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Spatial-temporal pattern of malaria in Burkina Faso from 2013 to 2020

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ABSTRACT

Despite the implementation of different strategies to fight against malaria in Burkina Faso since 2005, it remains today the leading cause of hospitalization and death. Adapting interventions to the spatial and temporal distribution of malaria could help to reduce this burden. This study aims to determine the structure and stability of malaria hotspots in Burkina Faso, with the objective of adapting interventions at small geographical scales.

Data on malaria cases from 2013 to 2020 were acquired at municipalities level. Municipality-wise malaria endemicity levels were mapped through geographical information system (GIS) tools. Spatial statistical analysis using Kulldoff sweeps were carried out to identify malaria hotspots. Then we mapped the monthly malaria risk.

Malaria is endemic in all the municipalities of Burkina Faso. However, two stable main spatial clusters (South-Western and Eastern part of the country) are emerging with seasonal reinforcement.

Interventions targeting the identified clusters could significantly reduce the incidence of malaria in Burkina Faso. This also prompts for further studies to identify the local determinants of this high transmission for the future success of malaria control.

1. Introduction

The World Health Organization (WHO) has reported 229 million malaria cases and 409,000 deaths in 87 malaria endemic countries in 2019 (WHO, 2020). About 51% of all malaria deaths were occurred in 31 Sub-Saharan Africa countries including Burkina Faso (with 4%) (WHO, 2022a). Malaria is endemic in Burkina Faso and remains a major public health problem. It is the first cause of outpatient consultations, hospitalizations and death in Burkina Faso (Institut national de la statistique et de la démographie, 2020; Ministère de la

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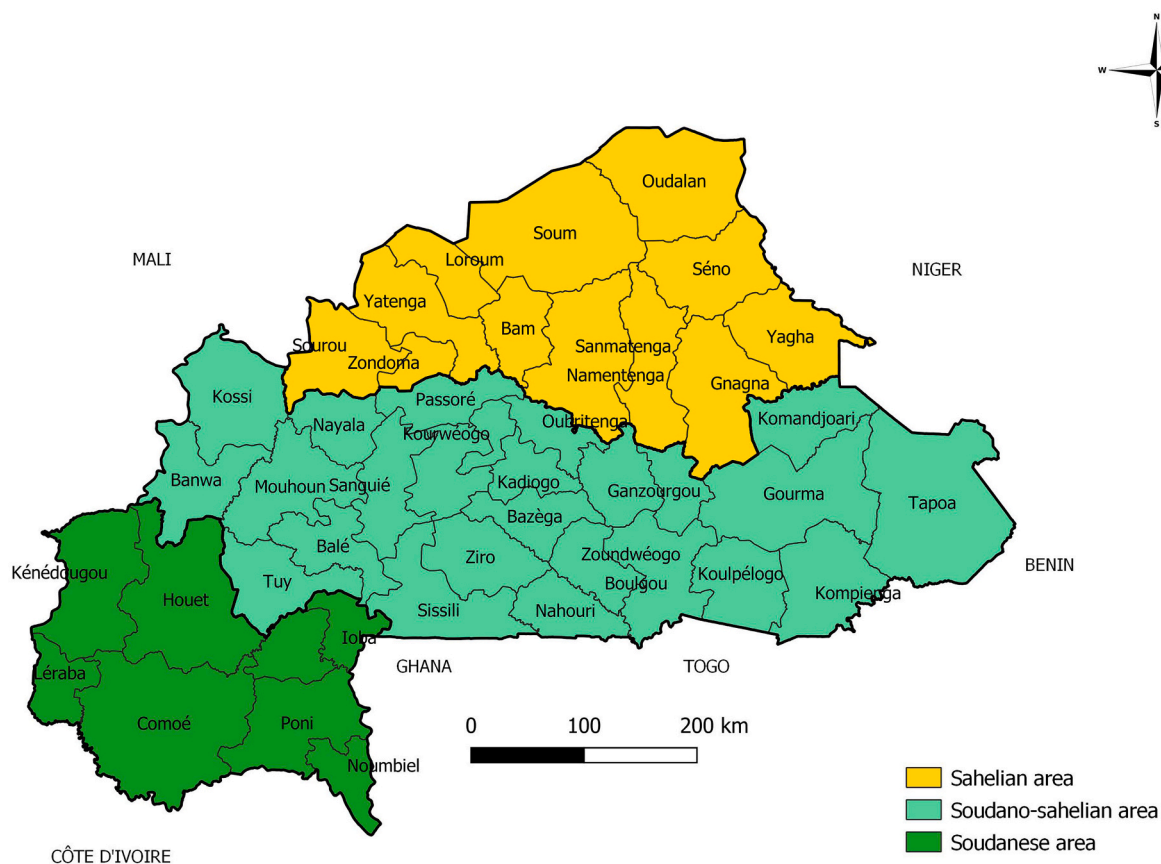*E-mail addresses:* babaibrasangare@yahoo.fr (I. Sangaré), sbassogba@mrc.gm (B.S. Assogba).
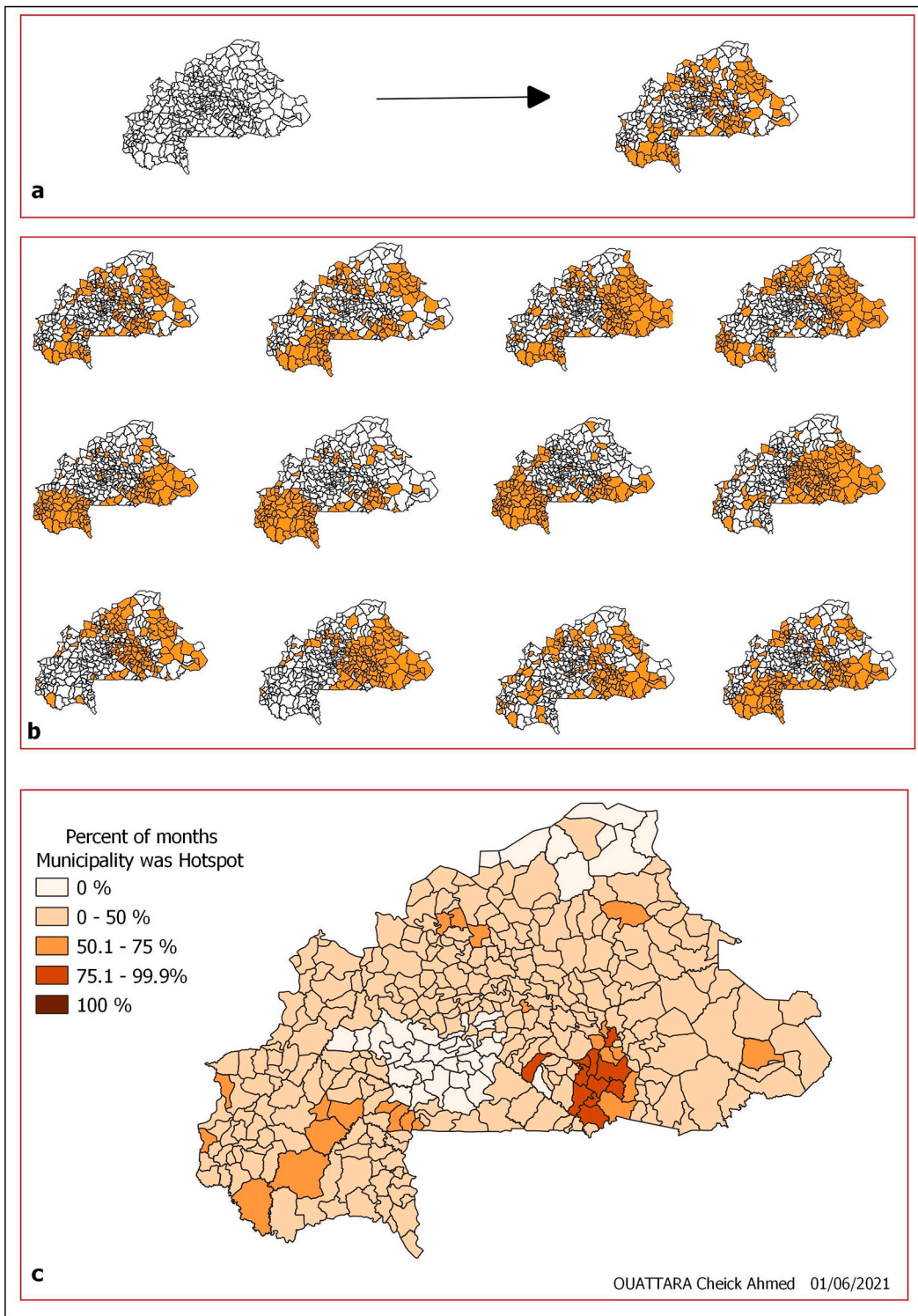
OUATTARA Cheick Ahmed   01/06/2021   Source: Adapted from the Geographic Institut of Burkina Faso

Fig. 1. Municipalities of Burkina Faso with the climatic areas.

santé, 2019).

Since 2005, the main strategies for malaria control worldwide have been vector control, diagnosis and case management. However, with the emergence of chloroquine resistance, malaria control policies in Burkina Faso included the artemisinin-based combination therapies (ACTs), for the treatment of uncomplicated malaria, Intermittent Preventive Treatment (IPT) for pregnant women, Rapid Diagnostic Tests (RDTs) for malaria diagnosis in health facilities (Ministère de la santé, 2016) and Seasonal Malaria Chemoprevention (SMC) for children aged 3–59 months (Ministère de la santé, 2016; Sermé et al., 2018). The National Malaria Control Program (NMCP) of Burkina Faso, implemented the indoor residual spraying (IRS) with carbamates in 2011 to 2012 in Diébougou health district and 2018 to 2020 with an organophosphate and clothianidin in Kongoussi, Kampti and Solenzo districts as a pilot intervention (Ministère de la santé, 2016; Institut National de la Statistique et de la Démographie (INSD), Programme d'Appui au Développement Sanitaire (PADS), Programme National de Lutte contre le Paludisme (PNLP), and ICF, 2018). In addition, free long-lasting insecticidal nets (LLINs) have been distributed in 2010, 2013, 2014 and 2016 (Ministère de la santé, 2016). These different strategies have contributed to reducing malaria-related mortality in Burkina Faso, but its incidence is plateaued at unsatisfied level (Ministère de la santé, 2016; Ouedraogo, 2020). Malaria transmission and incidence have been varied at different geographical levels and even in places with relatively uniform geographical characteristics (Noé et al., 2018; Dieng et al., 2020; Kangoye et al., 2016) such as Burkina Faso (Ouedraogo et al., 2018a). In addition, some authors have shown that heterogeneity in levels of infectious disease transmission has a negative impact on control efforts, as it can be inefficient to use the same interventions over a large and heterogeneous area (Ministère de la santé, 2019; Nourein et al., 2011). The identification of landscapes associated with high malaria risk would allow malaria control strategies to be adapted at smaller geographical scales. The objective of this study was to assess the spatial variation of malaria risk and identify malaria hotspots in Burkina Faso from 2013 to 2020 using spatial statistical analysis approach.

Percent of months
Municipality was Hotspot
- 0 %
- 0 - 50 %
- 50.1 - 75 %
- 75.1 - 99.9%
- 100 %

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(caption on next page)

Fig. 2. Depiction of the stability map production process. The three panels show an example of how a stability map was produced using monthly incidence data for a year. a- Hotspot analysis for a month. Kulldoff's scanning method identifies clusters of malaria incidence to a 95% confidence level. The municipality included in these clusters are hotspots (marked in red). Municipality that are not hotspots are marked in white. b-Municipalities that are hotspots for each month of the year. c Hotspot stability identification. Each municipality is examined for how many months it was identified to be a hotspot in the year. For example, a municipality that has been a hotspot for all 12 months of the year has a percentage of months in which it has been a hotspot is 100%. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1

: Annual malaria incidence in Burkina Faso.

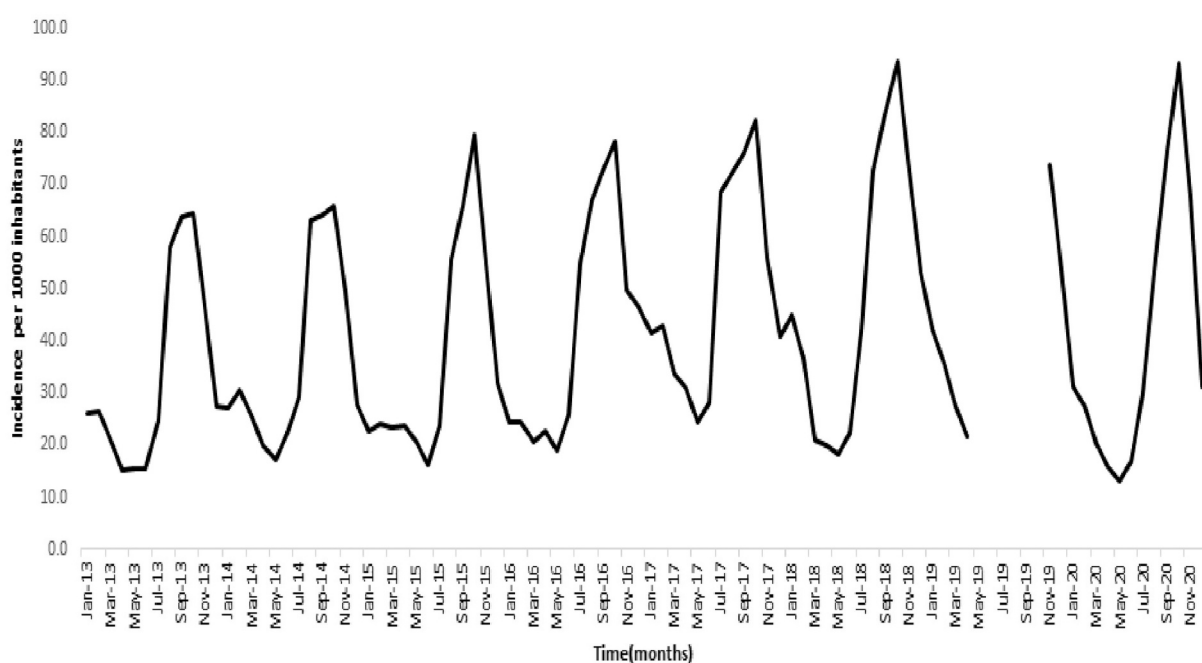| Year	Incidence per 1000 inhabitants
2013	406.3
2014	456.0
2015	442.4
2016	506.5
2017	597.9
2018	582.6
2019	324.4
2020	517.8

Fig. 3. Monthly malaria incidence from 2013 to 2020.

2. Methodology

2.1. Study area

The study was conducted in 13 regions of Burkina Faso (Fig. 1). The study area is partitioned into 45 provinces and 351 municipalities with an estimated population of 21,478,529 inhabitants in 2020 (Institut national de la statistique et de la démographie, 2007). This study focused on the municipality scale which is considered as the basic territorial community unit. Malaria transmission is permanent with a peak during the rainy season between May to October. Three climatic areas were described with specific malaria epidemiological facies. The Sahelian area covers the north part of the country with very short (two to three months) seasonal and annual malaria transmission. The Sudano-Sahelian area covers the center of the country with annual transmission rhythmed by the rainy season (about six months). The southern Sudanese area covers the south and south-west of the country where annual malaria transmission is permanent (Ministère de la santé, 2016; Kulldorff, 1997).
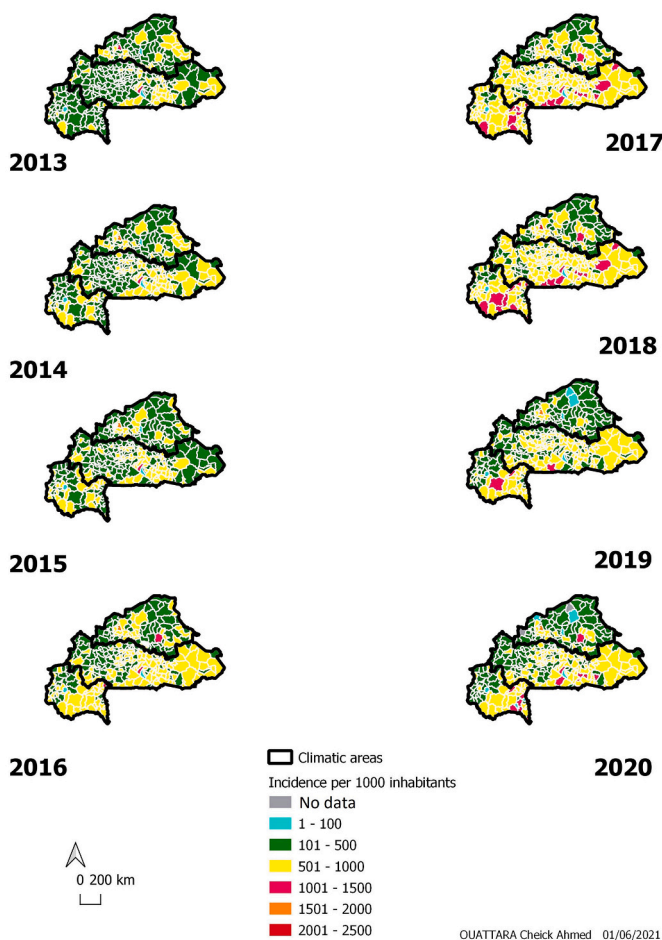
Fig. 4. Map of annual malaria incidence from 2013 to 2020 at municipality scale.

2.2. Epidemiological data

Data of individual malaria cases were extracted from the national epidemiological surveillance system named, Télégramme Lettre Officiel Hebdomadaire (TLOH). In this system, health centers provide weekly reports on 11 diseases, including malaria mainly diagnosed using rapid diagnostic tests SD Bioline Pan/Pf. All data were checked at health districts level before sending them to NMCP. In this study, malaria cases were extracted for an 8-years period (2013−2020) and for each municipality. The monthly malaria cases extracted for a municipality are the sum of the monthly cases reported by the health facilities in the area of this municipality.

2.3. Ethics statement

This study analyzed only anonymized, aggregated secondary data thus ethical approval was not required.

2.4. Data analysis

Malaria monthly cumulative incidence was calculated using cases and population size depending to the administrative level.

By adding geographic coordinates to the incidence dataset, the incidence data for each municipality were matched to the corresponding polygons in an administrative unit shapefile using QGIS 3.16.3 to generate malaria incidence maps for 2013 to 2020.

We searched for high risk clusters (hotspots) using the scanning method developed by Kulldorff with SaTScan v9.6 (Kulldorff, 1997). Following this approach, neighbouring municipalities were aggregated into groups with similar incidence using an elliptical window with variable size, centre and rotation. Kulldorff's statistics based on the likelihood ratio (Poisson model with a purely spatial analysis) were tested using a Monte Carlo algorithm (999 replicates). The pure spatial analysis was performed on data aggregating by month. A hotspot was then selected when the incidence inside the window was significantly higher ($p < 0.05$) than the incidence outside the window. For a target period, a municipality was defined as a hotspot if it belonged to a significant cluster detected by SaTScan. Monthly hotspot municipalities maps were generated. The percentage of months that a municipality was a hotspot was used
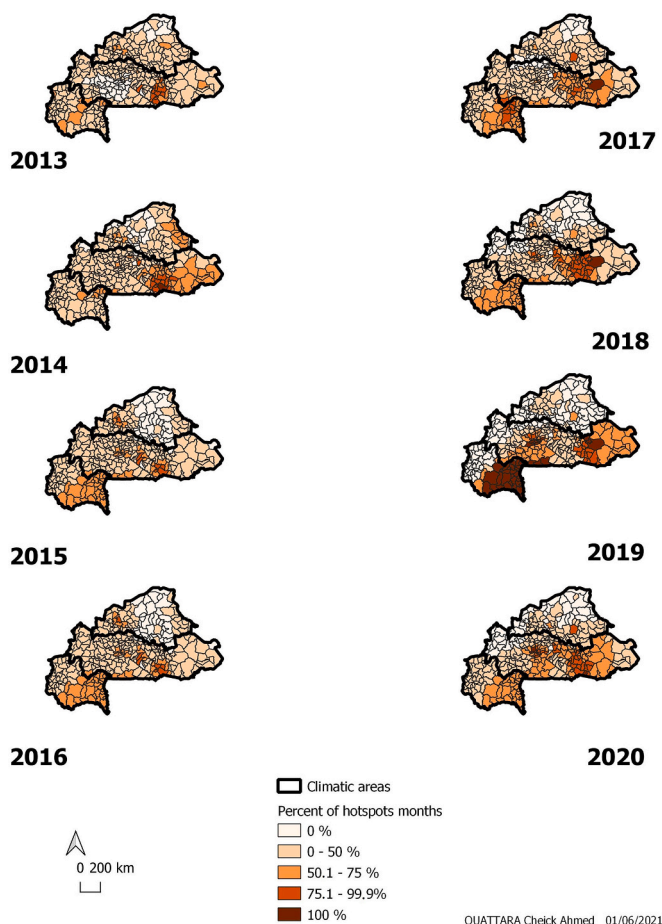
Fig. 5. Map of annual stability of malaria hotspots from 2013 to 2020 at municipality scale.

as a stability score (Fig. 2). This process was performed for each year from 2013 to 2020 and by season (comparing high transmission season (July to December corresponding to rainy season) to low transmission season (January to June corresponding to dry season)). Using these percentages, malaria hotspot stability maps were created (Noé et al., 2018).

3. Results

The total number of malaria cases reported by health facilities in Burkina Faso between 2013 and 2020 was 75,559,397, with 7,146,026 in 2013; 8,278,408 in 2014; 8,286,453 in 2015; 9,785,822 in 2016; 11,915,816 in 2017; 11,970,321 in 2018; 687,2720 in 2019 and 11,303,831 in 2020. From 2013 to 2020, the Sahelian, Sahelo-Sudanese and Sudanese zones accounted for 22%, 59% and 19% of malaria cases, respectively.

The average annual incidence was 480 cases of malaria per 1000 inhabitants. It increased from 407 cases per 1000 inhabitants in 2013 to 518 per 1000 inhabitants in 2020 with a peak of 598 cases per 1000 inhabitants in 2017 (Table 1).

This increase in incidence during the 2013–2020 period was marked by seasonality from July to December (Fig. 3). Malaria incidence peaks were observed in September (Fig. 3).

The number of municipalities with an incidence of >500 cases per 1000 from 83 in 2013 to 160 in 2020 with a peak of 243 in 2017 (Fig. 4). Moreover, these municipalities were mainly located in the Sahelo-Sudanian (151/199 in 2017) and Sudanian (48/199 in 2017) zones (Fig. 4).

There were two main clusters at high risk of malaria stable from 2015 onwards. The first is located in the Sudanian zone which includes the provinces of Poni, Noumbiel, Ioba, Sissili and the municipalities of Karangasso Vigué and Koumbia. The second main cluster is located in the Sahel-Sudanian zone which includes the provinces of Bazéga, Boulgou, Ganzourgou, Kompienga, Koulpélgo, Kouritenga and Zoundwéogo. The stable secondary clusters involved the province of Boulkiemdé and the municipalities of Ouahigouya, Namissiguima and Tougouri (Figs. 5, 6).

Most of the municipalities outside these clusters have experienced overage malaria cases for less than half of the 2013–2020 period. Two municipalities (Arbinda and Koutougou in Soum province) have never been at high risk.
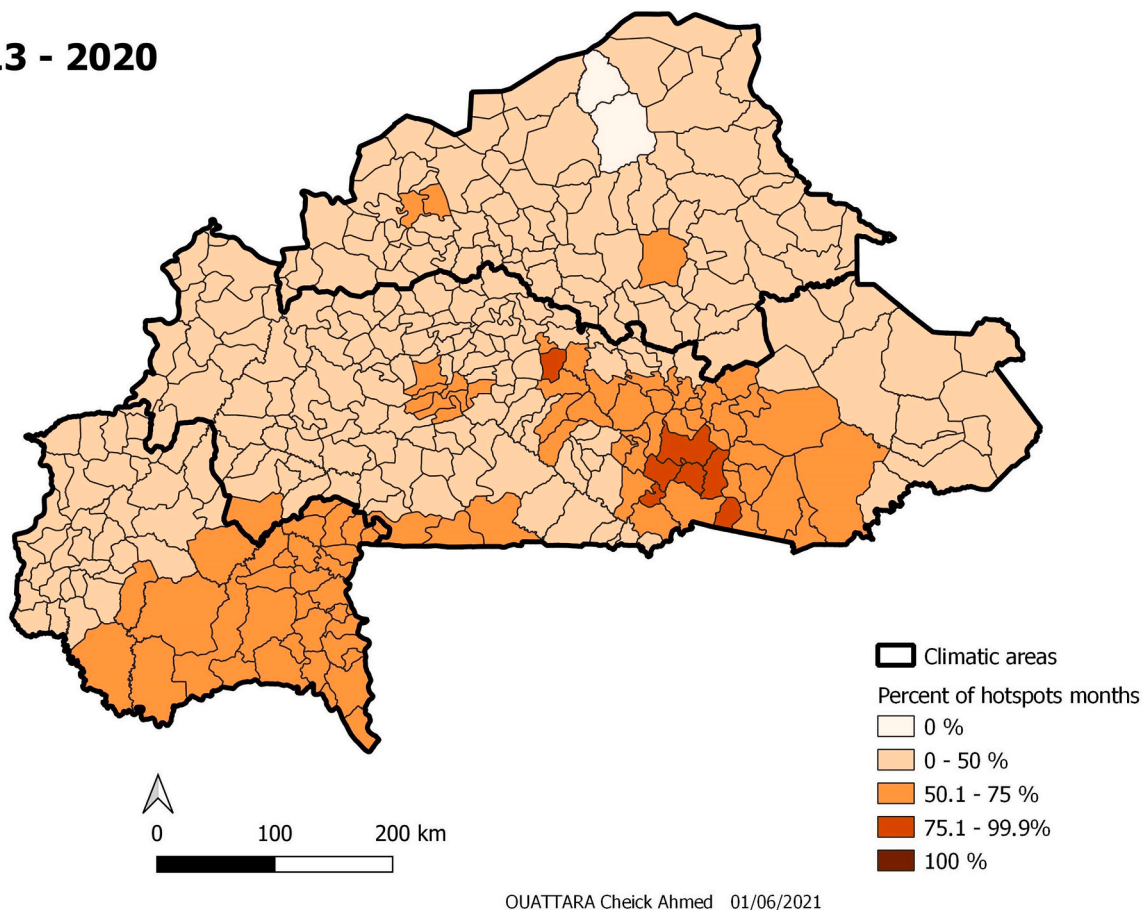
2013 - 2020

Fig. 6. Global stability map of malaria hotspots from 2013 to 2020 at municipality scale.

The main cluster in the Sudanian zone remained stable and predominant during the first half of each year. The main cluster in the Sudano-Sahelian zone remained stable over the two semesters of each year with an increase in risk in the second half of the year (Fig. 7).

4. Discussion

The average annual incidence of malaria cases reported in Burkina Faso was 480 per 1000 inhabitants between 2013 and 2020. According to malaria indicator surveys, Burkina Faso is listed as a high burden malaria country (WHO, 2020). Thus, the national strategic plan for the fight against malaria (2016–2020) has adopted uniform control interventions throughout the country (Ministère de la santé, 2016). These interventions were implemented by the NMCP, mainly targeting the vulnerable groups such as children and pregnant women by using anti-malaria drugs, LLINs and IRS (Ministère de la santé, 2016).

The implementation of those tools has led to a significant reduction in malaria mortality without an affect on the incidence curve (Ministère de la santé, 2016). Indeed, the annual incidence of malaria increased from 407 cases per 1000 inhabitants in 2013 to 518 per 1000 inhabitants in 2020, an average annual increase of 14 cases per 1000 inhabitants. This could be due to increased access to care and changes in population behaviour.

A number of studies have highlighted the importance of targeting high incidence areas to reduce malaria transmission (P et al., 2017; Larsen et al., 2017). In this sense, the World Health Organization (WHO) recommends the implementation, in addition to universal strategies based on vector control, locally adapted strategies that target vulnerable populations and areas at high spatial and temporal risk of malaria (WHO, 2022b).

The heterogeneity of malaria incidence and transmission rates in Burkina Faso has been reported by other authors at various geographical scales (Ouedraogo, 2020; Ouedraogo et al., 2018a; Ssempiira et al., 2018). We have identified two main stable clusters at the country level, the first one is covering the South-West region and the second one in the Centre-East region.

This study was not designed to identify the factors responsible for cluster stability, although cautious conclusions can be made. On the one hand, the climatic conditions and vegetation in these areas are favourable to the development of *Anopheles* spp. On the other hand, behavioural factors are favourable to malaria transmission (e.g. 26% use of insecticide-impregnated mosquito nets for a 75%
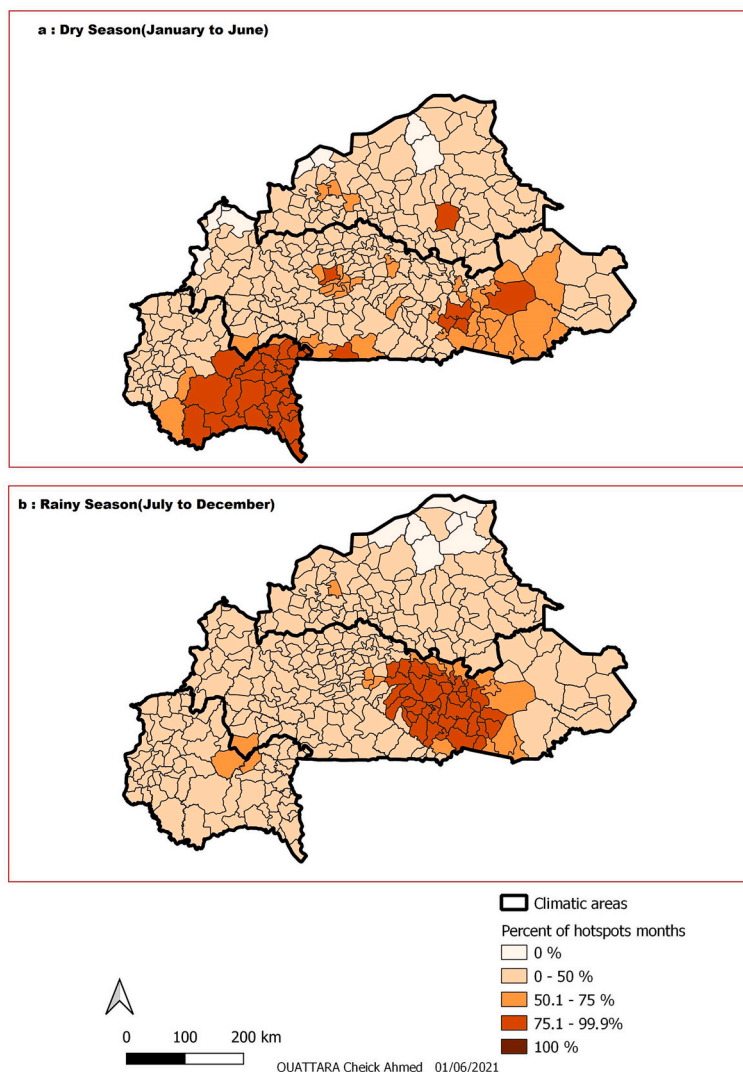
Fig. 7. Map of seasonal stability of malaria hotspots from 2013 to 2020 at municipality scale.

ownership in the South-West region (Ministère de la santé, 2016)). Several studies have reported multi-resistance of *Anopheles gambiae* s.l. populations to insecticides in several regions in Burkina Faso (Dabiré et al., 2008; Namountougou et al., 2012). These resistances are thought to be due to the pressure of insecticides used against adult mosquitoes in households (LLINs, IRS), to the pressure exerted on larvae in breeding sites contaminated by insecticides used in agriculture, to the use of repellents in homes (Soma et al., 2021). In addition, antimalarial drug resistance in *Plasmodium* spp. populations could be an obstacle to the success of current malaria control programme (White, 2003; Menard and Dondorp, 2017).

Moreover, we found that one of the main clusters was more stable outside the high transmission period from July to December. This suggests a temporal adaptation of the control strategies according to the zones for a better efficiency (Mogeni et al., 2017).

This study has a number of limitations. The malaria cases used might underestimate, because not all private health services report in the national surveillance system. In addition, the data are based on diagnosed morbidity, cases of malaria without recourse to a health facility and asymptomatic carriers can constitute a significant burden of morbidity and infectious reservoir.

Other limitations to this study are related to a range of missing data over the study period and the Kuldoff approach.

Burkina Faso has a pyramidal health system organised around health facilities that report weekly on cases of disease under surveillance and monthly on their activities. This organization facilitates the management of health resources and decision, but can easily be undermined if health facilities stop reporting their data. This was the case in the second half of 2019 when data transmission was interrupted due to a strike by health staff. This is represented by the interruption of the curve in Fig. 3. Although Rouamba et al. in 2020 have proposed a Bayesian data imputation method in this context, we have excluded the four months where malaria data were not reported as we believe that this would not have changed the overall monthly trend in cases at the municipality level (Rouamba et al., 2020).

Kulldorff approach does not detect hotspots in a general sense, but hotspots relative to other areas. For example, during the period of low transmission, a municipality can be defined as a hotspot with a low level of incidence, but higher than other municipalities. This implies that the results of the hotspots presented can be interpreted as persistence of malaria transmission, but not as a high incidence level. Also the shape of the scan window, circular or elliptical, available in the Satscan software can have an impact on the results in case of non-circular clusters, and the performance of this approach decreases for low baseline incidences or small populations (Ouedraogo et al., 2018b).

Finally, it should be noted that the division into high and low transmission seasons is relative and that malaria continues, in a delayed manner, beyond the end of the rains (Dieng et al., 2020; Ouedraogo et al., 2018b).

5. Conclusion

The incidence of malaria has increased in Burkina Faso from 2013 to 2020 and the most municipalities are endemic with emerging high and stable risk areas. Taking this heterogeneity into account in the development of control strategies would help to significantly reduce malaria incidence in Burkina Faso. These data might help Ministry of Health for decision-making about malaria control strategies in Burkina Faso.

Declaration of Competing Interest

The authors declare that there are no competing interests regarding the publication of this paper.

Acknowledgements

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