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Examining the Relationship between Precipitation, Drainage Connectivity, and Malaria Incidence in India

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Abstract—*Malaria continues to pose a major public health challenge in India, where climatic variability and infrastructural deficiencies contribute to favorable breeding conditions for disease vectors. While stagnant water has long been recognized as a driver of mosquito proliferation, empirical, population-level evidence linking rainfall and drainage infrastructure to malaria transmission in India remains limited. This study examines the relationship between environmental factors and malaria incidence in India, focusing on average annual precipitation and household drainage infrastructure as potential drivers of disease transmission. Using national-level data from 1996 to 2011 for precipitation and state-level data from 2011 for drainage connectivity, the study applies Pearson correlation and linear regression to assess associations with the Annual Parasite Incidence (API), a standardized measure of malaria prevalence. The results indicate a statistically significant positive correlation between higher rainfall and increased malaria cases over time, as well as a significant association between inadequate drainage (measured as the percentage of households with open or no wastewater connectivity) and elevated API across Indian states. While the explanatory power of each model is modest, both tests reject the null hypotheses and identify environmental conditions that contribute meaningfully to disease burden. The study provides quantitative evidence linking infrastructural and climatic factors to public health outcomes, offering a statistical foundation for targeted policy interventions. These findings underscore the importance of climate-responsive urban planning and investment in drainage systems as part of a broader strategy to reduce the incidence of malaria (and other vector-borne diseases) in endemic regions.*

I. Introduction:

Having lived in India for over a decade, I have witnessed the annual monsoon season bring not only vital rain but also significant challenges. Flooding, a consequence of excessive rainfall and inadequate drainage systems, not only disrupts the daily flow of traffic and drowns necessary crops but also poses another fatal risk: Malaria.

Malaria is caused by a protozoan parasite named *Plasmodium*, primarily transmitted by the female *Anopheles* mosquito, which breeds in stagnant water accumulated by rainfall and subpar drainage systems (World Health Organization, 2018; Crutcher & Hoffman, 1996). Globally, malaria continues to affect vulnerable populations, especially in tropical and subtropical regions that offer ideal environmental conditions for mosquito vectors. In 2015, malaria was responsible for an estimated 429,000 deaths and 212 million infections across 91 countries, with 3.2 billion people considered at risk (Centers for Disease Control and Prevention). Warm temperatures, persistent humidity, and seasonal rainfall patterns in such regions enable the *Anopheles* mosquito population to thrive, reinforcing the importance of understanding local ecological conditions in malaria transmission.

According to the World Health Organization, Regional Office for South-East Asia (WHO SEARO, 2014), 95% of India's population lives in malaria-endemic areas, making the disease a pervasive and pressing issue. In 2009, around 1.6 million Indians were affected by malaria, as reported by the National Vector Borne Disease Control Program (NVBDCP), with studies estimating the actual number of malaria cases to be between 9 to 50 times higher (Hay, Gething, & Snow, 2010). These figures underscore the persistent and widespread nature of the disease and the scale of the challenge it poses to the Indian sub-continent.

In India, the most prevalent vector is *Anopheles culicifacies*, accounting for about 60% of all malaria cases (Sharma, 1996). This species has demonstrated remarkable adaptability over time, thriving under harsh conditions and developing resistance to both traditional and synthetic insecticides, such as pyrethroids, making it exceedingly common in both rural and urban ecosystems (Raghavendra et al., 2017). In addition to *Anopheles culicifacies*, other species including *Anopheles fluviatilis*, *Anopheles stephensi*, *Anopheles minimus*, *Anopheles dirus*, and *Anopheles sundaicus* also contribute to malaria transmission across India (Ramachandra Rao, 1984).

Although these species differ in their preferred ecological niches, they share a common breeding behavior: laying eggs in stagnant water (Dash, Adak, Raghavendra, & Singh, 2007). Abiotic environments such as ornamental pools, unused swimming pools, clogged drains, and rain-filled pits serve as fertile breeding grounds. This is of particular concern in India, where poor sewage infrastructure and inadequate drainage systems during the monsoon season result in widespread stagnant water bodies that directly support mosquito proliferation (National Vector Borne Disease Control Programme, 2014).

Given this, this study will examine and analyze the relationship between the average annual precipitation (measured in millimeters per annum) and the Annual Parasite Incidence (API - also referred to as Annual Parasite Index), a metric measuring the total confirmed cases of the malaria Plasmodium standardized by population size, at state-level. Furthermore, it will also examine the relationship between the API and drainage connectivity for wastewater outlets, as an indicator of the number of open bodies of water present. Ultimately, these factors connect to form the basis of the study; Is there a relationship between precipitation rates and malaria cases in India and is there a statistically significant correlation between the number of cases of malaria and the number of stagnant wastewater bodies?

II. Hypotheses:

This study presents 2 sets of null and alternative hypotheses, related to precipitation levels and water bodies. While it is theorized that both these factors are interconnected, it is possible that external factors have an unforeseen impact (i.e. a reduction in mobility during the monsoon season leading to decreased encounters with potential vectors) (Cools, Moons, & Wets, 2009). Therefore, each hypothesis pair should be evaluated independently of the other.

Precipitation Rates:

I. Null Hypothesis: There is no statistically significant relationship between average precipitation rates and the API

II. Alternative Hypothesis: As the average precipitation increases, the API will also increase. There is a positive relationship between these factors. This is theorized as an increase in precipitation should lead to an increase in stagnant water bodies, providing additional nesting spaces for malaria vectors.

Drainage Connectivity:

I. Null Hypothesis: There is no statistically significant relationship between drainage connectivity and API.

II. Alternative Hypothesis: There is a negative correlation between drainage connectivity and API. The worse the drainage connectivity, the higher the API will be, as there will be more stagnant water bodies which will serve as nesting grounds for possible malaria vectors.

III. Data Constraints:

There are inherent challenges when analyzing data from a database that are important to consider. The first issue is that of uncertainties. For example, the data collected by the Government of India (the database used in this study) can't include all cases of malaria, but rather just the reported cases. This is especially significant because a country like India, which lacks an affordable medical infrastructure and has a large rural populace, is likely to have numerous unreported cases. This is commonly mitigated by considering and combining data from various sources; however, this method leads to the significant drawback of not being able to ensure uniformity in the data collection process. Moreover, it is important to note, that the Government of India conducted various studies to ascertain the amount of malaria cases but ended up with vastly differing results over the same time period. This, combined with the challenges of collecting data across a nation as geographically and ethnically diverse as India, led to various published studies all utilizing contradictory base data (Sharma, 2011; Hay, Gething, & Snow, 2010).

In order to combat this, the Indian government has set up a special committee under the purview of the NVBDCP, to determine an accurate representation of malaria cases. While there are contradictions to this data, at the time of writing, this data is considered to be the most comprehensive and accurate, and thus, is utilized in this study. The NVBDCP tests 9 - 10% of the total population per year, with testing rates consistent across years apart from a slight dip below 9% between 2007-2009 and is standardized for population changes (National Vector Borne Disease Control Programme, 2014)

It should also be noted that while the actual scale of malaria cases differs between studies, the relative distribution of cases across regions remains consistent (ICMR-National Institute of Malaria Research (NIMR) - Malaria Research Centre), and thus, for the purposes of this study, we can establish a correlation between malaria cases and drainage connectivity using state-level information. Albeit the results of this study must be considered in light of the constraints of the data and replicated before generalization.

IV. Variables:

Table 1: Variables and Sources

Type of Variable	Name of Variable	Definition/Units	Source
Independent I	Precipitation	Millimeters of rainwater per annum	Ministry of Earth Sciences; India Meteorological Department (IMD)
Dependent I	Annual Parasite Incidence (also referred to as the Annual Parasite Index)	Number malaria cases, expressed per 1,000 individuals surveyed, for a given region/annum	National Center for Vector Borne Diseases Control (NCVBDC)
Independent II	% Households with Open/No drainage - by State	# of houses with open or no drainage divided by total # households in 2011	Government of India, National Census - 2011
Dependent II	Annual Parasite Incidence (also referred to as the Annual Parasite Index) - by State	Number malaria cases, expressed per 1,000 individuals surveyed, for a given region in 2011	National Center for Vector Borne Diseases Control (NCVBDC)

All raw data tables (Tables 2 & 3) are included in the Appendix for review and replication.

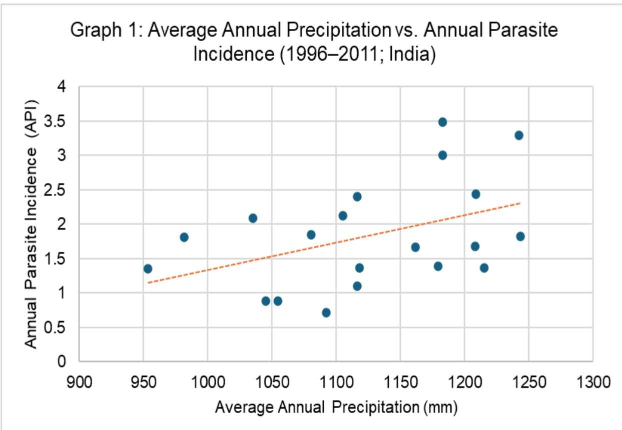
V. Method & Results:

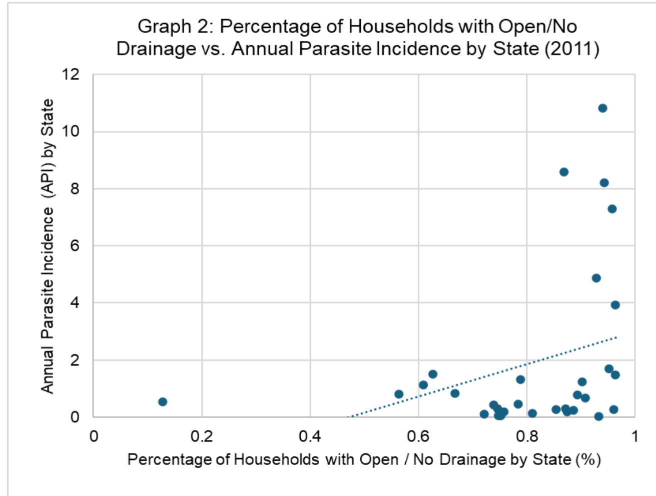
In order to determine whether a relationship existed between average annual precipitation and the Annual Parasite Incidence (API) across India, a dataset was created comparing the two variables across a 16-year period from 1996 to 2011. Precipitation data was sourced from the “All India Weighted Monthly, Seasonal, and Annual Rainfall (mm) 1901–2012” dataset, published by the India Meteorological Department (IMD) under the Ministry of Earth Sciences. Annual values were extracted from the “Annual” column of this dataset, and the years 1996 to 2011 were selected due to their consistency, alignment with verified external data, and overlap with available malaria case records. Corresponding data for the Annual Parasite Incidence — defined as the number of malaria cases per 1,000 individuals surveyed — was obtained from the National Center for Vector Borne Disease Control (NCVBDC).

The data were compiled into Table 2: Average Annual Precipitation (mm) and Annual Parasite Incidence (API) in India, 1995 – 2014, and a scatterplot (Graph 1) was produced to visualize the relationship, with the independent variable (Average Annual Precipitation) was placed on the X-axis, and the dependent variable (API) on the Y-axis. A linear trendline was added to the plot to examine the direction of the relationship. To quantitatively assess the correlation, a Pearson Correlation Coefficient ($r = 0.432$) was calculated, and a one-sided t-test was performed to test the hypothesis that precipitation is positively associated with malaria incidence. Given that both variables are continuous and observed over time, the Pearson correlation and accompanying one-sided t-test were chosen to best evaluate the strength and significance of the hypothesized positive linear relationship. The test returned a t-statistic of 2.035 and a one-tailed p-value of 0.0284, indicating that the relationship was statistically significant at the 5% level, providing evidence against the null hypothesis; supporting the alternative hypothesis that higher annual rainfall is associated with increased malaria incidence over the time period studied.

To further explore environmental determinants of malaria, a second test was conducted to assess the relationship between inadequate household drainage connectivity and Annual Parasite Incidence (API) across different Indian states in the year 2011. Data on the percentage of households with open or no drainage systems was sourced from the 2011 Census of India, published by the Government of India. For each state and union territory, this figure was calculated by dividing the number of households with open/no drainage by the total number of households, resulting in a percentage value for inadequate drainage connectivity. Corresponding API data for each state in 2011 was obtained from the NCVBDC and measured as the number of malaria cases per 1,000 individuals surveyed. This data was consolidated into Table 3: State-wise Household Drainage Conditions and Annual Parasite Incidence (API) in India, 2011.

Furthermore, the data was plotted on a scatterplot (Graph 2) with the independent variable (% of households with open/no drainage) on the X-axis and the dependent variable (API) on the Y-axis. A linear regression was then conducted to quantify the relationship. Linear regression was selected as the appropriate statistical test in this context because the study involved two continuous variables measured across different states in a single year, allowing for the estimation of both the strength and direction of association while accounting for proportional effects. The resulting regression produced a coefficient of 5.65, suggesting that for every 1% increase in open/no drainage households, API increases by 5.65 cases per 1,000 people. The model returned an R^2 value of 0.109, indicating that 10.9% of the variance in API could be explained by inadequate drainage conditions. A one-tailed p-value of 0.035 confirmed that the result is statistically significant at the 5% confidence level, rejecting the null hypothesis, illustrating that there is a positive correlation between poor drainage infrastructure and malaria incidences, in India.





VI. Conclusion and Evaluation:

This study set out to examine whether there exists a statistically significant relationship between two key environmental factors — average annual precipitation and household drainage connectivity — and the prevalence of malaria cases in India, as measured by the Annual Parasite Incidence (API). Given India's climatic diversity, inadequate infrastructure, and continued public health challenges, the aim was to determine whether quantifiable environmental patterns could be linked to malaria transmission in order to better inform disease prevention strategies.

To expand further, the key findings of the study demonstrate that both precipitation and drainage conditions have a measurable and statistically significant impact on malaria incidence. In the first test, a moderate positive correlation was found between average annual precipitation and API over the period 1996–2011. This suggests that years with higher rainfall are often accompanied by increased malaria cases; likely due to a greater number of stagnant water bodies forming during the monsoon season, providing favorable breeding grounds for malaria vectors. In the second test, a regression analysis across Indian states in 2011 showed that as the percentage of households with open or no drainage increased, so too did the incidence of malaria. Specifically, for every 1% increase in such households, the API increased by 5.65 cases per 1,000 people. The strength of this relationship, while modest in explanatory power (with R^2 values of 0.053 and 0.109, respectively), was statistically significant — indicating that inadequate drainage systems are likely a contributing factor to malaria prevalence. In sum, the findings reveal clear environmental risk signals, which, though not exhaustive, offer valuable insight into how infrastructure and ecological factors influence public health outcomes.

These results underscore the broader implications of the study. While both environmental variables individually explained only a modest portion of the variation in malaria incidence, their statistical significance reinforces the role that infrastructure and climate conditions play in public health. This study is therefore intended not only as a statistical investigation but as a policy-relevant prompt: it provides quantitative justification for governmental investment in urban planning, drainage infrastructure, and water management, particularly in states with persistently high malaria incidence. Enhanced drainage systems could disrupt mosquito breeding cycles and significantly reduce disease transmission, especially during the monsoon season.

Beyond infrastructure, the study's findings have broader public health implications. Understanding how ecological conditions influence vector-borne disease transmission allows for more targeted interventions, such as pre-monsoon vector control programs, improved monitoring in high-risk areas, and health education campaigns tailored to specific regions.

However, the study is not without its limitations. It focuses solely on precipitation and drainage, while omitting potentially confounding factors such as population density, urban-rural demographics, public health infrastructure, vector control efforts, climatic variation across states, and socioeconomic conditions — all of which can affect malaria transmission and reporting. Moreover, while data were obtained from the most reliable national sources available, the study is limited by underreporting and variation in diagnostic access, particularly in rural regions. Future studies should seek to incorporate multivariate analysis and longitudinal data across more variables to provide a more comprehensive model of malaria transmission dynamics.

In summary, the evidence presented here supports the conclusion that both increased precipitation and poor drainage infrastructure are positively associated with malaria incidence in India. Though complex and multifactorial, malaria transmission is closely tied to environmental conditions, and this study provides statistical impetus for future public health planning. Reducing malaria, and other vector-borne disease incidents, will not depend solely on medical intervention, but also on environmental engineering, climate-aware urban design, and proactive governance.

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Appendix - Raw Data Tables:

Table 2: Average Annual Precipitation (mm) and Annual Parasite Incidence (API) in India, 1995 – 2014

Year	Precipitation (Annual mm)	API
1995	1242.4	3.2995
1996	1182.9	3.4838
1997	1183.1	3.0075
1998	1208.8	2.4377
1999	1116.6	2.4027
2000	1035.4	2.091
2001	1105.2	2.1224
2002	981.9	1.8147
2003	1243.6	1.8194
2004	1080.5	1.8426
2005	1208.3	1.6806
2006	1161.6	1.6666
2007	1179.3	1.388
2008	1118	1.3668
2009	953.7	1.3565
2010	1215.5	1.3705
2011	1116.3	1.0946
2012	1054.7	0.8852
2013	1092.5	0.7187
2014	1045.2	0.8884

Table 3: State-wise Household Drainage Conditions and Annual Parasite Incidence (API) in India, 2011

Area Name	Total Number of Households	Households with Open Water or No Drainage Connectivity	% of Households with Open Water or no Drainage connectivity
India	246,740,228	201,994,907	82%
State - Andaman & Nicobar Islands	93,376	86,481	93%
State - Andhra Pradesh	21,024,534	16,492,807	78%
State - Arunachal Pradesh	261,614	246,043	94%
State - Assam	6,367,295	6,137,270	96%
State - Bihar	18,940,629	17,674,323	93%
State - Chandigarh	235,061	30,000	13%
State - Chattisgarh	5,622,850	5,326,955	95%
State - Dadra & Nagar Haveli	73,063	53,336	73%
State - Daman & Diu	60,381	36,807	61%
State - Goa	322,813	181,895	56%
State - Gujarat	12,181,718	7,639,512	63%
State - Haryana	4,717,954	3,721,388	79%
State - Himachal Pradesh	1,476,581	1,109,833	75%
State - Jammu & Kashmir	2,015,088	1,761,739	87%
State - Jharkhand	6,181,607	5,736,335	93%
State - Karnataka	13,179,911	9,740,831	74%
State - Kerala	7,716,370	5,768,329	75%
State - Lakshadweep	10,703	9,483	89%
State - Madhya Pradesh	14,967,597	13,504,251	90%
State - Maharashtra	23,830,580	15,910,350	67%
State - Manipur	554,713	532,624	96%
State - Meghalaya	538,299	507,627	94%
State - Mizoram	221,077	192,082	87%
State - Nagaland	399,965	380,737	95%
State - Nct Of Delhi	3,340,538	1,362,745	41%
State - Odisha	9,661,085	9,243,650	96%
State - Puducherry	301,276	228,097	76%

State - Punjab	**5,409,699**	**3,903,149**	**72%**
State - Rajasthan	**12,581,303**	**11,234,789**	**89%**
State - Sikkim	**128,131**	**109,394**	**85%**
State - Tamil Nadu	**18,493,003**	**13,804,027**	**75%**
State - Tripura	**842,781**	**811,781**	**96%**
State - Uttar Pradesh	**32,924,266**	**28,685,501**	**87%**
State - Uttarakhand	**1,997,068**	**1,617,219**	**81%**
State - West Bengal	**20,067,299**	**18,213,517**	**91%**