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Spatio-Temporal Analysis of Malaria Incidence in Batubara District, North Sumatera, Indonesia 2018-2020

Rd. Halim[1], Frans Yosep Sitepu[2], Elpiani Br Depari[3]

[1]Public Health Study Program, Faculty of Medicine and Health Sciences, Jambi University
[2]Provincial Health Office, North Sumatera, Indonesia
[3]Grandmed Hospital, Deliserdang, Indonesia

Abstract—Malaria infection is still a public health concern in Batubara District, North Sumatera, Indonesia. Spatial clusters and hotspots of malaria cases are needed to help design elimination strategies in the district. To that end, research was undertaken to detect clusters and hotspot of malaria during 2018-2020 in the district. All malaria cases' house geo-coordinate were captured by using GPS. A retrospective space-time scan statistics analysis based on population data and annual malaria incidence was performed using SaTScan TM v9.4.4. The Poisson model was employed to determine the high risk of malaria and the highest of likelihood ratio (LLR) stated as most likely cluster, with the significance level of 0.05. There were 1,229 malaria cases reported in Batubara District and the annualized average incidence was 2.73 per 1,000 population. The SaTScan analysis identified that there were three most like clusters and three secondary clusters, while Morans'I showed that there was spatial autocorrelation of malaria in the district. The sub-district of Tanjung Tiram, Sei Suka, and Talawi were consistently the location of clusters. There is evidence for the existence of statistically significant malaria clusters in Batubara District, North Sumatera, Indonesia. These findings may assist health authorities to improve the malaria preventive strategies and develop public health interventions, with special reference to the areas where the clusters and hotspots were found to achieve the malaria elimination goal.

Keywords: Malaria, SaTscan, GeoDa, space time analysis, spatial autocorrelation, Batubara

1. Introduction

Malaria is still a major and one of the most severe public health problems worldwide.[1] It is a vector-borne disease that spreads to people through the bites of infected female *Anopheles* mosquito. Malaria is caused by protozoa from genus *Plasmodium sp*. In 2021, there were an estimated 247 million malaria cases and 619,000 malaria deaths globally. Even though malaria has been effectively eradicated in the majority of high and middle income countries, the illness still poses a serious threat to public health and is the leading cause of infectious disease deaths in low-income countries.[1, 2]

In Indonesia, malaria is still a major public health concern.[3]The Indonesian Ministry of Health is targeting malaria elimination by 2030, in line with the WHO target. However, the number of malaria cases in the country increased to 415.140 cases in 2022 from 304.607 cases in 2021. In early of 2023, there were only five out of thirty eight provinces (13%) and 381 out of 514 districts (74%) have succeeded in eliminating malaria.[1]

North Sumatra Province is one of the provinces that has not eliminated yet malaria in Indonesia.[3, 4]It is the largest contributor of malaria cases in Sumatera Island. In 2023, ten out of 33 districts(30%)that have not yet obtained the malaria elimination certificate, and one of them is Batubara.[4]

In order to comprehend the patterns of the spread and dispersion of infectious diseases, geographic information systems (GIS) and spatial analysis have been used extensively in recent years.[5–9] Prior studies have indicated that malaria tend to a non-random and clustered spatial distribution.[10–14] In GIS, spatial temporal analysis is frequently employed and can be carried out by secondary data analysis. Therefore, by concentrating attention on malaria control programs, this study can identify high-risk locations and clusters of malaria cases that can help with health planning.

We therefore aimed to investigate the presence of malaria clusters in this district and investigate the temporal distribution pattern of malaria clusters over the three last years (2018-2020).

2. Methods

2.1. Study area

The study area was in Batubara district, North Sumatera, Indonesia. The district is endemic of malaria. It is located in the east side of North Sumatera province, which is consisting of 12 sub-districts. The sub-districts consist of 151 villages (Figure 1). The population density varies in each village, from 233 to 812 people per km2. Batubara district is geographically positioned between 3^0-4^0 N and 99^0-100^0 E (Figure 1). Batubara District features a tropical climate with dry season (April–October) and rainy season (November–March). The total rainy days were 125 days with monthly total rainfall varies from 24–419 mm.[15]

Figure 1

2.2. Data

The malaria data were the monthly numbers of microscopy confirmed cases. The data were obtained from 1 January 2018 to 31 December 2020 from the District Health Office of Batubara. Data of village's population were obtained from the Batubara District Bureau of Statistics.[15] All malaria cases' house geo-coordinate were captured by using GPS.

2.3. Space time scan statistic

To conduct the retrospective space-time scan statistic, we downloaded the free space time statistic software SaTScan TM v9.4.4 (https://www.satscan.org/). The software used to detect the malaria clusters in the study area. Space-Time Poisson model was adopted to identify villages at high risk of malaria cases by month over the study period. The test of significance of the identified clusters of malaria was rested on comparing the likelihood ratio (LLR) against the null distribution obtained from the Monte Carlo hypothesis testing.[16] The number of permutation was conducted to 999 and the significance level was 0.05. The null hypothesis of this study assumed that the relative risk of malaria was the same within the window compared to outside. The most likely cluster determine as the highest LLR number, while the others were determined as the secondary clusters of malaria.[17, 18]

2.4. Spatial autocorrelation analysis

The univariate Moran's I by using GeoDa software was performed to test spatial autocorrelation analysis, in other hand the local indicator of spatial autocorrelation (LISA) was performed local spatial autocorrelation. Testing the spatial dependence or autocorrelation between observations or locations were conducted by using the Moran's I coefficient, which has a range of -1 to 1.[19] A positive score suggests that the distribution of malariacases tends to be spatially clustered, whereas a zero score indicates randomness (the absence of malaria cases cluster). A negative score means that malariahas completely spread.[19, 20]

2.5. Ethical consideration

Ethics clearance was not required as this study was part of routine mosquito-borne diseases surveillance conducted by the Batubara District Health Office and Provincial Health Office of North Sumatera.

3. Results

3.1. Descriptive analysis

In the three-year analysis of malaria data, 1,229 malaria cases had been reported in Batubara District and the annualized average incidence of malaria was 2.73 per 1,000 population. The annual average incidence of malaria ranges from 0 to 9.9 per 1,000 population.The highest village was Kwala Indah, Sei Suka Sub-district (Figure 2).

Figure 2

Malaria cases in Batubara District were significantly higher among males (56.9%) and people age 15-44 years (52.6%). Malaria cases by gender were not statistically significant(p= 0.52). While by age people ≥15-44 years (p= 0.02) statistically significant (Table 1). Mapping of malaria cases by year (2018-2020) illustrated in Figure 3.

Table 1

Figure 3

3.2. Space time analysis

Results of space-time Poisson model detected six clusters from 2018-2020.Most likely clusters were appeared in each year of the study. While, a total of three secondary clusters were detected which were two secondary clusters in 2018 and one secondary cluster in 2020 (Table 2). The findings from the study period's space-time scan statistics analysis of malaria are illustrated in Figure 4.

Table 2

Figure 4

3.3. Spatial autocorrelation

GeoDa was used to conduct spatial autocorrelation analysis. The analysis with *Morans' I*and the significance level was set as 0.05 resulted that there was spatial autocorrelation of malaria in Batubara District (Table 3).

Table 3

Figure 5

4. Discussion

We conducted the exploratory data analysis and space time scan statistics of malaria at villages level in Batubara District. We mapped malaria incidence data from 1 January 2018 to 31 December 2020. The two spatial analysis approaches (SaTScan and GeoDa) resulted that clusters and hotspots were located in similar locations. This finding support the hypothesis that malaria in the district tend to cluster significantly over time of the study period. It demonstrated the options were feasible for our study methods.

The clusters of malaria cases persisted consistently in Tanjung Tiram, Sei Suka and TalawiSub-district of Batubara. It could be happened because of the natural conditions of these sub-districts support malaria transmission. These sub-districts were located in coastal area. A coastal area serves as a point of transition between the land and the sea, making it useful for fishermen to go fishing. Fishermen use and perceive coastal and marine environments as a source of life on a daily basis. Coastal areas not only stimulate the economy of local people but can also be a site of malaria transmission due to the presence of fishpond and lagoon that serves as an *Anopheles sp.* breeding habitat.A previous malaria vector survey conducted by Ministry of Health of Indonesia, North Sumatera Provincial Health Office and Batubara District Health Office resulted that *Anopheles sundaicus* was the dominant vector in the district.[4]*A. sundaicus*is a significant malaria vector that is mostly located in coastal regions in Indonesia.[21–23]Unmanaged lagoons and fishponds in the coastal area make an ideal breeding habitats for *A. sundaicus*.Some previous studies determined that malaria cases in coastal were higher than non-coastal area.[22–26]

We also found that some malaria cases in Batubara were also located in remote forests and plantations area. The condition of many forests, plantations and rice fields also has potential for malaria mosquitoes breeding places.[15] Factors that support the breeding of malaria vectors include rivers, puddles, rice fields with non-technical irrigation, and of course community behavior.It is common knowledge that forest ecosystem facilitate the spread of malaria. The ecology of forests offers an ideal environment for the malaria mosquito vector to grow.[13, 14, 22, 27, 28] Climate, vegetation, and the presence of breeding sites are important environmental factors that have a significant role in the transmission of malaria. Many previous studies determined malaria transmission dynamics in remote forest ecosystems.[10, 11, 28, 29]

By evaluating the existence of clusters and hotspots, our results enhance understanding of the spatial analysis of malaria in Batubara District. The district's public health authorities can use these findings to guide the development of surveillance, prevention and control, and elimination strategies.

However, our study had limitations. Firstly, the malaria notification data used in this analysis came from passive surveillance, which may have led to underreporting and, as a result, does not accurately represent the true malaria burden in Batubara District. Secondly, we only conducted analysis for aggregate data, it would be better to determine individual and environmental risk factor all the malaria cases.

5. Conclusions

This study showed the presence of malaria spatial clusters in the Batubara District, Indonesia. Six statistically significant malaria clusters were identified in the 2018-2020 period. Tanjung Tiram, Sei Suka and Talawi Sub-district were detected as spatial clusters and hotspots of malaria in the three-year period of study. This finding may assist health authorities to improve the malaria preventive strategies and develop public health interventions especially in the areas with clusters and hotspots to achieve the malaria elimination goal.

Competing interests

The authors declare that they have no competing interests.

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Author contributions

Conceptualization: Rd. Halim, Frans Yosep Sitepu. Data curation: Frans Yosep Sitepu. Formal analysis: Frans Yosep Sitepu, Rd. Halim. Methodology: Frans Yosep Sitepu, Rd. Halim. Visualization: Frans Yosep Sitepu. Writing – original draft: Frans Yosep Sitepu, Elpiani Depari. Writing – review & editing: Rd. Halim, Frans Yosep Sitepu, Elpiani Depari

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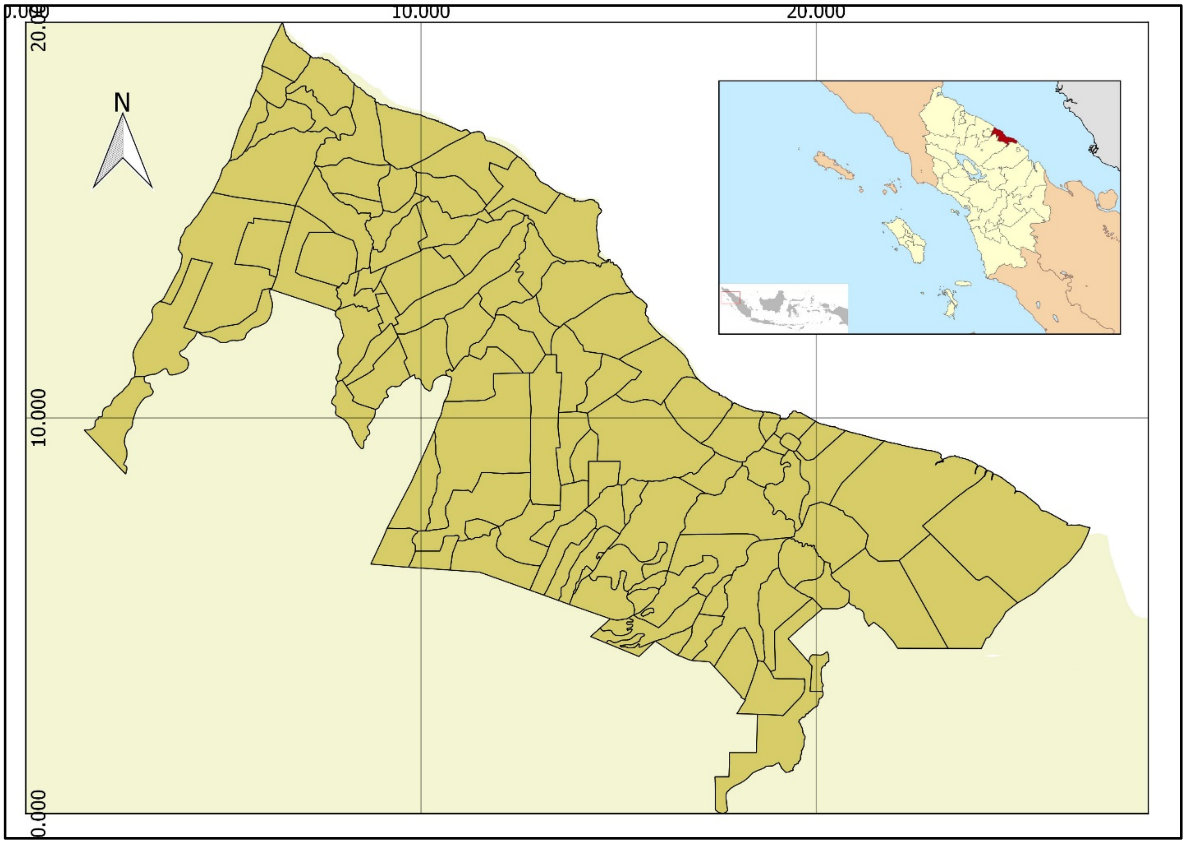

Figure 1. Location of the study area

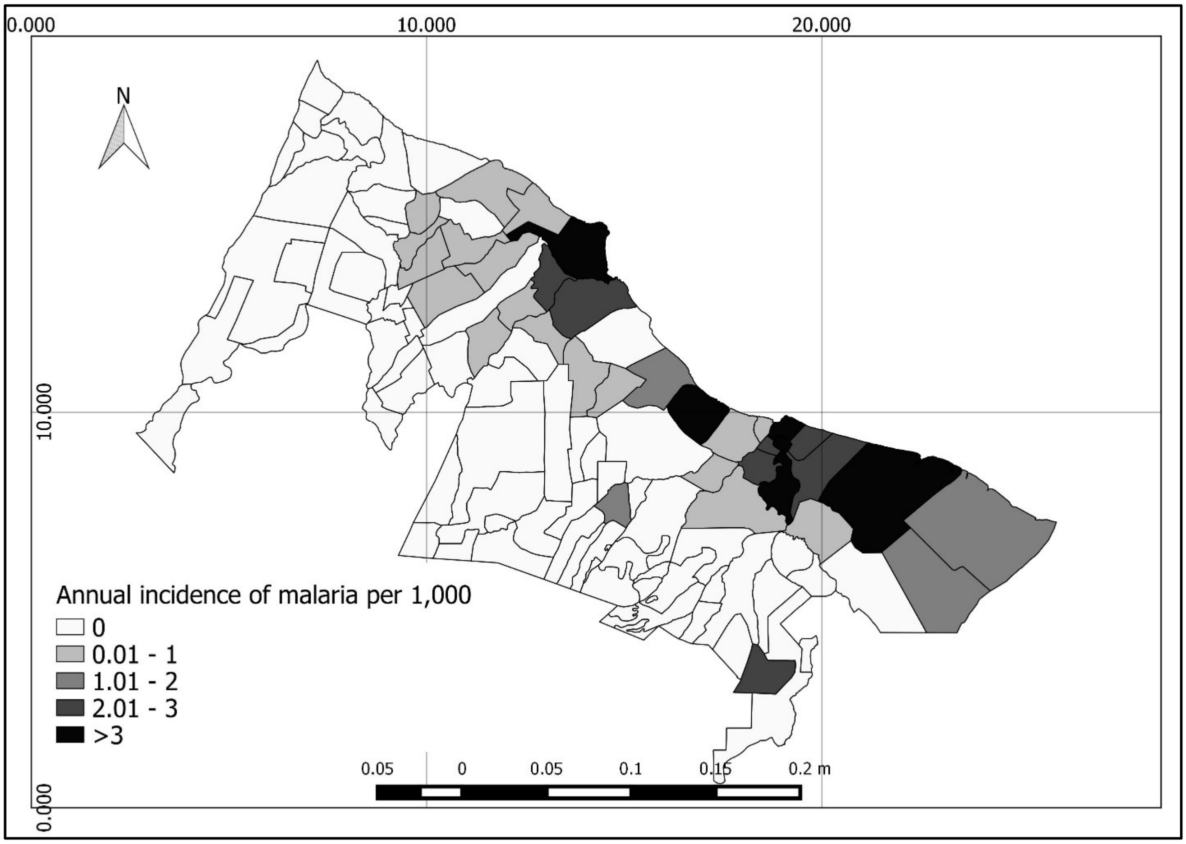

Figure 2. Annualized average incidence of malaria in Batubara District 2018–2020.

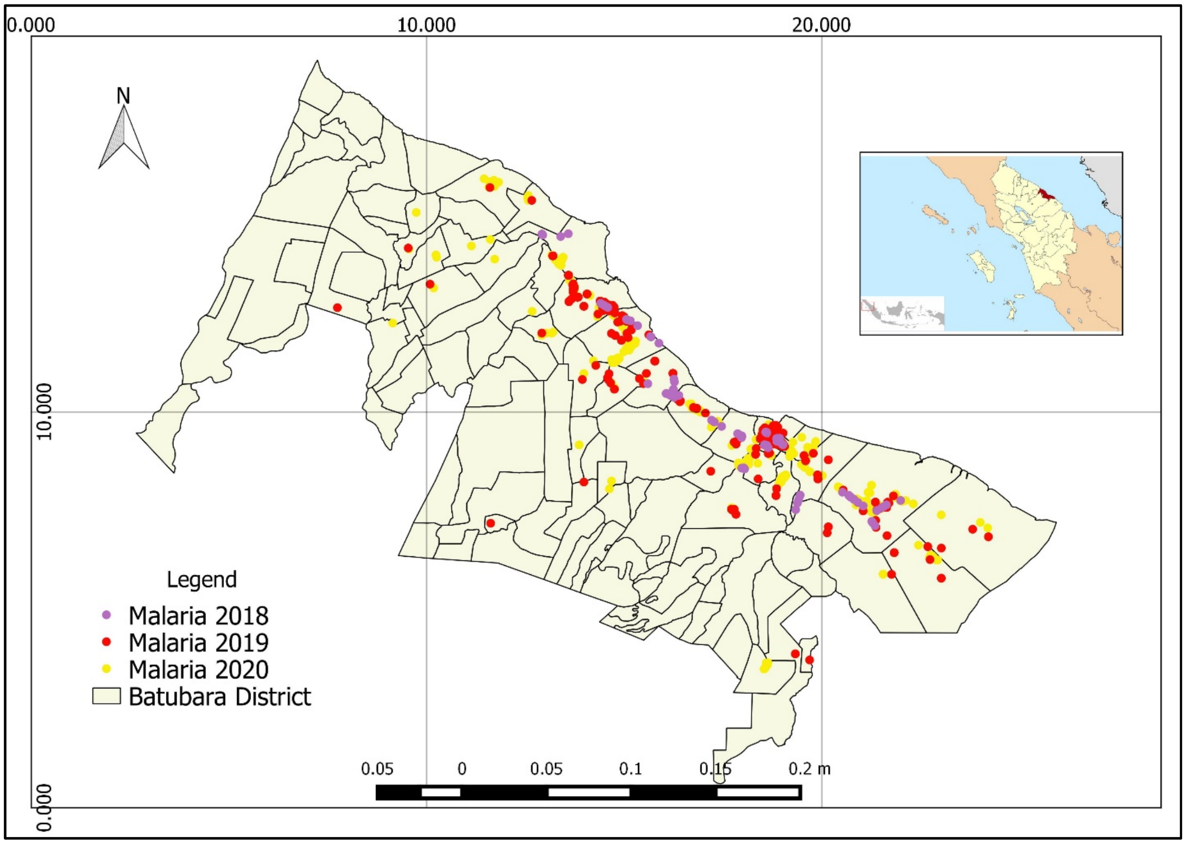

Figure 3. Map of malaria cases 2018-2020

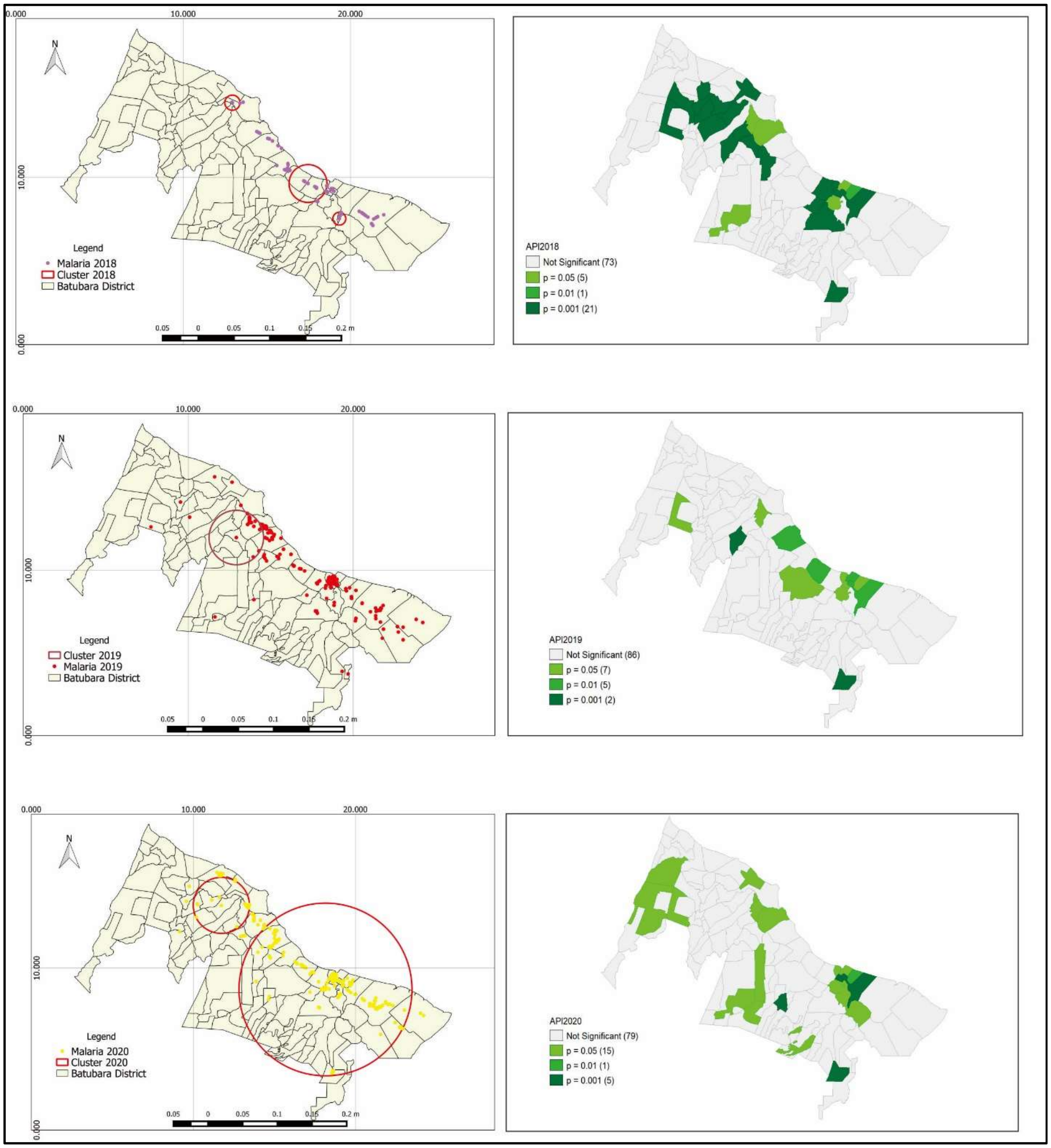

Figure 4. Map of malaria cases clusters, 2018-2020

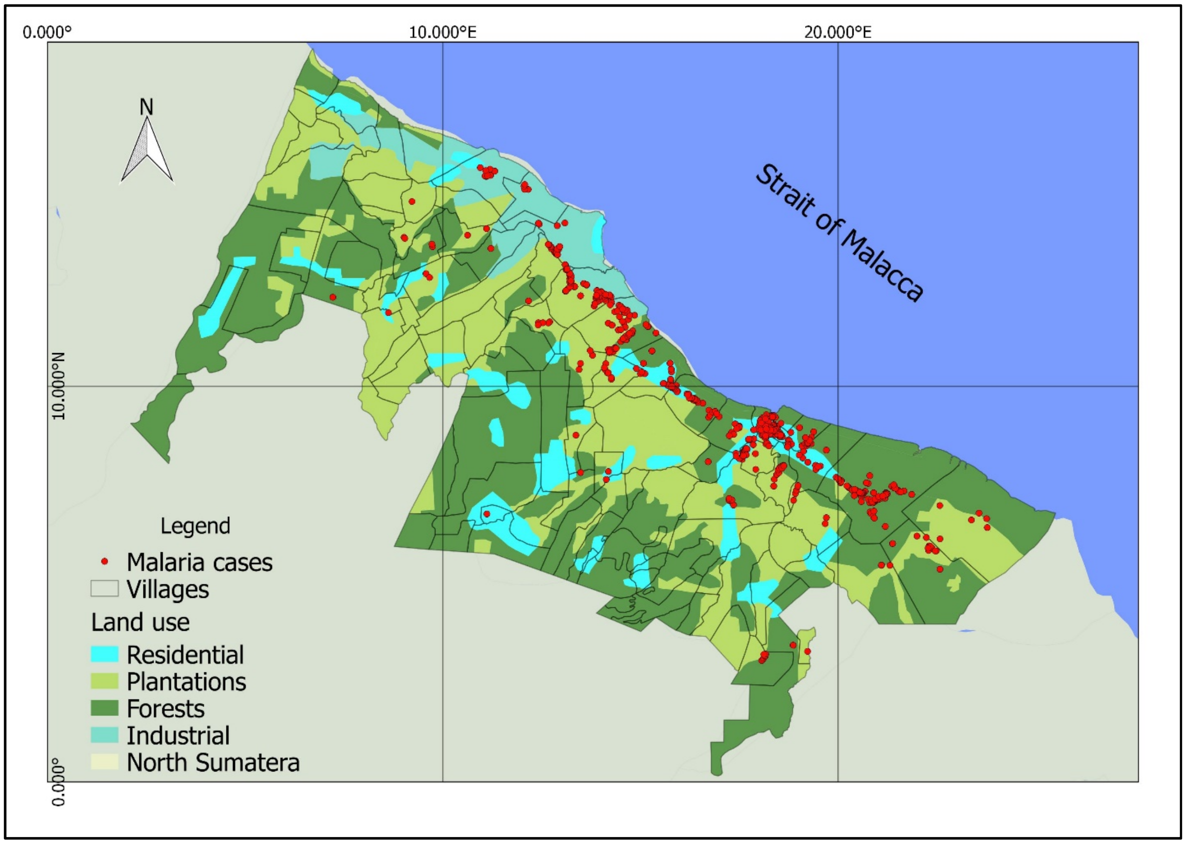

Figure 5. Map of land use and malaria cases in Batubara District

Table 1. Annual malaria cases and the proportion of cases by gender and age, Batubara District, North Sumatera, Indonesia (2018–2020)

Variables	Total, n (%)	2018	2019	2020	p-Value
Gender					0.52
Male	700 (56.9)	108 (53.7)	292 (55.9)	294 (58.2)	
Female	529 (43.1)	93 (46.3)	231 (44.1)	211 (41.8)	
Age (years)					0.02
<5	75 (6.1)	11 (6.2)	40 (7.6)	24 (4.6)	
5-14	401 (32.6)	61 (32.8)	161 (30.6)	179 (34.6)	
15-44	646 (52.6)	97 (52.2)	280 (53.1)	269 (52.1)	
>=55	107 (8.7)	16 (8.8)	46 (8.7)	45 (8.7)	

Table 2. Malaria clusters based on spatial temporal analysis in Batubara District 2018-2020

Year	Cluster type	Coordinates (latitude/longitude)	Radius (km)	Cases (n)	Expected cases (n)	People at risk (n)	RR	LLR	p
2018	Most likely	3.227447 / 99.554927	2.94	11	50	469	2.5	3.31	0.03
	1st Secondary	3.178250 / 99.598111	1.01	5	15	149	3.5	2.61	0.04
	2nd Secondary	3.340533 / 99.448500	1.18	3	17	74	4.1	1.97	0.04
2019	Most likely	3.282607 / 99.447976	4.28	131	115	16322	1.19	1.39	0.01
2020	Most likely	3.326279 / 99.420049	4.49	94	53	1333	1.79	60.24	<0.001
	1st Secondary	3.204966 / 99.570297	6.84	371	249	6298	2.77	15.11	<0.001

RR=relative risk; LLR= likelihood ratio

Table 3. Results of spatial autocorrelation

e	p-Value	Moran's I	z
2018	0.02	0.25	3.473
2019	0.001	0.35	6.072
2020	0.001	0.34	5.804