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Spatial analysis to evaluate risk of malaria in Northern Sumatera, Indonesia

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Abstract

Background: As Indonesia aims for malaria elimination by 2030, provisional malaria epidemiology and risk factors evaluation are important in pursue of this national goal. Therefore, this study aimed to understand the risk factor of malaria in Northern Sumatera.

Methods: Malaria cases from 2019 to 2020 were obtained from the Indonesian Ministry of Health Electronic Database. Climatic variables were provided by the Center for Meteorology and Geophysics Medan branch office. Multivariable logistic regression was undertaken to understand the risk factors of imported malaria. A zero-inflated Poisson multivariable regression model was used to study the climatic drivers of indigenous malaria.

Results: A total of 2208 (indigenous: 76.0% [1679] and imported: 17.8% [392]) were reported during the study period. Risk factors of imported malaria were: ages 19–30 (adjusted odds ratio [AOR] = 3.31; 95% confidence interval [CI] 1.67, 2.56), 31–45 (AOR = 5.69; 95% CI 2.65, 12.20), and > 45 years (AOR = 5.11; 95% CI 2.41, 10.84). Military personnel and forest workers and miners were 1,154 times (AOR = 197.03; 95% CI 145.93, 9,131.56) and 44 times (AOR = 44.16; 95% CI 4.08, 477.93) more likely to be imported cases as compared to those working as employees and traders. Indigenous *Plasmodium falciparum* increased by 12.1% (95% CrI 5.1%, 20.1%) for 1% increase in relative humidity and by 21.0% (95% CrI 9.0%, 36.2%) for 1 °C increase in maximum temperature. *Plasmodium vivax* decreased by 0.8% (95% CrI 0.2%, 1.3%) and 16.7% (95% CrI 13.7%, 19.9%) for one meter and 1 °C increase of altitude and minimum temperature. Indigenous hotspot was reported by Kota Tanjung Balai city and Asahan regency, respectively. Imported malaria hotspots were reported in Batu Bara, Kota Tebing Tinggi, Serdang Bedagai and Simalungun.

Conclusion: Both indigenous and imported malaria is limited to a few regencies and cities in Northern Sumatera. The control measures should focus on these risk factors to achieve elimination in Indonesia.

Keywords: Bayesian analysis, Elimination, Indigenous, Indonesia, Imported, Malaria, Northern Sumatera, Spatial analysis

Background

In 2020, globally there were an estimated 241 million malaria and 627,000 malaria deaths worldwide cases in 87 malaria endemic countries [1]. The World Health Organization (WHO) South-East Asia Region (SEAR) accounted for about 2% of the global malaria burden in

the same year [1]. Malaria cases decreased to 724,000 in 2019 from 1,819,000 in 2000 in Indonesia [2]. During the same period malaria deaths decrease to 1170 from 1898 [2]. In line with the *Global Technical Strategy for Malaria 2016–2030* (GTS) [3] and the Roll Back Malaria advocacy plan, *Action and Investment to Defeat Malaria 2016–2030* (AIM) [4], Indonesia has set a national goal of malaria elimination by 2030 [5].

In 2020, 318 out of 576 (62%) districts in Indonesia are classified as malaria-free areas, and 80.4% of Indonesia's total population are already living in malaria-free

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zone. However, after 2014 there is a trend of stagnant decrease of malaria cases throughout Indonesia which indicate that malaria control has reached its most difficult stage [6]. The Ministry of Health, Indonesia, Directorate of Disease Control, The Indonesian government has been committed to achieving malaria elimination by 2030 and has developed several strategies such as accelerating the reduction number of malaria cases, intensifying control to eliminate malaria residual foci, preventing the reintroduction in malaria-free areas and environmental management to reduce the influence of climatic on the transmission and vector breeding [7, 8]. In North Sumatera, malaria annual parasite incidence in 2020 was 0.07. Twenty-one out of 33 regencies/cities have been classified as malaria free in 2020 [8]. However, difficult geographical region and high mobility of the people continue to the main source of transmission and challenges malaria elimination efforts in North Sumatera.

In pre-elimination settings, malaria transmission is characterised by clustering of cases in transmission “hot-spots” driven by climatic, ecological and human factors [9–11] often in hard-to-reach areas [12]. Therefore, interventions should be focused in areas with higher incidence of malaria than uniform resource allocation for greater effectiveness. In addition, importation of infection should be prevented in areas where malaria has been eliminated [13, 14]. To understand the epidemiological drivers of malaria, stratified analysis of malaria including indigenous, imported and species are important to devise appropriate control and elimination efforts. In addition, identification of malaria hotspots can help delineate problem areas, which can be further investigated to pinpoint possible causes of relatively higher incidences of malaria in a particular area [15]. Hot spots analysis can be done through spatial epidemiological tools (including Geographical Information Systems [GIS] and spatial analytic methods) [16–18].

Therefore, this study aimed to identify risk factors of imported malaria and quantify climatic drivers of indigenous malaria. Secondary aims included identification of indigenous and imported malaria hot spots at regency level. The information for this study can be used to intensify control measures to achieve malaria elimination goals in Indonesia.

Methods

Study site

North Sumatera is a province of Indonesia located in the northern part of the Sumatera island. It is located between 0.589° S and 101.0° E and the capital and the largest city is Medan (Fig. 1). North Sumatera is the fourth most populous in Indonesia. The province covers an area of 72,981 km² and a population of 14,799,361

(statistics data 2021). Northern Sumatera is divided into 33 cities and regencies: 1—Asahan, 2—Batu Bara, 3—Dairi, 4—Deli Serdang, 5—Humbang Hasundutan, 6—Karo, 7—Binjai, 8—Gunungsitoli, 9—Medan, 10—Padangsidempuan, 11—Pematangsiantar, 12—Sibolga, 13—Tanjungbalai, 14—Tebing Tinggi, 15—Labuhanbatu, 16—Labuhanbatu Selatan, 17—Labuhanbatu Utara, 18—Langkat, 19—Mandailing Natal, 20—Nias, 21—Nias Barat, 22—Nias Selatan, 23—Nias Utara, 24—Padang Lawas, 25—Padang Lawas Utara, 26—Pakpak Bharat, 27—Samosir, 28—Serdang Bedagai, 29—Simalungun, 30—Tapanuli Selatan, 31—Tapanuli Tengah, 32—Tapanuli Utara, 33—Toba (Fig. 1).

Data source

Malaria

Malaria data of North Sumatera was collected from Indonesian Ministry of Health. The data were extracted from the electronic database from the year 2019–2020. It consists of the name of the regency or city, name of the health centre, demographic data such as age, sex, the month of visit, occupation, address, malaria species, type of malaria examination, outcome and type of transmission (indigenous/imported). Indigenous malaria case (referred to as indigenous case) was defined as those cases without a history of travel outside their place of residence within the last 3 weeks or no contact with imported cases [19]. Imported malaria case (referred to as imported case), the origin of which can be traced to a known malarious area outside the district or municipality in which the case was diagnosed [19]. An electronic map of regency boundaries in shapefile format was obtained from the Global Administrative Areas database (<http://www.gadm.org/country>).

Climate

Climate data was obtained from the Center for Meteorology and Geophysics (Badan Meteorologi, Klimatologi and Geofisik—BMKG) Medan branch office. Data from 10 (ten) weather monitoring stations were collected through 2019 and 2020; coming from Sampali Station, Belawan Station, Kualanamu Station, Tuntungan Station, Ngumban Surbakti Station, Sibolga Station, Aek Godang Station, Binaka Station, Onowembo Station and Silangit Station. The collected data was then distributed to obtain climate data in 33 regencies and cities in North Sumatera. The climate data included monthly rainfall, relative humidity level, maximum and minimum temperatures. The altitude of municipalities was obtained from the DIVA-GIS database (<https://www.diva-gis.org/>). Municipality polygon was used to extract the mean altitude using Zonal statistics in ArcMap 10.7.1 (ESRI Inc., Redlands, CA, USA).

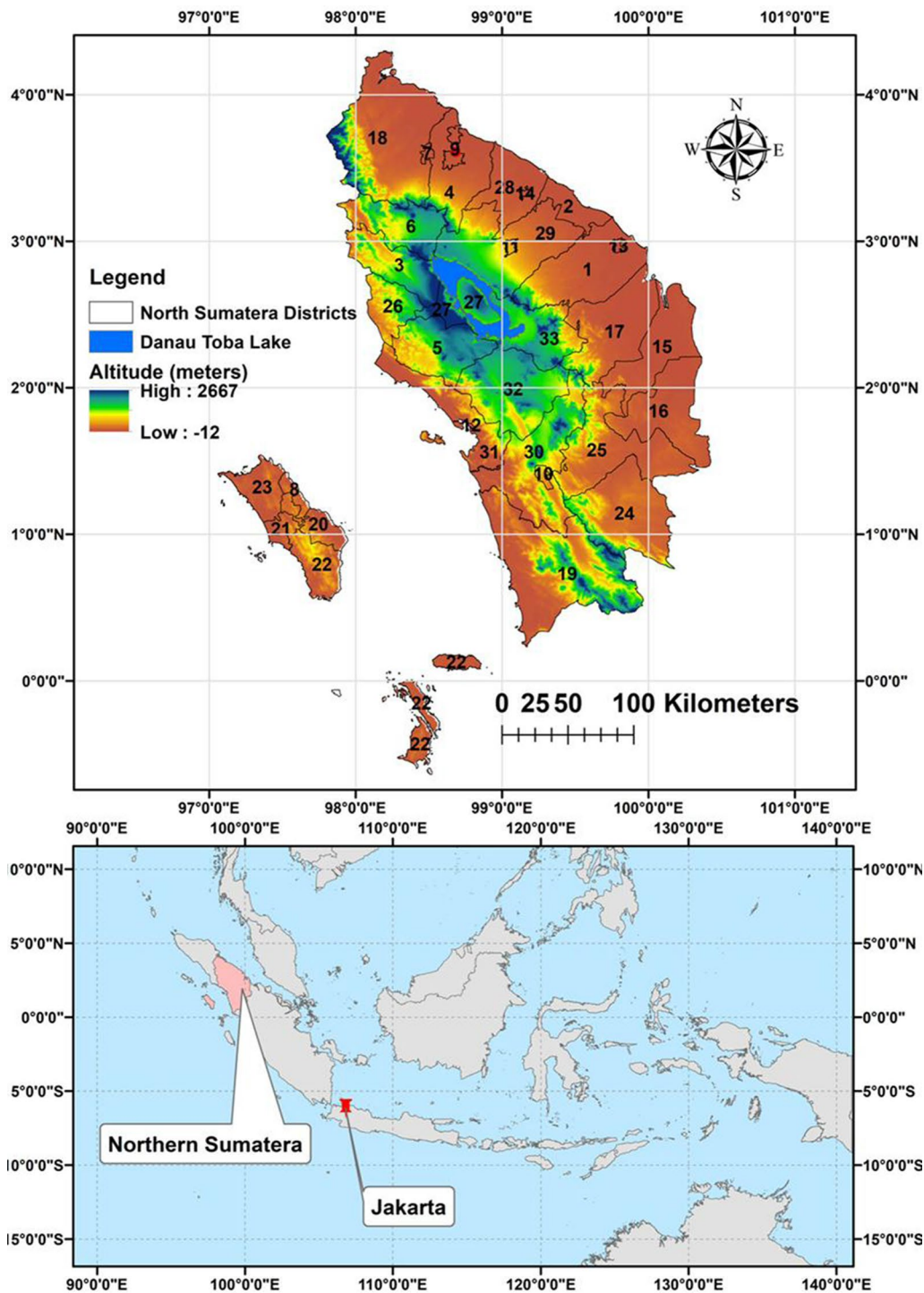


Fig. 1 Map of Northern Sumatera, Indonesia with malaria transmitting regencies. 1—Asahan, 2—Batu Bara, 3—Dairi, 4—Deli Serdang, 5—Humbang Hasundutan, 6—Karo, 7—Binjai, 8—Gunungsitoli, 9—Medan, 10—Padangsidempuan, 11—Pematangsiantar, 12—Sibolga, 13—Tanjungbalai, 14—Tebing Tinggi, 15—Labuhanbatu, 16—Labuhanbatu Selatan, 17—Labuhanbatu Utara, 18—Langkat, 19—Mandailing Natal, 20—Nias, 21—Nias Barat, 22—Nias Selatan, 23—Nias Utara, 24—Padang Lawas, 25—Padang Lawas Utara, 26—Pakpak Bharat, 27—Samosir, 28—Serdang Bedagai, 29—Simalungun, 30—Tapanuli Selatan, 31—Tapanuli Tengah, 32—Tapanuli Utara, 33—Toba

Population

Population data is obtained from the Central Statistics Agency (Badan Pusat Statistik—BPS) of North Sumatera. The population data were stratified by city and regency for 2019 and 2020 in North Sumatera province. The population was further stratified into male and female population data. A total of 25 regencies and 8 cities were included in this study.

Spatial autocorrelation analysis

At a global (study area) scale, Moran’s I statistic was used to explore spatial autocorrelation and its strength and to test the assumption of spatial independence. The Getis-Ord G_i^* statistic was used to undertake local (regency) level clustering and hot spots analysis [20]. The local G_i^* statistic indicates the intensity and stability of hot spot/cold spot clusters [21, 22]. The G^* statistic compares the local mean rate (i.e., the rates of a target regency and its neighbourhood regencies) to the global mean rate (the rates for all regencies). The G_i^* statistics contain a Z-score and p -value of each regency to indicate whether the local and global means are significantly different or not. Regency with a statistically significant and larger Z-score will have a more intense cluster of high values (hot spot), where it is very unlikely that the spatial clustering of high values is the result of a random spatial process; and regencies with a statistically significant and smaller Z-score will have more intense clustering of low values (cold spots) [22].

Crude standardized morbidity ratios

Crude standardized morbidity ratios (SMRs) analysis of both the species were undertaken to describe the malaria incidence by regency across the study period (2 years). SMR was calculated from:

$$Y_i = \frac{O_i}{E_i}$$

Y_i is the overall SMR in regency i , O_i —the total number of reported malaria cases in the regency i and E_i —expected number of malaria cases in the regency i . The E_i was derived by multiplying the average population for regency i with the national incidence of malaria [23].

Statistical analysis

The risk factor of imported malaria was assessed using logistic regression. The covariates included were sex, age, occupation, malaria species and year of reporting. The number of zero counts for *P. falciparum* and *P. vivax* was 1477/1584 (93.3%) and 1387/1584 (87.6%). Therefore, an analysis to determine the best model. Zero-inflated Poisson (ZIP) regression was selected over the standard Poisson regression because ZIP had a better fit with lower

AIC and BIC as compared to Poisson regression, and a Vuong test showed the two models were statically different (Additional file 1: Appendix Tables 1 and 2). Bayesian statistical software WinBUGS version 1.4 (Medical Research Council, Cambridge, UK and Imperial College London, UK) was used to run ZIP regression models for *P. falciparum* and *P. vivax*. The models were tested for each species; the explanatory covariates sex, relative humidity, rainfall and maximum and minimum temperature. The model, which had as an outcome the observed counts of malaria, Y , for i th regency ($i = 1 \dots 24$) in the j th month (January 2019-December 2020), and sex k was structured as follows:

$$P(Y_{ijkl} = y_{ijkl}) = \begin{cases} \omega + 1(1 - \omega)e^{-\mu}, & y_{ijkl} = 0 \\ (1 - \omega)e^{-\mu} \mu^{y_{ijkl}} / y_{ijkl}!, & y_{ijkl} > 0; \end{cases}$$

$$Y_{ijkl} \sim \text{Poisson}(\mu_{ijkl})$$

$$\log(\mu_{ijkl}) = \log(E_{ijkl}) + \theta_{ijkl}$$

$$\theta_{ijkl} = \alpha + \beta_1 \times \text{Sex}_k + \beta_2 \times \text{Rh}_{ij} + \beta_3 \times \text{rainfall}_{ij} + \beta_4 \times \text{Tempmax}_{ij} + \beta_5 \times \text{Tempmin}_{ij} + u_i$$

where E is the expected number of cases (acting as an offset to control for population size) and θ is the mean log relative risk (RR); α is the intercept, and $\beta_1, \beta_2, \beta_3, \beta_4$ and β_5 are the coefficients for sex (female reference), relative humidity, rainfall and maximum and minimum temperature, respectively; u_i is the unstructured random effect (assumed to have a mean of zero and variance σ_u^2).

A flat prior distribution was specified for the intercept, whereas a normal prior distribution was specified for the coefficients. The priors for the precision of unstructured and spatially structured random effects were specified using non-informative gamma distributions with shape and scale parameters equal to 0.01. Models were also developed with unstructured random effects to assess whether inclusion of these components improved model fit.

An initial burn-in of 10,000 iterations was run and these iterations were discarded. Subsequent blocks of 20,000 iterations were run and examined for convergence. Convergence was assessed by visual inspection of posterior density and history plots and occurred at approximately 100,000 iterations for each model. Ten thousand values from the posterior distributions of each model parameter were stored and summarised for the analysis (posterior mean and 95% CrI).

In all analyses, an α -level of 0.05 was adopted to indicate statistical significance (as indicated by 95% CrI for RR that excluded (1). ArcMap 10.5 software (ESRI,

Redlands, CA) was used to generate maps and run hot spot analysis. Stata version 16 (Stata Corporation, College Station, TX, USA) software.

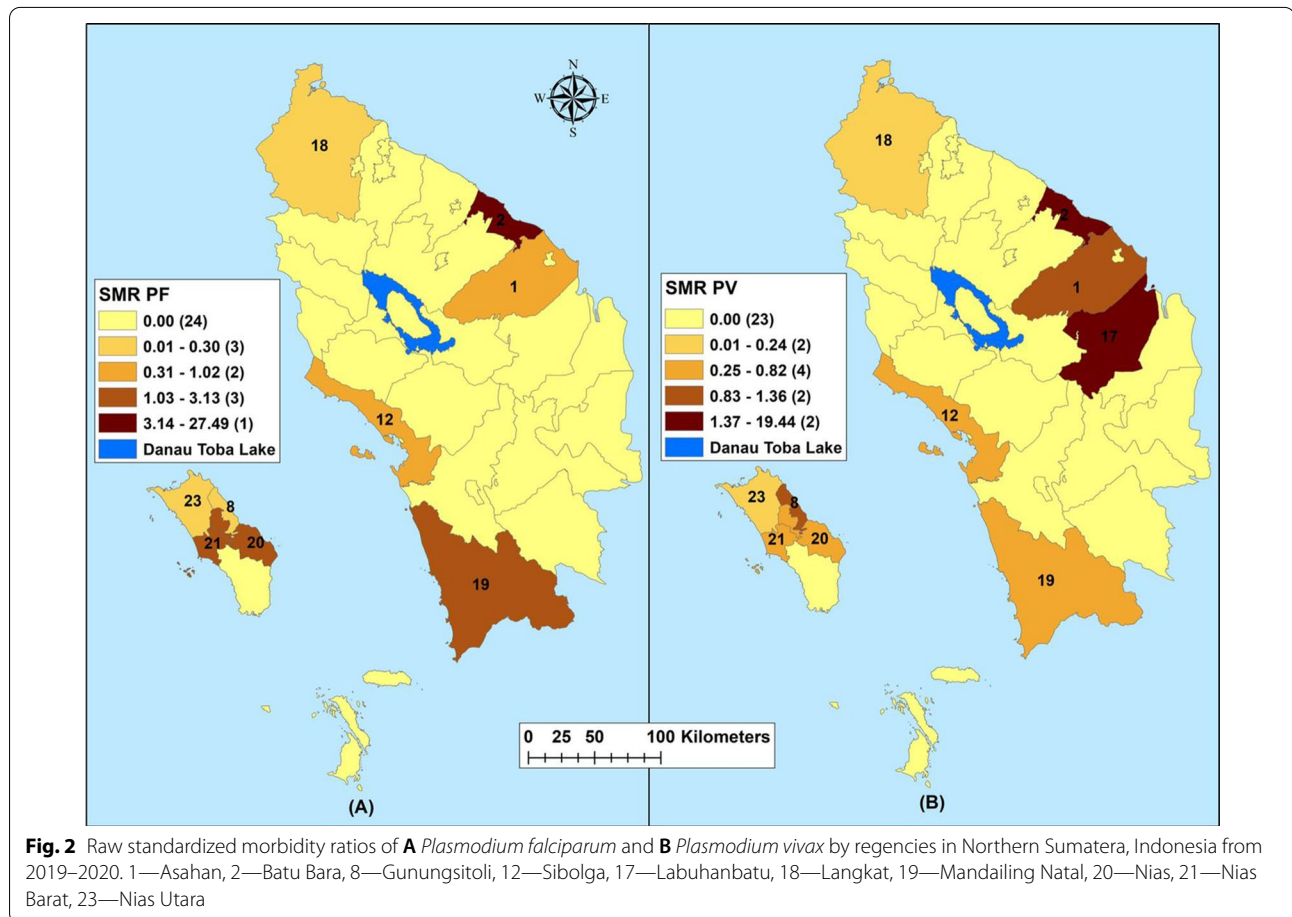
Results

Descriptive analysis

A total of 2,208 malaria cases were reported during the study period. There were 54.3% (1198) cases in 2019 and 62.1% (1371) were in males. Seventy-three per cent (1613), 14.3% (216), 12.6% (277) of cases were *P. vivax*, *P. falciparum* and mixed cases (*P. falciparum* and *P. vivax*). There was one case each of *Plasmodium malariae* and *Plasmodium ovale*. Mean age of patients were 24.7 years (range 1–83). Most (26.0%, 574) were in the age group of 19–30 years followed by 13–18 (22.2%, 490) and <13 (21.5%, 475), respectively. Students (37.4%, 825) and housewives (15.8%, 348) were the two most common occupations. Microscopy diagnoses comprised 54.7% (1208) of cases while rest were diagnosed with the rapid diagnostic test kits.

There were 76.0% (1679) and 17.8% (392) cases of indigenous and imported cases, respectively. Around 6.2% (137) of cases were discarded from the final analysis because the types of cases were not recorded. Males made up 82.6% (324) cases of imported cases with a mean age was 30.5 years (range 1–74 years). Nearly two-thirds of cases were in 19–45 year range followed by 19–30 (45.9%, 180) and 31–45 (31.6%, 124) years. Military personnel made up 48.7% (191) of imported cases. Sixty-four per cent (249) of imported cases were *P. vivax*. Mean altitude, rainfall and relative humidity were 370 m (range 4–1404), 232.5 mm (range 8.4–616.6) and 85.1% (range 75.6 to 95.9), respectively. Mean maximum and minimum temperature during the study was 32.8 °C (range 24.8–37.1) and 20 °C (range 12.7–25.0).

Maps of crude SMRs for *P. falciparum* varied between 0.0 and 27.49 during the study period. Batu Bara Regency reported the highest SMR (31.4–27.49) and 24 regencies reported an SMR of zero cases (Fig. 2). Crude SMR for *P. vivax* varied from 0.0 to 19.44 with Batu Bara and



Labuhan Batu Utara regencies reporting the highest SMR (1.37- 19.44). Twenty-three regencies reported an SMR of zero for *P. vivax* (Fig. 2). Indigenous malaria cases hot-spot was limited to Asahan and Tanjungbalai regencies

(Fig. 3), while imported cases were reported in five adjacent regencies: Batu Bara, Kota Pematang Siantar, Tebing Tinggi, Serdang Bedagai and Simalungun (Fig. 4).

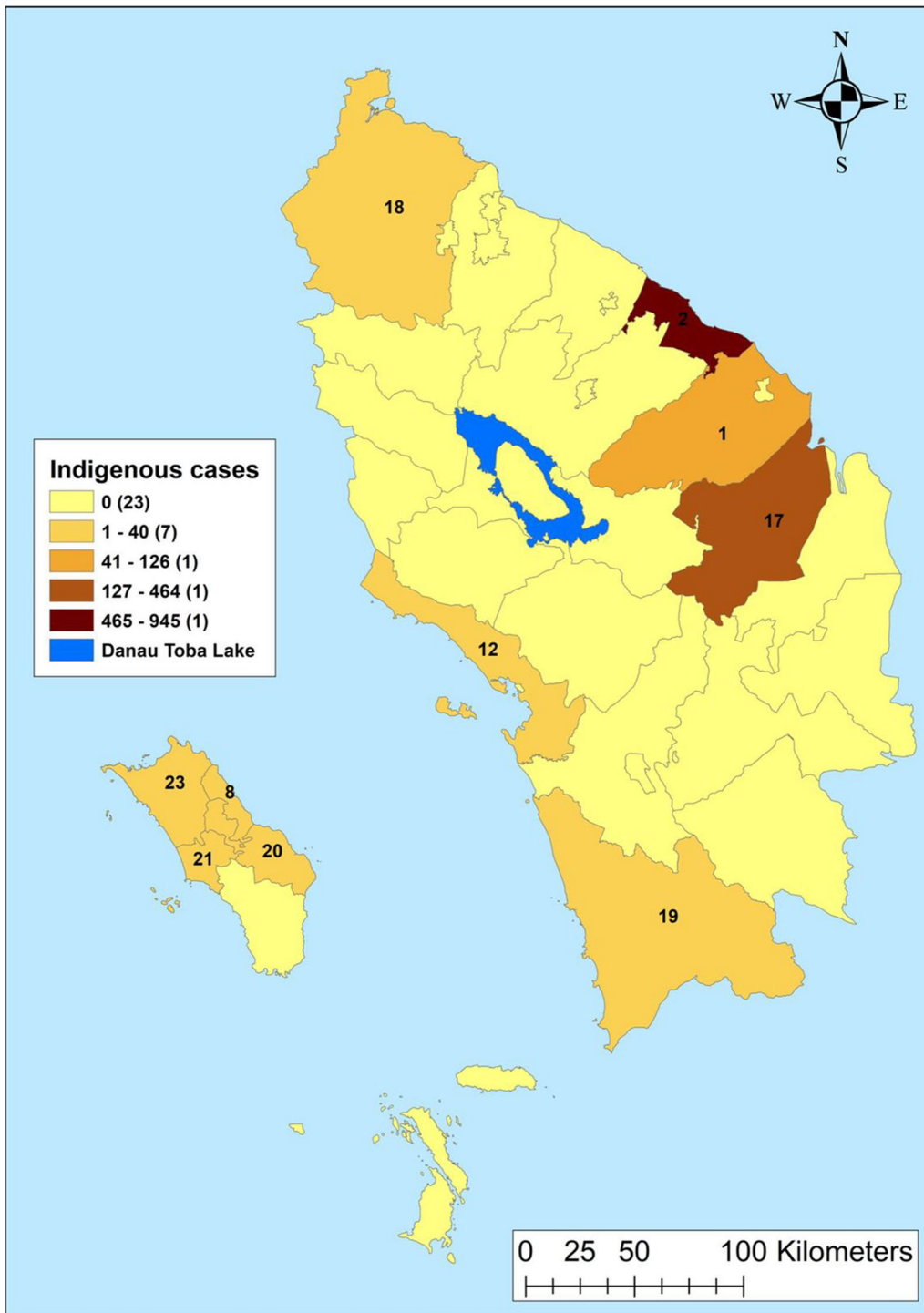


Fig. 3 Indigenous cases by regencies in Northern Sumatera, Indonesia from 2019–2020. 1—Asahan, 2—Batu Bara, 8—Gunungsitoli, 12—Sibolga, 17—Labuhanbatu, 18—Langkat, 19—Mandailing Natal, 20—Nias, 21—Nias Barat, 23—Nias Utara

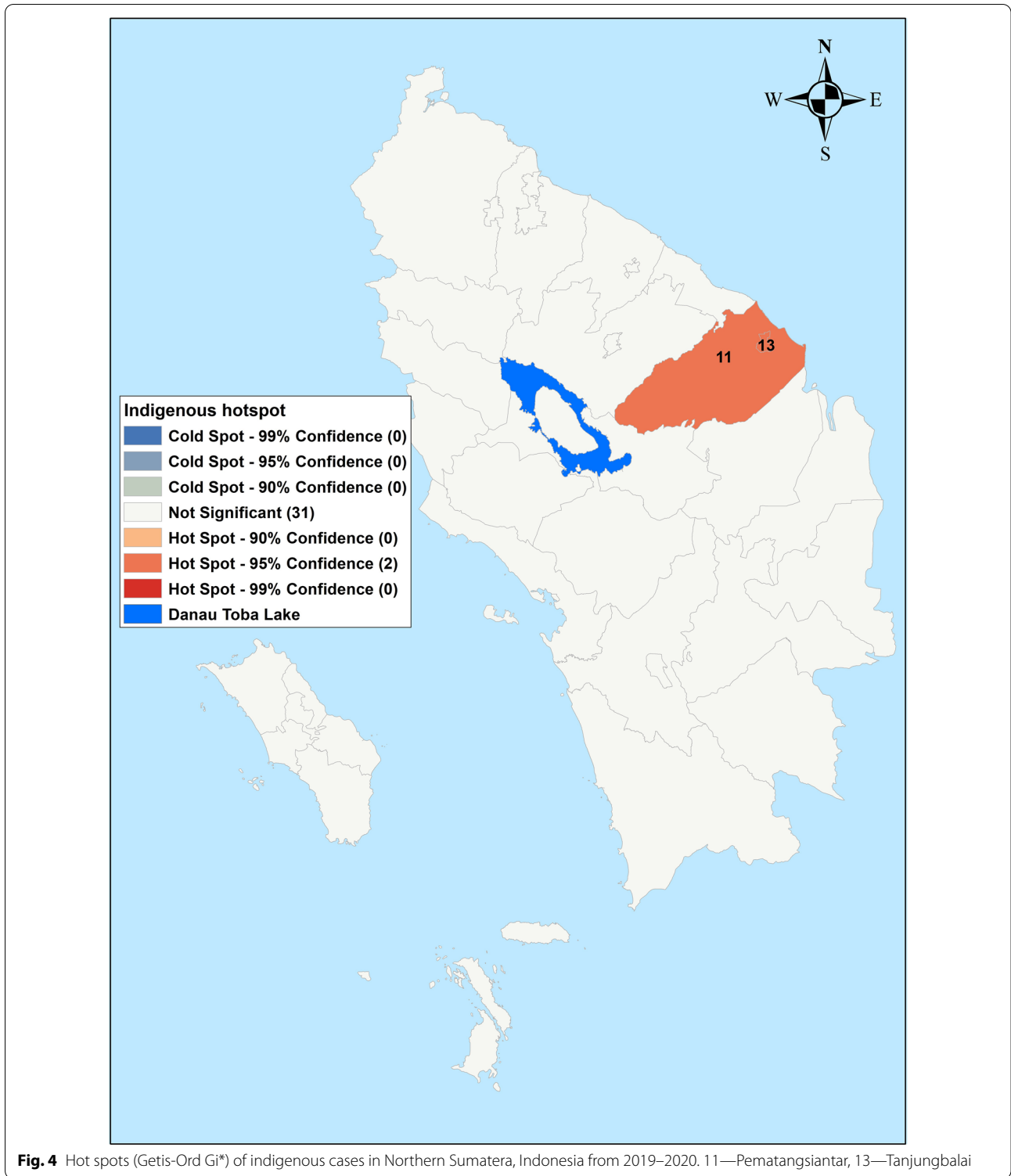


Fig. 4 Hot spots (Getis-Ord G_i^*) of indigenous cases in Northern Sumatera, Indonesia from 2019–2020. 11—Pematangsiantar, 13—Tanjungbalai

Hotspot of indigenous and imported malaria

Twenty-three regencies and cities did not report any indigenous malaria during the study period. The indigenous cases were reported by 10 regencies and the highest cases

were reported by Batu Bara (Fig. 3). Imported cases were reported by 14 regencies and the highest case was reported by Asahan and Deli Serdang regencies, respectively (Fig. 4). Indigenous hotspot was reported by Kota Tanjung Balai

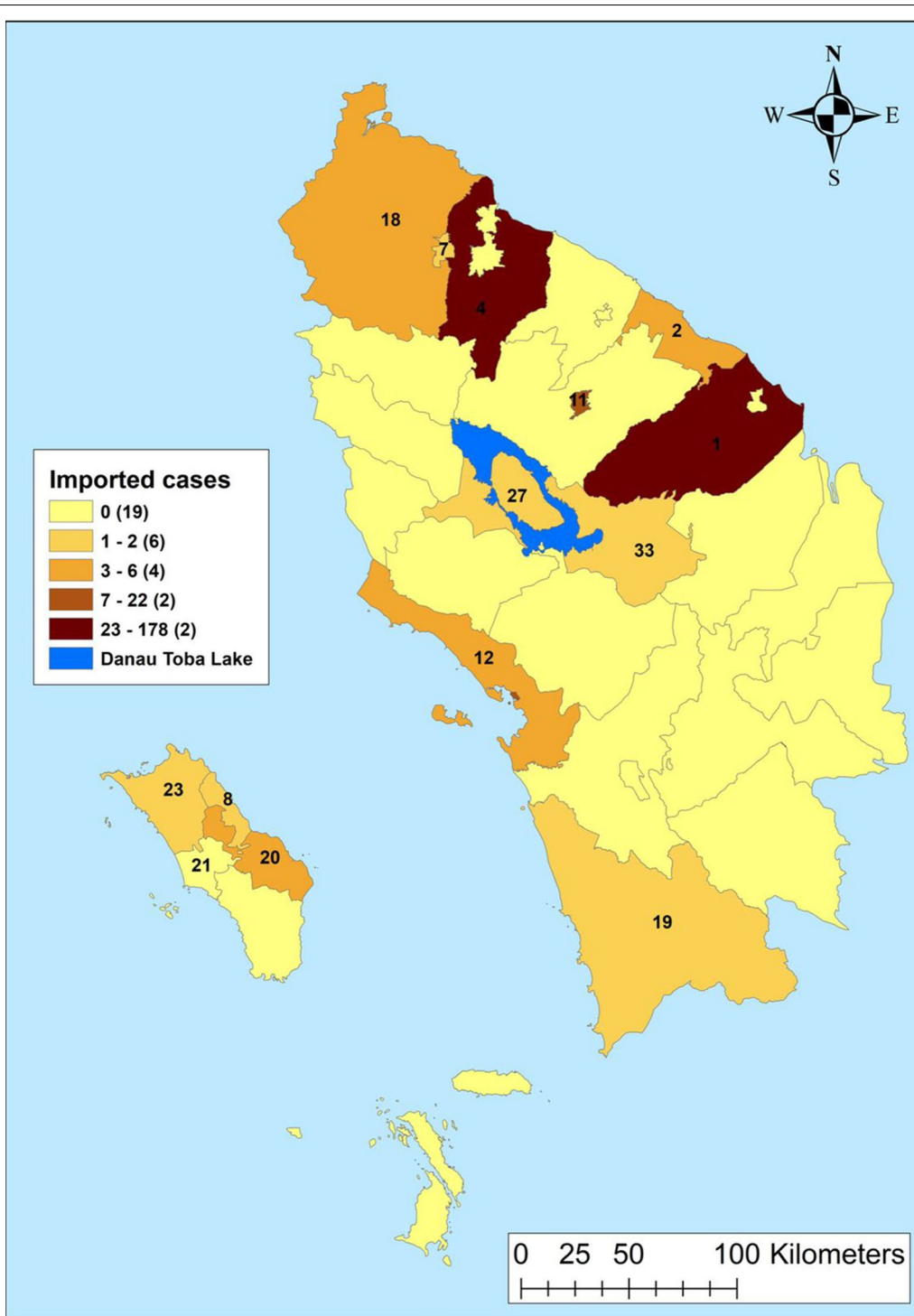
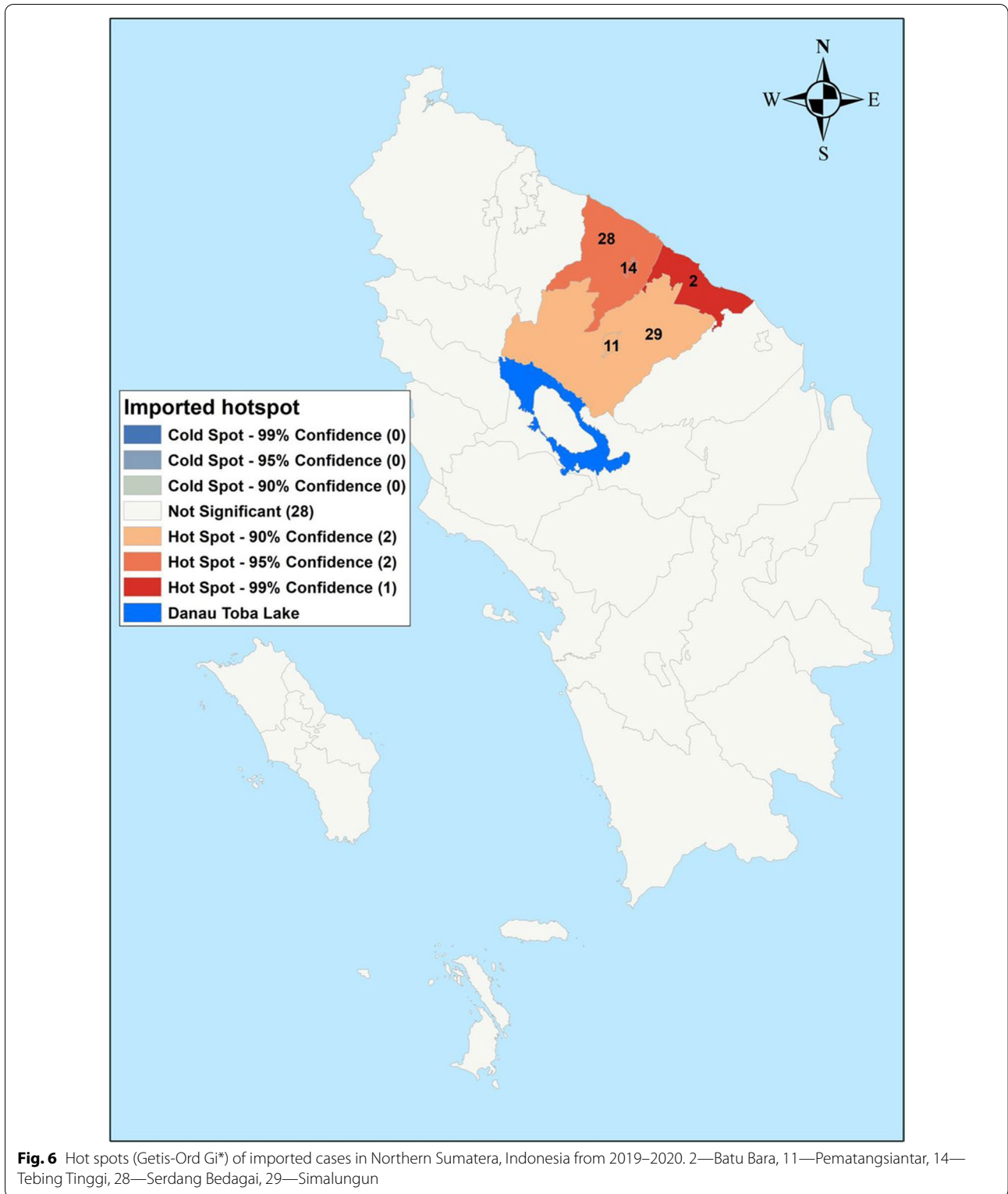


Fig. 5 Imported cases by regencies in Northern Sumatera, Indonesia from 2019–2020. 1—Asahan, 2—Batu Bara, 4—Deli Serdang, 7—Binjai, 8—Gunungsitoli, 11—Pematangsiantar, 12—Sibolga, 18—Langkat, 19—Mandailing Natal, 20—Nias, 21—Nias Barat, 23—Nias Utara, 27—Samosir, 33—Toba

city and Asahan Regency, respectively (Fig. 5). Imported malaria hotspots were reported in Batu Bara, Kota Tebing Tinggi, Serdang Bedagai and Simalungun (Fig. 6).

Risk factors of imported malaria

In multivariable logistic regression, ages 19–30, 31–45 and >45 were more likely to be an imported case



compared to the < 13 year age group: 3.3 (adjusted odds ratio [AOR]=3.31; 95% confidence interval [CI] 1.67, 2.56); 5.7 times (AOR=5.69; 95% CI 2.65, 12.20), and

5 times (AOR=5.11; 95% CI 2.41, 10.84). Military personnel, and forest workers and miners were 1154 times (AOR=197.03; 95% CI 145.93, 9131.56) and 44 times

(AOR = 44.16; 95% CI 4.08, 477.93) more likely to be as compared to those working as employees and traders. However, fishermen were 82% less likely to be an imported case (AOR = 0.18, 95% CI 0.08, 0.38) compared to working employees and traders. *Plasmodium falciparum* had lower odds of being imported cases compared to *P. vivax* (AOR = 0.58, 95% CI 0.38, 0.88) (Tables 1 2).

Climatic risk factors of indigenous malaria

Relative humidity and maximum temperature were significant climatic variables for *P. falciparum*. While the minimum temperature was the only significant climatic

variable for *P. vivax*. *Plasmodium falciparum* increased by 12.1% (95% CrI 5.1%, 20.1%) for 1% increase in relative humidity. One-degree increase of maximum temperature increased *P. falciparum* cases by 21.0% (95% CrI 9.0%, 36.2%). *Plasmodium vivax* decreased by 0.8% (95% CrI 0.2%, 1.3%) and 16.7% (95% CrI 13.3%, 19.9%) for each metre and 1 °C increase of altitude and minimum temperature, respectively (Table 3).

Discussion

Nearly one-fifth of malaria cases in Northern Sumatera in 2019 and 2020 were imported malaria. Both indigenous and imported malaria were limited to a few regencies and cities. Risk factors of imported malaria were: > 18 years, military personnel, and forest workers and miners. While fisherman was less likely to be imported malaria compared to employees and traders. Relative humidity and maximum temperature were associated with an increase of *P. falciparum* while altitude and minimum temperature were associated with a decrease in *P. vivax*.

Importation of malaria continues to be an important impediment of malaria elimination efforts [12, 24, 25], driven by complex and multi-faceted factors [25]. Economic migration for better economic, work and social opportunities are important drivers of imported malaria [17, 26–30]. As the country progresses towards malaria elimination, imported malaria becomes the main malaria type [31]. Imported malaria can reintroduce in areas/regions where malaria has been eliminated [32]. Therefore, to prevent the contribution of imported malaria on local transmission in malaria receptivity areas, malaria surveillance including access to prompt diagnosis and treatment to the returning travellers along the international borders should be strengthened [33, 34].

The hot spots of indigenous and imported malaria were located in the east part of Northern Sumatera. The Eastern part of North Sumatera is a coastal area with dense population compared to other parts of North Sumatera. The areas are surrounded by swamps and rivers, and the Hindia ocean. In addition, the main occupation of people in this region is fishermen and farmers [35]. These groups are at a higher risk for malaria infection [36]. Therefore, high coverage of long-lasting insecticidal nets (LLINs) along with prompt diagnosis and treatment need to be strengthened for to curb indigenous malaria in these hot-spot regencies.

Military personnel, forest workers and miners were risk factors for imported malaria [37, 38]. As reported earlier military personnel deployed in Papua were responsible for imported malaria in this study [38]. Therefore, strengthening service points for screening and surveillance in collaboration with relevant organizations like the department of military should be undertaken [39, 40]. This includes

Table 1 Socio-demographic characteristics of total and imported cases in North Sumatera, Indonesia, 2019–2020

Characteristic	Total case (2208) Number (%)	Imported (392) Number (%)	P value
Sex			
Female	836 (37.9)	68 (17.4)	<0.001
Male	1371 (62.1)	324 (82.6)	
Age groups (years)			
≤ 12	475 (21.5)	19 (4.9)	<0.001
13–18	490 (22.2)	27 (6.9)	
19–30	574 (26.0)	180 (45.9)	
31–45	428 (19.4)	124 (31.6)	
> 45	241 (10.9)	42 (10.7)	
Occupation			
ET	213 (9.7)	51 (13.0)	<0.001
FG	168 (7.6)	22 (5.6)	
Fisherman	194 (8.8)	9 (2.3)	
FM	10 (0.5)	9 (2.3)	
Housewife	348 (15.8)	42 (10.7)	
Military	193 (8.7)	191 (48.7)	
Students	825 (37.4)	44 (11.2)	
Unemployed	257 (11.6)	24 (6.1)	
Species			
PF	316 (14.3)	115 (29.4)	<0.001
PV	1613 (73.0)	249 (63.5)	
Mixed	277 (12.6)	28 (7.1)	
Others	2 (0.1)	0 (0.0)	
Diagnosis			
Microscope	1208 (54.7)	296 (75.5)	<0.001
RDT	1000 (45.3)	96 (24.5)	
Year			
2019	1198 (54.3)	241 (61.5)	<0.001
2020	1010 (45.7)	151 (9.5)	

ET: employees and traders; FG: farmers and gardeners; FM: forest goers and miners; PF: *P. falciparum*, PV: *P. vivax*; Mixed- Mixed infection of *P. falciparum* and *P. vivax*; RDT- rapid diagnostic test; Others: one *Plasmodium ovale* and *Plasmodium malariae* each

Table 2 Multivariable logistic regression of imported malaria in Northern Sumatera, 2019–2020

Characteristics	Univariate		Multivariable	
	OR	p value	AOR	p value
Sex				
Female	Ref		Ref	
Male	3.54 (2.68, 4.68)	< 0.001	1.46 (0.93, 2.27)	0.098
Age groups (years)				
< 13	Ref		Ref	
13–18	1.31 (0.72, 2.39)	0.38	1.39 (0.75, 2.58)	0.303
19–30	10.85 (6.62, 17.77)	< 0.001	3.31 (1.67, 6.56)	0.001
31–45	9.72 (5.86, 16.13)	< 0.001	5.69 (2.65, 12.20)	< 0.001
> 45	4.86 (2.75, 8.58)	< 0.001	5.11 (2.41, 10.84)	< 0.001
Occupation				
ET	Ref		Ref	
FG	0.49 (0.28, 0.86)	0.012	0.44 (0.25, 0.78)	0.005
Fisherman	0.16 (0.08, 0.33)	< 0.001	0.18 (0.08, 0.38)	< 0.001
FM	26.82 (3.32, 216.91)	0.002	44.16 (4.08, 477.68)	0.002
Housewife	0.44 (0.28, 0.69)	< 0.001	0.59 (0.33, 1.07)	0.082
Military	569.25 (77.77, 4,166.55)	< 0.001	1,154.35 (145.93, 9,131.56)	< 0.001
Students	0.18 (0.11, 0.28)	< 0.001	0.64 (0.33, 1.27)	0.205
Unemployed	0.35 (0.21, 0.60)	< 0.001	0.96 (0.52, 1.79)	0.91
Species				
PF	Ref		Ref	
PV	0.33 (0.25, 0.43)	< 0.001	0.58 (0.38, 0.88)	0.01
Mixed	0.20 (0.13, 0.31)	< 0.001	0.10 (0.04, 0.27)	< 0.001
Year				
2019	Ref		Ref	
2020	0.62 (0.49, 0.77)	< 0.001	1.68 (1.22, 2.32)	0.001

OR: odds ratio; AOR: adjusted odds ratio; Ref: reference group; ET: employees and traders; FG: farmers and gardeners; FM: forest workers and miners; PF: *P. falciparum*, PV: *P. vivax*, p-value significant at < 0.05

Table 3 Regression coefficients and 95% CrI from Bayesian models of *Plasmodium falciparum* and *Plasmodium vivax* cases reported by month and regency, North Sumatera, Indonesia, 2019–2020

Covariates	<i>Plasmodium falciparum</i>		<i>Plasmodium vivax</i>	
	Coefficient (95% CrI)	RR (95% CrI)	Coefficient (95% CrI)	RR (95% CrI)
Intercept*	− 5.79 (− 7.82, − 3.70)		− 6.38 (− 8.14, − 4.45)	
Sex (ref: female)	− 0.011 (− 0.204, 0.180)	0.989 (0.816, 1.197)	− 0.004 (− 0.109, 0.100)	0.996 (0.897, 1.105)
Altitude (meters)	− 0.005 (− 0.012, 0.000)	0.995 (0.988, 1.000)	− 0.008 (− 0.013, − 0.002)	0.992 (0.987, 0.998) [†]
Relative humidity (%)	0.114 (0.050, 0.183)	1.121 (1.051, 1.201) [†]	0.017 (− 0.005, 0.039)	1.017 (0.995, 1.040)
Rainfall (cm)	− 0.002 (− 0.015, 0.011)	0.998 (0.985, 1.011)	0.002 (− 0.005, 0.008)	1.002 (0.995, 1.008)
Maximum temperature (°C)	0.190 (0.086, 0.309)	1.210 (1.090, 1.362) [†]	0.010 (− 0.024, 0.042)	1.010 (0.977, 1.043)
Minimum temperature (°C)	− 0.022 (− 0.102, 0.060)	0.978 (0.903, 1.062)	− 0.182 (− 0.222, − 0.143)	0.833 (0.801, 0.867) [†]
Unstructured random effect	0.0617 (0.0211, 0.1353)		0.05 (0.0187, 0.1037)	

* Co-efficient; CrI: credible interval; DIC: deviation information criteria; RR: relative risk

[†] Significant at $p < 0.05$

provision of LLIN to the military personnel deployed at high malaria risk areas, health education, prompt diagnosis and treatment, and screening for malaria after

deployment. Malaria prophylaxis to military can be used as an adjunct in addition to other preventative measures to reduce malaria infection in military personnel [40].

Similarly, forest goers and miners continue to be important risk factors of imported malaria in malaria eliminating countries [39]. Therefore, targeting these high-risk groups will be imperative in pursue of malaria elimination [38, 40]. Further, screening posts can be set up at border crossings and migration portals such as taxi stands, and public bus and boat terminals for forest goers and miners [12, 41]. Intervention packages including LLINs, long-lasting insecticidal hammocks (LLIHs), pamphlets on malaria (signs and symptoms) and possible contact points for malaria diagnosis and treatment services in the destination area and education on malaria prevention can be disseminated through these portals. Further, free screening and treatment for asymptomatic malaria can be offered for both returning and travelling migrants [42]. Therefore, malaria control programmes need to integrate these novel methods to target the imported malaria cases. Other novel approaches such as the Malakit used for malaria self-care by the gold miners in French Guiana can be tested for Indonesia [43]. The Malakit supports illegal gold miners to self-diagnosis malaria and supports treatment for *P. falciparum*.

Plasmodium falciparum transmission was associated with maximum temperature. Similar findings have been reported in other studies [23]. Temperature plays a crucial role in the transmission cycle of the malaria parasite and mosquito survival [44, 45]. Studies found that at a temperature of 22 °C, the life cycle of malaria parasite development in mosquito vectors is completed in less than 3 weeks [46]. The biting rate and gonotrophic processes are also temperature dependent [47, 48]. Other studies have reported rainfall as an important driver of malaria transmission [49, 50]. However, rainfall was not associated with malaria transmission in this study. *Plasmodium vivax* was inversely associated with altitude and minimum temperature, which is in concordance with other published papers [51–54]. This can partly be due to the detrimental effects of temperature < 16 °C for mosquito survival and *P. vivax*. The temperature also decreases with the increasing altitude.

The limitations of this study are: the completeness and representativeness of surveillance data could not be ascertained. Secondly, sub-microscopic or asymptomatic malaria which could not be captured by surveillance can continue to transmit transmission [55]. Thirdly, unmeasured risk modifiers, such as socio-economic development, living standards, treatment, localised behavioural patterns, population mobility, bed net use and residual indoor insecticide coverage were unaccounted for in this study.

Conclusion

One-fifth of malaria in Northern Sumatera were imported malaria. Both indigenous and imported malaria hot spots were in the east part of Northern Sumatera. Strengthening surveillance of indigenous malaria, prompt diagnosis

and treatment, and provision of good coverage of LLINs in needed in pursue of malaria elimination efforts. Imported malaria can be combatted by expanding control measures such as malaria prophylaxis and other preventive measures through co-ordination with the relevant organizations.

Abbreviations

AIM: Action and Investment to Defeat Malaria 2016–2030; AOR: Adjusted odds ratio; CI: Confidence interval; GIS: Geographical Information Systems; GTS: Global Technical Strategy for Malaria 2016–2030; LLIHs: Long-lasting insecticidal hammocks; LLINs: Long-lasting insecticidal nets; RR: Relative risk; SEAR: South-East Asia Region; SMRs: Standardized morbidity ratios; WHO: World Health Organization; ZIP: Zero-inflated Poisson.

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s12936-022-04262-y>.

Additional file 1. Appendix Table 1. Model selection for *Plasmodium falciparum*. Appendix Table 2. Model selection for *Plasmodium vivax*

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Author contributions

All authors were involved in the conceptualization and design of the study. FF, APP and MT were involved in data acquisition. KW undertook the data cleaning and statistical analysis. KW drafted the manuscript. APP, FF and MT provided critical revision of the manuscript. All authors read and approved the final manuscript.

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Data availability

The datasets generated during and/or analysed for this current study will be made available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The study was approved by the ethical committee of Universitas Sumatera Utara No. 735/ KEPK/USU/2021.

Consent for publication

Not applicable.

Competing interests

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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References

- WHO. World Malaria Report 2021. Geneva: World Health Organization; 2021.
- WHO. World Malaria Report 2020. Geneva: World Health Organization; 2020.
- WHO. Confronting *Plasmodium vivax* malaria. Geneva: World Health Organization; 2015.
- RBM. Action and investment to defeat malaria 2016–2030. Geneva: World Health Organization; 2015.
- Indonesia <https://apmen.org/country/indonesia>.
- MoH. Laporan situasi terkini perkembangan program pengendalian malaria di Indonesia tahun. Jakarta: Director General of Disease Control MoH; 2019. p. 1–44.
- Sitohang V, Sariwati E, Fajariyani SB, Hwang D, Kurnia B, Hapsari RK, et al. Malaria elimination in Indonesia: halfway there. *Lancet Glob Health*. 2018;6:e604–6.
- Kementerian Kesehatan Republik Indonesia. National Malaria Programme Review Republic of Indonesia 2019. Jakarta: Kementerian Kesehatan Republik Indonesia; 2019. p. 39–44.
- Sturrock HJW, Bennett AF, Midekisa A, Gosling RD, Gething PW, Greenhouse B. Mapping malaria risk in low transmission settings: challenges and opportunities. *Trends Parasitol*. 2016;32:635–45.
- Wangdi K, Gatton ML, Kelly GC, Clements AC. Cross-border malaria: a major obstacle for malaria elimination. *Adv Parasitol*. 2015;89:79–107.
- Clements ACA, Reid HL, Kelly GC, Hay SI. Further shrinking the malaria map: how can geospatial science help to achieve malaria elimination? *Lancet Infect Dis*. 2013;13:709–18.
- Wangdi K, Pasaribu AP, Clements ACA. Addressing hard-to-reach populations for achieving malaria elimination in the Asia Pacific Malaria Elimination Network countries. *Asia Pac Policy Stud*. 2021;8:176–88.
- Churcher TS, Cohen JM, Novotny J, Ntshalintshali N, Kunene S, Cauchemez S. Measuring the path toward malaria elimination. *Science*. 2014;344:1230–2.
- Cotter C, Sturrock HJ, Hsiang MS, Liu J, Phillips AA, Hwang J, et al. The changing epidemiology of malaria elimination: new strategies for new challenges. *Lancet*. 2013;382:900–11.
- Sweeney AW. The Application of GIS in Malaria Control Programs. 10th Colloquium of the Spatial Information Research Centre, University of Otago, New Zealand, 16–19 November, 1998.
- Childs DZ, Cattadori IM, Suwonkerd W, Prajakwong S, Boots M. Spatiotemporal patterns of malaria incidence in northern Thailand. *Trans R Soc Trop Med Hyg*. 2006;100:623–31.
- Wangdi K, Kaewkungwal J, Singhasivanon P, Silawan T, Lawpoolsri S, White NJ. Spatio temporal patterns of malaria infection in Bhutan: a country embarking on malaria elimination. *Malar J*. 2011;10:89.
- Brooker S, Leslie T, Kolaczinski K, Mohsen E, Mehboob N, Saleheen S, et al. Spatial epidemiology of *Plasmodium vivax*. *Afghanistan Emerg Infect Dis*. 2006;12:1600–2.
- WHO. Disease Surveillance for Malaria Elimination: an operational manual. Geneva: World Health Organization; 2012.
- Anselin L. Local indicators of spatial association—LISA. *Geogr Anal*. 1995;27:93–115.
- Zulu LC, Kalipeni E, Johannes E. Analyzing spatial clustering and the spatiotemporal nature and trends of HIV/AIDS prevalence using GIS: the case of Malawi, 1994–2010. *BMC Infect Dis*. 2014;14:285.
- Ord JK, Getis A. Local spatial autocorrelation statistics: distributional issues and an application. *Geogr Anal*. 1995;27:286–306.
- Wangdi K, Canavati SE, Ngo TD, Tran LK, Nguyen TM, Tran DT, et al. Analysis of clinical malaria disease patterns and trends in Vietnam 2009–2015. *Malar J*. 2018;17:332.
- WHO. Eliminating malaria. Geneva: World Health Organization; 2016.
- WHO. Evidence review group on border malaria. Geneva: World Health Organization; 2018.
- Wangdi K, Xu Z, Suwannatrat AT, Kurscheid J, Lal L, Namgay R, et al. A spatio-temporal analysis to identify the drivers of malaria transmission in Bhutan. *Sci Rep*. 2020;10:7060.
- Hoyer S, Nguon S, Kim S, Habib N, Khim N, Sum S, et al. Focused Screening and Treatment (FSAT): a PCR-based strategy to detect malaria parasite carriers and contain drug resistant *P falciparum*, Pailin, Cambodia. *PLoS ONE*. 2012;7:e45797.
- Hewitt S, Delacollette C, Chavez I. Malaria situation in the Greater Mekong Subregion. *Southeast Asian J Trop Med Public Health*. 2013;44(Suppl 1):46–72. (discussion 306–307).
- Sriwichai P, Karl S, Samung Y, Kiattitubtr K, Sirichaisinthop J, Mueller I, et al. Imported *Plasmodium falciparum* and locally transmitted *Plasmodium vivax*: cross-border malaria transmission scenario in northwestern Thailand. *Malar J*. 2017;16:258.
- Lai S, Sun J, Ruktanonchai NW, Zhou S, Yu J, Routledge I, et al. Changing epidemiology and challenges of malaria in China towards elimination. *Malar J*. 2019;18:107.
- Gray TJ, Trauer JM, Fairley M, Krause VL, Markey PG. Imported malaria in the Northern Territory, Australia—428 consecutive cases. *Commun Dis Intell Q Rep*. 2012;36:107–13.
- Karunasena VM, Marasinghe M, Koo C, Amarasinghe S, Senaratne AS, Hasantha R, et al. The first introduced malaria case reported from Sri Lanka after elimination: implications for preventing the re-introduction of malaria in recently eliminated countries. *Malar J*. 2019;18:210.
- Sturrock HJW, Roberts KW, Wegbreit J, Ohrt C, Gosling RD. Tackling imported malaria: an elimination endgame. *Am J Trop Med Hyg*. 2015;93:139–44.
- Liu Y, Hsiang MS, Zhou H, Wang W, Cao Y, Gosling RD, Cao J, Gao Q. Malaria in overseas labourers returning to China: an analysis of imported malaria in Jiangsu Province, 2001–2011. *Malar J*. 2014;13:29.
- Pasaribu AP, Nasution IS, Sembiring K, Fahmi F, Pasaribu S. Comparison of the performances of the CareStart Malaria Pf/Pan Combo test and field microscopy in the diagnosis of malaria transmitted by *Plasmodium vivax* in North Sumatera, Indonesia. *Malar J*. 2022;21:27.
- Herdiana H, Cotter C, Coutrier FN, Zarlinda I, Zelman BW, Tirta YK, et al. Malaria risk factor assessment using active and passive surveillance data from Aceh Besar, Indonesia, a low endemic, malaria elimination setting with *Plasmodium knowlesi*, *Plasmodium vivax*, and *Plasmodium falciparum*. *Malar J*. 2016;15:468.
- Dharmawardena P, Premaratne R, Wickremasinghe R, Mendis K, Fernando D. Epidemiological profile of imported malaria cases in the prevention of reestablishment phase in Sri Lanka. *Pathog Glob Health*. 2021;116:38–46.
- Fernando SD, Dharmawardana P, Semege S, Epasinghe G, Senanayake N, Rodrigo C, et al. The risk of imported malaria in security forces personnel returning from overseas missions in the context of prevention of re-introduction of malaria to Sri Lanka. *Malar J*. 2016;15:144.
- Canavati SE, Kelly GC, Quintero CE, Vo TH, Tran LK, Ohrt C, et al. Risk factor assessment for clinical malaria among forest-goers in a pre-elimination setting in Phu Yen Province, Vietnam. *Malar J*. 2019;18:435.
- Fernando SD, Booso R, Dharmawardana P, Harintheran A, Raviraj K, Rodrigo C, et al. The need for preventive and curative services for malaria when the military is deployed in endemic overseas territories: a case study and lessons learned. *Mil Med Res*. 2017;4:19.
- Canavati SE, Kelly GC, Quintero CE, Vo TH, Tran LK, Ngo TD, et al. Targeting high risk forest goers for malaria elimination: a novel approach for investigating forest malaria to inform program intervention in Vietnam. *BMC Infect Dis*. 2020;20:757.
- Edwards HM, Canavati SE, Rang C, Ly P, Sovannaroth S, Canier L, et al. Novel cross-border approaches to optimise identification of asymptomatic and artemisinin-resistant *Plasmodium* infection in mobile populations crossing Cambodian borders. *PLoS ONE*. 2015;10: e0124300.
- Douine M, Sanna A, Galindo M, Musset L, Pommier de Santi V, Marchesini P, et al. Malakit: an innovative pilot project to self-diagnose and self-treat malaria among illegal gold miners in the Guiana Shield. *Malar J*. 2018;17:158.
- Brooker S, Clarke S, Njagi JK, Polack S, Mugo B, Estambale B, et al. Spatial clustering of malaria and associated risk factors during an epidemic in a highland area of western Kenya. *Trop Med Int Health*. 2004;9:757–66.

45. Noden BH, Kent MD, Beier JC. The impact of variations in temperature on early *Plasmodium falciparum* development in *Anopheles stephensi*. *Parasitology*. 1995;111:539–45.
46. Teklehaimanot HD, Lipsitch M, Teklehaimanot A, Schwartz J. Weather-based prediction of *Plasmodium falciparum* malaria in epidemic-prone regions of Ethiopia I. Patterns of lagged weather effects reflect biological mechanisms. *Malar J*. 2004;3:41.
47. Tompkins AM, Ermert V. A regional-scale, high resolution dynamical malaria model that accounts for population density, climate and surface hydrology. *Malar J*. 2013;12:65.
48. Paaijmans KP, Blanford S, Bell AS, Blanford JI, Read AF, Thomas MB. Influence of climate on malaria transmission depends on daily temperature variation. *Proc Natl Acad Sci USA*. 2010;107:15135–9.
49. Craig MH, Snow RW, le Sueur D. A climate-based distribution model of malaria transmission in sub-Saharan Africa. *Parasitol Today*. 1999;15:105–11.
50. Thomson MC, Mason SJ, Phindela T, Connor SJ. Use of rainfall and sea surface temperature monitoring for malaria early warning in Botswana. *Am J Trop Med Hyg*. 2005;73:214–21.
51. Sena L, Deressa W, Ali A. Dynamics of *Plasmodium falciparum* and *Plasmodium vivax* in a micro-ecological setting, Southwest Ethiopia: effects of altitude and proximity to a dam. *BMC Infect Dis*. 2014;14:625.
52. Woyessa A, Deressa W, Ali A, Lindtjørn B. Prevalence of malaria infection in Butajira area, south-central Ethiopia. *Malar J*. 2012;11:84.
53. Wangdi K, Canavati S, Duc TN, Nguyen TM, Tran LK, Kelly GC, et al. Spatial and temporal patterns of malaria in Phu Yen Province, Vietnam, from 2005 to 2016. *Am J Trop Med Hyg*. 2020;103:1540–8.
54. Wardrop NA, Barnett AG, Atkinson JA, Clements AC. *Plasmodium vivax* malaria incidence over time and its association with temperature and rainfall in four counties of Yunnan Province, China. *Malar J*. 2013;12:452.
55. Lindblade KA, Steinhart L, Samuels A, Kachur SP, Slutsker L. The silent threat: asymptomatic parasitemia and malaria transmission. *Expert Rev Anti Infect Ther*. 2013;11:623–39.

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