure 5 shows choropleth maps depicting the geospatial distribution of annual rainfall among all states in India from 2020 to 2022.

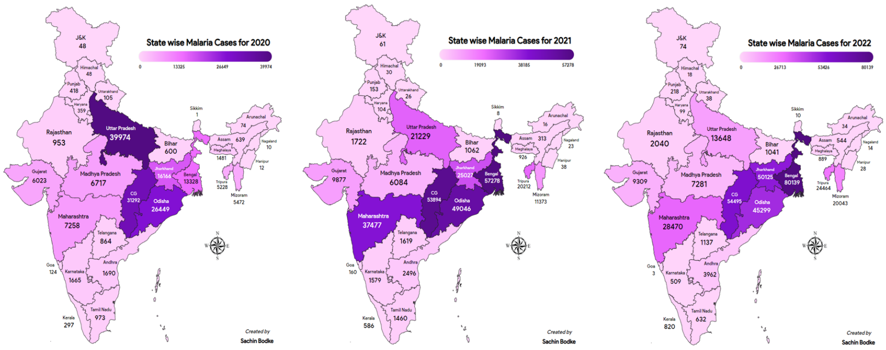

Figure 3: Total malaria cases in India from 2020 to 2022.

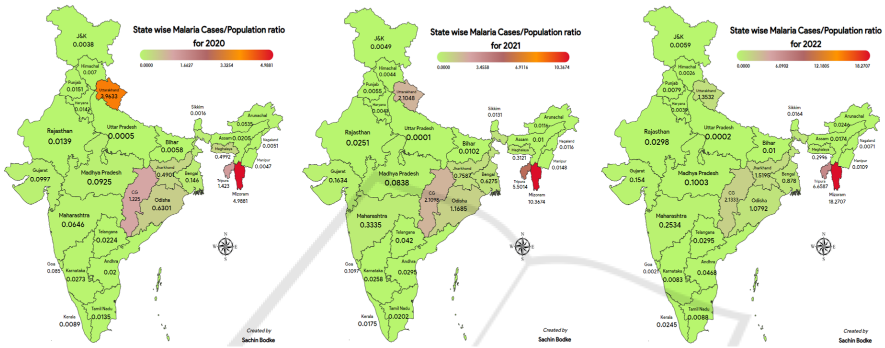

Figure 4: Malaria cases/Population ratio in India from 2020 to 2022.

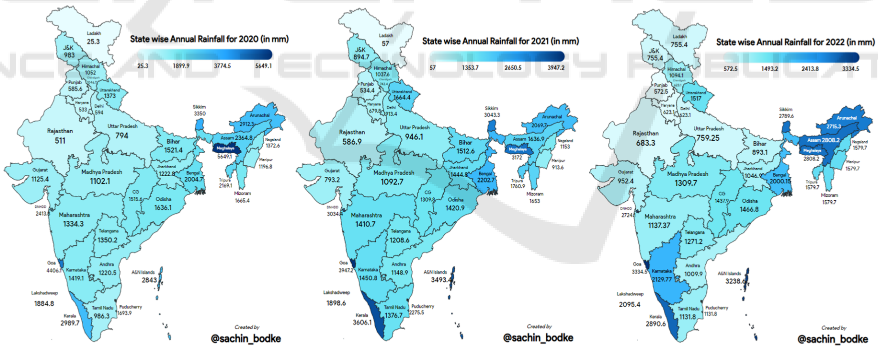

Figure 5: Annual Rainfall in India from 2020 to 2022.

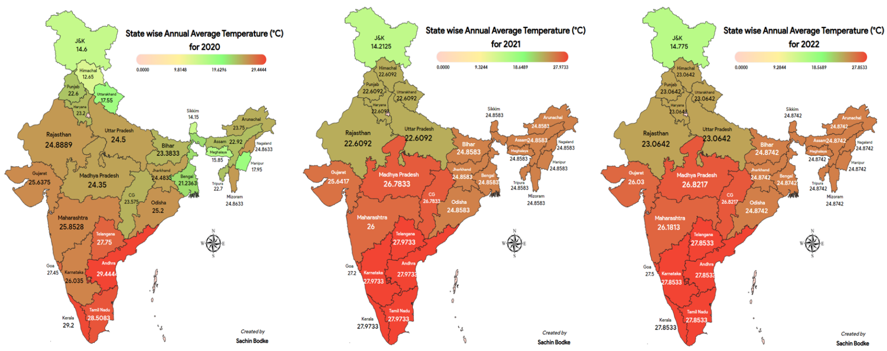

Figure 6: Annual Average Temperature in India from 2020 to 2022.

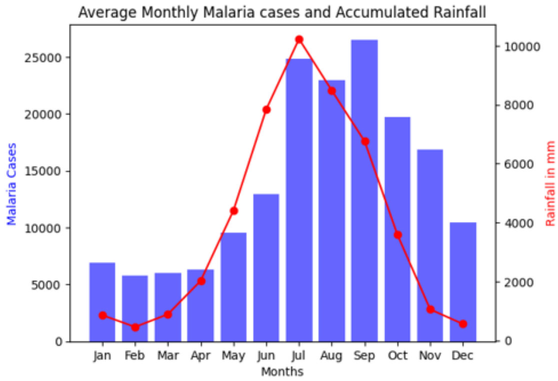

Figure 7: Monthly average malaria cases and rainfall.

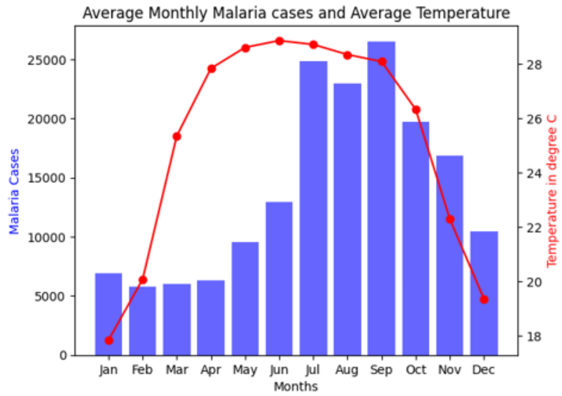

Figure 8: Monthly average malaria cases and temperature.

The overall rainfall pattern was high in 2021. Also, the south-region and northeast regions had higher rainfall records. Figure 6 shows choropleth maps depicting the geospatial distribution of annual average temperature among all states in India from 2020 to 2022. The overall temperature has increased by approximately 0.3 °C. The South-region states have a 27 °C to 28 °C average temperature, the North-East region has a 24 °C to 25 °C average temperature, the west region has 25 °C to 27 °C average temperature, and the north region has 23 °C to 24 °C (except Jammu and Kashmir, it has 14 °C to 15 °C). Summary statistics of monthly state-wise malaria cases and meteorological variables in India in the three-year period from 2020 to 2022 are as follows. The temperature was lowest (-13.6 °C) in the North region (Himachal Pradesh) in January month of 2020 year and highest (48.9 °C) in the Middle-west region (Rajasthan: Ganganagar) in May month of the year 2020. Monthly rainfall was highest (1470.9 mm) in July 2020, while monthly malaria cases were highest (15330 cases) in September 2020 in the Uttar Pradesh state of India.

India's diverse climatic conditions, encompassing distinct summer, winter, and monsoon seasons, contribute to a complex geographical and environmental tapestry. Figure 7 presents the average malaria cases along with the monthly average rainfall. The monsoon season, prevailing from June to September displays variations across the country. Desert regions witness minimal rainfall, while southern parts, particularly South India, receive substantial precipitation. The Himalayan region experiences pleasant spring and autumn seasons.

From April to June, summers in India are characterized by high temperatures, averaging 40 to 49 degrees Celsius. Different regions of India showcase a wide range of climates. Southern states enjoy a pleasant winter season from November to February, with temperatures ranging between 17 to 20 degrees Celsius. Western states also experience agreeable winter climates, while northern states endure freezing temperatures and heavy snowfall due to their proximity to the Himalayas. Eastern states similarly encounter extreme cold conditions. Figure 8 presents the average malaria cases along with the monthly average temperature. It can be seen that the range of 26 degrees Celsius to 29 degrees Celsius is the temperature for peak malaria cases. Leveraging geographical information systems (GIS), geospatial distribution mapping became a powerful tool to visualize the spatial patterns of malaria occurrences across different regions in India. Identifying hotspots and areas with higher disease prevalence contributed to a spatially informed understanding of malaria dynamics. This geospatial perspective provided crucial insights for targeted interventions, including resource allocation and region-specific control measures. Additionally, examining the correlation between malaria cases and meteorological factors allowed for a deeper understanding of dynamics of malaria. The summary statistics of these Pearson correlation coefficients are given in Table 2, highlighting the significance of these associations.

Table 2: Correlation Coefficient Between Monthly Malaria Cases and Meteorological Data.

Year	Monthly Rainfall (in mm)	Temperature (in °C)
2020	0.73*	NA
2021	0.70*	0.53
2022	0.83*	0.48

Note: In Table 2 * means p-value < 0.05, and NA means temperature data was not available.

Table 2 shows that the correlation coefficient between monthly malaria cases and rainfall was high and significant compared to the correlation coeffi-

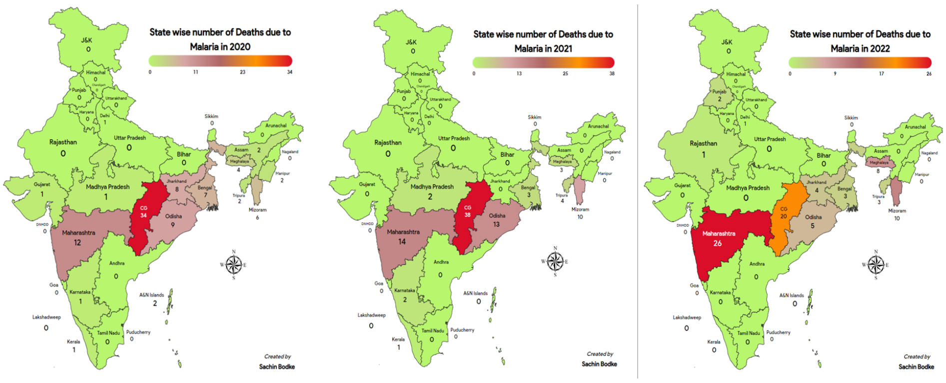

Figure 9: Deaths due to Malaria in India from 2020 to 2022.

cient between monthly malaria cases and temperature. A positive correlation was found between monthly malaria cases and rainfall, while no significant correlation was observed with temperature.

All of these aspects underscore the importance of considering spatial and environmental factors in malaria control strategies.

4.4 Deaths due to Malaria

Figure 9 shows the number of deaths due to Malaria in India from 2020 to 2022. Maharashtra, Chattisgarh, Odisha, Jharkhand, West Bengal, Mizoram, and Meghalaya had higher mortality. The mortality was at its peak in Maharashtra and Chattisgarh states.

5 DISCUSSION

The results of our study on the spatiotemporal clustering of reported malaria cases in India unveil valuable insights into the geographic and temporal dynamics of malaria incidence. Geospatial analysis using Geographic Information System (GIS) tools has allowed us to map the distribution of reported cases, revealing areas with significant clustering. Our findings indicate that certain regions within India exhibit higher concentrations of malaria cases, emphasizing the need for targeted interventions in these specific geographic hotspots. These interventions may include intensified vector control measures, improved healthcare accessibility, and community engagement initiatives. Establishing an early warning system based on the identified spatiotemporal patterns will enable public health authorities to respond promptly to potential outbreaks, thereby reducing the impact of malaria on affected communities.

As we move forward, continuous monitoring and evaluation will be crucial for assessing the effectiveness of implemented interventions and adapting strategies based on evolving spatiotemporal patterns. Our study is a vital resource for informing evidence-based and context-specific malaria control efforts in India, supporting public health initiatives with actionable insights from the comprehensive analysis of reported malaria cases.

REFERENCES

Adeola, A., Ncongwane, K., Abiodun, G., Makgoale, T., Rautenbach, H., Botai, J., Adisa, O., and Botai, C. (2019). Rainfall trends and malaria occurrences in limpopo province, south africa. *International Journal of Environmental Research and Public Health*, 16(24):5156.

CDCP (2020a). Cdc-centers for disease control and prevention (2019b), about malaria biology. https://www.cdc.gov/malaria/about/biology/index.html.

CDCP (2020b). Cdc-centers for disease control and prevention (2019b), about malaria disease. https://www.cdc.gov/malaria/about/disease.html.

Gage, K. L., Burkot, T. R., Eisen, R. J., and Hayes, E. B. (2008). Climate and vectorborne diseases. *American journal of preventive medicine*, 35(5):436–450.

Kar, N. P., Kumar, A., Singh, O. P., Carlton, J. M., and Nanda, N. (2014). A review of malaria transmission dynamics in forest ecosystems. *Parasites & vectors*, 7:1–12.

Kigozi, R., Zinszer, K., Mpimbaza, A., Sserwanga, A., Kigozi, S. P., and Kamya, M. (2016). Assessing temporal associations between environmental factors and malaria morbidity at varying transmission settings in uganda. *Malaria journal*, 15:1–6.

Kotepui, M., Kotepui, K. U., et al. (2018). Impact of weekly climatic variables on weekly malaria incidence throughout thailand: a country-based six-year retrospective study. *Journal of Environmental and Public Health*, 2018.

Mohammadkhani, M., Khanjani, N., Bakhtiari, B., Tabatabai, S. M., and Sheikhzadeh, K. (2019). The relation between climatic factors and malaria incidence in sistan and baluchestan, iran. *Sage Open*, 9(3):2158244019864205.

NVBDCP (2022). National vector borne disease control programme (nvbdcp), 2020-2022. https://ncvbdc.mohfw.gov.in/.

Palaniyandi, M., Anand, P., and Pavendar, T. (2017). Environmental risk factors in relation to occurrence of vector borne disease epidemics: Remote sensing and gis for rapid assessment, picturesque, and monitoring towards sustainable health. *International Journal of Mosquito Research*, 4(3):9–20.

Saxena, R., Nagpal, B., Srivastava, A., Gupta, S., and Dash, A. (2009). Application of spatial technology in malaria research & control: some new insights. *Indian Journal of Medical Research*, 130(2):125–132.

Singh Parihar, R., Bal, P. K., Kumar, V., Mishra, S. K., Sahany, S., Salunke, P., Dash, S. K., and Dhiman, R. C. (2019). Numerical modeling of the dynamics of malaria transmission in a highly endemic region of india. *Scientific Reports*, 9(1):11903.

Srivastava, A., Nagpal, B., Joshi, P., Paliwal, J., and Dash, A. (2009). Identification of malaria hot spots for focused intervention in tribal state of india: a gis based approach. *International Journal of Health Geographics*, 8:1–8.

Wangdi, K., Xu, Z., Suwannatrai, A. T., Kurscheid, J., Lal, A., Namgay, R., Glass, K., Gray, D. J., and Clements, A. C. (2020). A spatio-temporal analysis to identify the drivers of malaria transmission in bhutan. *Scientific Reports*, 10(1):7060.

WHO (2022). World malaria report 2022. https://www.who.int/teams/global-malaria-programme/reports/world-malaria-report-2022.

Zhao, X., Chen, F., Feng, Z., Li, X., and Zhou, X.-H. (2014). The temporal lagged association between meteorological factors and malaria in 30 counties in south-west china: a multilevel distributed lag non-linear analysis. *Malaria journal*, 13:1–12.