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Spatial analysis of malaria in Kotabaru, South Kalimantan, Indonesia: an evaluation to guide elimination strategies

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Background: Malaria remains a significant public health concern in Indonesia. Knowledge about spatial patterns of the residual malaria hotspots is critical to help design elimination strategies in Kotabaru district, South Kalimantan, Indonesia.

Methods: Laboratory-confirmed malaria cases from 2012 to 2016 were analysed to examine the trend in malaria cases. Decomposition analysis was performed to assess seasonality. Annual spatial clustering of the incidence and hotspots were identified by Moran's I and the local indicator for spatial association, respectively.

Results: The annual parasite incidence of malaria was significantly reduced by 87% from 2012 to 2016. *Plasmodium vivax* infections were significantly much more prevalent over time, followed by *Plasmodium falciparum* infections ($p<0.001$). The monthly seasonality of *P. vivax* and *P. falciparum* was distinct. High incidence was spatially clustered identified in the north, west and parts of south Kotabaru. Two persistent and four re-emerging high-risk clusters were identified during the period. Despite the significant reduction in the incidence of malaria, the residual high-risk villages remained clustered in the northern part of Kotabaru.

Conclusions: A spatially explicit decision support system is needed to support surveillance and control programs in the identified high-risk areas to succeed in the elimination goal of 2030.

Keywords: epidemiology, Indonesia, Kalimantan, malaria, spatial analysis

Introduction

Malaria is a mosquito-borne disease caused by *Plasmodium* and transmitted by the infected female *Anopheles* mosquitoes. Malaria remains a significant public health problem, especially in tropical and subtropical countries. In 2018, 228 million cases and 405 000 deaths were reported,[1] of which Southeast Asian countries reported approximately 3.4% of the total cases. The incidence rate of malaria in Southeast Asia decreased by 70% between 2010 and 2018, with the majority of malaria infections due to *Plasmodium vivax* (53%). The World Health Organization (WHO) has set a global target to reduce the incidence of malaria and mortality rates by 90% by 2030.[2]

Indonesia is one of the endemic archipelagic countries with approximately a quarter of its total population residing in active malaria transmission foci.[3,4] Findings from a nationwide community-based survey showed the prevalence of malaria was geographically varied, ranging from 0.02% to 12.07%, with the highest prevalence found in Papua.[5] Indonesia has set a target to eliminate malaria by 2030. The geographical variation in the incidence rate of *Plasmodium falciparum* and clinical cases are spatially heterogeneous at a subnational level. The Malaria Atlas Project (MAP) estimated that the incidence of *P. falciparum* and clinical cases in 2017 was 2.63 (95% confidence interval [CI] 2.40 to 2.88) per 1000 people and 698 (95% CI 638 to 767) per 1000 people, respectively.[6,7] However, the implementation of malaria control varies across Indonesia. Residual high-incidence areas remain on some islands of Indonesia, including in Kalimantan.[3,8]

South Kalimantan is one of the top 10 provinces with the highest annual parasite incidence (API) (0.68%) in Indonesia.[3,8] A recent estimate from the MAP indicated that the annual clinical cases were decreasing, from 8.37 (95% CI 7.70 to 9.19) in 2010 to 7.6 (95% CI 6.55 to 8.69) per 1000 people in 2017,[6] while the incidence of *P. falciparum* decreased from 2.15 (95% CI 1.98 to 2.36) in 2010 to 1.81 (95% CI 1.55 to 2.06) per 1000 people in 2017.[7] The Kotabaru district is one of the districts where malaria is prevalent. A number of intervention strategies have been tried, including the distribution of insecticide-treated nets (ITNs) and community-based interventions. Since 2012, the incidence of malaria has declined,[9] offering the opportunity to eliminate malaria. Despite this reduction, knowledge regarding changes in the temporal and spatial patterns of malaria are lacking in Kotabaru. Having a better understanding of recent temporal patterns and residual high-risk areas for malaria across the district would help the local health authority design effective specific interventions and reallocate necessary resources (e.g. ITNs, vector control programs).

Geographic information system (GIS) and spatial statistics have been widely used in many fields, including in public health studies aimed at mapping distribution, exploring high-risk clusters or predicting the heterogeneity of disease risk.[10] Studies have demonstrated the benefits of spatial analytical tools to support malaria control.[11–16] For instance, Rejeki et al.[12] used the GIS to locate hotspots of malaria in Menoreh Hills, Central Java Indonesia. Such spatial tools have been utilized in the decision-making process for malaria elimination in certain endemic areas.[15,16] However, no studies thus far have used spatial analytical approaches to understand the spatial and temporal patterns of malaria incidence in Kotabaru.

The objective of this study was to explore the temporal and geographic distribution of malaria and to identify residual hotspots of malaria incidence in Kotabaru. The results of this study will be used as a basis for the development of a spatial decision support system (DSS) to support local health managers in taking necessary actions to effectively target the residual malaria-endemic villages to ensure attainment of the elimination of malaria in Kotabaru.

Materials and methods

Study area

The district of Kotabaru is one of the nine districts in the South Kalimantan Province, Indonesia, located about 318 km from Banjarmasin, the capital of the province. Based on the 2010 census, the district has a population of 290 142 people. It covers an area of approximately 9482 km^2 and it is the largest district in South Kalimantan, accounting for 25% of the total area of the province.[17] In general, Kotabaru has a tropical climate, with average rainfall of 2584 mm/y, relative humidity ranging from 81 to 88% and temperature ranging from 25.9 to 27°C. Kotabaru is situated in the east of South Kalimantan province. It has an elevation ranging from 0 to >1800 m above sea level and borders the Makassar Strait in the east and East Kalimantan in the north (Figure 1). The landscape of Kotabaru varies greatly, ranging from tropical mountains along the western border, lowland coastal areas in the east and several islands. The district has 21 subdistricts, of which 8 subdistricts are located on islands off the coast and total 202 villages.[17] Several control measures for malaria in the study site, including vector control, bed nets and antimalarial treatment, have been implemented. To operationalize public health measures, including malaria control programs, a total of 27 public health centres (PHCs) are defined.

Data collection

Monthly data for laboratory-confirmed malaria cases reported during 2012–2016 were obtained from the District Health of Office (DHO) of Kotabaru. All malaria cases must be reported by the local PHCs to the DHO through the dedicated national reporting system for malaria. The notification data consist of age, gender, date of onset, diagnosis (*P. falciparum*, *P. vivax*, mixed) confirmed by microscopic examination or rapid diagnostic test (RDT) and geolocation (village information or the PHC). The community health workers (CHWs) in each PHC compile and send a monthly report form to the provincial level to be validated before sending it to the national Ministry of Health. The population data for each village were collected from the local Bureau of Statistics report.[17]

Data analysis

Descriptive and temporal analysis

A retrospective analysis of malaria notifications in Kotabaru from 2012 to 2016 was performed. Descriptive analysis was conducted to summarize the number of cases by age group (<5, 5–9, 10–14, 15–54 and ≥55 y), gender and type of malaria infection. Pearson's χ^2 test was used to determine the association of *Plasmodium* infections with age group and sex. Trend analysis was performed to examine trends in the number of malaria cases by age, sex and type of infection over time by using the χ^2 test for trend. A p-value <0.05 was considered statistically significant. Statistical analyses were conducted using SPSS version 21 (IBM, Armonk, NY, USA).

A multiplicative seasonal decomposition analysis was conducted using SPSS version 21 to decompose the monthly incidence of both *P. falciparum* and *P. vivax* malaria (Yt) into a combined trend (Tt), a seasonal component (St) and an error or residual component (Et).[18] The relationship between the different decomposition terms and malaria incidence is Yt=Tt+St+Et.

Examining spatial patterns and detecting hotspots

For the spatial analysis and operational purposes, the study defined a village (when finer spatial data were available) or PHC working area as the spatial unit of analysis. The analysis was restricted to the mainland of Kotabaru, as malaria cases are much more prevalent on the mainland. The centroids (the latitudes and longitudes) for each village were estimated by using GIS software. The malaria cases were linked to the identifier of the polygon of the village. Global spatial clustering of malaria incidence (API per 1000 people) was estimated using Moran's I statistic.[19] Furthermore, to locate high-risk villages in mainland

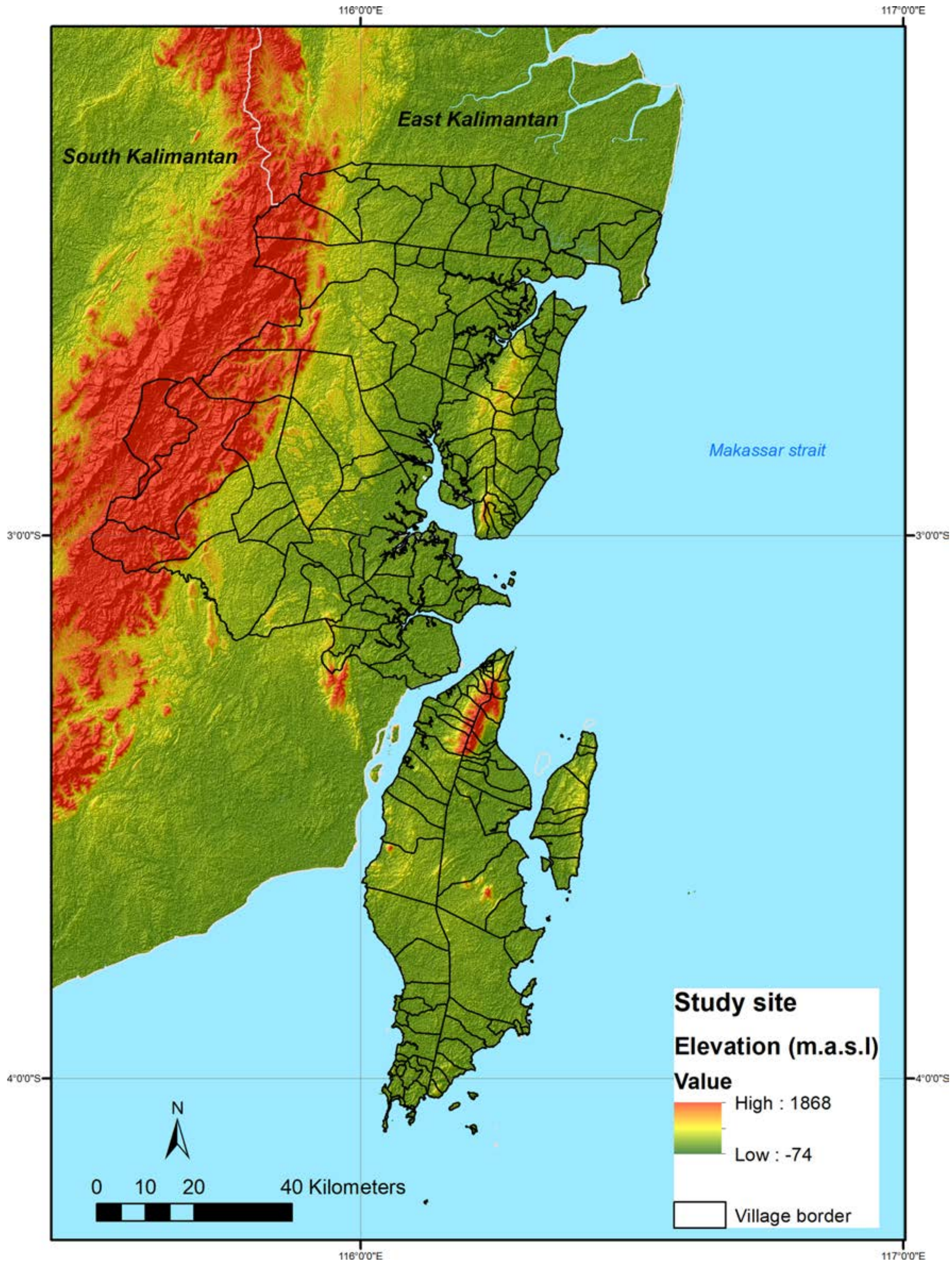

Figure 1. Map of the study site, Kotabaru district, South Kalimantan, Indonesia. Black line polygons represent the administrative boundaries of the village.

Table 1. Annual malaria cases and the proportion of cases by sex, age and type of infection, Kotabaru district, South Kalimantan, Indonesia (2012–2016)

Variables	Total, n (%)	No. of cases (%)					p-Value
		2012	2013	2014	2015	2016	
Sex							0.002
Male	3680 (82.6)	1198 (84.6)	1189 (82.2)	923 (82.3)	244 (82.2)	126 (72.4)	
Female	776 (17.4)	218 (15.4)	258 (17.8)	199 (17.7)	53 (17.8)	48 (27.6)	
Age (years)							<0.001
<5	88 (2.0)	26 (1.8)	31 (2.1)	15 (1.3)	6 (2.0)	10 (5.7)	
5–14	379 (8.5)	111 (7.8)	126 (8.7)	84 (7.5)	31 (10.4)	27 (15.5)	
15–54	3924 (88.1)	1255 (88.6)	1268 (87.6)	1008 (89.8)	258 (86.9)	135 (77.6)	
≥55	65 (1.5)	24 (1.7)	22 (1.5)	15 (1.3)	2 (0.7)	2 (1.1)	
Type of infection							<0.001
P. falciparum	855 (19.2)	348 (24.6)	224 (15.5)	205 (18.3)	48 (16.2)	30 (17.2)	
P. vivax	2589 (58.1)	729 (51.5)	916 (63.3)	667 (59.4)	180 (60.6)	97 (55.7)	
Mixed	1012 (22.7)	339 (23.9)	307 (21.2)	250 (22.3)	69 (23.2)	47 (27.1)	
Total	4456 (100)	1416 (100)	1447 (100)	1122 (100)	297 (100)	174 (100)	
Overall API per 1000 people		4.81	4.58	3.6	0.95	0.55	

Kotabaru, local indicator of spatial association (LISA) analysis was performed.[20] Spatial weight was constructed based on a first-order Queen contiguity matrix. Spatial analyses were performed by using GeoDA version 1.8 software (Center for Spatial Data Science, Chicago, IL, USA). Spatiotemporal API and cluster maps were then generated by using ArcGIS version 10.5 (Esri, Redlands, CA, USA).

Results

Descriptive statistics

A total of 4456 malaria cases were reported during 2012–2016. Malaria cases were significantly higher among males (82.6%) and individuals >15 y of age (89.51%) (Table 1). Overall, the number of malaria cases significantly decreased by 87% from 2012 to 2016. By sex, malaria cases were consistently significantly higher in males than females over time (p=0.002). By age, malaria cases were significantly reported among populations ≥15 y (p<0.001). All types of infection showed a decreasing trend throughout period studied. *P. vivax* infection was significantly more prevalent over time, followed by *P. falciparum* infection (p<0.001). There was a 25% increase in the number of *P. vivax* infections in 2012–2013, from 729 to 916 cases. The API of malaria showed a decreasing trend during 2012–2016, from 4.81 to 0.55 per 1000 people.

Decomposition analysis

The monthly pattern of *P. falciparum* and *P. vivax* infections in Kotabaru during 2012–2016 is shown in Figure 2. The highest mean number of *P. falciparum* cases was reported in February, while the mean number of *P. vivax* cases was relatively higher in January–February. The mean number of both *P. falciparum* and *P. vivax* cases was much lower from August to December.

The results of decomposition analysis indicate a substantial decreasing trend for *P. falciparum* (Figure 3) and *P. vivax* cases (Figure 4). In addition, the decomposition analysis reveals a clear seasonal pattern for both infections. For *P. falciparum* infection, a single peak is observed every February each year, but a bimodal seasonality pattern is observed for *P. vivax* infection (February and June).

Geographic distribution and residual malaria hotspots

Figure 5 shows the spatial variation in endemicity (indicated by API per 1000 people) at the village level across Kotabaru during 2012–2016. The distribution of overall malaria incidence was spatially heterogeneous at the village level over time. The incidence for both *P. falciparum* and *P. vivax* malaria varied geographically (Figure 6). Yet both *P. falciparum* and *P. vivax* malaria cases were mostly concentrated in Banian. Based on Moran's I analysis, the spatial distribution in the incidence of malaria was clustered over 2012–2016, with the strength of spatial clustering increasing during the period. Strong spatial clustering was observed in 2016 (Moran's I=0.356, p=0.001). Changes in the spatial distribution of high-risk clusters of malaria in Kotabaru were less profound over the period. High API was spatially clustered in the northwest (PHC Banian working area) and parts of the south. During the period studied, consistent high-endemic villages (API>5 per 1000 people) were identified, including Buluh Kuning, Gendang Timburu, Bungkukan, Siayuh, Manggalu Hulu, Teluk Sungai, Maradapan and Labuan Barat. High-risk clusters for malaria were identified by LISA analysis (Figure 7), including Magalau Hulu and Bungkukan. Four villages have re-emerged as high-risk clusters: Siayuh (2014–2016), Mangka (2015–2016), Tanjung Sari and Magalau Hilir (2016).

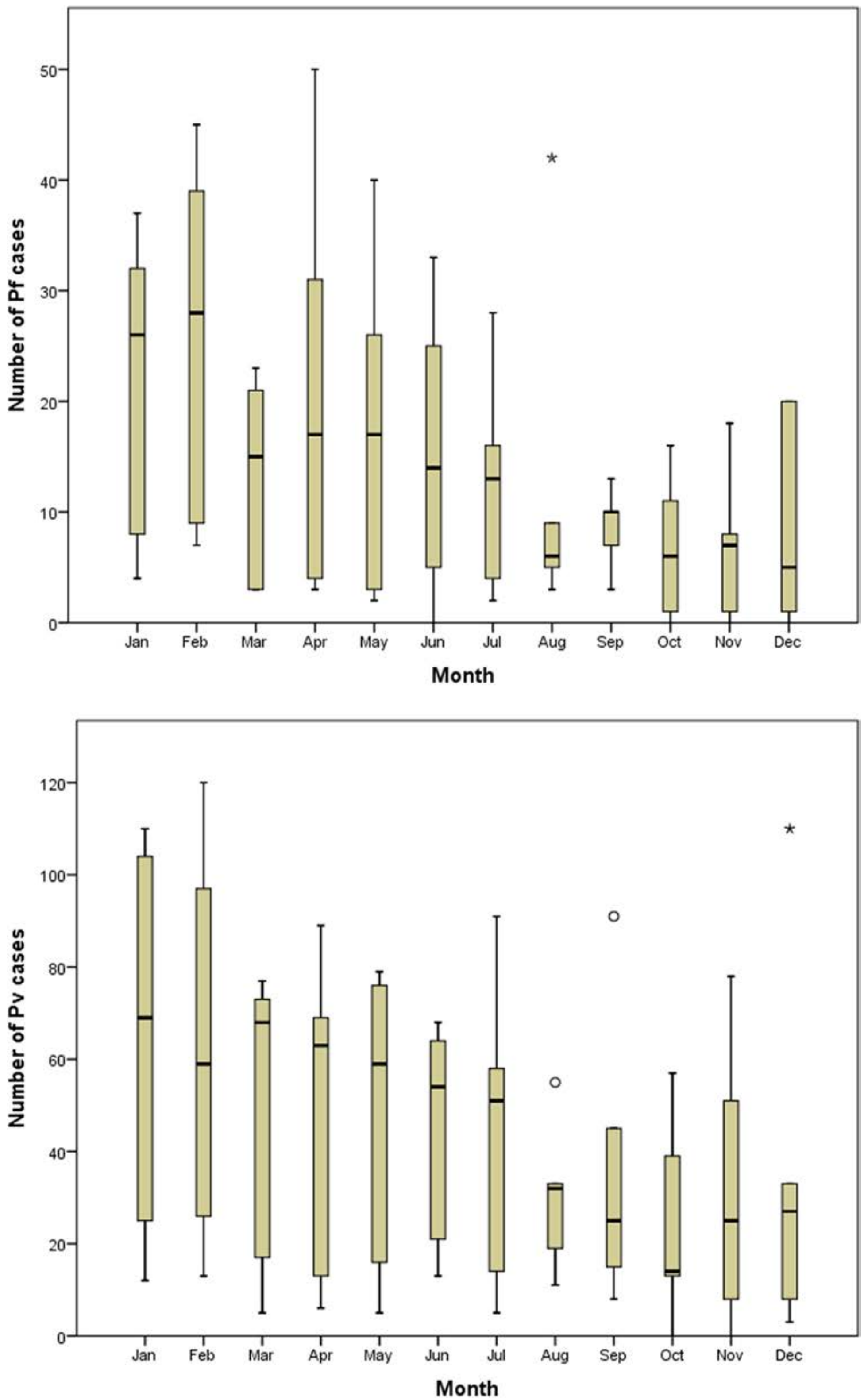

Figure 2. Monthly distribution of malaria in Kotabaru district, South Kalimantan during 2012–2016.

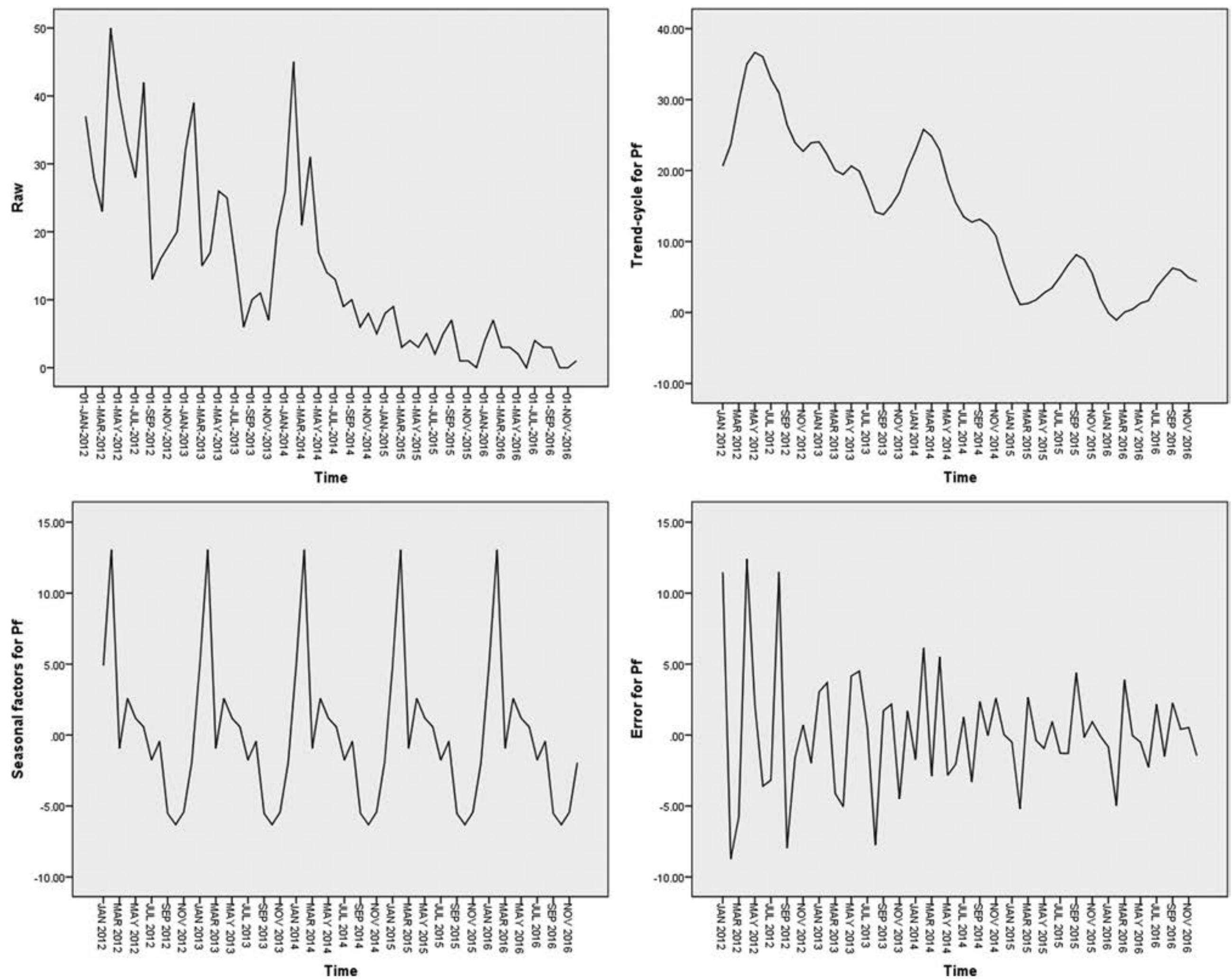

Figure 3. Seasonal decomposition of monthly *P. falciparum* cases (2012–2016), Kotabaru district, South Kalimantan.

Discussion

Using retrospective notification data for malaria during 2012–2016, this study described the trend in the incidence of malaria and its geographic variation in Kotabaru. The present study demonstrates a significant reduction in incidence over the 5 y. However, the residual high-endemic villages (API>5 per 1000 people) remain geographically clustered in the north of the district. These findings highlight the importance of reliable and improved surveillance and malaria control programs to ensure attainment of the elimination goal. Additionally, this study provides insights on the potential of the GIS and spatial analysis as tools for decision making to combat the residual foci of malaria transmission in Kotabaru.

The results of this study also demonstrate that males contracted most of the malaria cases relative to females, indicating that men are at higher risk of malaria than women. This finding is consistent with a study in the provinces in eastern Indonesia.[21] This could be related to occupation. In this region, most males engage in high-risk malaria-related activities, such as farming and mining.[22] The findings of this study suggest the local health authority should promote preventive measures among these high-risk populations. This could be done by providing intensive information, education and communication programs focused on these hotspots and evaluating the ownership and compliance level of ITN usage in the community in addition to providing artemisinin-based combination therapy (ACT).

Although it fluctuated quite dramatically, the proportion of *P. vivax* infection was significantly higher than *P. falciparum* infection over time, which is similar to areas in eastern Indonesia.[23] More than half of reported cases were *P. vivax* infection. There are some possible reasons that may explain these findings. First, while it has lower mortality than *P. falciparum* infection,[24] the *P. vivax* parasite can live for several weeks to months in humans as hypnozoites and patients can reactivate or relapse after an initial mosquito bite.[25] Such relapses may be due to the ineffectiveness of antimalarial treatment (e.g. incomplete medication due to poor adherence, drug resistance). Such infections may be asymptomatic and are unable to be detected by traditional passive surveillance. The higher number of *P. vivax* cases may

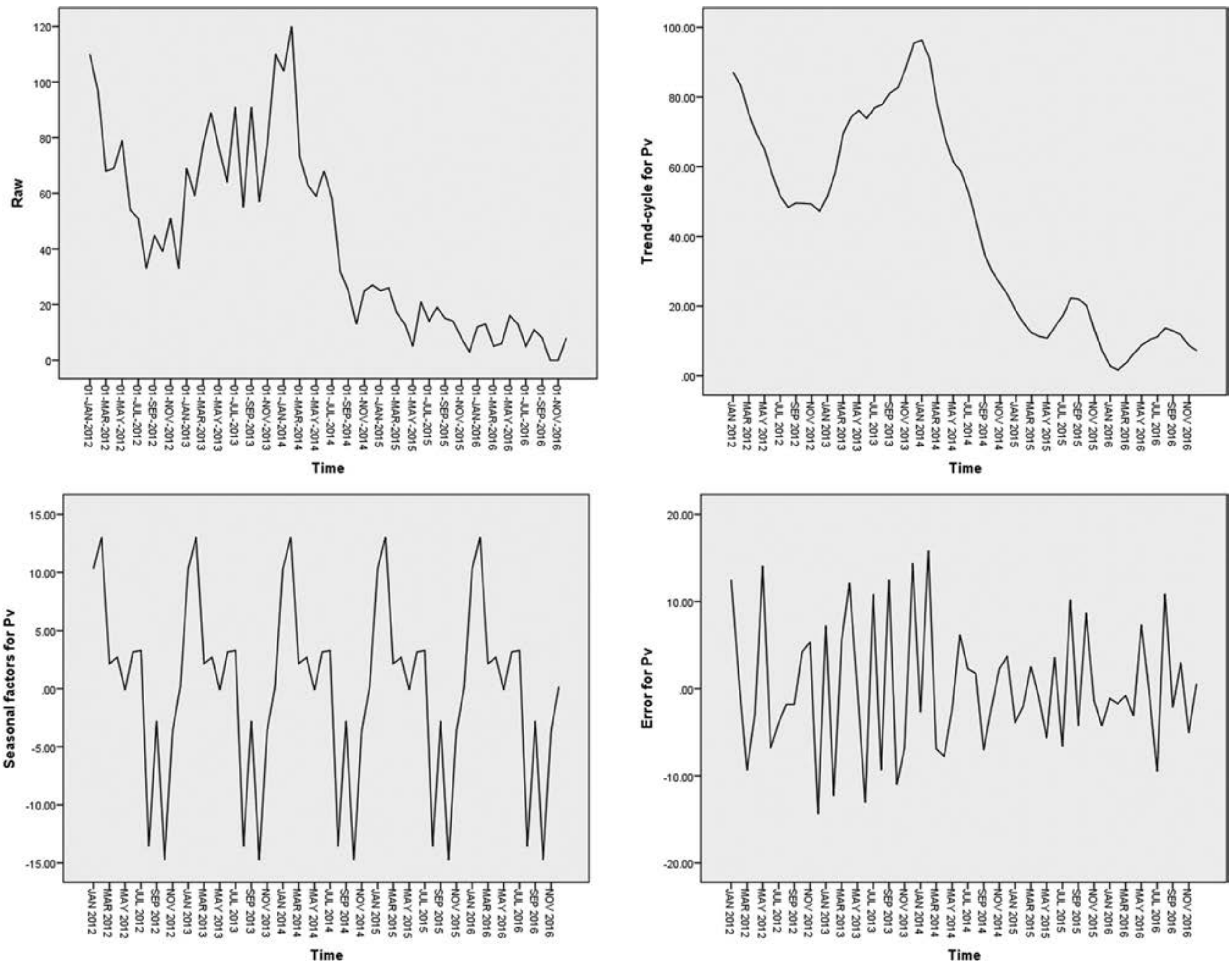

Figure 4. Seasonal decomposition of monthly *P. vivax* cases (2012–2016), Kotabaru district, South Kalimantan.

also be partly due to extensive active case detection (ACD) in the population during the study period. Also, relapses might have been reported more than once by the PHCs, thus affecting the cumulative number of reported cases. As *P. vivax* infection is epidemiologically and biologically different from *P. falciparum* malaria, more comprehensive and parasite-specific interventions are essential.[26] In particular, the fluctuating number of both *P. falciparum* and *P. vivax* infections seen in this study (i.e. sharp increases in the proportion of *P. vivax* cases during 2012–2013 and a significant reduction and increase in the proportion of *P. falciparum* cases in 2012–2013 and 2014–2015, respectively) might be related to higher investments and improved monitoring performed by the local government, though there are still several challenges in the implementation (e.g. geographic barriers). Recent evidence from other regions in Indonesia shows that improved implementation of ACTs in combination with vector control and bed net utilization might have impacted the epidemiology and genetic variation of both *P. falciparum* and *P. vivax* in Mimika district.[27] However, the study indicates a significant decrease in overall API from 2012 to 2016 in Kotabaru. This may be associated with the implementation of malaria interventions performed by the local government, stakeholders and communities in the past few years. In Kotabaru, integrated control programs have been implemented, including routine vector control (e.g. breeding site eradication), the distribution of ITNs, migrant surveillance, antimalarial treatment and indoor residual spraying.[4,9]

In the present study, the geographic variation in incidence was spatially heterogeneous at the village level. This could explain the variation in the socio-ecological features across the district. We identified residual high-risk clusters in the northwest of the district. The spatial analysis indicated that malaria incidence remains high in some areas, including Banian, Bungkukan and Marabatuan. In the past few years, Kotabaru district experienced substantial land conversion due to urbanization and mining activities, which affects the natural habitat of vector mosquitoes and increases the risk of human–mosquito contact. We hypothesize that such environmental changes might have influenced the spread of malaria in Kotabaru. Furthermore, such variation in the geographic distribution of malaria incidence could be partly explained by the heterogeneity in preventive behaviours, use of ITNs and socio-economic status either at

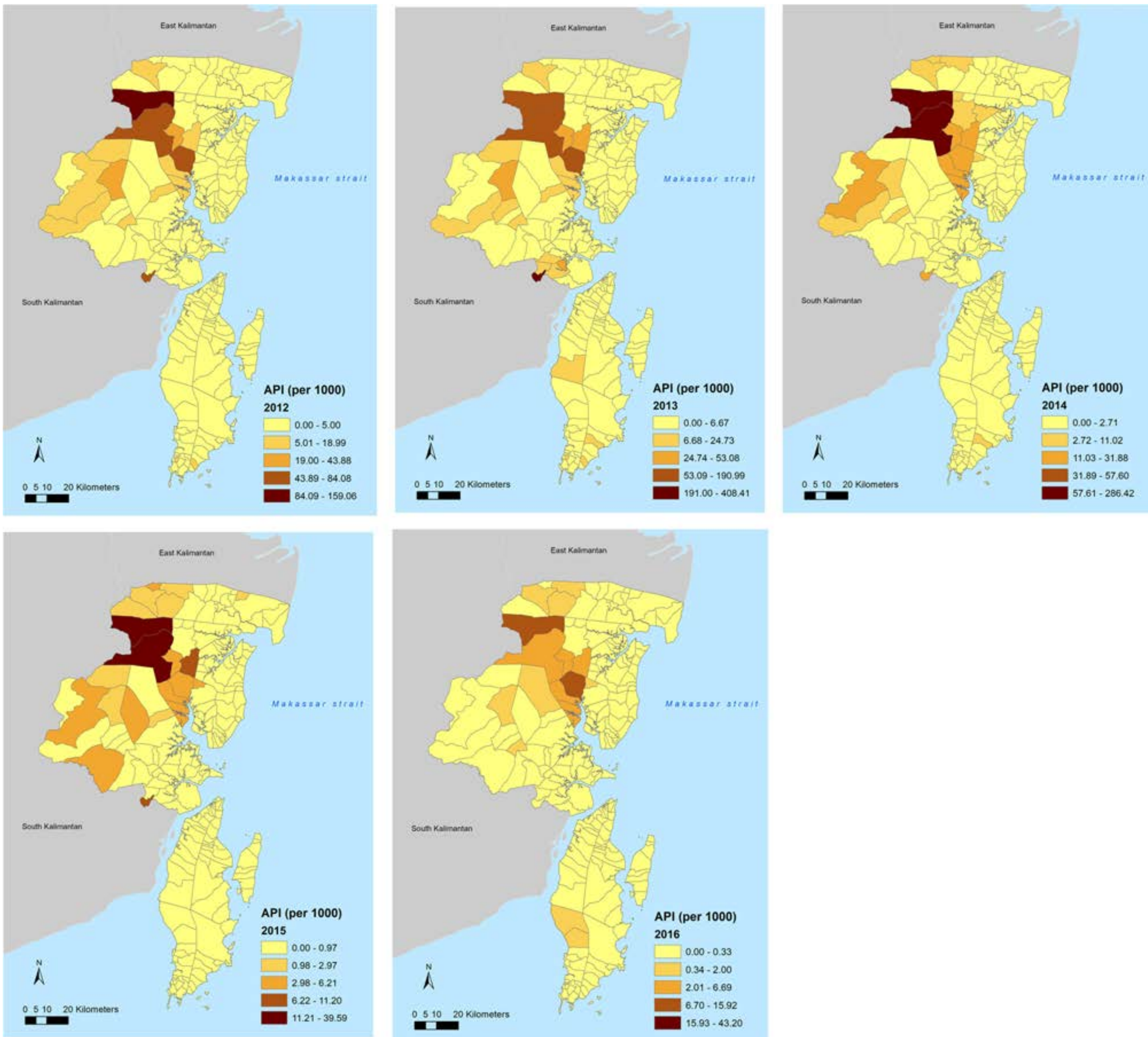

Figure 5. Spatial variation in API at the village level in Kotabaru district, South Kalimantan (2012–2016). The API was spatially heterogeneous at the village level over the study period.

the individual or household level between communities and villages.[21,28,29] The role of such environmental social factors on the distribution of malaria will be investigated in a future study.

The existence of intensive gold mining activities at remote sites along the slopes of Mount Banian might have considerably contributed to increased malaria cases in the Banian area.[22] Ecologically this area has favourable environmental characteristics that can maintain malaria vector populations, including swamps, forests and rice fields. A survey found that the water bodies near Trans Siayuh village are potential habitats for *Anopheles* sp.[30] Additionally, uncovered containers and abandoned gold mines have been found to be potential breeding sites of *Anopheles* sp. in Banian. This situation requires improving interventions to reduce the risk of malaria transmission, such as monitoring *Anopheles* breeding sites and modifying environmental conditions (i.e. mine reclamation).

Unfortunately, malaria control and surveillance such as ACD could not be delivered effectively in these remote areas due to geographic, logistical and cost constraints. For example, to reach the endemic highland areas such as Banian and Siayuh, it can take >8 h to travel from Kotabaru's capital (3–5 h by canoe and 6–8 h by motorcycle). Consequently, to conduct ACD, monitoring and awareness-raising activities can be costly. Therefore a new and efficient approach is required to address such challenges. To address such barriers, intervention strategies may need to be reformulated to reach these residual foci of malaria. Intensifying control measures on these residual hotspots could effectively

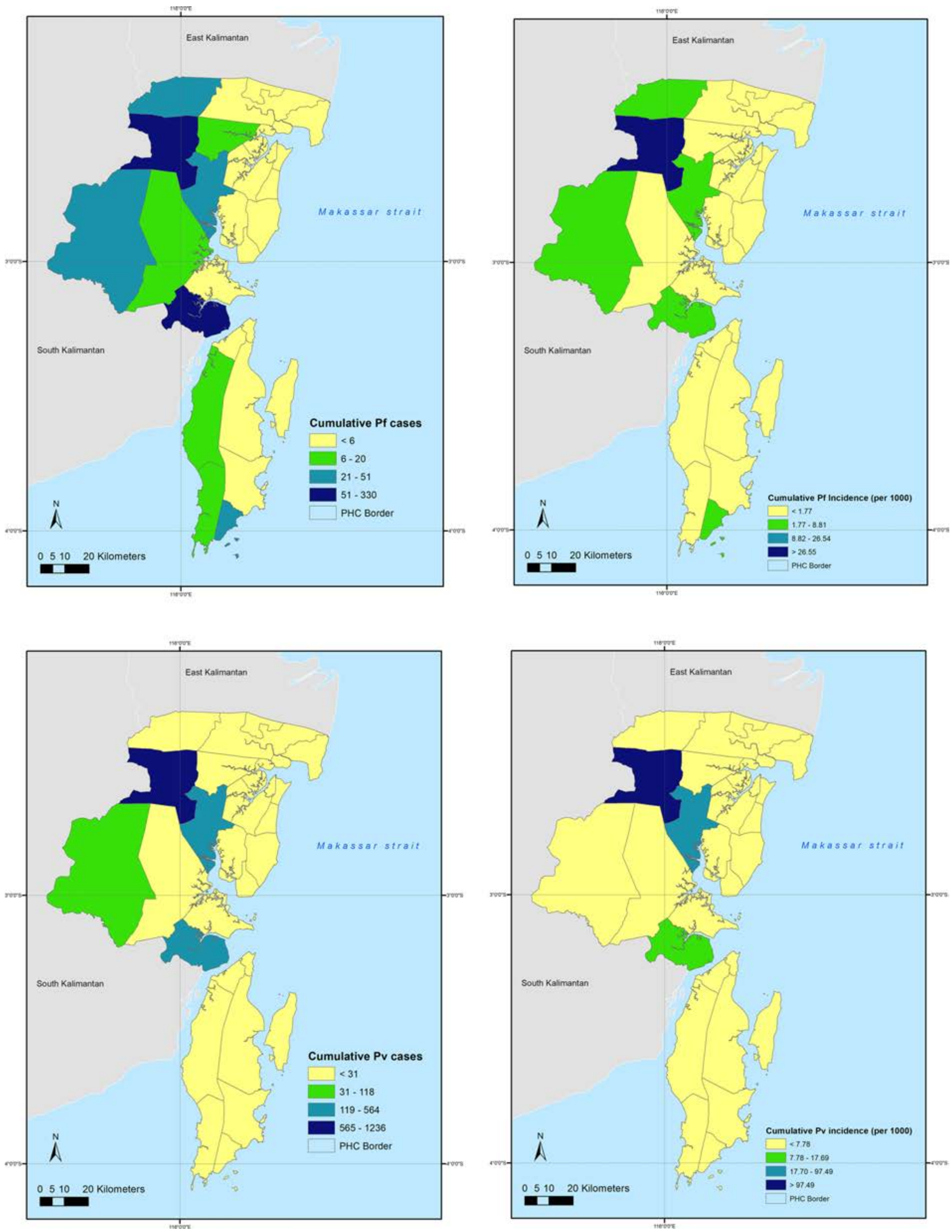

Figure 6. Maps of total *P. falciparum* and *P. vivax* cases by PHC working area. Most cases are concentrated in the Banian area.

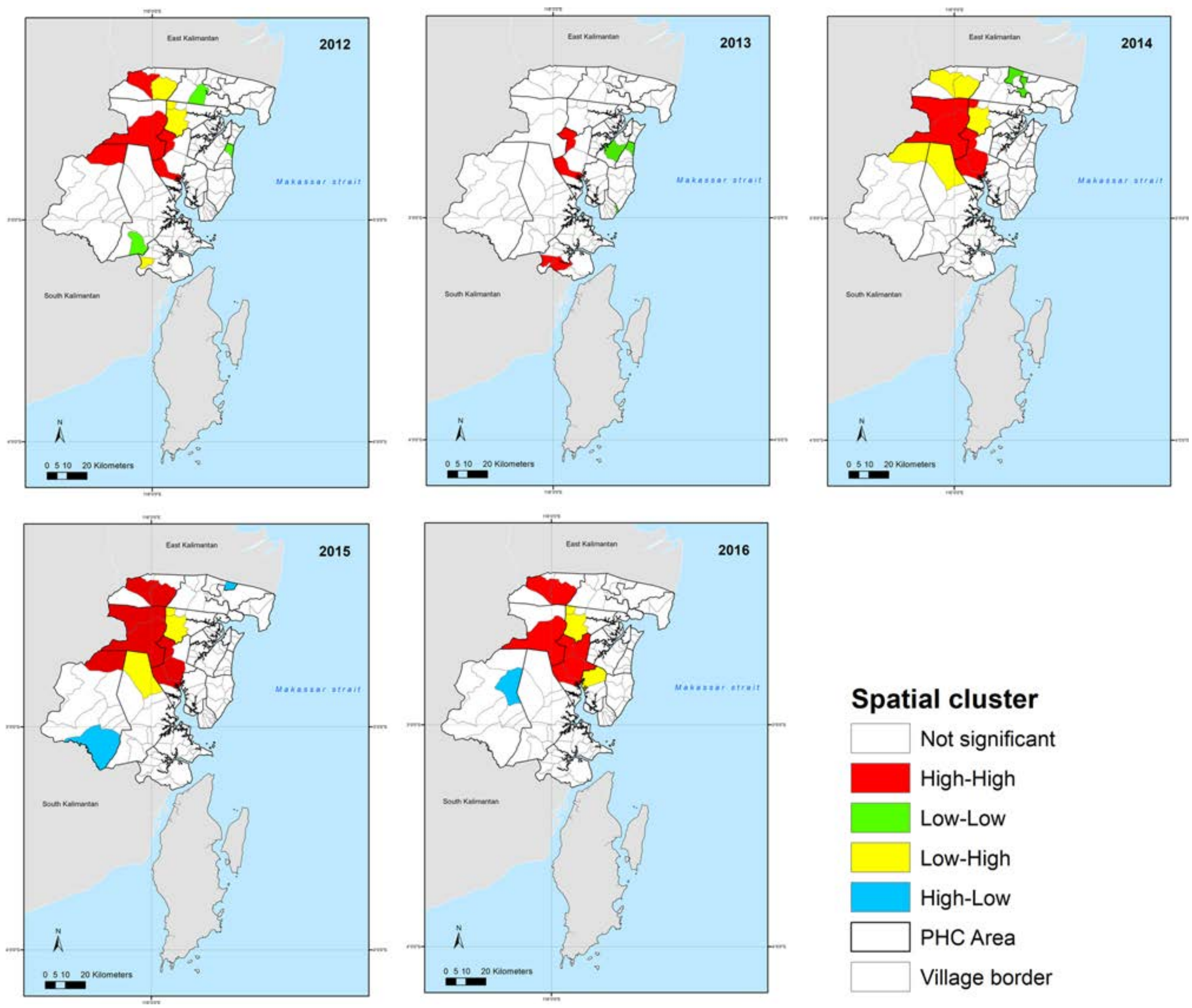

Figure 7. Spatial cluster maps of malaria as identified by LISA analysis. The residual high-risk (high-high) (red shaded) clusters of malaria were identified in the northern part of mainland Kotabaru district.

reduce malaria transmission, leading to malaria elimination in Kotabaru. Initially a GIS-based DSS could be developed to assist health authorities in combating malaria by identifying residual foci and estimating required resources (e.g. bed nets, drugs). Such a platform has been operationalized and evaluated in other malaria-endemic places such as Bhutan15 and Vietnam.[16] Along with surveillance activities (i.e. ACD, epidemiological investigations), researchers and health officials should conduct surveys and geocode each individual case, households and their characteristics (e.g. number of family members, ITN ownership, housing, symptoms, elevation, environmental features, etc.) in the remaining hotspots. Additionally, entomologists and spatial analysts could produce maps showing the distribution of malaria vectors in the targeted villages. Precision mapping needs to be done to help specifically target residual hotspots and to help design interventions and resource allocation (i.e. mass drug administration, bed nets, focal indoor residual spraying and reactive/proactive ACDs).

The study also detected different patterns of seasonality in the incidence of *P. falciparum* and *P. vivax* malaria. The seasonal peak is during the wet season in Kotabaru, which begins in October and lasts until May–June. Studies have reported the role of climate in the temporal variability of malaria incidence.[31] For instance, in West Sumba, Indonesia, the prevalence of malaria infection is likely to be higher during the wet season by 6.8-fold compared with the dry season.[31] Meteorological factors (i.e. rainfall, temperature and humidity) are reported as critical drivers for the mosquito vector populations and the seasonality of malaria transmission.[32,33] Thus this finding emphasizes the need to improved malaria control programs (i.e. larval source management) during the wet season, specifically in identified hotspots of malaria. Additionally, extensive campaigns can be conducted during the dry season to improve awareness in the community.

This study has several limitations. First, this analysis is primarily based on the malaria notification data obtained from passive surveillance, which may be prone to underreporting and thus does not reflect the actual malaria burden in Kotabaru. Underreported cases might be closely related with individual-level socio-economic conditions (e.g. health-seeking behaviour, perceived risk) and access to health facilities, especially in remote villages. Second, the spatial variation in notifications of malaria as shown in this study might be biased due to the heterogeneity of access to diagnostics. Some remote villages may have limited access to diagnostics and treatments, leading to underdiagnosis. However, detailed data regarding the variations and changes in access to diagnostics were not available. Third, in this study we used both village (in reporting overall malaria cases) and PHC working area (in reporting *P. falciparum* and *P. vivax* distribution) as the spatial unit of analysis. This was done because malaria data by species were not discreetly available at the village level in the monthly report forms, thus data for malaria by species were provided as an aggregated number by PHC working area. However, the overall malaria case data were available at the village level, allowing spatial analysis to be performed at a finer spatial resolution. Despite this limitation, this study provides the first report on the geographic trends of malaria incidence as well as provides recent evidence on the hotspots of malaria in Kotabaru at the village level, which could help local health authorities and CHWs in improving strategies towards the elimination of malaria in the region. Knowing where the hotspots of malaria are is essential, as it will help accurately identify where interventions should be targeted and be scaled-up.

Conclusions

Although there was a significant reduction in the incidence of malaria, residual high-endemic villages remained clustered in the northwest part of Kotabaru, suggesting the need to strengthen surveillance. Focal intervention strategies, such as ACDs, are needed. A GIS-based spatial analysis could be further explored to develop a spatial DSS for malaria to assist local health authorities in effectively implementing hotspot-targeted interventions in Kotabaru in order to achieve the malaria elimination goal.

Authors' contributions: JJ, DA and PWD designed the study. JJ, DA, LI and MRR implemented the study. JJ, DA, LI and PWD carried out the analysis and interpretation of data. JJ draft the initial manuscript and wrote the final manuscript. All authors critically revised the manuscript for intellectual content and approved the final version.

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Competing interests: None declared.

Ethical approval: This study did not require the approval of an ethics committee because it was an analysis of secondary aggregate data. Permission to use the data was granted by the District Health Office of Kotabaru, South Kalimantan.

Data availability: The datasets that support the findings of this study are available from Provincial Health Office (PHO) of South Kalimantan but restrictions apply to the availability of these data. Interested individuals/parties can apply for the data by contacting the PHO (email: dinkes@kalselprov.go.id). All other relevant data are within the manuscript.

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