Original Article

Do Climatic and Socioeconomic Factors Explain Population Vulnerability to Malaria? Evidence from a National Survey, India

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Abstract

Background: Malaria remains a public health challenge across several African and South-East Asia Region countries, including India, despite making gains in malaria-related morbidity and mortality. Poor climatic and socioeconomic factors are known to increase population vulnerability to malaria. However, there is scant literature from India exploring this link using large population-based data. **Objectives:** This study aims to study the role of climatic and socioeconomic factors in determining population vulnerability to malaria in India. **Materials and Methods:** We used logistic regression models on a nationally representative sample of 91,207 households, obtained from the National Sample Survey Organization (69th round), to study the determinants of household vulnerability. **Results:** Households that resided in high (odds ratio [OR]: 1.876, $P < 0.01$) and moderately high (OR: 3.427, $P < 0.01$), compared to low climatically vulnerable states were at greater odds of suffering from malaria. Among households that faced the problem of mosquitoes/flies compared to the reference group, the urban households were at higher risk of suffering from malaria (OR: 8.318, $P < 0.01$) compared to rural households (OR: 2.951, $P < 0.01$). Households from the lower income quintiles, caste, poor physical condition of their houses, poor garbage management, and water stagnation around the source of drinking water, strongly predicted malaria vulnerability. **Conclusion:** Household's vulnerability to malaria differed according to state climatic vulnerability level and socioeconomic factors. More efforts by integrating local endemicity, epidemiological, and entomological information about malaria transmission must be considered while designing malaria mitigation strategies for better prevention and treatment outcomes.

Key words: Climate change, India, malaria, population vulnerability, socioeconomic

Introduction

Globally, in the last two decades, there has been impressive efforts made toward reducing malaria-related mortality and morbidity.[1] Despite such efforts, malaria remains a public health challenge for several African and South-East Asian countries. The WHO South-East Asia Region (SEAR), which includes India, contributed only 2% of global malaria cases in 2020. However, India's case reporting and malaria deaths were disproportionately high in the region, respectively, around 83% and 82%.[1] Such high malaria burden, coupled with the fact that about 95% of India's population reside in malaria-endemic areas,[2] suggest that the population is likely vulnerable to this parasitic disease.

Population vulnerability is generally determined by the level of exposure, sensitivity, and adaptive capacity of any unit (i.e., individual/family/community).[3] It can be assessed through multiple dimensions, including, but not limited to, economic, sociological, anthropological, climate change, nutrition, health, and civil or international unrest.[4] Studies from Africa (contributed to 95% of global malaria cases in 2020)[1] and SEAR countries, using both large and small samples, indicated that population vulnerability to malaria is exacerbated by climate-related and socioeconomic factors.[5-8] Evidence from India that has explored population vulnerability to malaria through climatic factors are mostly conceptual in

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nature.[9,10] Other Indian studies using socioeconomic lens lacks generalizability as they either use a small sample or are state specific.[11,12] To the best of our knowledge, very little evidence from India exists that has explored population vulnerability to malaria through the lens of climatic and socioeconomic factors using a large, nationally representative sample. Our study aims to address this lacuna. In this study, we measure population vulnerability through self-reported cases of household member(s) suffering from malaria.

Materials and Methods

Data and variables

This study was approved by the Research Ethics Review Board (RERB), O. P. Jindal Global University. We created our analytical cross-sectional dataset by merging relevant variables from three secondary data sources. None of our data sources have any personally identifiable information. We used the 69th round of the national sample survey (NSS) unit-level nationally representative data that focused on "Drinking Water, Sanitation, Hygiene and Housing Condition."[13] Data for this round were collected between July and December 2012, by randomly selecting households using a stratified multi-stage design. The first stage units (FSU) consisted of census villages and Urban Frame Survey blocks, from rural and urban sectors, respectively. The ultimate stage units comprised 91,207 households from these sectors, with approximately 56% rural households. We obtained data for the dependent variable and a set of independent variables on households' socioeconomic condition from the NSS. The binary dependent variable enquired if any household member(s) suffered from malaria during the last 30 days from the date of survey. We created dummy variables for all socioeconomic factors, which included categorical variables on income quintile, caste, the highest level of education among male and female members in a household, religion, drainage arrangement, household type, water stagnation around source of drinking water, whether residing in slums, and whether living in rural areas. Second, we obtained information on our main variable of interest – quartile-classified state-level climatic vulnerability– from the "Climate Vulnerability Assessment for Adaptation Planning in India Using a Common Framework" 2019–2020 report.[14] Fourteen indicators, under three major categories (socioeconomic features and livelihood, biophysical aspects, and institution and infrastructure), were used to obtain the state-level climate vulnerability score. Secondary data for these 14 indicators that was used to construct the climatic vulnerability index spanned from 2011 to 2019. In the absence of similar index for 2012 (corresponding to the NSS period), we assume this index as a proxy of state's climatic vulnerability. Third, we computed state-level malaria prevalence based on the caseload of malaria cases in the states in 2012, using the National Health Profile 2015 report.[15]

Methods

Our analysis comprised studying the estimates for the combined, rural, and urban samples separately. We used binary logistic regression technique to explore the association between predictor variables (levels of climatic vulnerability and socioeconomic factors) and a binary response variable (self-reported malaria status, i.e., whether or not any household member is suffering from malaria). This technique allows for studying the probability of a household member suffering from malaria, P, by regressing the logit of the probability on the predictor variables. The generic regression model is as below:

$$logit\left(p_{ij}\right) = \log\left(p_{ij} / (1 - p_{ij})\right) = \beta + \gamma VOI_{ij} + \delta OC_{ij} + \varepsilon_{ij}$$

Where subscripts i and j indicate any member from household i residing in FSU j; VOI is a vector of the primary variable of interest and OC is a vector comprising of socioeconomic covariates; γ and δ are vectors of estimated regression coefficients, respectively, associated with VOI and OC; ε_{ij} is the error term. The above model for the combined sample comprises an additional independent variable that indicates whether a household is from the rural area. Similarly, the model for urban sample comprises an interaction term of whether the household complained of suffering from mosquitoes/flies and live in a slum area. Owing to nonavailability of malaria-causing mosquito data (i.e., anopheles) in the NSS dataset, we assume that it is plausible to test the association between households' vulnerability to malaria by looking at whether they reported suffering from mosquitoes/flies, even though mosquitoes may cause other vector-borne diseases (VBDs). In addition, we conducted multicollinearity test to determine collinearity between variables.

We used unadjusted (UA) and adjusted (A) odds ratio (OR) to determine the extent to which members of a household suffered from malaria; an OR >1 is interpreted as members in a household are that many times at greater odds of suffering from malaria compared to the reference group of households (those not suffering from malaria). We derived the regression estimates using robust standard errors clustered at the FSU level and applied sampling weights provided by the NSS dataset. In addition, to test the robustness between household members malaria reporting and state-level malaria prevalence, we performed a Chi-square test of association. We used STATA 14 (StataCorp LLC, College Station, Texas, USA) to conduct our statistical analysis.

Results

Table 1 presents the descriptive statistics of the variables used in the study for combined (all India), rural, and urban samples. Approximately 5% of the Indian households reported that either of their household members suffered from malaria during the past 30 days from the survey date. More households from rural (6%) compared to urban areas (3.6%) reported suffering from malaria. Around 27% and 33% of households resided in states with high and moderately high climatically vulnerable states, respectively. Approximately 19% and 60% of households lived in high and medium malaria-prevalent states,

Table 1: Summary statistics

Variables	Combined		Rural		Urban	
	Mean	SD	Mean	SD	Mean	SD
Household member (s) suffered from malaria	0.049	0.217	0.060	0.237	0.036	0.186
States by climatic vulnerability						
Highly vulnerable states	0.266	0.442	0.290	0.453	0.233	0.423
Moderately high vulnerable states	0.331	0.471	0.343	0.475	0.315	0.465
Moderately low vulnerable states	0.175	0.380	0.163	0.369	0.190	0.392
Lowly vulnerable states*	0.229	0.420	0.204	0.403	0.261	0.439
States by prevalence of malaria						
High	0.185	0.389	0.195	0.396	0.173	0.379
Medium	0.608	0.488	0.607	0.488	0.610	0.488
Low	0.206	0.404	0.198	0.398	0.217	0.412
Household had mosquito/flies problem	0.986	0.118	0.987	0.113	0.985	0.123
Living in rural areas	0.561	0.496				
Living in a slum	0.058	0.234			0.133	0.339
Income quintiles						
Poorest	0.279	0.449	0.202	0.402	0.378	0.485
Poor	0.168	0.374	0.192	0.394	0.138	0.345
Middle	0.186	0.389	0.214	0.410	0.149	0.356
Rich	0.188	0.391	0.203	0.402	0.169	0.375
Richest*	0.179	0.383	0.189	0.392	0.165	0.372
Caste						
ST	0.125	0.331	0.163	0.370	0.077	0.266
SC	0.185	0.388	0.206	0.404	0.158	0.365
OBC	0.395	0.489	0.402	0.490	0.386	0.487
Others*	0.295	0.456	0.229	0.420	0.379	0.485
Highest education level among male members						
Upto primary	0.285	0.451	0.352	0.478	0.199	0.399
Upto higher secondary	0.538	0.499	0.554	0.497	0.517	0.500
Above higher secondary*	0.177	0.382	0.093	0.291	0.285	0.451
Highest education level among female members						
Upto primary	0.413	0.492	0.510	0.500	0.282	0.450
Upto higher secondary	0.473	0.499	0.446	0.497	0.510	0.500
Above higher secondary*	0.114	0.318	0.044	0.205	0.208	0.406
Religion						
Hinduism*	0.777	0.417	0.789	0.408	0.760	0.427
Islam	0.135	0.342	0.119	0.324	0.156	0.362
Christianity	0.053	0.225	0.056	0.230	0.050	0.218
Others	0.035	0.184	0.036	0.186	0.034	0.182
Drainage arrangement						
Underground*	0.174	0.379	0.059	0.236	0.320	0.467
Covered *pucca*	0.084	0.277	0.046	0.209	0.133	0.339
Open *pucca*	0.201	0.401	0.149	0.356	0.268	0.443
Open *kutcha*	0.157	0.364	0.211	0.408	0.088	0.283
No drainage	0.384	0.486	0.535	0.499	0.191	0.393
Household type						
Self-employed	0.435	0.496	0.490	0.500	0.366	0.482
Regular wage/salary earning	0.228	0.42	0.120	0.325	0.366	0.482
Casual labor	0.259	0.438	0.334	0.472	0.163	0.370
Others*	0.077	0.267	0.056	0.231	0.104	0.306
Physical condition of the house						
Good*	0.401	0.490	0.311	0.463	0.516	0.500
Satisfactory	0.433	0.496	0.478	0.500	0.376	0.484
Bad	0.165	0.371	0.211	0.408	0.107	0.309

Contd...

Table 1: Contd...

Variables	Combined		Rural		Urban	
	Mean	SD	Mean	SD	Mean	SD
Garbage collection by arrangement						
Panchayat/municipality/corporation*	0.215	0.410	0.027	0.162	0.454	0.498
Resident/group of residents	0.229	0.420	0.252	0.434	0.200	0.400
Others	0.027	0.161	0.026	0.161	0.027	0.161
No arrangement	0.530	0.499	0.694	0.460	0.319	0.466
Stagnant water around the source of drinking water						
Yes	0.104	0.305	0.143	0.350	0.055	0.228
No*	0.517	0.500	0.623	0.485	0.382	0.486
Not applicable	0.379	0.485	0.234	0.424	0.563	0.496
Observations	91.207		51.172		40.035	

*Reference category. Author's computation using NSS 69th round data. SD: Standard deviation, Sc: scheduled caste, ST: Scheduled tribe, OBC: Other backward caste, NSS: National sample survey

respectively. Almost all the households (approximately more than 98%) reported facing the problem of malaria/flies. Around 13% of the urban households reported living in the slums. The distribution of households by various socioeconomic factors followed the typical established pattern in the country. For example, a higher percentage of male and female members from households in urban compared to rural areas were educated above a higher secondary level. Thirty-two percent of the drainage arrangement in urban areas were underground, compared to only 6% in rural areas, whereas more than half (53.5%) of the rural households reported no drainage compared to around 19% in urban areas. Around 14% of rural households compared to 5.5% of urban households reported water stagnation around the source of drinking water. On the contrary, an overwhelming 62% of rural households reported no water stagnation around the source of drinking water compared to only 38% in the urban areas. In addition, we performed a multicollinearity test using variance inflation factor (VIF) to determine collinearity between different pairs of study variables [Table 2]. As values of VIF for all the variables across the samples were >10, we assumed that there was no multicollinearity.[16]

The UA and A OR estimates demonstrating association between climatic vulnerability and socioeconomic factors, by household's residence area, are presented in Table 3. The UA OR demonstrated that almost all variables across all the samples significantly predicted higher risks of malaria. However, as the A OR provided more robust estimates by controlling for other covariates in the regression model, we focused our presentation using these estimates. Overall, in India, households that lived in high (OR: 1.876, $P < 0.01$) and moderately high (OR: 3.427, $P < 0.01$), compared to low climatically vulnerable states (reference group) were at greater odds of suffering from malaria. Rural households in these two climatically vulnerable categories compared to the reference group were more vulnerable to malaria than their urban counterparts. Rural and urban households in moderately highly vulnerable states were 3.9 and 2.7 times ($P < 0.01$), respectively, at higher risk of malaria than lowly vulnerable states. At the country level, households that faced the problem of mosquitoes/flies were 3.76 times ($P < 0.01$) more likely to be affected by malaria compared to households that did not face such problems. In rural areas, households that suffered from mosquitoes/flies were almost three times at higher risk of suffering from malaria (OR: 2.951, $P < 0.01$) compared to the households that did not report such issues. In comparison, urban households with mosquitoes/flies problem were more than eight times likely to be suffering from malaria compared to their urban counterparts (OR: 8.318, $P < 0.01$). Households from the urban areas that faced mosquitoes/flies problem as well as lived in the slums (compared to those who did not live in the slums) were 1.57 times ($P < 0.01$) more likely to suffer from malaria. Households from all income quintiles (poorest, poor, middle, and rich) in the country, compared to the richest quintile were at greater odds of suffering from malaria, though not statistically significant (highly significant for UA model). However, the poorest households from urban areas were 1.72 times ($P < 0.10$) at higher risk of malaria than the richest households. The caste of a household also played a significant role in self-reported malaria, both at the country level and in rural areas. Households form the scheduled caste (SC), scheduled tribe (ST), other backward caste (OBC), and compared to others (read General) were around 1.4 times ($P < 0.05$) at higher odds of malaria.

The quality of physical condition of the house also strongly and significantly predicted malaria. In the combined as well as rural samples, households with the satisfactory or bad condition were around 1.4 times ($P < 0.01$) at higher risk of malaria than houses in good condition. Households with informal arrangement of garbage collection compared to Panchayat/municipal level collection in urban areas (OR: 1.42, $P < 0.10$) were at greater odds of reporting sick with malaria. Finally, households that had reported any form of water stagnation around the source of drinking water compared to no stagnation were at higher risk of malaria at the country level (OR: 1.27, $P < 0.01$), as well as in rural (OR: 1.24, $P < 0.01$) and urban (OR: 1.52, $P < 0.10$) areas.

Table 2: Multicollinearity test

Variables	Combined	Rural	Urban
States by climatic vulnerability (base: Lowly vulnerable states)			
Highly vulnerable states	1.89	2.11	1.75
Moderately high vulnerable states	1.87	2.09	1.69
Moderately low vulnerable states	1.51	1.59	1.45
Household suffered from mosquitoes/flies	1.01	1.02	1.01
Household suffered from mosquitoes/flies X living in a slum			1.11
Whether living in rural areas	1.95		
Income quintiles (base: Richest)			
Poorest	2.9	2.24	3.84
Poorest	2.04	2.02	2.17
Middle	1.96	1.98	1.95
Rich	1.83	1.82	1.89
Caste (base: Others)			
ST	1.72	1.91	1.53
SC	1.65	1.84	1.47
OBC	1.6	1.81	1.43
Highest education level among male members (base: above higher secondary)			
Up-to primary	3.23	4.29	2.39
Up-to higher secondary	2.67	3.68	1.99
Highest education level among female members (base: above higher secondary)			
Up to primary	4.48	7.66	2.88
Up to higher secondary	3.63	6.94	2.28
Religion (base: Hinduism)			
Islam	1.13	1.16	1.15
Christianity	1.32	1.33	1.36
Others/rest of the religions	1.08	1.1	1.06
Drainage arrangement (base: Underground)			
No drainage	3.2	5.31	1.88
Open *katcha*	2.26	3.99	1.44
Open *pucca*	1.96	3.14	1.55
Covered *pucca*	1.42	1.72	1.29
Household type (base: others)			
Self employed	5.93	7.85	4.37
Regular wage/salary earning	4.42	3.99	4.2
Casual labor	5.26	7.35	3.36
Physical condition of the house (base: Good)			
Satisfactory	1.46	1.49	1.41
Bad	1.55	1.61	1.48
Garbage collection by arrangement (base: Panchayat/municipality/corporation)			
Resident/group of residents	2.05	8.74	1.2
No arrangement	2.63	9.48	1.44
Others	1.17	2.1	1.05
Stagnant water around the source of drinking water (base: No)			
Yes	1.1	1.08	1.11
Not applicable	1.43	1.24	1.35
Mean VIF	2.28	3.3	1.86

Author's computation using NSS 69th round data. VIF: Variance inflation factor, NSS: National sample survey, SC: Scheduled caste, ST: Scheduled tribe, OBC: Other backward caste

Education level among male and female members of the household and nature of employment, which determined household type, had insignificant impact on the incidence of malaria. Surprisingly, the drainage arrangement produced results contrary to our initial hypothesis across all sample types. Compared to underground drainage (reference group), in the rural areas, households with no drainage, open and covered *pucca* drainage were at higher odds of malaria, although insignificantly. In the urban areas, households with no drainage and open *kutcha* drainage were at lower odds of malaria, albeit insignificantly.

Table 3: Regression results-odds ratio (unadjusted and adjusted estimates)

Variables	Combined		Rural		Urban	
	UA	A	UA	A	UA	A
States by climatic vulnerability (base: Lowly vulnerable states)						
Highly vulnerable states	2.134*** (0.286)	1.876*** (0.242)	2.285*** (0.328)	2.255*** (0.326)	1.010 (0.263)	1.058 (0.236)
Moderately high vulnerable states	3.757*** (0.455)	3.427*** (0.426)	4.080*** (0.541)	3.943*** (0.540)	2.557*** (0.537)	2.649*** (0.562)
Moderately low vulnerable states	0.642** (0.115)	0.591*** (0.105)	0.725 (0.144)	0.665** (0.138)	0.440*** (0.130)	0.454*** (0.123)
Household suffered from mosquitoes/flies	3.874*** (1.606)	3.674*** (1.529)	2.898** (1.333)	2.951** (1.368)	8.510*** (5.913)	8.318*** (5.917)
Household suffered from mosquitoes/flies X living in a slum					1.385* (0.250)	1.572*** (0.331)
Whether living in rural areas	1.990*** (0.177)	1.437*** (0.149)				
Income quintiles (base: Richest)						
Poorest	1.986*** (0.207)	1.158 (0.134)	1.915*** (0.219)	1.051 (0.130)	2.669*** (0.634)	1.715* (0.496)
Poor	1.588*** (0.173)	1.096 (0.128)	1.654*** (0.197)	1.068 (0.134)	1.537* (0.388)	1.152 (0.333)
Middle	1.348*** (0.142)	1.019 (0.113)	1.390*** (0.157)	0.994 (0.116)	1.305 (0.357)	1.065 (0.334)
Rich	1.272** (0.136)	1.078 (0.118)	1.268** (0.147)	1.039 (0.122)	1.379 (0.363)	1.258 (0.363)
Caste (base: Others)						
ST	2.190*** (0.235)	1.453*** (0.166)	2.081*** (0.243)	1.492*** (0.192)	1.056 (0.301)	1.121 (0.325)
SC	1.626*** (0.154)	1.286** (0.135)	1.605*** (0.176)	1.335** (0.165)	1.141 (0.196)	1.011 (0.185)
OBC	1.538*** (0.123)	1.331*** (0.112)	1.579*** (0.147)	1.401*** (0.139)	1.101 (0.158)	1.074 (0.158)
Highest education level among male members (base: above higher secondary)						
Up-to primary	1.607*** (0.158)	0.942 (0.107)	1.218 (0.157)	0.925 (0.129)	1.333** (0.191)	0.883 (0.163)
Up-to higher secondary	1.492*** (0.137)	1.021 (0.104)	1.184 (0.148)	0.987 (0.123)	1.369** (0.173)	1.070 (0.203)
Highest education level among female members (base: above higher secondary)						
Up-to primary	1.928*** (0.241)	0.985 (0.135)	1.419* (0.284)	0.965 (0.194)	1.405** (0.219)	0.922 (0.179)
Up-to higher secondary	1.599*** (0.197)	1.101 (0.146)	1.268 (0.255)	1.070 (0.212)	1.331* (0.196)	1.110 (0.211)
Religion (base: Hinduism)						
Islam	0.827* (0.0847)	0.857 (0.092)	0.708*** (0.0908)	0.739** (0.098)	1.505*** (0.238)	1.153 (0.238)
Christianity	0.592** (0.124)	0.955 (0.183)	0.732 (0.165)	1.113 (0.232)	0.320*** (0.100)	0.479** (0.159)
Others/rest of the religions	1.067 (0.203)	2.005*** (0.359)	1.057 (0.247)	2.086*** (0.470)	1.326 (0.366)	1.619* (0.452)
Drainage arrangement (base: Underground)						
No drainage	1.528*** (0.163)	0.971 (0.109)	1.081 (0.141)	1.038 (0.139)	0.905 (0.180)	0.819 (0.177)
Open *kutcha*	1.425*** (0.176)	0.764** (0.095)	0.984 (0.143)	0.794 (0.116)	1.276 (0.307)	0.922 (0.231)
Open *pucca*	1.217 (0.145)	1.079 (0.124)	0.982 (0.148)	1.197 (0.175)	0.988 (0.174)	0.991 (0.178)
Covered *pucca*	1.214 (0.174)	1.159 (0.163)	1.038 (0.190)	1.187 (0.213)	1.119 (0.239)	1.176 (0.263)
Household type (base: others)						
Self employed	1.595*** (0.256)	1.144 (0.186)	1.389 (0.285)	1.099 (0.227)	1.612** (0.348)	1.179 (0.265)
Regular wage/salary earning	0.883 (0.154)	0.960 (0.169)	0.935 (0.216)	0.964 (0.225)	1.114 (0.248)	0.972 (0.222)
Casual labor	1.404** (0.227)	0.988 (0.165)	1.171 (0.240)	0.956 (0.199)	1.442 (0.348)	1.052 (0.246)
Physical condition of the house (base: Good)						
Satisfactory	1.759*** (0.106)	1.371*** (0.088)	1.642*** (0.116)	1.373*** (0.103)	1.494*** (0.160)	1.253* (0.148)
Bad	1.761*** (0.164)	1.412*** (0.140)	1.644*** (0.168)	1.437*** (0.159)	1.315 (0.251)	1.028 (0.188)
Garbage collection by arrangement (base: Panchayat/municipality/corporation)						
Resident/group of residents	2.054*** (0.261)	1.409** (0.212)	2.476** (0.929)	1.742 (0.671)	1.387* (0.245)	1.417* (0.259)

Contd...

Table 3: Contd...

Variables	Combined		Rural		Urban	
	UA	A	UA	A	UA	A
No arrangement	2.324*** (0.271)	1.246 (0.172)	2.697*** (0.993)	1.575 (0.597)	1.346* (0.212)	1.127 (0.187)
Others	2.882*** (0.597)	1.668** (0.356)	3.433*** (1.434)	2.030* (0.857)	1.858 (0.739)	1.829 (0.725)
Stagnant water around the source of drinking water (base: No)						
Yes	1.372*** (0.112)	1.268*** (0.103)	1.323*** (0.113)	1.242** (0.107)	1.452 (0.367)	1.518* (0.380)
Not applicable	0.602*** (0.0534)	0.972 (0.089)	0.684*** (0.0735)	0.955 (0.102)	0.834 (0.123)	1.005 (0.167)
Observations	80.111		46.928		33.183	

*P<0.1, **P<0.05, ***P<0.01. Author's computation using NSS 69th round data. Robust standard errors clustered at FSU level are in parenthesis. UA: Unadjusted model, A: Adjusted model, NSS: National sample survey, FSU: First stage units, SC: Scheduled caste, ST: Scheduled tribe, OBC: Other backward caste

Discussion

Existing evidence from India that has established the role of climatic factors in malaria vulnerability has done so by providing two sets of arguments either through shift in the transmission window or the disease now occurring in newer areas within the country.[17] Studies exploring population vulnerability to malaria through the lens of climatic factors have been scarce in the Indian context. Using unit-level data from a nationally representative survey, our study confirms that households residing in high and moderately high climatically vulnerable states in India were more prone to suffering from malaria.

Another highlight of this study is greater vulnerability to malaria among the urban households, a fact supported by other researchers.[10,18] Compared to the reference group of rural and urban households that did not suffer from mosquitoes/flies, households with mosquitoes/flies problem in rural and urban areas, respectively, were three ($P < 0.05$) and eight ($P < 0.01$) times at high risk of malaria [Table 3]. Efforts made by local agencies also make a huge difference in terms of controlling malaria. The importance of garbage collection and final disposal in a sustainable manner cannot be discounted, lack of which increased malaria vulnerability of urban households [Table 3]. Urban households compared to their rural counterparts were also at higher risks of malaria when they resided in satisfactory quality houses and had water stagnation problem around the source of drinking water [Table 3]. Such increase in vulnerability among the urban households could be due to spatial changes linked to unplanned urbanization and migration that lead to the formation of slums, as well as poor implementation of developmental activities.[19,20] Slums, which are typically characterized by poor housing, sanitation, and irregular supply of water, affect, and get disproportionately affected by its surrounding environment increasing vulnerability to malaria. Our findings substantiate this aspect; households residing in slums and suffering from mosquitoes are 1.6 times ($P < 0.01$) at higher risks of malaria [Table 3].

Household income is a major determinant of exposure and vulnerability to malaria.[12] Low income alone increased the risk of being affected by malaria 1.7 times ($P < 0.10$) among household members that belonged to the poorest income quintiles in urban areas [Table 3]. Lack of money prohibits households' from taking adequate preventive measures and appropriate treatment, making them vulnerable to malaria and sometimes pushing them below poverty, and subsequently getting trapped in the vicious cycle.[21-23] In addition, ST, SC, and OBC households are more vulnerable to malaria compared to other caste groups across the combined and rural samples [Table 3].

Findings from this study also highlight the importance of integrating malaria management programs with climate change and other related factors across all levels, local, district, and state. An integrated approach is likely to produce effective outcomes. Areas where malaria prevalence is high, a more dedicated approach of changing human behavior, using public health tools of information, education, and communication, should be adopted to propel sustainable control measures. Such tools could be used to inform and educate communities about their health-care needs and availability of quality health services in the neighboring health-care centers to improve malaria-related health outcomes.[24] Malaria management measures should also include households, and school children, apart from the usual VBD management cadre while designing policies, which will ensure greater community-level participation as well as outcome.[25] Apart from this, local endemicity and area-specific epidemiological and entomological information about malaria transmission must be considered while designing malaria mitigation strategies.[26,27] Even though some these aspects are highlighted in the National Program Implementation plans, due to systemic bottlenecks (e.g. human resource gaps at various levels; knowledge, skills, and trainings), development and implementation of micro-plans remain limited.[28]

To address the issue of any possible bias in self-reported malaria cases among surveyed household members across sample types, we performed a Chi-square test of association between state-level malaria prevalence and household members malaria status by their residence areas. Table 4 indicates a high degree of association between these two factors across residence types ($P < 0.001$). The percentage of households

Table 4: Robustness check of self-reported malaria cases

States by prevalence of malaria	Combined (P=0.000)	Urban (P=0.000)	Rural (P=0.000)
Low	2.27	1.48	2.56
Medium	4.96	2.96	5.94
High	8.3	4.01	9.99

Author's computation using NSS 69th round data. NSS: National sample survey

suffering from malaria is directly proportional to the level of malaria prevalence, i.e., more households from high malaria prevalent states compared to medium and low prevalent states, across all residence types, had reported suffering from malaria. Almost 10% of rural and 4% of urban households resided in high malaria prevalent states, compared to 2.6% and 1.5% rural and urban households from low prevalent states reported having malaria.

There are two primary limitations to this study. One, we used self-reported data on malaria status. Although there are studies that are critical of self-reported health data, such data have been used by researchers globally, including developing countries in the absence of medically tested, verified, or reported universal health records.[29] In addition, state-level climatic vulnerability could have been different in states during 2012, the year when the NSS was conducted. In the absence of such comprehensive data on climatic vulnerability, and with the assumption that state-level vulnerability may not have changed significantly over the years, along with the fact that the indicators that were used to compute vulnerability were based on data from 2011 to 2019, we believe this is a valid effort to explore household-level malaria vulnerability.

Conclusion

In this study, we explored whether state-level climatic vulnerability and household's socioeconomic factors determine self-reported malaria. Findings indicated that households from high and moderately high climatically vulnerable states, those who lived in slums and rural areas were at higher risk of malaria. In addition, households from the poorer socioeconomic sections were at greater odds of malaria. Urban households were also disproportionately at greater risk. We also established that there is a strong positive association between self-reporting of malaria from households and the level of state's malaria prevalence.

Any effort to control endemic and epidemic malaria would not succeed without an in-depth understanding of the process of social determinants of health, in the context of malaria. One of the key themes that emerged from the study is that living conditions, particularly those that prevailed in urban slums made such households disproportionately vulnerable. It is important to recognize that a thorough improvement in the standard of living would go a long way in addressing the problem of malaria. At the same time, focused preventive efforts from local bodies and state governments can address the issue considerably and should complement holistic efforts of development. However, strengthening these efforts would mean greater public investment in preventive measures. It is important that the findings of the study are corroborated with the nature of treatment-seeking behavior and consequences of illness on vulnerable households to capture the entire magnitude of the problem, an area of future research.

Even though malaria is on a decline in typically endemic states, it is spreading to newer territories where the disease was rather rare earlier.[17] At the same time another VBD, dengue is on the rise.[30] Findings from the study would be crucial, we believe, to identify the sources of dengue vulnerability among the households. It would be interesting to study whether the socioeconomic vulnerability of dengue is similar to that of malaria or not. Since the dengue mitigation plans typically mimic the existing malaria program, findings from such a comparative vulnerability study would help shape local mitigation efforts against dengue. The NSS data used in the study did not allow us to undertake such a comparison.

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Conflicts of interest

There are no conflicts of interest.

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