# Environmental Changes and Evolution of Morbidity due to Malaria: A Case Study of Burundi, East Africa

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## ABSTRACT

Burundi is in sub-Saharan Africa, the most affected region by malaria in spite of efforts to reduce malaria transmission and its vector proliferation. Since the biological activity and the distribution of malaria parasites and their vectors are influenced by climatic factors, the epidemiology of malaria might be strongly correlated with altitude and hence climate. In addition, conversion of aquatic ecosystems and wetlands into agricultural land in traditionally non-endemic areas would have favoured the proliferation of malaria vectors, leading to greater vulnerability of these regions to malaria. Data on the number of malaria cases in eco-climatic regions from 2011 to 2020 were analysed to determine the evolution of malaria in Burundi and the variation of this evolution in these regions. The number of cases increased from 2013 to reach peaks with more than 8 million cases in 2016, 2017 and 2019, while a significant decrease was observed in 2018 and 2020. However, this change was significant only in Central Plateaus and the North-East depression regions. These highly populated regions have undergone major changes in land use by converting natural marshes into crop fields between 2012 and 2018 as implementation of development projects. These regions should therefore be given priority in terms of strategies to eradicate malaria. It is crucial to support agricultural intensification projects with adequate environmental management and monitoring programs, in particular in order to avoid the proliferation of malaria vectors and significantly reduce the transmission of malaria parasites, and thus overcome this scourge in the long term.

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**Keywords:** Malaria; Environmental health; Eco-climatic; Morbidity; Malaria

## INTRODUCTION

Burundi is a country located in Central East Africa with 27,834 km$^2$ of surface area. Despite its relatively limited area, the country's landforms are diverse and make it divided into different eco-climatic regions. Its altitude varies from 774 m on Lake Tanganyika shoreline to more than 2,200 m at the top of mountains lying on the ridge separating the Congo and Nile rivers watersheds [1]. This country is located in sub-Saharan Africa, the most affected region by malaria worldwide. Malaria is identified as one of the most critical public health issues in terms of morbidity and mortality. The United Nations' General Assembly declared malaria as a serious public health issue that slows down global development, especially in the least developed countries [2].

In Burundi, malaria is a major socio-economic burden for households and the country as a result of direct and indirect costs related to medical consultations and hospitalization, patients and patients' attendants travels, labor absenteeism, etc. It is also the leading cause of morbidity and mortality with an incidence rate of 81.5‰. In 2017, it represented 45.4% of the reasons for general consultations recorded in health facilities with a rate of 50.5% for children below 5 years old and caused 50.8% of deaths in hospitals [3].

Efforts to reduce malaria transmission and its vectors proliferation as well as to improve access to medical care in order to eradicate the disease have been made by various partners. These efforts have contributed to the decrease in the incidence of malaria. For example, between 2001 and 2003, the substantial expansion of malaria interventions resulted in a 47% reduction in malaria mortality rate worldwide, thus averting an estimated 4.3 million deaths. In spite of these efforts, malaria is still endemic in all the six WHO regions, and is particularly severe in the African region where it causes around 90% of the deaths [4]. In Burundi, these efforts include increase in the number of health facilities, number of tests conducted, number of mosquito nets distributed and changes in treatment guidelines. However, the number of malaria cases has steadily increased since 2000 [5].

Malaria is caused by parasites from Protozoans group of the genus *Plasmodium* and transmitted by female mosquitoes of the genus *Anopheles*. Up to recently, six species of *Anopheles* were known in Burundi, of which *A. gambiae* and *A. funestus* are the most abundant representing more than 90%. Two other species, *A. merus* and *A. arabiensis*, confused with *A. gambiae* have been identified by a recent study based on molecular analysis [6]. There are four different species of *Plasmodium* transmitting human malaria, of which *P. falciparum* and *P. vivax* are the most widespread and *P. falciparum* the most dangerous. The biological activity and the distribution of these parasites and their vectors are influenced by climatic factors, particularly temperature and precipitation [7,8]. In addition, Gallup and Sachs indicate that the location and severity of malaria are mainly determined by climate and ecology. In Burundi, landforms include plains regions characterized by a tropical climate, mountains regions with a rather temperate climate as well as plateaus with tropical cool climate [9]. Monthly records show that the majority of cases of malaria cases are found in plain areas with some relatively high extent in regions of higher altitude [10]. Thus, the epidemiology of malaria in Burundi might be strongly correlated with altitude and hence climate.

Other potential determinants of malaria epidemics in Burundi have been reported, particularly related to land use. For example, the extension of rice farming to natural marshes located in high plateaus was reported to have contributed to the extension of malaria endemic zone [3]. Indeed, several studies have shown that the modifications of natural environments for subsistence agriculture or the application of irrigation create favourable conditions for mosquitoes, thus causing an increase in malaria cases [11-17]. It has been indicated that the stagnation of water and secondary vegetation development in the newly established rice field ditches lead to the proliferation of mosquitoes [18]. Several marshland management projects were implemented countrywide partly by converting natural marshes into rice fields following a national strategy for the development of the rice sector [19]. The concerned areas are mainly located in the Imbo region in Cibitoke and Bubanza provinces, in the Moso depression region, in the central plateaus and Bugesera depression regions. The transformation of the natural aquatic ecosystems and wetlands of these regions into agricultural land would have favoured the proliferation of malaria vectors and thus caused more transmission of malaria in these regions [15,20,21]. This would have led to greater vulnerability of these regions to malaria than other regions especially those eco-climatic regions where malaria was not endemic.

Therefore, malaria control strategies should take into account the variability of malaria epidemiology according to altitude and climate as well as the occurrence of environments favourable to the proliferation of vectors following the conversion of natural wetlands and ecosystems in the eco-climatic regions of Burundi. The objective of this study is to determine the evolution of malaria in Burundi from 2010 to 2020 and to evaluate the variations of this evolution in the different eco-climatic regions of Burundi. The implementation of strategies to fight against this pandemic as well as the effects on the prevalence of malaria in the different eco-climatic regions of Burundi over the last decade are also analysed.

## MATERIALS AND METHODS

### Study area

Burundi's landforms vary greatly over a relatively limited area [22]. The country is divided into five major eco-climatic regions (Figure 1):

- The Imbo region, covering the eastern part of the country, includes the Burundian part of the Rusizi plain and the region bordering Lake Tanganyika shoreline; the altitude is between 774 meters and 1100 meters.
- The Mirwa region which is mainly an escarpment located between the Imbo region and the Congo-Nile ridge with an altitude varying between around 1100 m and 2000 m.

- The Congo-Nile ridge region where altitude varies between around 1700 m and 2500 m and is located between the Mirwa escarpment and the central plateaus. This region lies on the divide that separates the drainage basins of the Congo and Nile rivers in the west of Burundi.
- The Central Plateaus region, mainly covering the centre of the country, is very hilly with an altitude between 1400 m to 1900 m.
- The Northeast depressions region which includes the Buragane, Moso and Bugesera depressions, which cover the eastern and the north-eastern regions of the country with depressions whose altitude varies between 1,100 m and 1,400 m.

On the other hand, malaria endemicity shows variations from one region to another according to climatology and altitude. Hence, based on the epidemiological stratification, 3 epidemiological strata have been identified [3]:

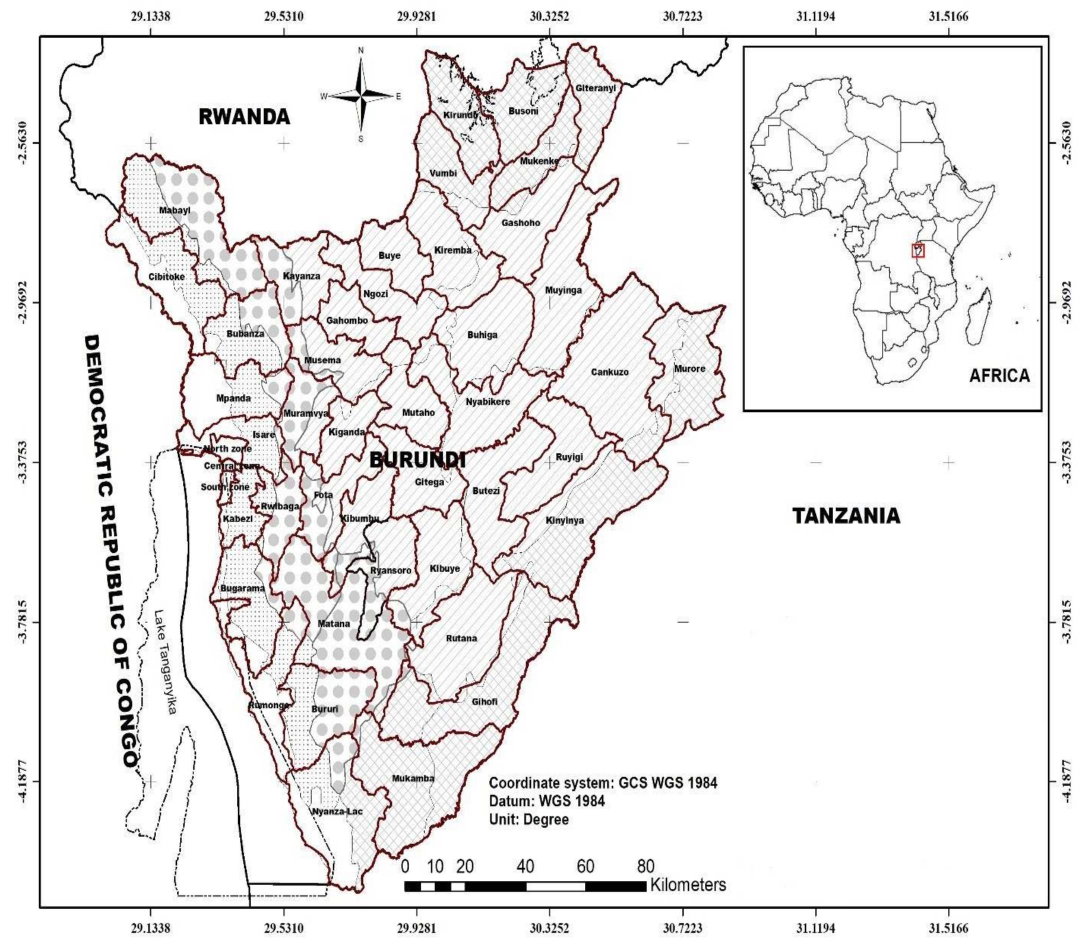
- The hyper-endemic zone below 1,400 m altitude where transmission is intense;
- The meso to hypo-endemic zone located at altitudes between 1,400 meters and 1,750 meters where transmission varies from low to medium transmission with a high epidemic potential and;
- The non-endemic zone located above 1,750 meters of altitude where sporadic cases are encountered, some of which are imported.

Based on this altitudinal variation and the classification based on malaria endemicity, we have retain four eco-climatic regions. In this classification, Imbo and Mirwa regions are merged to form the Imbo-Mirwa region (774 m-1700 m high). These regions cover an area that has been identified as hyper-endemic in the west of the non-endemic area mainly covering the Congo-Nile ridge. This region has similar altitude range with the Northeast depressions region but the latter has much more hilly relief and has more recently undergone significant land use change due to intensive agricultural projects, in particular the development of marshes for rice farming. The other eco-regions are kept as described above.

### Data source and eco-climatic regions distribution

Our data were collected from the National Integrated Program for Combating Malaria (PNLIP) of the Ministry of Public Health and the Fight against AIDS. The data on malaria cases were annually reported by health districts and cover an 11-year period from 2010 to 2020. However, there is one health district that was created in 2019, that is Bukinanyana, which resulted from the split up of Mabayi district. It also includes 6 health centres that belonged to Cibitoke district until 2018. Thus, for the data of 2019 and 2020, we included them in the health districts they belong to from 2010 to 2018 for practical purposes. The various health districts have been grouped into eco-climatic regions. Some health districts are covered by two regions, they were included in the region that covers their largest part (Figure 1).

**Figure 1**. Map of Burundi showing health districts and eco-climatic regions. **Note:** ( ) Health districts; ( ) Imbo; ( ) Mirwa; ( ) Congo-Nile Ridge; ( ) Central plateaus; ( ) Northeast depression




Hence, the eco-climatic regions and the health districts they include are as follow;

- The Imbo-Mirwa region from merged Imbo plain and Mirwa escarpment regions: Bubanza, Bugarama, Bujumbura center, Bujumbura north, Bujumbura south, Cibitoke, Isale, Kabezi, Mpanda, Nyanza-Lac, Rumonge.
- The Central Plateaus region: Buhiga, Butezi, Buye, Cankuzo, Gahombo, Gashoho, Gitega, Kibumbu, Kibuye, Kiganda, Kiremba, Musema, Mutaho, Muyinga, Ngozi, Nyabikere, Rutana, Ruyigi, Ryansoro.
- The Congo-Nile ridge region: Bururi, Fota, Kayanza, Mabayi, Matana, Muramvya, Rwibaga.
- The Northeast depressions region: Busoni, Gihofi, Giteranyi, Kinyinya, Kirundo, Makamba, Mukenke, Murore, Vumbi.

## Data analysis

The data were analysed using SPSS 25.0 software (IBM Corp., Armonk, NY, USA) for anova while Microsoft Excel 2013 and Sigmaplot 14.0 software (Systat Software, Erkrath, Germany) were used to generate graphs. The ANOVA analysis was based on annual data on malaria cases from the different health districts. The t-test was used to identify differences among mean values of annual numbers of malaria cases in eco-climatic regions. The differences were considered significant if p-values<0.05.

## RESULTS

Our results show that the year 2019 has the highest number of malaria cases while 2012 has the lowest number in Burundi (Table 1 and Figure 2). There was an increase in the number of malaria cases from the year 2013 while from 2010 to 2014, the number of malaria cases per year was less than 5 million cases. However, peaks are observed with more than 8 million cases in 2016, and 2017, and more than 9 million in 2019. In addition, the results based on the boxplot figure showed a greater variability in the annual number of cases in the health districts from 2015. Hence, the increase in number of malaria cases observed from 2015 onward in Burundi was sharp for some health districts compared to others (Figures 2 and 3).

**Table 1**. Summary of data on numbers of Malaria cases in eco-climatic regions.

| | | **Years** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ecoclimatic regions | Statistics | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
| Congo-Nile ridge | Total | 280282 | 212799 | 134305 | 173438 | 207894 | 256832 | 565410 | 548788 | 258953 | 425908 | 250456 |
| | Average | 40040.3 | 30399.9 | 19186.4 | 24776.9 | 29699.1 | 36690.3 | 80772.9 | 78398.3 | 36993.3 | 60844 | 35779.43 |
| Northeast depression | Total | 785698 | 907071 | 879653 | 1384887 | 1441504 | 1722673 | 2286684 | 2245354 | 1761605 | 3051321 | 1527545 |
| | Average | 87299.8 | 100785.7 | 97739.2 | 153876.3 | 160167.1 | 191408.1 | 254076.0 | 249483.8 | 195733.9 | 339035.7 | 169727.2 |
| Imbo Mirwa | Total | 842041 | 754420 | 527408 | 632411 | 649571 | 668833 | 950779 | 1124607 | 914868 | 1286464 | 979781 |
| | Average | 84204.1 | 75442 | 52740.8 | 57491.91 | 59051.91 | 60803 | 86434.45 | 102237 | 83169.82 | 116951.3 | 89071 |
| Central Plateaus | Total | 2319910 | 1535081 | 1142208 | 2136855 | 2529779 | 2805630 | 5043823 | 4251752 | 2214010 | 4661711 | 2479073 |
| | Average | 122100.5 | 80793.7 | 60116.2 | 112466.1 | 133146.3 | 147664.7 | 265464.4 | 223776.4 | 116526.8 | 245353.2 | 130477.5 |
| | Overall total | 4227931 | 3409371 | 2683574 | 4327591 | 4828748 | 5453968 | 8846696 | 8170501 | 5149436 | 9425404 | 5236855 |

**Figure 2**: Evolution of the number of malaria cases from 2010 to 2020 in Burundi.

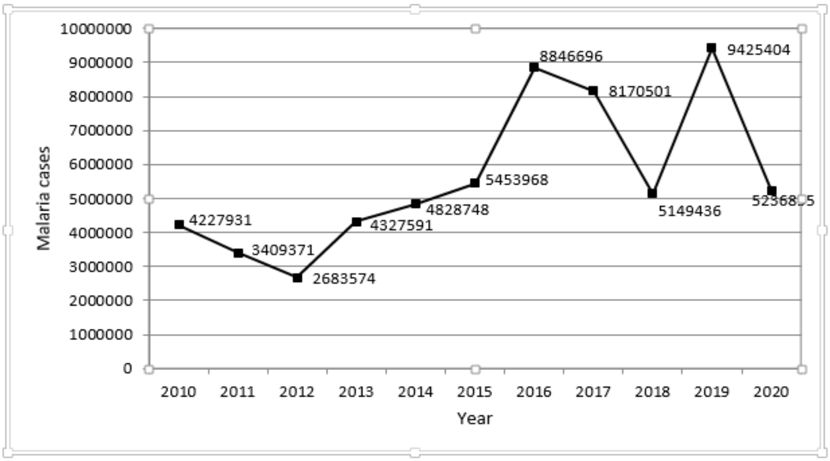
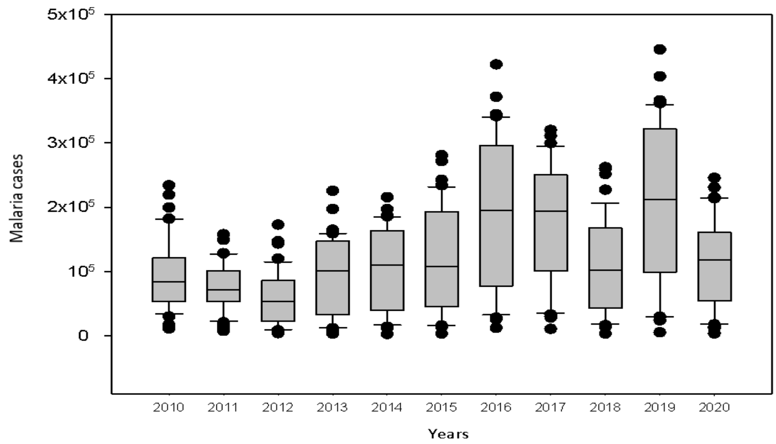



**Figure 3**: Boxplots for comparison of Malaria cases in Burundi from 2010 to 2020.

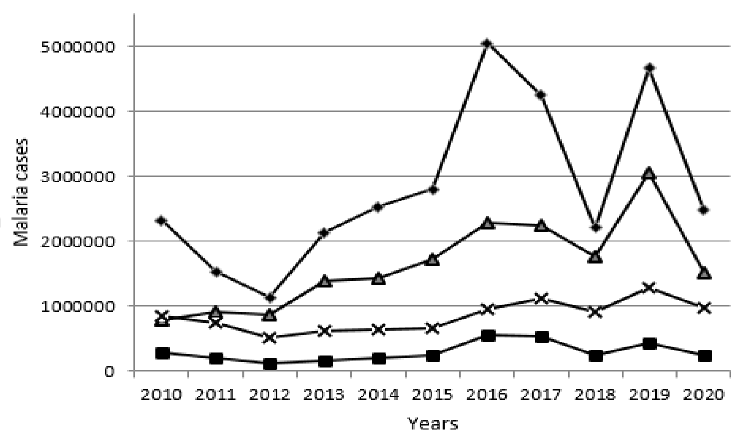



The evolution of malaria cases over studied period does not show the same trend in the different eco-climatic regions. Indeed, there are slight variations for the Imbo-Mirwa and Congo-Nile Ridge regions while the curves for North-East Depressions and Central Plateaus regions show great variations. The peaks were observed for years 2016, 2017 and 2019 but only for the regions of North-East Depressions and Central Plateaus while there has been a significant decrease in the number of cases of malaria in 2018 and 2020. Indeed, the ANOVA analysis shows that the difference in number of cases between the years is not significant for the Imbo-Mirwa and Congo-Nile Ridge regions, whereas it is significant for the Central Plateaus and the Northeast Depressions. Thus, unlike the Central Plateaus and Depression regions, the Imbo-Mirwa and Congo-Nile ridge regions did not experience significant change in the number of malaria cases (Table 2 and Figure 4).

**Table 2.** ANOVA 1 test results for comparisons of years' means for Malaria cases in eco-climatic region.

| Ecoclimatic regions | Years | Sum of squares | DOF | medium square | F | p-value |
|---|---|---|---|---|---|---|
| Imbo-Mirwa | Between groups | 4.410*10^ 10 | 10 | 4.1E+08 | 1.34 | 0.219 |
| | In groups | 3.524*10^ 11 | 107 | 3.3E+09 | | |
| | Total | 3.965*10^ 11 | 117 | - | | |
| Congo-Nile ridge | Between groups | 3.059*10^ 10 | 10 | 3.1E+09 | 1.25 | 0.278 |
| | In groups | 1.616*10^ 11 | 66 | 2.4E+09 | | |
| | Total | 1.922*10^11 | 76 | - | | |
| Central plateaus | Between groups | 8.49*10^11 | 10 | 8.5E+10 | 23.02 | <0.001* |
| | In groups | 7.30*10^11 | 198 | 3.7E+09 | | |
| | Total | 1.58*10^12 | 208 | - | | |
| North-east depressions | Between groups | 5.29* 10^11 | 10 | 5.3E+10 | 39.07 | <0.001* |
| | In groups | 1.19*10^11 | 88 | 1.4E+09 | | |
| | Total | 6.48* 10^11 | 98 | - | | |
| **Note:** *significant difference at the threshold of p<0.05 | | | | | | |

**Figure 4**: Evolution of the number of cases of Malaria from 2010 to 2020 in the eco-climatic regions of Burundi. **Note:** (■) Congo-Nile Ridge; (▲) North-East depressions; (✕) Imbo-Mirwa; (◆) Central plateaus.




## DISCUSSION

The results of this study showed that during the last decade, the number of cases of malaria increased from 2013 to reach peaks with more than 8 million cases in 2016 and 2017 and even more than 9 million in 2019 while a significant decrease was observed in 2018 and 2020. In March 2017, given the number of cases and deaths from malaria in 2016 and the number of people affected in January 2017, the public health authorities had declared malaria as an epidemic [5].

The numbers of malaria cases in health districts are closer to each other from 2010 to 2014 but there is greater variability from 2015. Our results show that only in the Central Plateaus and the North-East depression regions there was a significant increase in the number of malaria cases during the studied period. These results are consistent with a report by OCHA which indicated that provinces most affected by the epidemic declared early 2017 belong to these two regions where malaria incidence rate was higher than 80%. Most of these provinces are densely populated, and recent studies have also mentioned that they found concentration of most of the malaria cases, higher than average malaria mortality rates and more cases of malaria in children under 5 years old [23-25]. On the other hand, some parts of the country were not affected by the increase in the malaria number of cases and the epidemic declared in 2017, namely the Imbo-Mirwa and Congo-Nile ridge regions. There was no significant change in the number of malaria cases during the studied period in these regions.

Although Imbo-Mirwa and Congo-Nile ridge regions had similar trends of the number of malaria cases from 2010 to 2020, they have different eco-climatic characteristics mainly due to topography and altitude. This similarity could be explained by the fact that, on one hand, the Imbo-Mirwa region is experiencing the fastest urbanization and rural areas are characterized by rugged terrain where agriculture is less intensive and; on the other hand, the Congo-Nile ridge region has the lowest temperatures which do not favour the proliferation of malaria vectors and their larvae. A study on the relationship between altitude and the intensity of malaria transmission showed that low temperatures would prevent the development of malaria parasites in mosquitoes, especially during the rainy season [26]. In addition, Coosemans indicated that the Imbo region is known to be traditionally endemic and favourable to the proliferation of malaria vectors [11]. Land management projects for rice growing in this region were introduced in the 1950's in the plain of the Rusizi River with a considerable boom in 1972. Thus, malaria fighting projects have been applied long ago, so government structures and the population are more experienced in effective control methods to fight malaria in this region. In addition, the inhabitants of this area would be less affected by malaria owing to premunition [27].

In the central plateaus and the northeast depressions which mainly cover the center, north and east of the country, the increase in malaria cases from 2013 is significant and the epidemic declared in 2017 was more severe. These results could be explained by favourable temperatures, a high population density and a favourable environment resulting from agricultural intensification, the relief of this part of the country being characterized by an altitude ranging from about 1200 m to 1850 m with wide flat-bottomed and marshy valleys [22]. A recent study conducted in this region of Burundi gives similar results for malaria cases in children under 5 years old. The authors explain these results by very high population density and intensification of subsistence agriculture, with people spending more time in the fields and thus being exposed to parasite-infested mosquitoes [20].

The transformation of natural ecosystems, in particular the marshy valleys, into land for agriculture would have contributed to the creation and expansion of habitats favourable to the reproduction of malaria vectors as well as to the change of the microclimate by the alteration of the temperature which becomes conducive to larval development and adult survival [21]. For example, a study has shown that Anopheles do not reproduce in papyrus natural marshes whereas they are found in the ditches made by farming work [28]. In addition, entomological studies indicate that at least more than a third of the habitats of malaria vector larvae are found in agricultural land [29,30]. The fact that these habitats produce more vectors could be explained by the increase in water temperature in the breeding sites, which is 6.6ºC and 2.4ºC higher in the agro-ecosystems than in forests and natural marshes, respectively [30]. Natural ecosystems are less likely to harbour mosquito larvae whereas swampy or irrigated agricultural environments favor their proliferation [16,17]. The regions of the Central plateaus and northeast depression have undergone development projects to convert natural habitats into rice fields between 2012 and 2018 as part of the implementation of the National Strategy for the rice sector. With the aim to increase agricultural production and improve food security in the country in general and in regions of the country with high population densities in particular, 21,300 ha of plains and marshes should be converted and rehabilitated during this period [19]. The rice fields created from marshes and natural ecosystems would have favoured the development of mosquitoes in these regions [15,21], which would have been the cause of the increase in malaria cases in these parts of the country during the last decade.

Nevertheless, interventions to reduce malaria transmission have been carried out and have resulted in significant decrease in the number of malaria cases. This is the case for the campaigns of mass distribution of long-lasting insecticide-treated mosquito nets which were carried out in September 2017 and December 2019, prior to the observed significant decrease in the number of cases in 2018 and 2020 respectively [31].

## CONCLUSION

The results of this study showed that during last decade, the number of cases of malaria increased from 2013 to reach peaks in 2016, 2017 and 2019 with significant decrease in 2018 and 2020. However, this trend was not consistent in all eco-climatic regions of the country. The Imbo-Mirwa and Congo-Nile ridge regions did not experience a significant increase in the number of cases while the Central Plateaus and Northeast depression regions experienced significant change. The Imbo-Mirwa region is the most urbanized in the country with some regions with intensive agriculture. In this region traditionally endemic to malaria, the premunition and the experience in farming and malaria combatting techniques would have resulted in a lower malaria cases change while the high-altitude and mountainous Congo-Nile ridge region experience the lowest temperatures which are not favourable for malaria vectors development.

On the other hand, the Central plateaus and the North-East depression regions were most concerned by the increase in malaria cases and the epidemic declared in 2017. High population density, intensification and expansion of agriculture particularly rice fields in natural ecosystems would explain this increase in the number of malaria cases in the last decade. These regions should therefore be given priority in terms of strategies to eradicate malaria. Interventions, in particular the mass distribution of mosquito nets impregnated with long-lasting insecticide, have made it possible to reduce the number of cases of malaria. However, they should be conducted on a regular basis and at reasonable intervals. These interventions should also be specific to each region, taking into account the most affected areas and where environmental conditions are favourable for the proliferation of malaria vectors.

Burundi is a developing country with socio-economic and food security challenges to meet, in particular by improving crop production. However, it is crucial to support agricultural intensification projects with adequate environmental management and monitoring programs, in particular in order to avoid the proliferation of malaria vectors and significantly reduce the transmission of malaria parasites, and thus overcome this scourge in the long term.

## DECLARATIONS

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## Conflicts of interest/Competing interests

The authors declare no conflicts of interests/competing interests.

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