

Malaria in Haiti: A Descriptive and Temporal Study from 2009 to 2018.

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Abstract

Background

Haiti is one of the Caribbean countries where malaria still persists. Malaria occurs throughout the country at altitudes below 600 meters. More than 99% of the malaria cases are caused by *Plasmodium falciparum* and the main vector is *Anopheles albimanus*. This paper aims to describe the epidemiological profile of malaria in Haiti between 2009 and 2018.

Methods

We analyzed information on malaria cases reported by both the Health Ministry of Haiti (Ministère de la Santé Publique et de la Population-MSPP) and the World Health Organization (WHO) during the study period.

Results

Between 2009 and 2018, a total of 232,479 malaria cases were reported by the MSPP. There was an increase in the incidence of malaria in the country in 2010 followed by a decrease in 2011. Due to efforts made by Haiti over the past decade to reduce malaria by 2020, malaria incidence has declined from 60,130 cases in 2010 to 8,978 cases in 2018. We verified that the MSPP and the WHO data are conflicting in relation to the number of cases reported. However, the results from both data sets presented the same malaria trend in Haiti from 2009 to 2018. The results also show the endemicity of the disease throughout Haiti, both in rural and urban areas, especially along the coast.

Conclusion

This work emphasizes the need to promote official data collection and analyses and the application of epidemiological surveillance of malaria for a better knowledge about the real impact of malaria on the Haitian population aiming more appropriate interventions.

Background

Haiti and the Dominican Republic (DR) occupy the island of Hispaniola and are the only countries in the Caribbean where malaria still persists [1]. Of all reported cases of malaria on this island, more than 95% are from Haiti [2]. Malaria remains one of the top ten causes of death in Haiti up today [3]. Occurring in all regions of the country [4], malaria puts at risk more than 80% of the Haitian population [2], mainly for those living below 300m altitude [5]. The predominant malaria parasite is *Plasmodium falciparum* [6, 7]. *Plasmodium malariae* was registered in Haitian refugees in Jamaica [8], and recently in an infant in Les Irois in the department du Sud of Haiti (personal communication). Furthermore, some cases due to *Plasmodium vivax* were confirmed in Haiti in 1946 [9] and 1983 [10]. However, no study has shown the autochthonous circulation of *P. vivax* in Haiti ever since. Therefore, the transmission of *P. vivax* malaria is considered absent in Haiti [11, 12].

Anopheles (Nyssorhynchus) albimanus Wiedemann is the only species that meets all the malaria vector criteria in Haiti to date [13, 2]. The role of a secondary vector in Haiti could be played by *Anopheles (Nyssorhynchus) pseudopunctipennis* Theobald, as this species has played important role in malaria transmission in Mexico, Guatemala, Nicaragua, Bolivia, Ecuador, Peru, and Argentina. However, *An. pseudopunctipennis* has not been found in the country since October 1986. At that time, only 55 *An. pseudopunctipennis* were captured in Haiti and its local breeding sites remain unknown until now [14, 15].

In 2009 Haiti and the Dominican Republic have developed a binational strategic plan with the aim of eliminating malaria on the island of Hispaniola by 2020 [16, 17]. Despite the fact that this goal has not been achieved, progress has been made by strengthening prevention and treatment activities [3]. In this context, Haitian national health policy presently prohibits presumptive treatment of malaria in Haiti, requiring a parasitological diagnosis prior to any treatment and considers chloroquine as the first-line drug for the treatment of uncomplicated malaria with the incorporation of primaquine [18]. Prior to 2012, microscopic examination of thick and thin blood smears from suspected patients was the only available diagnostic method for malaria in Haiti [19], which requires trained technicians. However, after the 2010 earthquake the use of rapid diagnostic tests (RDTs) was temporarily approved for only 90 days [20, 21] and, as of 2012, the Ministère de la Santé Publique et de la Population (Ministry of Public Health and Population in French-MSPP) in partnership with the Center for Disease Control and Prevention (CDC Atlanta USA) authorized RDT as the malaria diagnostic method in Haiti [16]. Despite such progress, the true incidence of clinical infections and/or prevalence of asymptomatic parasitemia in the country are not yet clear. Thus, the malaria trend in Haiti is unknown [22], as official data provide an underestimated view of the disease situation in the country in terms of morbidity and mortality. Besides, even confirmed cases of malaria are poorly investigated. For example, in 2017 only 0.2% of the total number of confirmed cases was investigated [2]. This article aims to carry out a **spatial and temporal analysis of malaria in the Republic of Haiti** from 2009 to 2018, using secondary data on malaria cases reported by the MSPP and WHO.

Material And Methods

Study area. Haiti is an Antillean country, located in the western part of the island of Hispaniola. Its surface is 27,750 km² containing 10 departments (equivalent to states or provinces) named: Artibonite, Centre, Grand'Anse, Nippes, Nord, Nord-Est, Nord-Ouest, Ouest, Sud and Sud-Est. The country population was estimated at around 11.2 million inhabitants in 2018 [23] (Fig. 1). Due to its position in latitude, Haiti presents a tropical climate characterized by the alternation between a wet season, from May to November, and a dry season, from November to May. Average temperatures range from 32°C in the plains and 8°C in the mountains in January (winter) [24]. The annual precipitation varies from one

region to another between 400 mm and 3,000 mm. There are two primary rainy seasons that occur from April to June and from September to November. Haiti is prone to hurricanes and seasonal tropical storms [25].

Literature review. To carry out this descriptive research, articles in the national and international literature were indexed in MEDLINE, PUBMED, Scielo, Roll Back Malaria (RBM) and World Health Organization (WHO) reports from 2009 to 2019, adapting the method of "integrative literature review" [26]. The results and conclusions of previous studies with epidemiological data on malaria in Haiti were summarized to assess the state of the art within the proposed subject. This method is mainly used in medical and nursing practice [27].

Data compilation. This work was also carried out based on reported cases of malaria in the ten departments of Haiti. Data were obtained from MSPP statistical reports published on the website <https://mspp.gouv.ht> which can be accessed freely. The reports provide information on the malaria positive lamina index and positivity rate for malaria by 10000 inhabitants per year and Department. Therefore, the numbers of malaria cases reported in Haiti from 2009 to 2018 were evaluated and analyzed from those data.

Statistical analysis. Descriptive analyzes of the variables used were performed. A database was built in Excel with the data obtained from the Ministry of Health of Haiti. Occurrence measures or morbidity indicators (the annual parasite index, incidence rate, prevalence and prevalence rate) and the proportion of malaria cases confirmed by department and per year were used.

As previously mentioned, in some MSPP statistical reports only the suspected cases and the proportions of the corresponding confirmed cases are shown. As the number of cases is a discrete quantitative variable, for its calculation, the following formula was applied:

$$\text{Confirmed cases} = \frac{\text{Suspected cases}}{100} \times \text{Proportion of confirmed cases}$$

Results with decimal values are rounded up to the first decimal place, upwards: ≥ 5 and downwards: ≤ 4 .

As the WHO data only shows the global malaria cases, and not by Haitian Departments, the calculation of the annual parasite index (API) was done only with the MSPP data. The API of each department for each year studied was integrated into Geographic Information Systems (GIS), allowing analyzes to have a spatial vision of malaria risk in Haiti by department and by year. For these analyzes, we used ArcGIS 10 software (Environmental Systems research Institute, Redlands, CA) and IBM (Chicago, IL) SPSS Statistics 22 software.

Results

Between 2009 and 2018, a total of 232,479 and 303,295 confirmed malaria cases were respectively reported by the MSPP and the WHO for Haiti. Between 2010 and 2018, Haiti strongly reduced the number of malaria cases: from 84,153 to 8,828 considering the WHO data, and from 36,106 to 9,128, according to MSPP (Fig. 2; Table 1). A decrease was of 89.33% and 74.71% when taking into account the WHO and MSPP data, respectively. The average between both percentages is 82.02%. As compared to 2009, the WHO data showed more than 40% increase in 2010, following a small increase of 4.21% in 2013 and 17.95% in 2016. The MSPP data showed the same trend, however with a slight increase (2.55%) between 2014 and 2015 and 22.80% increase in 2016 in comparison to 2015.

Table 1
National malaria cases reported by the MSPP and WHO in Haiti from 2009 to 2018.

Year	Population at risk	Tested studied individuals		Confirmed cases		Incidence rate		Prevalence		Prevalence rate	
		MSPP	WHO	MSPP	WHO	MSPP	WHO	MSPP	WHO	MSPP	WHO
2009	9923243	159049	270438	28933	49535	2.92	4.99	0.18	0.18	0.29	0.50
2010	10085214	172937	270427	36106	84153	3.58	8.34	0.21	0.31	0.36	0.83
2011	10258126	184586	184934	34081	32969	3.32	3.21	0.18	0.18	0.33	0.32
2012	10413211	164893	167772	25745	25423	2.47	2.44	0.16	0.15	0.25	0.24
2013	10579230	172624	176995	20956	26543	1.98	2.51	0.12	0.15	0.20	0.25
2014	10745665	273707	261403	17094	17696	1.59	1.65	0.06	0.07	0.16	0.16
2015	10911819	302740	303740	17543	17583	1.61	1.61	0.06	0.06	0.16	0.16
2016	11078033	339781	302044	22723	21430	2.05	1.93	0.07	0.07	0.21	0.19
2017	11244774	335145	295572	20170	19135	1.79	1.70	0.06	0.06	0.18	0.17
2018	11411527	288294	288249	9128	8828	0.80	0.77	0.03	0.03	0.08	0.08

The prevalence (P), the prevalence rate (Pr) and the incidence rate (Ir) per year calculated from both of the MSPP and WHO data from 2009 to 2018 is shown at Table 1. The incidence rate (Ir) is equal to the API). The reason for that is the fact that the period of time considered for the Ir calculation in this study is one year. The population at risk is represented by the general population of Haiti for each year (sum of the population of the ten departments by year).

Table 2 shows from the MSPP data, the exposed population, the number of confirmed cases and the API per year and department in Haiti from 2009 to 2018. The API of each department varies depending on the corresponding population and the case number for each year. Figure 3 shows the API per year (2009–2018) in each department of Haiti.

Table 2
Number of confirmed cases population at risk annual parasitic index and total cases for the period 2009 to 2018 by department in Haiti (MSPP data)

Department		Year									
		2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Artibonite	PR	1571020	1596659	1622014	1648586	1674870	1701220	1727524	1753838	1780236	1806636
	CC	3397	5564	4227	2101	1266	2023	1123	1258	1014	637
	API	2.16	3.48	2.61	1.27	0.76	1.19	0.65	0.72	0.57	0.35
Centre	PR	678626	689705	702415	712138	723492	734876	755688	757603	769006	780410
	CC	2710	2102	1608	1063	833	679	410	268	606	358
	API	3.99	3.05	2.29	1.49	1.15	0.92	0.54	0.35	0.79	0.46
Grand'Anse	PR	425878	432826	439699	446901	454026	461172	467866	475434	482590	489747
	CC	1904	1329	2418	1381	1073	3532	6966	11118	9049	3011
	API	4.47	3.07	5.50	3.09	2.36	7.66	14.89	23.38	18.75	6.15
Nippes	PR	311497	316577	321604	326874	332084	337310	342207	347743	352977	358211
	CC	1119	1775	745	433	489	1202	717	1167	1115	388
	API	3.59	5.61	2.32	1.32	1.47	3.56	2.10	3.36	3.16	1.08
Nord	PR	970495	986334	1001998	1018411	1034648	1050922	1066185	1083433	1099740	1116048
	CC	2551	3375	3075	2070	2820	362	410	201	61	27
	API	2.63	3.42	3.07	2.03	2.73	0.34	0.38	0.19	0.06	0.02
Nord-Ouest	PR	662777	673599	684295	695502	706960	717707	728129	739909	751045	762183
	CC	1086	1123	894	750	721	327	236	194	157	28
	API	1.64	1.67	1.31	1.08	1.02	0.46	0.32	0.26	0.21	0.04
Nord-Est	PR	358277	364123	383653	375966	381960	387967	393601	399968	405988	412009
	CC	3619	3888	2124	2898	1994	142	254	87	89	303
	API	10.10	10.68	5.54	7.71	5.22	0.37	0.65	0.22	0.22	0.74
Ouest	PR	3664620	3724441	3783586	3845570	3906880	3968343	4025958	4091087	4152664	4214246
	CC	4162	7043	8869	9116	8252	7094	5645	4840	1901	1575
	API	1.14	1.89	2.34	2.37	2.11	1.79	1.40	1.18	0.46	0.37
Sud	PR	704760	716269	727643	739565	751356	763176	774255	786781	798623	810466
	CC	7922	9009	9594	5698	3209	1177	1291	3356	6088	2697
	API	11.24	12.58	13.19	7.70	4.27	1.54	1.67	4.27	7.62	3.33
Sud-Est	PR	575293	584681	591217	603698	613323	622972	632013	642237	651904	661571
	CC	463	898	527	235	299	557	491	234	90	104
	API	0.8	1.54	0.89	0.39	0.49	0.89	0.78	0.36	0.14	0.16
Haiti	PR	9923243	10085214	10258126	10413211	10579230	10745665	10911819	11078033	11244774	11411527
	CC	28933	36106	34081	25745	20956	17094	17543	22723	20170	9128
	API	2.92	3.58	3.32	2.47	1.98	1.59	1.61	2.05	1.79	0.8

API = annual parasite index, CC = confirmed cases, and PR = people at risk.

The proportions of malaria cases are displayed in Fig. 4, where we can observe from 2016 to 2018 a concentration of malaria transmission mainly in three (3) of the ten (10) departments: Grand'Anse, Sud, and Ouest. These three departments reported together over 80% of all malaria cases in Haiti. Grand'Anse

ses did not exceed 7% per year during the period 2009–2013, experienced an elevated level of malaria

transmission in 2014. The number of malaria cases tripled in 2014, as compared to those in 2013. In that department, a significant increase was also observed after the hurricane Matthew in 2016 with approximately a half (49%) of malaria cases reported in Haiti that year. Therefore, Grand'Anse registered the highest proportion of malaria cases in 2016 for the period 2009–2018. Grand'Anse was the only department where there was an increase in malaria cases between 2009 and 2018 (158%). And, considering the period 2009–2017, the increase was even more pronounced (450%).

Besides being one of the three departments of Haiti where malaria was more concentrated during the ten-year period studied, the Sud Department has registered remarkable proportions of malaria cases between 2009 and 2013, and has been explicitly ranked the first place during this period and the second place in 2012 (Fig. 4). The number of malaria cases declined significantly from over 20% to less than 8% in 2014 and 2015. Despite malaria cases decrease between 2014 and 2015, Sud Department returned to occupy the third place with more than 15% of the malaria cases in 2016 and the second place in 2017 and 2018 with 30% of all malaria cases registered in Haiti for the respective years.

Data on malaria morbidity among pregnant women and children under-five (U5) in Haiti is available only from 2015 to 2018 from MSPP (Table 3). During this period, 8,815 (12.67%) malaria cases were reported among U5 and 732 (1.05%) among pregnant women. The proportions of cases among the U5 show significant differences by year and geographic areas, varying from 5.5% in the Northeast to 27.2% in the West in 2015; from 0.0% in the Center and the Southeast to 22.9% in the West in 2016; from 0.3% in Nippes to 17.2% in West 2017 and from 1.0% in Southeast to 24.9% in West in 2018. On the other hand, the proportions of confirmed cases of malaria in pregnant women were lower, except in the Northeast, which recorded 20.2% in 2017 and 56.3% in 2018. The variations in 2015, 2016, 2017 and 2018 are as follows: 0.6% in the South to 7.6% in the North-West; from 0.0% in the Center, the North West and the South East to 2.2% in the Artibonite; from 0.0% in the North to 20.2% in the Northeast and from 0.0% in the North to 56.3% in the Northeast, respectively.

Table 3
Trends in reported malaria cases among children under-five years old and pregnant women reported by MSPP-Haiti from 2015 to 2018

Department	Year																
	2015					2016					2017						
	Tot. conf. cases	PW (+)	% PW	U5 (+)	%U5	Tot. conf. cases	PW (+)	% PW	U5 (+)	% U5	Tot. conf. cases	PW (+)	% PW	U5 (+)	% U5	Tot. conf. cases	PW (+)
Artibonite	1123	16	1.42	185	16.47	1258	28	2.23	161	12.80	1014	9	0.89	50	4.93	637	12
Centre	410	4	0.98	40	9.76	268	0	0.00	39	14.55	606	8	1.32	43	7.10	358	10
Grand'Anse	6966	61	0.88	1005	14.43	11118	112	1.01	1446	13.01	9049	48	0.53	288	3.18	3011	51
Nippes	717	8	1.12	64	8.93	1167	5	0.43	60	5.14	1115	1	0.09	3	0.27	388	2
Nord	410	11	2.68	73	17.80	201	2	1.00	39	19.40	61	0	0.00	2	3.28	27	0
Nord-Ouest	236	18	7.63	49	20.76	194	0	0.00	15	7.73	157	2	1.27	19	12.10	28	1
Nord-Est	254	4	1.57	14	5.51	87	1	1.15	8	9.20	89	18	20.22	2	2.25	303	17
Ouest	5645	56	0.99	1533	27.16	4840	15	0.31	1108	22.89	1901	8	0.42	326	17.15	1575	9
Sud	1291	8	0.62	146	11.31	3356	40	1.19	463	13.80	6088	61	1.00	329	5.40	2697	67
Sud-Est	491	6	1.22	47	9.57	234	0	0.00	0	0.00	90	2	2.22	1	1.11	104	2
Total	17543	192	1.09	3156	17.99	22723	203	0.89	3339	14.69	20170	157	0.78	1063	5.27	9128	321

Tot. conf. cases: Total confirmed cases. PW: Pregnant women, U5: Children under 5 years old.

Discussion

Malaria in Haiti. Still a challenge. An overall increase of malaria incidence was reported in Haiti in 2010 as compared to 2009 and, a trending decline from 2010 to 2018 (Fig. 2). Curiously, the number of malaria cases estimated by the WHO in the 2009–2018 period is higher than that reported by the MSPP (Table 2). Nevertheless, both the MSPP and WHO data showed a decrease in malaria incidence from 2011 as compared to 2010, while the MSPP data showed a small increase in 2012 contrasting with the decline recorded by the WHO. Additionally, the number of malaria cases reported by the MSPP decreased in 2013, while they increased according to WHO.

A considerable difference between malaria cases reported in 2009 and 2010 by the MSPP and the WHO was detected (Fig. 2). The data of both institutions overlap between 2011 and 2018 (post-earthquake period), with the exception of 2013, when values deviate slightly. Therefore, the conflicting values for the first two years of the series may be due to the different Haitian sources of primary data. Even before the 2010 earthquake, Haiti faced socioeconomic problems [28], which inevitably affected the country's health system. In 2010, in response to the earthquake, the MSPP in collaboration with the CDC and various NGOs, established a surveillance system for infectious diseases including malaria [29]. The incongruity of MSPP data with those from WHO between 2009 and 2010 may be related to deficiencies in the epidemiological surveillance system prior to the support of CDC and NGOs. This may interfere with data collection and updating of the official MSPP database. Bony and collaborators [16] pointed out some difficulties in the delivery of monthly reports of laboratory results to the central level of the MSPP and the lack of communication from the central to the local structures in Haiti.

Improving malaria data collection in Haiti. It should be noted that malaria data after the 2010 earthquake in Haiti is more robust. The reduction in conflicting data from 2011 is probably due to the MSPP's actions in collaboration with their partners in the days and months following the earthquake. Although apparently conflicting, data from WHO and MSPP showed the same trend of malaria in Haiti during the ten years studied. In other words, malaria declined during the 2009–2018 period with little variation since 2011 (Fig. 2).

Malaria in the different departments/ regions of Haiti. Challenges and suggestions. Our analysis suggests that Grand'Anse Department has always been one of the highest malaria-burden areas of Haiti, and malaria cases were probably underreported in the years prior to 2014. The underreporting of malaria cases in Grand'Anse may be related to the difficulty of access by land route to malaria foci in the municipalities of the department who presents rugged terrain [30]. Consequently, Grand'Anse and its spread and remote municipalities remain isolated. This problem results in particularly difficult and expensive access to health care, particularly in locations of high malaria burden [31], where people must walk hours to access medical care [32]. Lack of access to health facilities can be a discouraging factor, and may lead residents to use self-medication as the first alternative. It is worth noting that in Haiti, a country where the sale of drugs is not regulated, anyone can buy any drug from informal street drug vendors or in informal pharmacies without a doctor's prescription. In any case, apparently the surveillance and case records of malaria in this department in the analyzed period were more effective and realistic than in the others, for several reasons such as a major scale-up community case management such as diagnostic testing deploying RDTs and reporting thanks to the financial support provided by a global fund in 2012 to fight against AIDS, tuberculosis and malaria in Haiti [32, 33]. In addition, Haiti received technical supports from some international malaria actors such as the CDC Foundation and Malaria Zero to implement active research on malaria in the Grand'Anse Department from 2014. Probably, the significant decrease in malaria records in the Sud Department in 2014 and 2015 may be attributed to an underreporting of cases in this department in consequence of this special investment in the neighboring Grand'Anse during the same period 2014–2015.

No work has been published exploring on why Sud Department is a malaria-prone endemic area. However, some ecological determinants may hypothetically explain the fact that Sud presents high malaria endemicity, as observed in the years prior to the passage of Hurricane Matthew in October 2016, that is, since the beginning of the series in 2009. According to MSPP [34], Sud is considered to be one of the departments where the highest number of malaria cases has always been registered. The southern department is mainly made up of plains located along the coast. The hydrographic network of the Sud is dense because it is made up of 69 rivers, 250 springs, 20 ponds, one lake and 11 lagoons [34], what favors the formation of larval habitats of anophelines. This large plain faces the green Massif de la Hotte which favors the precipitation and infiltration of rainwater.

CHAI and collaborators [1] have described the high risk of malaria transmission along the coast of Haiti. Malaria is mostly distributed along the coasts of the southern region of the country where are located both the Sud and Grand'Anse departments [35]. This coastal distribution of malaria is mainly related to the main anopheline vector bioecology, besides low local socioeconomic conditions. *An. Albimanus* has been described as essentially a coastal mosquito and often found in brackish water [36]. This species of anopheline is also considered a lowland mosquito [37] that breeds in a wide variety of sunny breeding sites at altitudes below 400 m [38]. Therefore, in the, there are very favorable ecological conditions for malaria transmission.

The occurrence of Hurricane Matthew in October 2016 may be considered the cause of the increase in malaria records in 2016 compared to 2015. Hurricane Matthew, which is a Category 5 Atlantic hurricane (maximum on the Saffir-Simpson scale), with winds reaching up to 260 km/h, caused catastrophic damage and a humanitarian crisis in Haiti. Haiti's departments most affected by this hurricane were Grand'Anse and Sud. Indeed, the after-effects of Matthew are likely to have included: displaced human populations, environmental changes, flooding that increased the number of malaria vector larval habitats, high exposure to mosquitoes and overcrowded human shelters. These changes in human conditions and in the environment may have facilitated the occurrence and transmission of vector-borne diseases. Even if the population of Anophelines may have temporarily decreased in numbers right after a hurricane, these conditions favored its subsequent proliferation. Actually, malaria cases have also increased after Hurricane Jeanne in Haiti in 2004 and Hurricane Flora in 1963 [39, 40]).

The majority of the communes where malaria cases are notified in the Ouest Department are urbanized areas and 2/3 of the Haitian population live there. Port-au-Prince, the capital of Haiti is located in Ouest. The department has also recorded high malaria incidence in Haiti, with its municipalities accounting for 53% of malaria cases reported between 2012 and 2014 [41]. This data though, seems to be misleading. Patients travel long distances to receive better health care and malaria cases' reports are based on the health unit location where the diagnosis occurred not where the patient lives [42].

To estimate malaria risk at the department level in this study we have used API. The results showed that malaria occurs in all departments of Haiti with a degree of risk ranging from low (0.02 to 7.71) to medium (10.68 to 23.38) (Table 2). It is known that API is influenced by the size of the population, which grows each year, regardless whether the number of cases increases [43]. Therefore, a given area may have a very low API even with high number of cases, and vice versa. For example, in 2011 Ouest Department had an API of 1.89 with a total of 8,869 cases. Since in the same year, the Department Nord-Est presented an API of 10.68 with 2124 representing 6% of the total cases for the ten departments. In 2011, the population of the Ouest Department and that of the Nord-Est department were estimated at 3,783,586 and 383,653 respectively. The population of Nord-Est department represented only 10.14% of the population of Ouest. Hence, the increase and decrease of the API value depends on the denominator that is the population size at a given time; that is, the larger the population, the lower the API will be, and vice versa.

Malaria control efforts in Haiti. Despite the objective set by Haiti and DR to eliminate malaria on the island of Hispaniola until 2020 was not achieved, an overall trending decline in the number of malaria cases in Haiti in the last years was recorded. Due to Haiti's efforts to reduce the malaria burden over the past decade prior 2019, the number of malaria cases considerably dropped in the country from 2010 to 2018. Access to early diagnosis and treatment is one of the most important strategies for malaria control and elimination. This includes two components: 1) the patient must seek care, as soon as possible when sick; 2) health facilities with diagnosis and adequate treatment within easy access to the patient must be available [44]. Consequently, progress has been seen in improving access to malaria diagnosis and treatment in Haiti over the last years.

The use of bednets for malaria control in Haiti. The use of insecticide-treated nets (ITNs) is currently the most effective means of individual protection against malaria. ITNs have been implemented since 2010 in almost all the endemic areas of Haiti [45]. In the same context, approximately 800 thousand ITNs were distributed by The Mentor Initiative in collaboration with UNICEF from October to December 2010 [46, 35]. More than 350 thousand families in four departments of the country have benefited. In the same period, thousands of other mosquito nets were distributed by the Haitian Red Cross [47]. Subsequently, 2 million long-lasting insecticidal nets (LLINs) were distributed in Haiti by PSI in 2012. This resulted in that for the first time in the Americas it was reported that a higher number of people were protected by ITNs than by indoor residual spraying (IRS), the most common method used for malaria vector control [31]. Additionally, the Global Fund to fight AIDS, Tuberculosis and Malaria subsidized more than 400,000 mosquito nets in Haiti in December 2016 [48]. ITNs ensure individual protection by helping to limit contact between the individual and vector, as it is one of the best strategies against malaria. According to the WHO, a coverage rate with impregnated mosquito nets above 80% reduces infant and juvenile mortality by about 25% and guarantees effective protection of more than 60% against parasitemia [49]. Therefore, considering the reduction in the number of cases between 2011 and 2018, it can be said that, probably, there was an effect of the mosquito nets distribution campaigns in the reduction of malaria cases that we analyzed in the country.

The outstanding departments for malaria reduction in Haiti. While only three departments reported over 80% of all malaria cases in Haiti from 2016 to 2018, five departments (Nord, Nord-Est, Nord-Ouest, Sud-Est and Centre) showed together less than 7% of malaria cases, the smallest proportion of cases, during the period 2009–2018. In terms of reducing malaria cases over the period 2009–2018, the most outstanding departments for malaria reduction of Haiti were: Nord, Nord-Est, and Sud-Est.

Nord-Est is one of the departments of Haiti where malaria was a major concern in the years prior to 2014. Due to the binational project between Haiti and Dominican Republic, covering the border communities of Ouanaminthe (a municipality of Nord-Est Department) and Dajabon (a municipality in the Dominican Republic) [17], malaria cases in Nord-Est dropped from 3,888 in 2010 to 87 cases in 2016, a reduction of 97.76% (Table 2).

Similar observation is made for the Nord Department where a total of 14,952 malaria cases between 2009 and 2013 dropped to 942 malaria cases between 2014 and 2018, which represents only 6.3% of the total of case (more than 15 times lower). Therefore, Nord Department showed the greatest reduction in malaria incidence (almost 99%) among all departments of Haiti, when we compared 2018 with 2009. There was no work in the literature reporting the actions taken in that department to justify this important decrease. However, there is a hypothesis that the actions carried out within the framework of the binational project were extended to the Nord Department. Nord and Nord-Est Departments are close one to another. The distance between Limonade (a town in the Nord) and Ferrier (a town in the Nord-Est) is 36.29 km according to this website: https://distancecalculator.globefeed.com/Haiti_Distance_Calculator.asp. Accessed on 22 April 2020.

For decades, Sud-Est Department has been the area with the lowest malaria burden in Haiti. Over the period 2009–2018, the largest number of cases reported in that department was only 989 cases in 2010, the year in which malaria had a significant rise in the country. A study carried out by Raccurt and collaborators [50] has shown that malaria occurs in the form of heterogeneous foci in the coastal areas of Sud Department with strong variations in the carrying rates of the gametocyte and/or trophozoite forms of *P. falciparum* from one locality to the other.

Sud-Est Department, covering an area of 2,153 km², is made up of more than 65% of very steep mountainous regions [51] including the highest mountain range in Haiti, the Massif de la Selle (2,600 m altitude). The plains, representing nearly 35% of the area of the department, are all coastal; landlocked and separated from each other by an accentuated relief. The department is also characterized by its rainfall deficits which are recorded for decades (600 mm at most) and by high risks of drought [52]. Probably the highest proportion of the population of the department lives in the mountains. As the transmission of malaria in the southern region of Haiti occurs mainly at the coastal areas [4, 35], the low incidence of malaria, historically recorded in the Sud-Est Department, is probably due to the fact that the proportion of the population of the department exposed to the risk of contracting malaria is low.

Malaria in Pregnant and Children under 5 years old. According to WHO [53], malaria is considered one of the greatest health threats to children under five and pregnant women in malaria-burden areas. In high transmission areas, the majority of malarial disease occurs in young children without acquired immunity. The most commons of the severe clinical pictures of malaria seen in children are: severe anaemia, hypoglycemia and cerebral malaria. One of the WHO recommendations for the prevention of malaria in children is the use of long-lasting insecticidal nets (LLINs). As shown in Table 3, malaria morbidity among pregnant women and U5 has been included in the MSPP statistic reports only from 2015 to 2018. The proportions of reported malaria cases among pregnant women increased significantly in 2018 in the Nord-Est Department. However, Nord-Est is one of departments with low transmission areas from 2014 to 2018. Indeed, more than half of the cases (56.44%) were among pregnant women, despite the fact that few cases were recorded in this department in 2018. The MSPP data also show that in 2018 no confirmed cases were recorded in pregnant women in the North and the Nippes.

Malaria infection during pregnancy represents substantial risks for the pregnant woman, her fetus, and the newborn child having as consequences maternal illness and low birth weight [54]. According to WHO [55], the levels of acquired immunity may increase in areas of high burden of *P. falciparum* malaria. In those areas, malaria is usually asymptomatic in pregnant women with the presence of parasites in the placenta. This might contribute to maternal anaemia without peripheral parasitemia. Therefore, low confirmed malaria case among pregnant women in Haiti does not mean absence of *Plasmodium* spp. infection among them. In other words, the low number of cases registered among pregnant women during the study period may not show the malaria trend in pregnant women in Haiti. Because of the lack of health facility and education, pregnant women, especially in rural zones, do not have the habit of doing prenatal care before the third trimester of pregnancy, unless they feel really seek (personal communication).

On the other hand, in areas of low density of malaria transmission, women of reproductive age have relatively little acquired immunity to malaria. To avoid the risk of severe malaria that can lead to miscarriage, stillbirth, and prematurity and low birth weight, all pregnant women, regardless of their gestational age, are very vulnerable to malaria [54]. As solution, the WHO recommends an intermittent preventive treatment in pregnancy (IPTp), in all areas with moderate to high malaria transmission, especially in Africa. This therapy consists of administering to pregnant women at least two doses of an antimalarial drug, currently

Loading [MathJax]/jax/output/CommonHTML/jax.js scheduled antenatal visit after the first trimester of pregnancy, whether or not they have symptoms malaria [54]. At

the date of writing of this paper, the Ministry of Health of Haiti has no IPTp in its malaria treatment protocol and, no scientific and official data on malaria case management among pregnant women were published by the MSPP.

Infant malaria. An important cohort in Haiti. Malaria in U5 in Haiti-MUF represents an important amount in the total cases. For the period 2015–2018 MUF varied from 0.78 to 17.99% in the total Haitian population. Despite total reduction in malaria cases in 2018, MUF was higher compared to the three previous years. Results between 2015 and 2018 showed inconsistency in terms of proportion of cases by department and by year with a great variation from 5.51 to 27.16% in 2015; 0 to 22.89% in 2016; 0.27 to 17.15% in 2017 and from 0.96 to 24.89% in 2018 (Table 3). At community level, and for each municipality in Haiti, MUF risk factors linked to socio-economic and environmental factors such as type of dwelling, access to health care, parental education level, household size and bed nets use should be investigated. These factors significantly influence the odds for MUF [56].

Conclusions

The results from this study indicate that in Haiti, the official malaria data from 2009 to 2018 were reported by department instead of by municipality. According to data from 2015 to 2018, malaria also affects both U5 children and pregnant women. In view of those facts, malaria risk should be assessed at municipal level in order to target appropriate specific local interventions. As well, prevention efforts should be focused on U5 and IPTp should be included in the malaria treatment for pregnant women in Haiti. This set of actions may help Haiti achieve the goal of eliminating malaria and prevent the reintroduction of the disease in areas where it will be eliminated.

Declarations

Authors' contributions

JRJ, TFNS and JA conceived and designed the study; JRJ and EJB collected the data; TFSN, HA, MGRF and MCSM contributed to the analyses of the data; JRJ drafted the manuscript, MGRF, MCSM, CR, JA and TFNS helped with manuscript editing. All authors read and approved the final manuscript.

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Availability of data and material

The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no conflict of interest.

Ethics approval

Data analysis did not require additional ethical clearance. For this manuscript, we used data collected from Literature review, World Health Organization (WHO) reports and from statistical reports published on the Ministry of Health of Haiti's website which was accessed freely. The publication of this paper will be done in close collaboration with the Ministry of Health of Haiti.

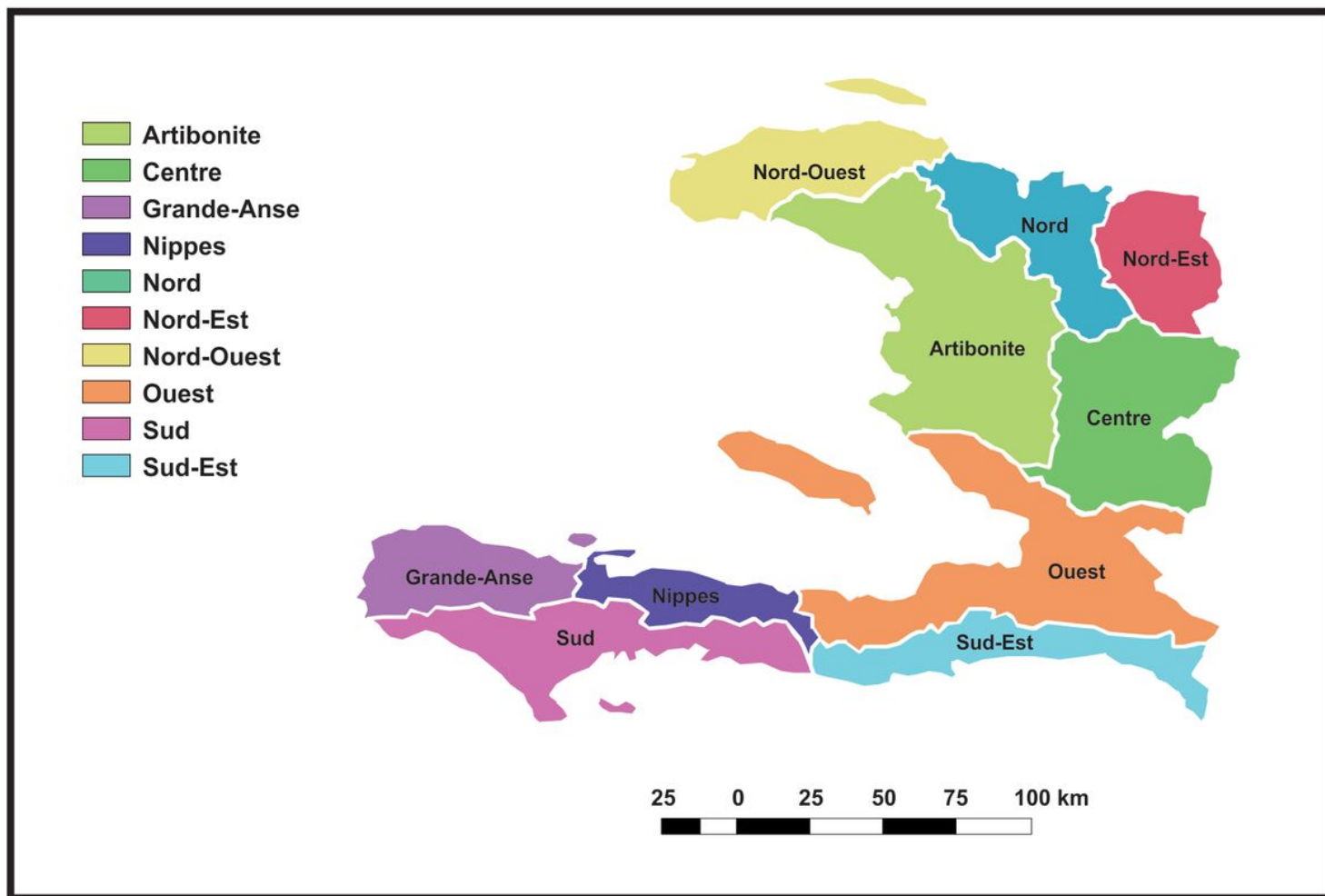
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Figures



Map of Haiti with the ten Departments. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

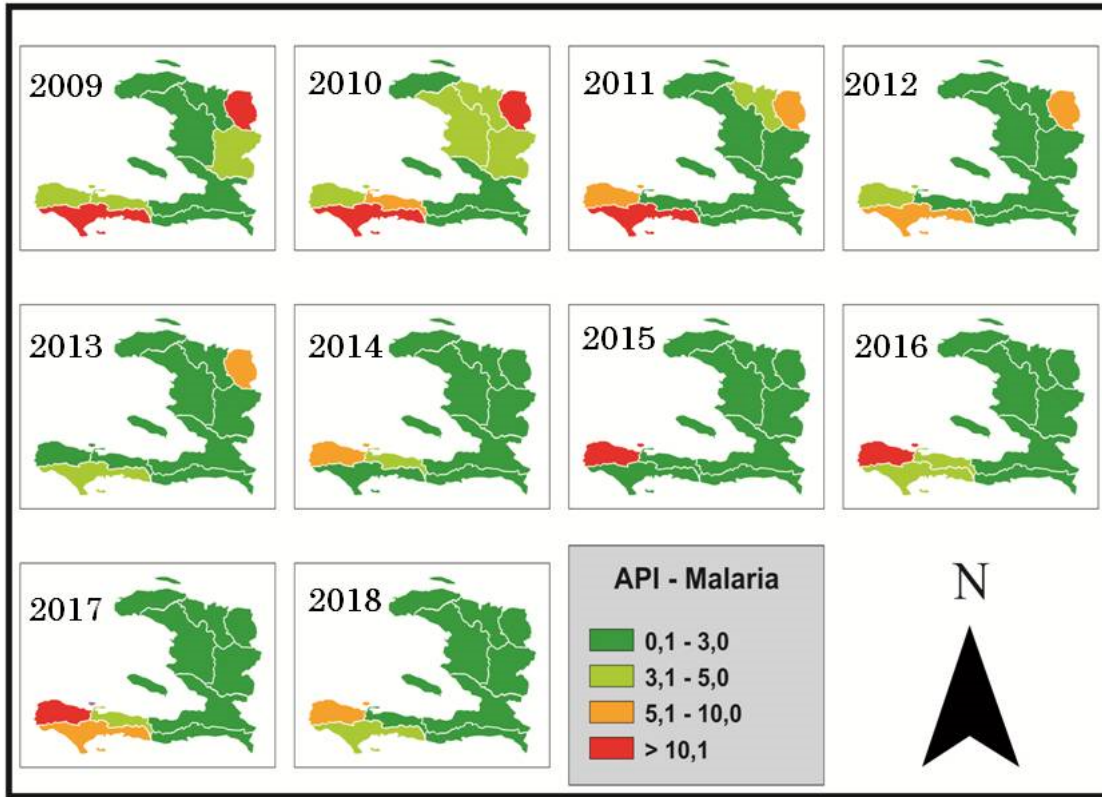


Figure 2
Representation of the malaria trend in Haiti from 2009 to 2018 using both the MSPP and WHO data. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

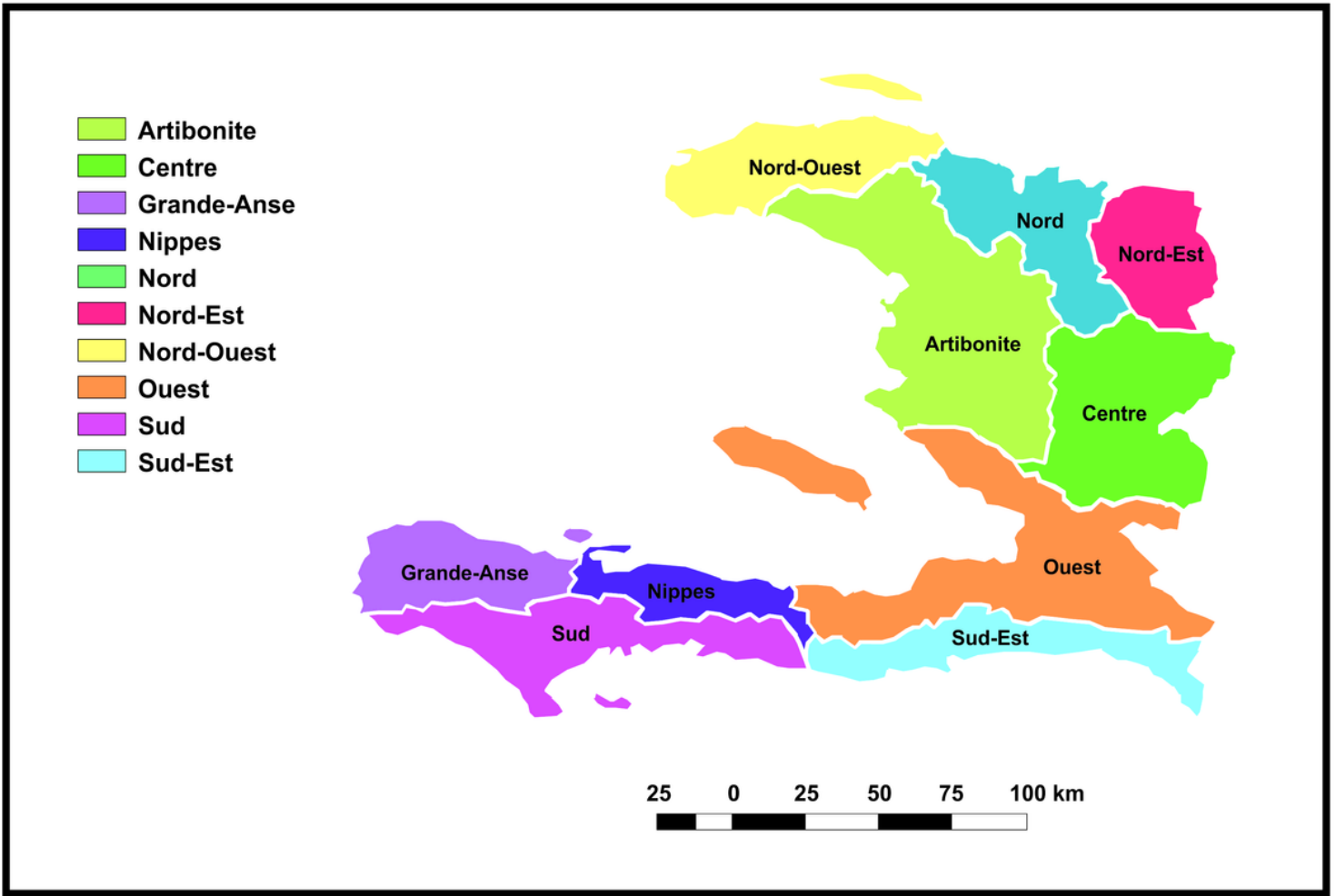


Figure 3

Maps of malaria transmission risk by annual parasitic index (API) 2009–2018 in the ten departments of Haiti. The strata presented in this study were: 0.1–3.0 for very low transmission; 3.1–5.0 for low transmission; 5.1–10 for moderate transmission and > 10 for high transmission. In other words, ratios greater than 10 indicate the department with a high risk of malaria infection and those below 3.1 indicate the departments with very low risk of malaria infection. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

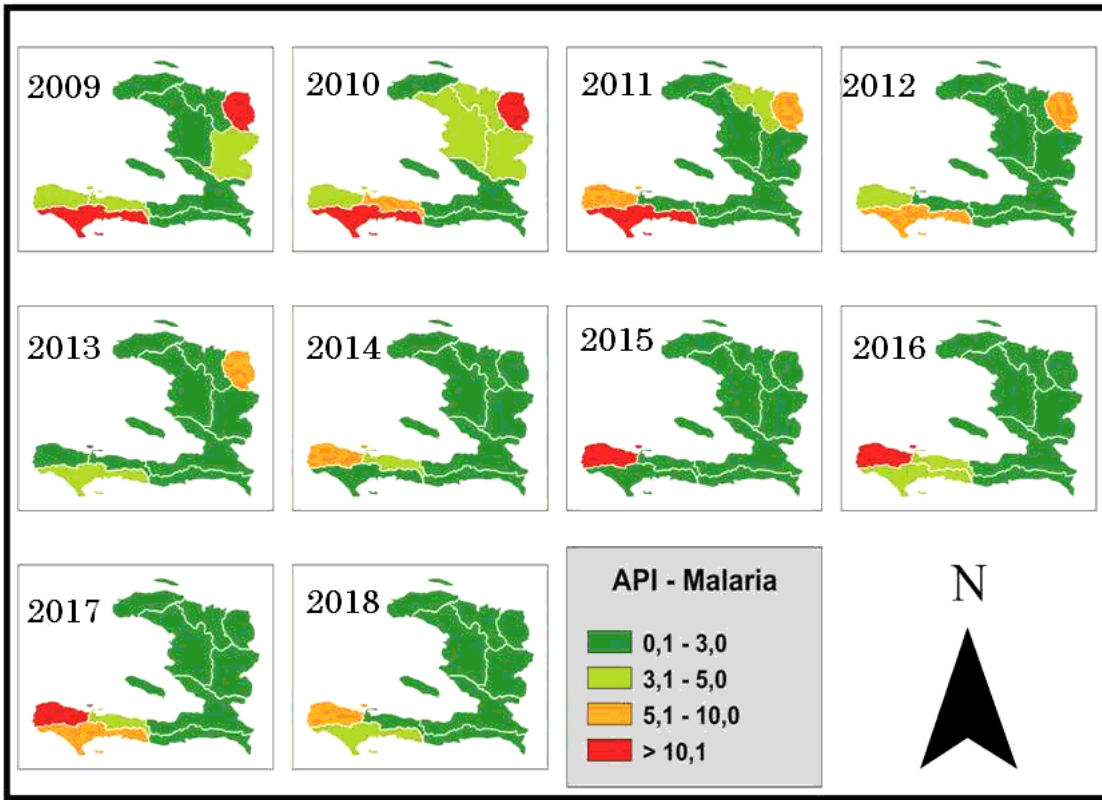


Figure 4
 Proportion of confirmed malaria cases in Haiti by department from 2009–2018 (MSSP data). Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.