Research Article
Artigo de Pesquisa
Artículo de Investigación

DOI: https://doi.org/10.12957/reuerj.2024.87139

Sociodemographic and ecological characterization of malaria among indigenous people in the Amazon in the state of Pará from 2013 to 2022

Caracterização sociodemográfica e ecológica da malária entre indígenas da Amazônia paraense de 2013 a 2022

Caracterización sociodemográfica y ecológica de la malaria entre indígenas de la Amazonia de la región de Pará de 2013 a 2022

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ABSTRACT
Objective: to analyze the sociodemographic and ecological dynamics of malaria incidence among indigenous people living in special indigenous health districts in the Amazon in the state of Pará. **Method:** we conducted a cross-sectional quantitative epidemiological study using secondary data from the period 2013-2022. The data were obtained from the Ministry of Health and analyzed using descriptive statistics. The study did not require ethical approval. **Results:** the findings show that malaria was more prevalent among young people (n=7,304, 31.3%), males (n=13,137, 56.3%) and people who had not completed primary education (n=11,761, 50.4%). The most common form of malaria was Plasmodium vivax (n=21,485, 92.1%) and the most used test was drop/thick smear (n=17,358, 74.4%). There was an upward trend in annual parasite incidence in the River Tapajós district (p=0.022). **Conclusion:** malaria prevalence varied across the special indigenous health districts, with the highest rates being found in the River Tapajós district, representing a greater risk of infection.
Descriptors: Geographic Information Systems; Health Profile; Spatial Analysis; Malaria; Indigenous Peoples.

RESUMO
Objetivo: analisar a dinâmica sociodemográfica e ecológica da incidência da malária entre indígenas segundo os distritos sanitários especiais indígenas da Amazônia paraense. **Método:** estudo epidemiológico, de corte transversal e abordagem quantitativa, realizado com dados secundários do estado do Pará, correspondentes ao período de 2013 a 2022. Os dados são originados do Ministério da Saúde e foram analisados por meio de estatística descritiva, dispensando apreciação do Comitê de Ética em Pesquisa. **Resultados:** o estudo apontou maior ocorrência de malária entre jovens (n=7.304, 31,3%), no sexo masculino (n=13.137, 56,3%) e em pessoas com ensino fundamental incompleto (n=11.761, 50,4%). Predominou a forma clínica da doença por *Plasmodium vivax* (n=21.485, 92,1%) e maior proporção de diagnóstico por gota espessa/esfregaço (n=17.358, 74,4%). Houve tendência de crescimento da incidência parasitária anual no Distrito Rio Tapajós (p=0,022). **Conclusão:** a ocorrência da malária é desigual entre os distritos sanitários indígenas, sendo mais incidente no Rio Tapajós, configurando maior risco de adoecimento.
Descritores: Sistemas de Informação Geográfica; Perfil Epidemiológico; Análise Espacial; Malária; Povos Indígenas.

RESUMEN
Objetivo: analizar la dinámica sociodemográfica y ecológica de la incidencia de la malaria entre los pueblos indígenas según los distritos sanitarios especiales indígenas de la Amazonía de la región de Pará. **Método:** estudio epidemiológico, transversal y cuantitativo, realizado con datos secundarios del estado de Pará, correspondientes al período de 2013 a 2022. Los datos provienen del Ministerio de Salud y fueron analizados mediante estadística descriptiva, sin necesidad de aprobación del Comité de Ética en Investigación. **Resultados:** hay una mayor incidencia de malaria entre jóvenes (n=7.304, 31,3%), sexo masculino (n=13.137, 56,3%) y personas con educación primaria incompleta (n=11.761, 50,4%). Predominó la forma clínica de la enfermedad causada por *Plasmodium vivax* (n=21.485, 92,1%) y una mayor proporción de diagnósticos mediante gota gruesa/frotis (n=17.358, 74,4%). Hubo una tendencia al aumento de la incidencia parasitaria anual en el Distrito Río Tapajós (p=0,022)). **Conclusión:** la incidencia de malaria es desigual entre los distritos sanitarios indígenas, siendo más frecuente en el Río Tapajós, lo que configura un mayor riesgo de enfermedad.
Descriptores: Sistemas de Información Geográfica; Perfil Epidemiológico; Análisis Espacial; Malaria; Pueblos Indígenas.

INTRODUCTION

Malaria is an infectious disease and leading cause of death worldwide with the potential to develop into severe forms, representing a serious public health problem[1,2]. The disease is associated with environmental, sociodemographic, economic, biological and anthropic conditions, and disproportionately affects vulnerable minority groups[3]. The World

This study was financed in part by the *Fundação Amazônia de Amparo a Estudos e Pesquisas* – Brazil (FAPESPA), Institutional Scientific Initiation Scholarship Program PIBIC - UEPA – FORMA PARÁ – Call 072/2023, Finance code 00000.9.000523/2023.
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Editor in chief: Cristiane Helena Gallasch; Associate Editor: Mercedes Neto

Received: Sep 8th 2024 – Accepted: Oct 21st 2024

DOI: https://doi.org/10.12957/reuerj.2024.87139

Health Organization (WHO) acknowledges this vulnerability by recognizing populations at greater risk of contracting and developing fatal forms of the disease, such as children under five and nomadic people[1,4].

The WHO estimates that there were 249 million cases of malaria worldwide in 2022, with an incidence of 58.4 cases per 1,000 people and 608,000 deaths. These cases were mainly in developing countries, which have distinctive population profiles. Socioeconomic inequalities therefore have a direct impact on the perpetuation of the current epidemiological situation[4].

The Amazon region in Brazil accounts for more than 99% of the country's malaria cases. The region concentrates a broad diversity of human groups and is home to the country's largest contingent of indigenous people. The latter is a growing population that, according to the 2022 Census, amounts to 1,694,836 people nationwide spread across 305 ethnic groups and speaking 274 native languages[6]. In the state of Pará, there are 80,980 indigenous people, making it the sixth state with the highest number of indigenous people[6].

In 2023, 22,930 cases of malaria were recorded in the state, 5,200 of which were among indigenous people[7]. The complex interplay between biological, cultural, socio-political and geographical factors results in a unique epidemiological pattern in indigenous areas[3]. Group immunity, influenced by culture and social relationships, together with limited access to health services due to the remoteness of indigenous communities, significantly contribute to this situation[8]. In addition, type of dwelling and cultural competencies also influence the spread and control of the disease in these specific settings[8,9].

The indigenous population requires special attention because this group is vulnerable to complications from infectious and contagious diseases such as malaria[10]. The identification of situations that harm the health of this population is a sine qua non, as the data generated can guide clinical outcomes and action strategies and help prioritize care and assist in the development and implementation health policies[11].

Studies in indigenous areas in the Brazilian Amazon, in the Tapajós River Special Indigenous Health District (DSEI, acronym in Portuguese), have revealed a high incidence of malaria, with rates of 112.6/1,000 inhabitants and 238.6/1,000 inhabitants in 2019 and 2020, respectively. These areas are subjected to intense exploitation of natural resources and predatory activities, increasing the exposure of indigenous populations to a variety of diseases, including malaria, and exacerbating the affliction historically imposed on these peoples[12].

This situation reinforces the need for studies investigating the determinants of malaria, especially given the magnitude of this problem among this group[13]. The relevance of this topic and knowledge gaps warrant the development of studies to explore parasite incidence, exposure to the malaria vector and control strategies, particularly those emphasizing the importance of cultural aspects.

In light of the above, the aim of this study was to analyze the sociodemographic and ecological dynamics of malaria incidence among indigenous populations living in special indigenous health districts in the Amazon in the state of Pará.

METHOD

We conducted a cross-sectional quantitative epidemiological study in the state of Pará using secondary data on indigenous malaria cases during the period 2013-2022, allowing for a more comprehensive analysis.

According to the 2022 census carried out by the Brazilian Institute of Geography and Statistics (IBGE), Pará has 8,120,131 million inhabitants[14], 51,020 of which are indigenous people living on lands encompassed by four DSEIs: the Altamira DSEI, with an area of 159,696 Km² (5,238 inhabitants) covering eight municipalities, 154 villages and 13 indigenous lands; the Kaiapó do Pará DSEI with an area of 35,240 Km² (6,546 inhabitants), covering eight municipalities, 80 villages and three indigenous lands; the Guamá-Tocantins DSEI, with an area of 325,754 Km² (24,223 inhabitants) covering 26 municaplities, 282 villages and 21 indigenous lands; and the River Tapajós DSEI, with an area of 231,906 Km² (15,627 inhabitants), covering five municaplities, 186 villages and eight indigenous lands[15]. DSEIs are decentralized health hubs covering several indigenous communities that are demarcated based on territorial and cultural criteria rather than geographical boundaries.

The study population consisted of 24,946 malaria cases. After exclusions due to inconsistencies in the variables chosen for the study, the final sample consisted of 23,325 cases, corresponding to 93.50% of the original study population.

The malaria case data were obtained from the "Malaria Epidemiological Situation" website[16], from the file named "Interactive Data". The latter are extracted from the "Interactive Bulletin - Malaria in indigenous areas" tab of the Ministry of Health's Epidemiological Surveillance Information System (SIVEP Malaria). The population data were

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obtained from the Secretariat of Indigenous Health (SESAI) by making an online request via the Ministry of Health's Integrated Ombudsman and Access to Information Platform, called "Fala. BR" (https://falabr.cgu.gov.br/web/login). The data were collected between December 2023 and March 2024.

The variables were categorized as follows: number of malaria cases, age, gender, education level, activity over the last 15 days, test result, type of test, DSEI of infection, year of notification and Annual Parasite Incidence (API).

For analysis purposes, the malaria case data were tabulated in a Microsoft Office Excel® spreadsheet and shapefiles representing the DSEIs were obtained from the National Indian Foundation's (FUNAI) website (https://geoserver.funai.gov.br/geoserver/web). We performed a descriptive analysis of the sociodemographic and clinical variables, the results of which are expressed as absolute and relative frequencies.

The API was calculated for each DSEI (unit of analysis) using the following formula: number of positive tests divided by the total population in the year of analysis multiplied by 1,000 inhabitants. The API is an indicator of areas prone to the risk of illness and is divided into four categories: very low risk (< 1.0), low risk (1.0 to 9.9), medium risk (10.0 to 49.9) and high risk (≥ 50.0)[5].

Linear regression analysis was used to assess trends in API over the years, adopting a 5% significance level. Relative risk (RR) of infection was calculated adopting a 95% confidence interval (CI). A space-time analysis was performed, where DSEI was the space and year of notification was the time. After spatialization, thematic maps were created and processed using QGIS® version 3.16. All statistical analyses were carried out using R version 4.1.1.

The study did not require ethical approval as it was conducted using exclusively secondary data available in the public domain.

RESULTS

There were 23,325 cases of indigenous malaria. Prevalence was highest in the River Tapajós DSEI (n=18,794, 80.6%), followed by the Guamá-Tocantins DSEI (n=2,173, 9.3%), Kaiapó do Pará DSEI (n=1,337, 5.7%) and Altamira DSEI (n=1,021, 4.4%), as shown in Tables 1 and 2.

There was a predominance of men (n=13,137, 56.3%), people aged between 20 and 29 years (n=7,304, 31.3%), and people who had not completed primary education (n=11,761, 50.4%). Data on education level was missing in 22.3% (n=5,198) of cases. The most common occupation was "other activities" (n=12,964, 55.6%), followed by agriculture (n=3,310, 14.2%) and wildcat mining (n=2,292, 9.8%). The most common form of malaria was Plasmodium vivax (n=21,485, 92.1%), and most used test was drop/thick smear (n=17,358, 74.4%).

The highest RR was found in the Guamá-Tocantins DSEI, in 2017 (4.06; 95%CI=3.716 - 4.415), followed by the Kaiapó do Pará DSEI, in 2022 (3.39; 95%CI=3.101-3.695).

It is worth highlighting that there was an upward trend in API in the River Tapajós DSEI (p=0.022), representing a greater risk of malaria (Figure 1).

In 2013, the highest APIs were found in the River Tapajós and Altamira DSEIs. In 2014, there was a significant reduction in API in the River Tapajós DSEI, with results similar to those in the Altamira DSEI. There was a sharp rise in API in 2016 in the Kaiapó DSEI of Pará, with similar increases in the Guamá-Tocantins and River Tapajós DSEIs in 2017. Also in 2017, the Altamira DSEI recorded its lowest API throughout the study period. The Altamira and River Tapajós DSEIs showed an upward trend in API from 2017 and 2018, respectively. Peaks of malaria were identified in the Altamira and River Tapajós DSEIs in 2020, and from 2022 onwards, together with a rise in API in the Kaiapó do Pará and River Tapajós DSEIs and stabilization of rates in the Guamá-Tocantins and Altamira DSEIs.

Figure 2 presents the API risk classification, showing that risk was low in the Guamá-Tocantins DSEI in the first four years of the time series, high in 2017 and medium from 2018-2022.

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Table 1: Characteristics according to location, gender and activity in the indigenous population during the period 2013-2022. Pará, Brazil, 2024.

Characteristics	**2013 (n=2,212)**	**2014 (n=524)**	**2015 (n=419)**	**2016 (n=696)**	**2017 (n=1,882)**	**2018 (n=1,455)**	**2019 (n=2,522)**	**2020 (n=4,631)**	**2021 (n=3,785)**	**2022 (n=5,199)**	**Total (n=23,325)**
Altamira	130 (5.9%)	120 (22.9%)	38 (9.1%)	5 (0.7%)	1 (0.1%)	35 (2.4%)	85 (3.4%)	355 (7.7%)	127 (3.4%)	125 (2.4%)	1.021 (4.4%)
API*	16.5	10.4	5.8	0.5	0.2	5.9	14.3	72.0	28.3	33.8	2.173 (9.3%)
RR** (95% CI)	1.54(1.284-1813)	1.36(1.131-162)	0.42(0.295-0.56)	0.05(0.017-0.109)	0.01(0-0.04)	0.33(0.231-0.451)	0.77(0.614-0.942)	3.12(2.807-3.457)	1.11(0.925-1.312)	1.04(0.862-1.225)	
Guamá-Tocantins	69 (3.1%)	25 (4.8%)	15 (3.6%)	26 (3.7%)	517 (27.5%)	397 (27.3%)	344 (13.6%)	268 (5.8%)	242 (6.4%)	270 (5.2%)	
API*	7.4	2.4	1.8	2.9	48.8	21.4	19.2	14.5	12.2	13.5	1.337 (5.7%)
RR** (95% CI)	0.59(0.457-0.733)	0.21(0.135-0.299)	0.12(0.069-0.193)	0.21(0.137-0.298)	4.06(3.716-4.415)	1.57(1.416-1.724)	1.05(0.939-1.16)	0.81(0.712-0.904)	0.73(0.638-0.822)	0.86(0.759-0.963)	
Kaiapó do Pará	12 (0.5%)	55 (10.5%)	104 (24.8%)	323 (46.4%)	60 (3.2%)	76 (5.2%)	109 (4.3%)	56 (1.2%)	41 (1.1%)	501 (9.6%)	
API*	1.2	10.3	7.9	19.3	2.4	8.8	4.4	4.6	24.6	83.9	
RR** (95% CI)	0.1(0.052-0.168)	0.46(0.344-0.585)	0.83(0.681-1.001)	2.5(2.238-2.784)	0.47(0.356-0.592)	0.54(0.429-0.674)	0.76(0.626-0.912)	0.4(0.3-0.508)	0.28(0.202-0.375)	3.39(3.101-3.695)	
Rio Tapajós	2.001 (90.5%)	324 (61.8%)	262 (62.5%)	342 (49.1%)	1.304 (69.3%)	947 (65.1%)	1.984 (78.7%)	3.952 (85.3%)	3.375 (89.2%)	4.303 (82.8%)	18.794(80.6%)
API*	161.2	25.0	19.3	21.6	91.7	55.8	112.6	238.6	289.3	318.7	
RR** (95% CI)	1.26(1.203-1.313)	0.2(0.175-0.218)	0.15(0.134-0.171)	0.19(0.171-0.212)	0.7(0.664-0.74)	0.5(0.473-0.537)	1(0.959-1.048)	1.94(1.876-1.997)	1.6(1.546-1.654)	1.99(1.927-2.045)	
Sex											
Female	959 (43.4%)	212 (40.5%)	163 (38.9%)	233 (33.5%)	831 (44.2%)	602 (41.4%)	1.021 (40.5%)	1.959 (42.3%)	1.750 (46.2%)	2.458 (47.3%)	10.188(43.7%)
Male	1.253 (56.6%)	312 (59.5%)	256 (61.1%)	463 (66.5%)	1.051 (55.8%)	853 (58.6%)	1.501 (59.5%)	2.672 (57.7%)	2.035 (53.8%)	2.741 (52.7%)	13.137(56.3%)
Activity over the last 15 days											
Agriculture	82 (3.7%)	19 (3.6%)	14 (3.3%)	26 (3.7%)	106 (5.6%)	171 (11.8%)	282 (11.2%)	887 (19.2%)	814 (21.5%)	909 (17.5%)	3.310 (14.2%)
Hunting/fishing	302 (13.7%)	89 (17.0%)	27 (6.4%)	64 (9.2%)	450 (23.9%)	161 (11.1%)	102 (4.0%)	259 (5.6%)	195 (5.1%)	213 (4.1%)	1.862 (8.0%)
Road/dan construction	3 (0.1%)	2 (0.4%)	2 (0.5%)	1 (0.1%)	4 (0.2%)	4 (0.3%)	10 (0.4%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	26 (0.1%)
Domestic	264 (11.9%)	88 (16.8%)	58 (13.8%)	57 (8.2%)	149 (7.9%)	75 (5.2%)	157 (6.2%)	245 (5.3%)	198 (5.2%)	279 (5.4%)	1.570 (6.7%)
Plant extraction	2 (0.1%)	34 (6.5%)	11 (2.6%)	16 (2.3%)	41 (2.2%)	0 (0.0%)	5 (0.2%)	4 (0.1%)	4 (0.1%)	14 (0.3%)	131 (0.6%)
Wildcat mining	101 (4.6%)	40 (7.6%)	66 (15.8%)	194 (27.9%)	70 (3.7%)	103 (7.1)	445 (17.6%)	824 (17.8%)	271 (7.2%)	178 (3.4%)	2.292 (9.8%)
Mining	0 (0.0%)	1 (0.2%)	0 (0.0%)	0 (0.0%)	1 (0.1%)	0 (0.0%)	0 (0.0%)	1 (0.0%)	3 (0.1%)	0 (0.0%)	6 (0.0%)
Cattle farming	2 (0.1%)	1 (0.2%)	0 (0.0%)	1 (0.1%)	0 (0.0%)	2 (0.1%)	6 (0.2%)	4 (0.1%)	3 (0.1%)	2 (0.0%)	21 (0.1%)
Tourism	1 (0.0%)	1 (0.2%)	0 (0.0%)	2 (0.3%)	1 (0.1%)	3 (0.2%)	10 (0.4%)	23 (0.5%)	2 (0.1%)	5 (0.1%)	48 (0.2%)
Travelling	16 (0.7%)	2 (0.4%)	5 (1.2%)	1 (0.1%)	8 (0.4%)	13 (0.9%)	13 (0.5%)	17 (0.4%)	28 (0.7%)	26 (0.5%)	129 (0.6%)
Other	1.348 (60.9%)	233 (44.5%)	218 (52.0%)	277 (39.8%)	1.033 (54.9%)	887 (61.0%)	1.468 (58.2%)	2.220 (47.9%)	2.211 (58.4%)	3.069 (59.0%)	12.964(55.6%)
Blank	91 (4.1%)	14 (2.7%)	18 (4.3%)	57 (8.2%)	19 (1.0%)	36 (2.5%)	24 (1.0%)	147 (3.2%)	56 (1.5%)	504 (9.7%)	966 (4.1%)

Notes: *Annual Parasite Incidence; **Relative risk.

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Table 2: Characteristics according to age, educarion, malária clinics and laboratorial test in the indigenous population during the period 2013-2022. Pará, Brazil, 2024.

Characteristics	2013 (n=2,212)	2014 (n=524)	2015 (n=419)	2016 (n=696)	2017 (n=1,882)	2018 (n=1,455)	2019 (n=2,522)	2020 (n=4,631)	2021 (n=3,785)	2022 (n=5,199)	Total (n=23,325)
Age group (years)											
0 - 9	8 (0.4%)	5 (1.0%)	7 (1.7%)	14 (2.0%)	24 (1.3%)	22 (1.5%)	49 (1.9%)	86 (1.9%)	41 (1.1%)	73 (1.4%)	329 (1.4%)
10 - 19	21 (0.9%)	13 (2.5%)	13 (3.1%)	40 (5.7%)	48 (2.6%)	42 (2.9%)	125 (5.0%)	196 (4.2%)	109 (2.9%)	149 (2.9%)	756 (3.2%)
20 - 29	963 (43.5%)	167 (31.9%)	149 (35.6%)	166 (23.9%)	605 (32.1%)	475 (32.6%)	674 (26.7%)	1.193 (25.8%)	1.190 (31.4%)	1.722 (33.1%)	7.304 (31.3%)
30 - 39	696 (31.5%)	160 (30.5%)	110 (26.3%)	151 (21.7%)	581 (30.9%)	425 (29.2%)	673 (26.7%)	1.365 (29.5%)	1.279 (33.8%)	1.691 (32.5%)	7.131 (30.6%)
40 - 49	335 (15.1%)	74 (14.1%)	61 (14.6%)	139 (20.0%)	334 (17.7%)	248 (17.0%)	461 (18.3%)	879 (19.0%)	666 (17.6%)	875 (16.8%)	4.072 (17.5%)
50 - 59	107 (4.8%)	73 (13.9%)	44 (10.5%)	107 (15.4%)	173 (9.2%)	147 (10.1%)	343 (13.6%)	510 (11.0%)	289 (7.6%)	420 (8.1%)	2.213 (9.5%)
60 - 69	71 (3.2%)	22 (4.2%)	33 (7.9%)	71 (10.2%)	91 (4.8%)	80 (5.5%)	172 (6.8%)	322 (7.0%)	169 (4.5%)	211 (4.1%)	1.242 (5.3%)
70 - 79	9 (0.4%)	8 (1.5%)	1 (0.2%)	2 (0.3%)	14 (0.7%)	7 (0.5%)	18 (0.7%)	65 (1.4%)	24 (0.6%)	39 (0.8%)	187 (0.8%)
80 - 100	2 (0.1%)	2 (0.4%)	1 (0.2%)	6 (0.9%)	12 (0.6%)	9 (0.6%)	7 (0.3%)	15 (0.3%)	18 (0.5%)	19 (0.4%)	91 (0.4%)
Education level											
Higher	4 (0.2%)	2 (0.4%)	1 (0.2%)	6 (0.9%)	14 (0.7%)	11 (0.8%)	25 (1.0%)	13 (0.3%)	10 (0.3%)	14 (0.3%)	100 (0.4%)
Secondary	46 (2.1%)	9 (1.7%)	7 (1.7%)	18 (2.6%)	48 (2.6%)	56 (3.8%)	136 (5.4%)	364 (7.9%)	282 (7.5%)	352 (6.8%)	1.318 (5.7%)
Primary	100 (4.5%)	17 (3.2%)	19 (4.5%)	65 (9.3%)	124 (6.6%)	151 (10.4%)	339 (13.4%)	745 (16.1%)	723 (19.1%)	776 (14.9%)	3.059 (13.1%)
Did not complete primary education	1.181 (53.4%)	345 (65.8%)	253 (60.4%)	364 (52.3%)	988 (52.5%)	702 (48.2%)	1.367 (54.2%)	2.392 (51.7%)	1.703 (45.0%)	2.466 (47.4%)	11.761(50.4%)
No education	209 (9.4%)	33 (6.3%)	37 (8.8%)	82 (11.8%)	311 (16.5%)	179 (12.3%)	166 (6.6%)	295 (6.4%)	208 (5.5%)	369 (7.1%)	1.889 (8.1%)
Missing data	672 (30.4%)	118 (22.5%)	102 (24.3%)	161 (23.1%)	397 (21.1%)	356 (24.5%)	489 (19.4%)	822 (17.7%)	859 (22.7%)	1.222 (23.5)	5.198 (22.3%)
Test result											
Falciparum (F)	268 (12.1%)	97 (18.5%)	28 (6.7%)	20 (2.9%)	21 (1.1%)	19 (1.3%)	36 (1.4%)	126 (2.7%)	292 (7.7%)	182 (3.5%)	1.089 (4.7%)
Vivax (V)	1.793 (81.1%)	335 (63.9%)	355 (84.7%)	596 (85.6%)	1.739 (92.4%)	1.298 (89.2%)	2.464 (97.7%)	4.464 (96.4%)	3.448 (91.1%)	4.993 (96.0%)	21.485(92.1%)
Mixed	21 (0.9%)	6 (1.1%)	1 (0.2%)	3 (0.4%)	12 (0.6%)	7 (0.5%)	7 (0.3%)	41 (0.9%)	43 (1.1%)	26 (0.5%)	167 (0.7%)
Non-*Falciparum* (Non-F)	130 (5.9%)	86 (16.4%)	35 (8.4%)	77 (11.1%)	110 (5.8%)	131 (9.0%)	15 (0.6%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	584 (0.1%)
Type of test											
Drop/ thick	2.060 (93.1%)	418 (79.8%)	378 (90.2%)	610 (87.6%)	1.719 (91.3%)	1.123 (77.2%)	2.121 (84.1%)	3.255 (70.3%)	2.507 (66.2%)	3.167 (60.9%)	17.358(74.4%)
Rapid test	152 (6.9%)	106 (20.2%)	41 (9.8%)	86 (12.4%)	162 (8.6%)	332 (22.8%)	401 (15.9%)	1.376 (29.7%)	1.276 (33.7%)	2.032 (39.1%)	5.964 (25.6%)

DOI: https://doi.org/10.12957/reuerj.2024.87139

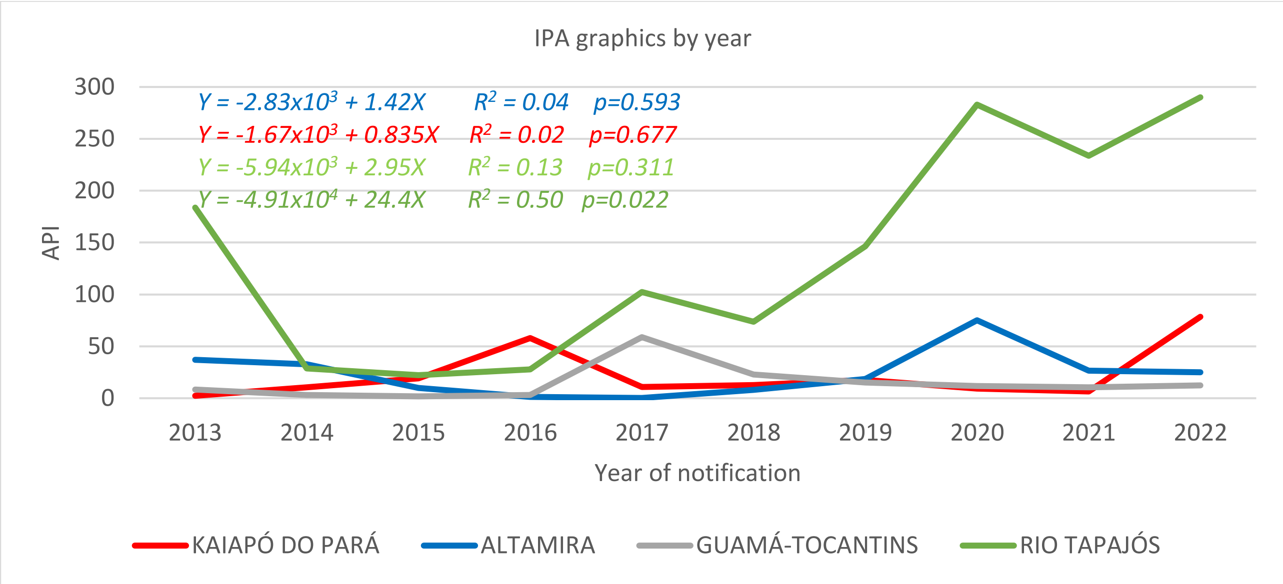

Figure 1: Time series showing the Annual Parasitic Incidence of malaria in the indigenous population between 2013 and 2022 by DSEI. Pará, Brazil, 2024.

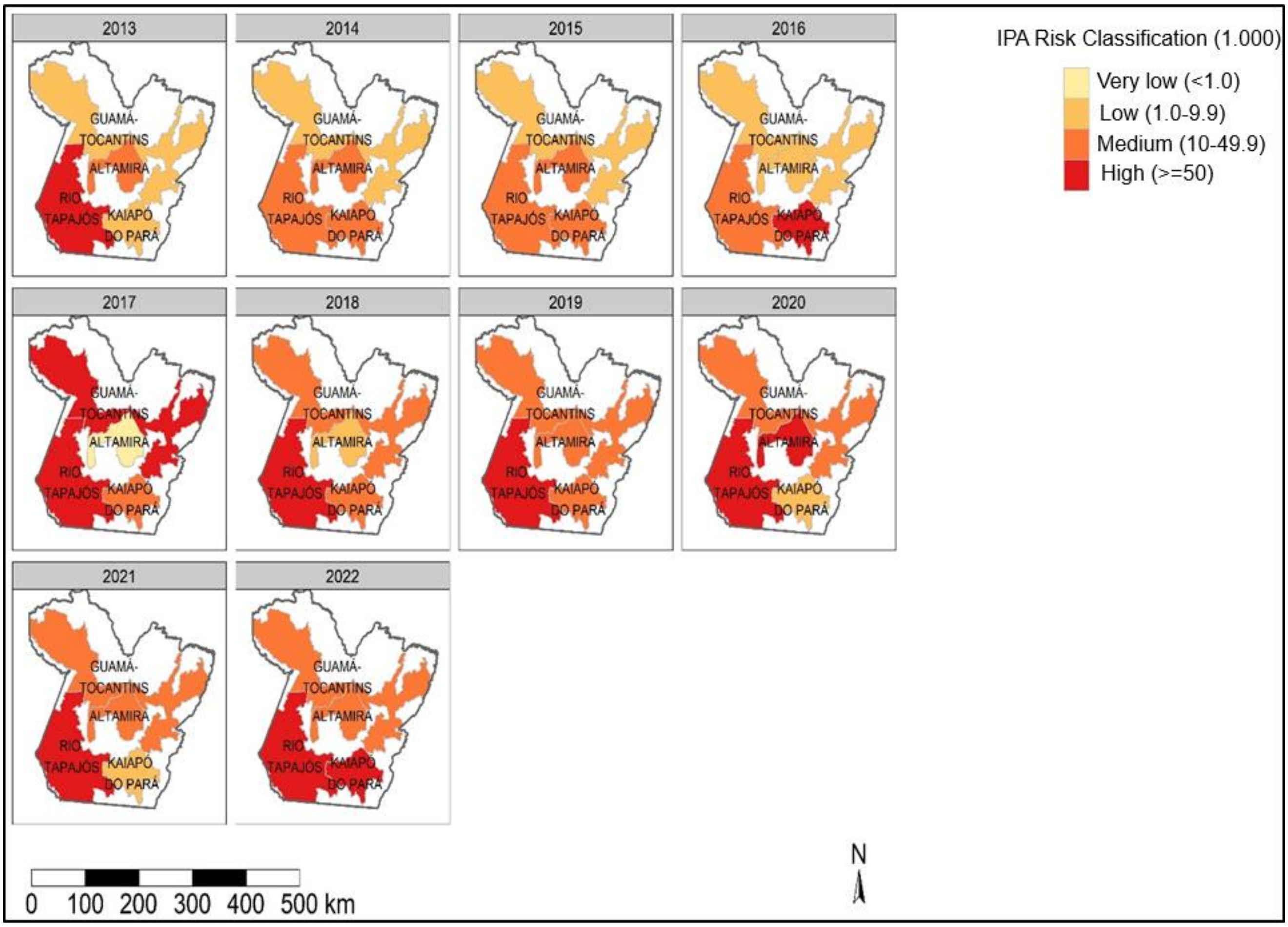

Figure 2: Spatial distribution of the Annual Parasite Incidence of malaria in the indigenous population from 2013 to 2022. Pará, Brazil, 2024.

DOI: https://doi.org/10.12957/reuerj.2024.87139

The Altamira DSEI showed the largest fluctuations in API throughout the period, ranging from medium between 2013 and 2015 to low in 2016, very low in 2017, low in 2018, medium in 2019, high in 2020 and medium in 2021 and 2022. In the Kaiapó do Pará DSEI, API ranged from low in 2013 to medium in 2014 and 2015, high in 2016, medium between 2017-2019, low in 2020 and 2021 and high in 2022. It is worth noting that the API was predominantly high in the River Tapajós DSEI throughout the time series.

DISCUSSION

Malaria is widespread in Pará, especially among the indigenous population, who are particularly susceptible to the disease due to social and environmental vulnerability.

Our findings show higher prevalence of malaria among males. These results are similar to those reported by a study conducted between 2010 and 2020, which showed a predominance of cases among men. This was attributed to activities away from or around the home, such as hunting, fishing, extractivism and mining. Women are less affected, despite working in agriculture[17].

Also, in relation to sociodemographic characteristics, malaria incidence rates were highest in young adults, which may also be related to occupational exposure to malaria. This finding has been repeated in other studies and is cause for concern because these people are economically active. The predominance of malaria in these age groups reflects exposure to higher vector densities while working outdoors, since activities are often performed during periods when mosquitos are most active (dusk and dawn), which may contribute significantly to the high incidence of malaria in this age group[18].

In addition, low levels of education among indigenous peoples has been shown to be a factor driving informal work such as extractive activities[19]. Low education levels, combined with cultural factors, can also pose a barrier to accessing information on disease prevention and changes in lifestyle habits[9,20].

Low-income levels also perpetuate the pursuit of livelihoods in the form of family farming and illegal wildcat mining, which involve practices and habits that lead to exposure to the malaria vector[21]. The potential for infection of indigenous people during mining activities raises the question of whether malaria is an occupational disease. One of the factors influencing the association between the disease and the presence of wildcat mines is the clearing of forest at mining sites and consequent formation of pools of water in the excavated soil, as well increasing population flows due to migration, creating environments that are conducive to increased incidence[22].

The most common form of malaria was Plasmodium vivax. This is confirmed by the Ministry of Health, which recognizes that P. vivax accounts for most cases (84.2%) of malaria due to its short infectious cycle, increasing the chances of transmission[5]. Similar results were observed by a study of indigenous peoples in the state of Roraima between 2013 and 2022, which reported 72,828 cases of malaria, 78.0% of which were caused by *Plasmodium vivax*[23].

Our results show that the tests used in the villages were the thick smear and rapid diagnostic test (RDT). The thick smear is the gold standard for malaria diagnosis, since it provides a morphological confirmation of each species of parasite. The National Malaria Prevention and Control Program recommends the use of the RDT to enable early treatment. However, the availability of this test is often limited, especially in remote and hard-to-reach areas where microscopy services are not available[5].

The geographic distribution of API risk classifications across the DSEIs was uneven, with high risk being found in the River Tapajós DSEI, where the highest disease incidence rates were recorded. Located in the south-west of the state, the River Tapajós DSEI is the district with the largest indigenous population. The district also has high levels of social, economic, cultural and environmental vulnerability, which are risk factors for the maintenance of high rates of the disease[24,25]. These factors may have contributed to the upward trend in API in this district observed since 2017, fueled by the growth of clandestine mining, which is increasingly encroaching on indigenous lands and subsistence farming[23,24].

Increasing environmental degradation exposes indigenous populations to Plasmodium, heightening the risk of malaria. According to a management report produced by the Pará State Department of Public Health in 2020, case numbers show a positive significant correlation with deforestation rates, revealing that higher rates of deforestation are directly related to higher API[25]. Peaks in malaria between 2020 and 2022 may be related to the COVID-19 pandemic, which was declared a global public health emergency. As a result, health services began to prioritize COVID prevention, diagnosis and treatment, hampering malaria control, especially due to the interruption of preventive actions, such as mosquito net and insecticide distribution campaigns and provision of

DOI: https://doi.org/10.12957/reuerj.2024.87139

diagnostic and therapeutic supplies. This situation was further compounded by a reduction in the amount of people seeking health services due to the risk of exposure to the coronavirus[26].

Our findings reveal a sharp rise in malaria rates in the Kaiapó do Pará DSEI in 2022, reaching 80 cases/1,000 inhabitants, an increase of approximately 800% in relation to the previous year[27]. The results of a survey carried out by the Ministry of Health in 2021 reveal an upward trend in eight of the 17 DSEIs that reported disease transmission[27]. This includes the Kaiapó of Pará DSEI, whose status report published in 2023 corroborated these findings, showing that the infections were autochthonous cases caused by Plasmodium vivax[28]. A context analysis attributed this epidemiological behavior to illegal gold mining on indigenous lands, which facilitates the proliferation of the vector, and large migration flows in the region[28]. Indigenous lands in this region have also been subjected to external threats from major infrastructure projects such as road construction, which has had a negative impact on socioenvironmental indicators[24,29].

Creator of the Protected Area Monitoring Program, Instituto Socioambiental (ISA) maps indigenous lands in the Amazon using different indicators to assess institutional, legal and socioenvironmental conditions. The analysis of the Kayapó indigenous lands resulted in a territorial integrity score of 0.78, suggesting high fire outbreak rates[30].

It is worth noting that the rise in API among the Kaiapó people may be related to the high rate of RDT use in the Kaiapó do Pará DSEI, which reached 55% of all tests in 2021, the highest rate of use among DSEI in Brazil, facilitating early diagnosis and the elimination of sources of infection[27]. Although the RDT is not the gold standard for disease detection, its use is recognized as a malaria control strategy, especially among socially vulnerable populations living in remote and hard-to-reach areas, such as indigenous people. The systematic use of this test can reduce cases by up to 50%[27,31].

The Altamira DSEI showed little variation in API over the study period, except in 2020, when there were more than 50 cases/1,000 inhabitants. This result is similar to findings of a previous study that led the Ministry of Health to classify the district as a high risk area[12,32]. This increase may be due to high rates of deforestation driven by the construction of a hydroelectric dam on the Xingu River, mining activities and the large indigenous population living in the municipalities encompassed by DSEI[12,29,32]. A study of indigenous malaria cases in the state of Pará reported an API of 72.0 in 11 wildcat mining sites in the Altamira DSEI[12]. The presence of wildcat mines results in environmental degradation and poses a serious threat to the health of indigenous peoples and traditional communities[12,20,33].

The annual rate of deforestation in the Brazilian Amazon increased to 10,000 km2 between 2019 and 2021, an increase of 56.6% in relation to 2018. In 2020, the state of Pará had the highest deforestation rate among the nine states that make up the Legal Amazon, at 5,084.54 km2, and highest percentage of deforested areas in the Amazon (42.29%)[33,35]. The municipality of Altamira, which houses the administrative center of the Altamira DSEI, accounted for 5.21% of the area deforested in the state, followed by São Félix do Xingu, corresponding to 4.72%[34].

The Guamá-Tocantins DSEI showed little variation in the number of cases over the study period; however, the district showed high rates of malaria in 2017, entering the high risk category. This rise may be due to an increase in the catchment population resulting from the incorporation of the indigenous population living in the Lower Tocantins River and Arapiuns River regions into the district in 2016. In this respect, the Lower Tocantins region has numerous villages, most of which are isolated and only accessible by boat[36].

However, it is important to note that the communities in this district have a similar standard of living to the indigenous peoples living in the other districts, with low socioeconomic status being associated with high malaria prevalence rates. Precarious living conditions in indigenous communities contribute significantly to the spread of the disease. In this sense, poor access to basic sanitation and quality health services, combined with a lack of malaria prevention education, create an environment that is conducive to vector spread and malaria transmission[37].

Understanding the relationship between case increases and distinctive climate-related factors in the Amazon can provide valuable insights into disease dynamics. Climate variability, particularly in terms of temperature and rainfall, has a direct impact on the reproduction and survival of *Anopheles*, with periods of intense rainfall creating ideal mosquito breeding conditions. In addition, high temperatures have been shown to speed up the parasite development cycle, causing outbreaks of the disease at specific times of the year[4,10].

DOI: https://doi.org/10.12957/reuerj.2024.87139

It is also important to explore the relationship between high disease incidence and the region's environmental characteristics. The region's huge swathes of forest, high rainfall and vast river network facilitate mosquito reproduction. High rates of deforestation, agricultural expansion and illegal mining have a clear impact on the proliferation of breeding sites and increase the exposure of indigenous populations to malaria[8].

The variability of geographical factors in DSEIs in the state of Pará, including poor access to health services due to the remoteness of indigenous villages, is one of the factors affecting the spread of the disease[38]. Poor access to services is also influenced by the huge size of DSEIs, with large distances between villages and health centers and administrative centers, as is the case with Santarém and Oriximiná, which are only accessible by air, and Parauapebas, which is more than 700 km from the administrative center of the Guamá-Tocantins DSEI in Belém[36].

In addition to access difficulties, these peoples are invisible in the municipalities where they live. A study carried out in the Guamá-Tocantins DSEI analyzing the incorporation of indigenous health actions and services into municipal health plans revealed the absence of an anthropological approach and that services failed to consider territorial specificities[38].

These factors, together with other specific characteristics of the Guamá-Tocantins DSEI, pose a challenge to health agencies, which need to adopt a comprehensive approach to address this problem and establish efficient disease control and prevention strategies in the district[39].

In this sense, Sustainable Development Goal 3 (good health and well-being), set out in the United Nations 2030 Agenda for Sustainable Development, aims to end global epidemics by 2030, including malaria and other neglected tropical diseases[8,37]. As a result, in 2023, the Ministry of Health stepped up actions to tackle malaria, increasing the number of endemic disease control agents in indigenous areas and the provision of medicines and rapid tests for patient tracing[40].

Study limitations

This study used secondary data, which may limit the analysis of sociodemographic and clinical variables due to the possibility of underreporting and incomplete and inconsistent data. It should be noted that mistakes may have occurred during data collection and recording, affecting data accuracy and, consequently, the results of the study.

Despite these limitations, it is important to stress that health professionals play a key role in encouraging and democratizing the participation of indigenous peoples in health services, focusing on disease prevention, treatment and rehabilitation in tackling this problem. In this respect, knowledge of the reality of indigenous people living in these areas can help professionals evaluate results and, together with local indigenous leaders and public authorities, guide, plan and implement health actions that can meet the needs of this population.

CONCLUSION

The study shows spatial patterns of malaria and fluctuating trends in DSEIs in the state of Pará. The findings reveal a statistically significant upward trend in API in the River Tapajós DSEI.

The findings also show that prevalence of malaria was higher in the male population, people aged between 20 and 39, people with a low level of education and those who perform activities involving greater exposure to the vector.

Disease mapping identified areas with a higher concentration of malaria cases, where the risk of malaria transmission is higher, and provided information that enables risk assessment, monitoring, action planning and the evaluation of healthcare networks.

Given the high prevalence of exposure to the disease, the findings confirm the need to reformulate vector control strategies on indigenous lands, considering the social and spatial factors highlighted above. Given the high incidence of the disease, especially in the Legal Amazon, our results provide new insights for future research on the topic using alternative approaches in different locations in the region.

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Author's contributions

Conceptualization, R.J., R. C. and L.M.; methodology, R.J., R. C. and L.M.; software, R.J. and R.C.; validation, R.J., R.C., I.B., E.F., L.K., L.M., e I.L.; formal analysis, R.J., R.C., I.B., e L.M.; investigation, R.J., R.C., I.B., E.F., L.K., L.M., e I.L.; resources, R.J., R.C., e L.M.; data curation, R.J. and R.C.; manuscript writing, R.J., R.C., I.B., E.F., e L.M.; writing – review and editing, R.J., R.C., I.B., E.F., L.K., L.M. and I.L.; visualization, R.J., R.C., I.B., E.F., L.K., L.M., e I.L.; supervision, L.M. and R.J.; project administration, L.M. and R.J.; financial aquisition, L.M. All authors read and agreed with the published version of the manuscript.