Status of Malaria in the African continent - Data Mining Insights from Heterogeneous, but Interrelated Data Sources.

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Abstract. Malaria is a life-threatening mosquito-borne infectious disease, mainly caused by the plasmodium parasites. African continent still suffers the most from this disease for many reasons such as poverty, lack of awareness, lack of investments, insufficient infrastructure and precaution measures, weak policy as well as management, and improper diagnosis practices. In this research, we have performed extensive malaria data analysis for several African countries for the period 2000-2020, and were able to extract some key insights for actionable insights. Our analysis shows that, overall, the continent has reduced the malaria infection rate from 37% to 25% (and associated death rates from 0.15% to 0.05%) in the last twenty years - a big achievement indeed. Unfortunately, some countries couldn't follow this trend, leading the progress and the development curve to be stalled or constant and sometimes even negative for the last few years. These rates are still higher when we compare them to other parts of the world. We were also able to make some concrete associations with finances, associated investments, and the malaria diagnostics methodologies, adopted and practiced by certain countries. The overall healthcare spending (as a share of the Gross Domestic Product (GDP)) in Africa is way below the global healthcare spending as reported (5.6% vs 8.5%) in 2000 and (5.18% vs 9.8%) in 2019 by the World Health Organization (WHO). More alarming is, due to healthcare cuts, in recent years many countries switched from the more orthodox and effective microscopy diagnostics tests to comparatively cheaper and less effective Rapid Diagnostic Tests (RDTs) leading to severe consequences. We have made some concrete recommendations to combat malaria and to reduce infection and associated mortality rates.

Keywords: Malaria, Anopheles Mosquitoes, Africa, World Health Organization (WHO), Gross Domestic Product (GDP), Microscopy Tests, Rapid Diagnostic Tests (RDTs).

1 Introduction

Malaria is an infectious disease transmitted to humans through the bites of female Anopheles mosquitoes. Although nowadays, it is quite unfamiliar to the developed world, in some parts of the globe, it is still a challenging issue, especially in tropical and subtropical regions. Usually, malaria is transmitted to humans through five species of Plasmodium, with Plasmodium Falciparum being the most dangerous one [1][15][29]. This disease manifests with symptoms such as fever, chills, and anemia, and can be deadly, leading to severe death. Young children are the most

vulnerable group as they are the easy targets of mosquitoes [4][29][30]. In 2020, the World Health Organization (WHO) reported 241 million malaria cases, which resulted in 0.63 million malaria-related deaths [18]. Young children, elderly people, and pregnant women are the most severely affected groups. In some parts of the world, this disease has been exacerbated in multiple folds due to malnutrition and coinfections. Central Africa, and the Sub-Saharan regions, continue to be the most affected regions in the world [14][16][27] as illustrated through the malaria infection distribution shown in Figure 1, extracted through the using tool developed by the Malaria Atlas Project (MAP) project[13].
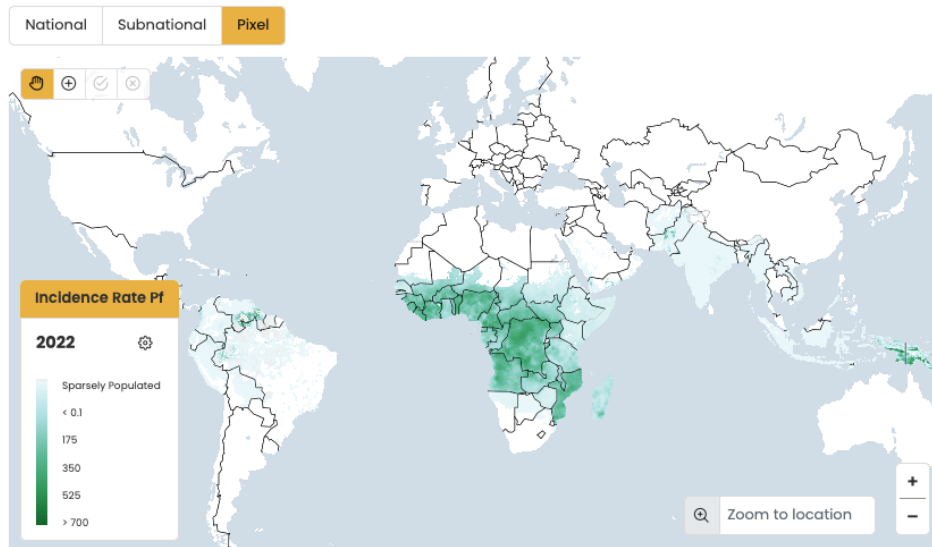
Fig. 1. A snapshot of the malaria Incidence Rate Pf (per thousand) through using the MAP dashboard [13]; the greener the region, the higher the malaria infection rates (record date: June 25, 2024). We can see, the prevalence of malaria in Africa, compared to the rest of the world.

The world has been combating this deadly disease for years, and some of the common practices are the usage of insecticide-treated bed nets, residual spraying, and antimalarial drugs. Over the last decades, considerable progress has been made; however, we still have a long way to go to make the world malaria-free. Some of the major challenges include lack of coordinated healthcare planning, negative and bad environmental practices, improper insecticides, and resistance to insecticides and certain drugs. Addressing malaria requires a coordinated and multifaceted approach by the scientific community, health workers, and different government and non-government policymakers [23][28]. This research aimed the following objectives:

- Investigate the malaria and associated death trends in Africa for the period 2000-2020.
- Assess the impact of malaria on different age groups.
- Examine the association between finances (in the form of investments and Growth Domestic Product (GDP)) and malaria infections and associated deaths.
- Evaluate the effectiveness of different malaria diagnosis methods and assess any correlation between diagnostic practices and the prevalence of malaria.

The rest of the paper is organized as follows: section two reviews different available malaria and associated data sources; in section three, we have explained our multi-source data mining process, including some key observations; section four tries to correlate the malaria status in Africa with finances and associated investments; in section five, we have explored different adopted malaria diagnosis methods, and their possible relationship with malaria outbreaks and associated mortality rates. We summarize our major findings including future research directions in section six, followed by conclusions in section seven.

2   Malaria Data - a Review

To our knowledge, until now, we don't have a complete and integrated database or data warehouse for this kind of multi-source malaria data research. Different government, non-government, and international organizations have put forward their efforts to collect and analyze malaria data, mainly from local, regional, or sub-regional sources for corresponding activity and progress analysis.

The availability of quality malaria data in Africa varies across regions and countries. While some countries have developed well-established surveillance systems and regularly publish malaria data, others have data gaps and limited access to complete information. For example, Kenya has implemented innovative systems like the Kenya Health Information System (KHIS)[26][11] and the electronic Community Health Information System(eCHIS) as part of their healthcare system. KHIS collects and organizes health data from all government healthcare facilities, assuring consistency and accuracy. It keeps track of disease outbreaks, trends, and issues early alerts about potential health hazards. The system delivers regular reports on performance, resource utilization, and service delivery. It facilitates policy creation, resource allocation, and program administration by allowing for modifications and evaluations[9]. KHIS also connects with other health information systems such as the eCHIS, ensuring synchronization and alignment of data among various subsystems. Thus, a coordinated healthcare system has facilitated the collection of timely malaria data in the country.

The Ugandan health system structure, on the other hand, is divided into the following levels: Health Centers, Health Sub-District Systems, District Health System, Regional, and National. Unfortunately, the majority of these levels are manual (paper-based), with only a partial electronic deployment. The Uganda Malaria

Table 1. Several available malaria and associated data sources; these seem to have some overlaps, both in terms of the data and their sources of origin.

data source	Description
World Health Organization (WHO)[23]	Yearly world malaria reports (2017-2023) are available, including downloadable Excel format data as annexes. The latest reports share data for the period (2000- 2022); this is our primary source of data for our malaria data analysis; (link).
Malaria Atlas Project (MAP)[8][13]	The Malaria Atlas Project (MAP) is a nonprofit academic group funded by the Bill and Melinda Gates Foundation. They provide downloadable *.csv format data (incidence, infection prevalence, and mortality rates), and is available for the period: 2010-2022. They also have a nice dashboard showing different analytical results, including overall trend and other patterns; (link).
United Nations International Children's Emergency Fund (UNICEF)[7]	Children healthcare coverage (in downloadable Excel format) plus indicators for different diseases, including malaria (Last updated: December 2023); (link).
Institute of Health Metrics and Evaluation (IHME)[5]	IHME is a public health agency and research institute at the University of Washington, Seattle, USA. They provide global malaria incidence, prevalence, and mortality data for the period (2000-2019) mainly in the *.csv file format for all countries and for all age groups. They also provide some image files for data visualization purposes. (link);
Kaggle[24]	Number of malaria cases and associated data from 2010; data available in the *.csv file format; (link).

**Table 2.** Some entities or organizations, helping the malaria controlling efforts.

Service provider	Description
Malaria Eradication Research Agenda (MESA)[10]	Led by the Barcelona Institute for Global Health (ISGlobal) and in collaboration with WHO, MESAs' goal is to gather, analyze, and share information and knowledge to combat malaria worldwide. MESA is supported by the Bill and Melinda Gates Foundation.(`https://mesamalaria.org/`)
Alliance for Malaria Prevention (AMP)[6]	The Alliance for Malaria Prevention and it's partners assist planning and distribution of insecticide-treated nets (ITNs) to malaria affected countries and regions. `https://allianceformalariaprevention.com/`
Malaria Threats Map by WHO	A tracking and visualization tool to study and understand the spread of biological threats to malaria. `https://www.who.int/teams/global-malaria-programme/surveillance/malaria-threats-map`
International Centers of Excellence for Malaria Research (ICEMR)	Established by the National Institute of Allergy and Infectious Diseases (NIAID), ICEMRS are a global network of independent research centers providing the infromation, knowledge and tools needed to understand, control, and combat malaria. `https://www.niaid.nih.gov/research/excellence-malaria-research`

Surveillance Program (UMSP)[31] was formed in 2006 to gather high-quality malaria surveillance data at six high-volume public health facilities known as Malaria Reference Centers (MRCs), in partnership with the Ugandan National Malaria Control Division. Although the Uganda health sector has made significant progress in recent days, it still falls short of the Kenyan Health system.

Internal organizations, such as WHO[17][18][20], Pan American Health Organization (PAHO) [2][25], and UNICEF[7] have put forward their efforts as supervisory entities to combat malaria at the regional, sub-regional, and global levels. In Table 1, we have compiled a set of data resources available today for malaria data analysis, research and development; these sources seem to have some overlaps, however, these are invaluable resources for our fight against malaria. Many other entities and organizations are working with this common goal, and a small but important list is provided in Table 2.

## 3   Exploratory Data Analysis (EDA) and Data Mining Process

The primary focus of this project is a comprehensive study of available malaria data, with a specific focus on the continent of Africa; more specifically, some severely affected countries such as Nigeria, Kenya, Uganda, and Burkina Faso. We can classify
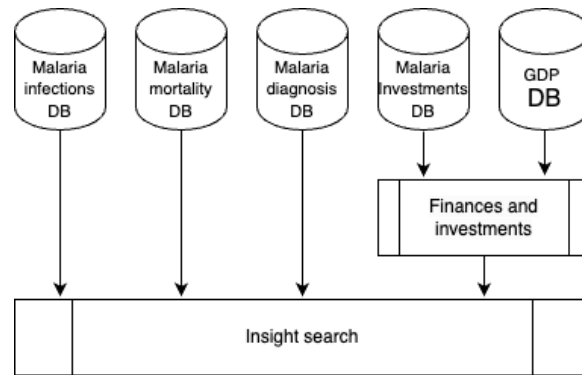
Fig. 2. The schematic block diagram of our data mining process flow, including different input databases.

the used data sources into two major categories: (i) Malaria infections, mortality, diagnosis, and investment databases [17][18][19][20][22], and (ii) The financial and the GDP data from World Bank [3]. Figure 2 shows the schematic block diagram of our data mining and insight search process and their relationship to corresponding databases in our query. The World Health Organization (WHO) data, as reported in Table 1, is our primary source of information for malaria-related data [17][18][20],

and the economic data such as investments and different nation's GDPs are from sources such as the World Bank and WHO[3][19].

Normalized malaria cases (in %) over Years

Normalized malaria related deaths (in %) over Years
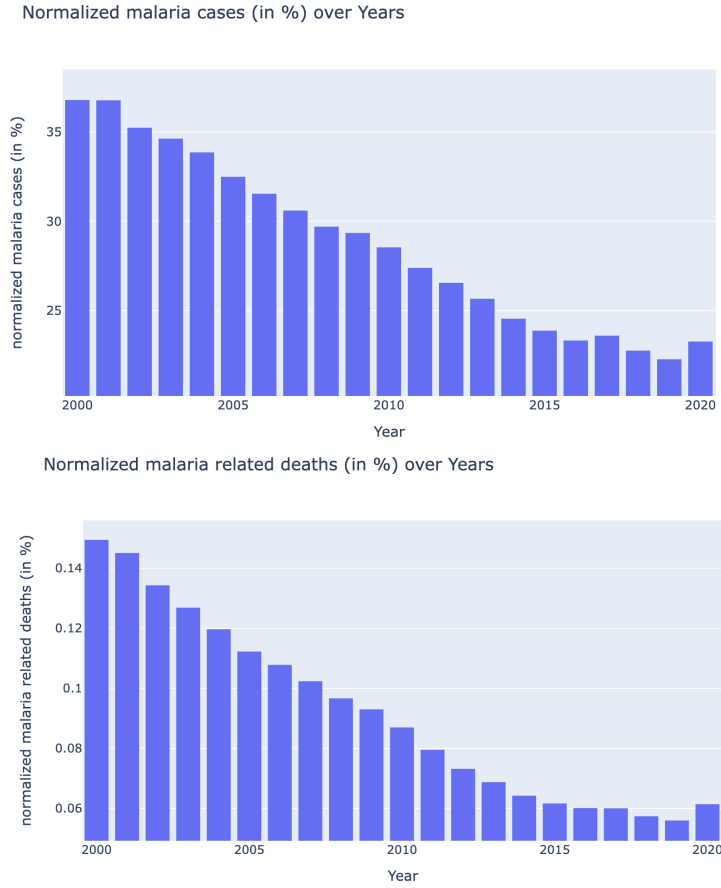
Fig. 3. (top) Normalized (in %) malaria cases, (bottom) normalized (in %) malaria-related deaths in Africa for the period 2000 - 2020. Normalization is done by dividing corresponding frequencies by the total population (reported in a year), and then multiplying by 100.

Figure 3 (top) shows the malaria infection rates in % (number of infections divided by corresponding population), and (bottom) shows the malaria-related death rates (death counts divided by the total population) in Africa for the period 2000-2020 [18]. It is encouraging to see that noticeable progress has been made in pulling down the overall infection rate from around 37% to 25%, and the corresponding death rate from around 0.15% to 0.05% (a three-fold death rate decrease, which is a big achievement indeed). Despite this progress, one thing is clear, we still have a long way to go; to highlight, the trend of improvement from year 2015 somehow stopped as we see a constant rate from this period onwards, both in terms of in-

Average normalized malaria cases

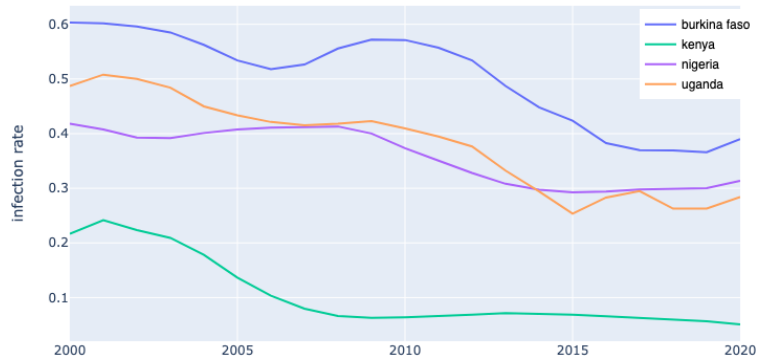**Average normalized malaria related deaths**
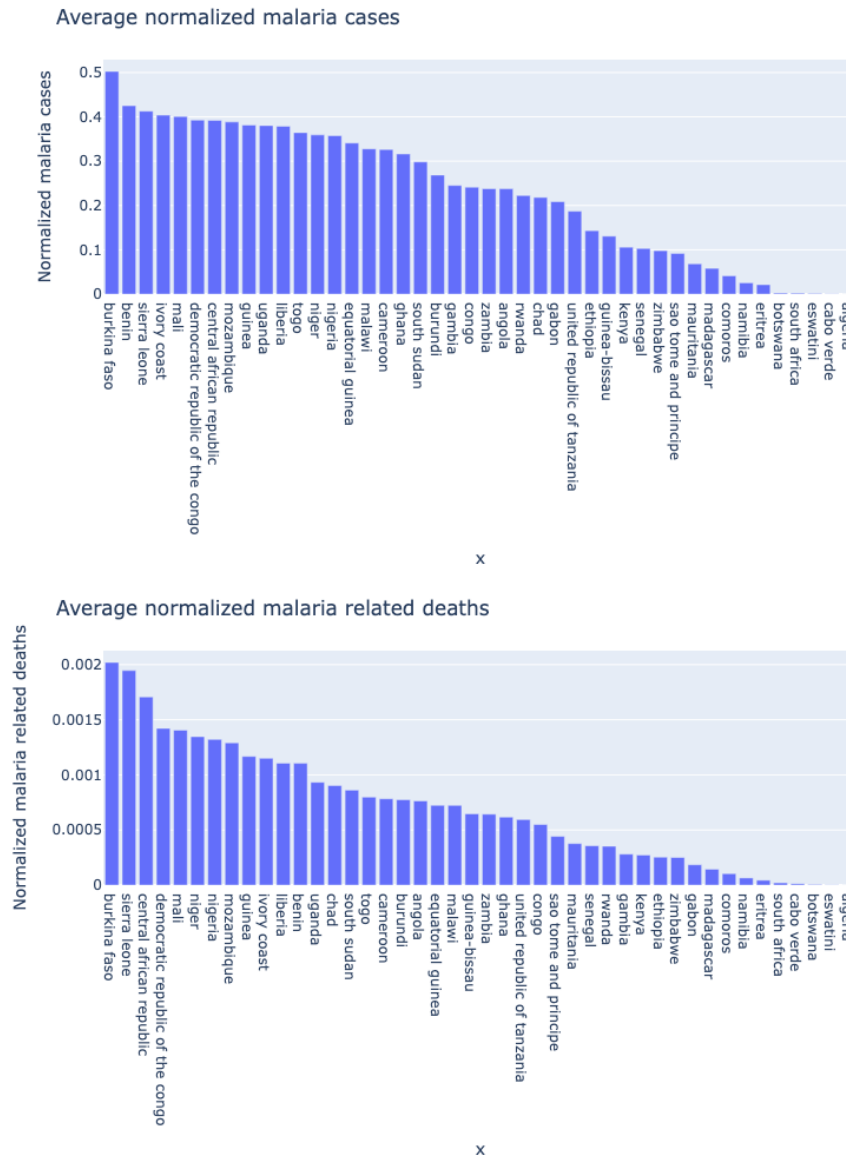
Fig. 4. (top) Normalized number of identified cases by country, (bottom) number of malaria-related deaths, normalized by the average population (over the period 2000-2020) of a country.

fections and associated death rates. More alarming is we are seeing an increasing infection and death rate for 2020; more recent data, once available, will help us confirm whether the 2020 data point was true, or whether it is merely an outlier.

Figure 4 (top) compiles country-wise infection statistics and (bottom) corresponding malaria-related death rates in Africa for the period 2000-2020. It is sur-
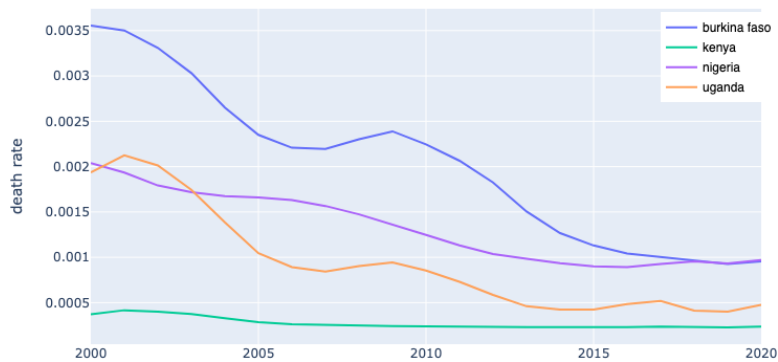
Fig. 5. Historical trend: (top) Number of identified cases, (bottom) number of malaria-related deaths, normalized by the population, for the period 2000-2020 (a sample of African countries).

prising that, on average, about half of the Burkina-Fasos' population was infected by this deadly disease. In some other countries such as Benin, Ivory Coast, Uganda, and Nigeria, this infection rate was around 40% (on average) for the selected period. Countries such as South Africa, Botswana, and Algeria are doing relatively better in keeping their infection and death rates low and controlled. Their geographical location and weather might have also helped them to keep this rate low. Out of the forty-four (44) African countries, for which we managed to collect data, thirteen

(13) reported over 0.1% (on average) malaria-related deaths, with Burkina Faso and Sierra Leone doubling this number to around 0.2%.

To further populate our analysis, we have selected a sample of four countries: Nigeria, Kenya, Uganda, and Burkina-Faso. Figure 5 compares the malaria infection and associated death rates for these countries, and we can see Kenya did an excellent job both in controlling the infection and the death rates. Malaria is still a big problem for the other three countries, and we wanted to investigate and examine why the difference is that big.
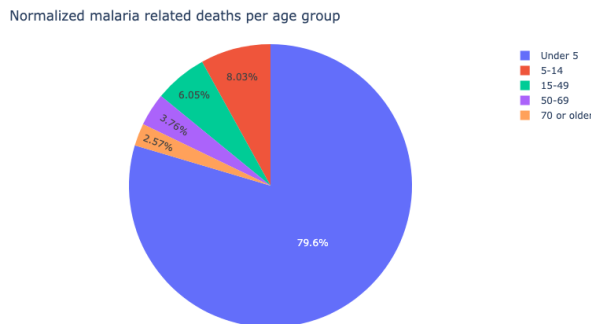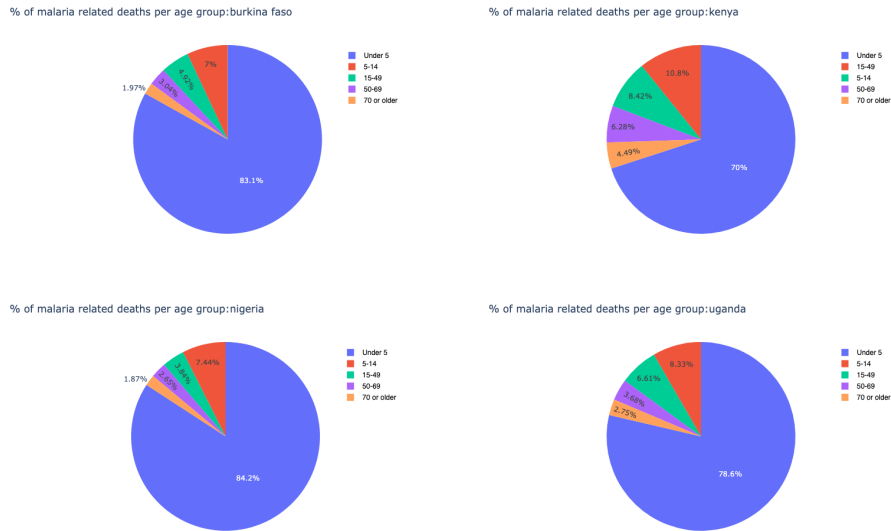

Fig. 6. Proportion of malaria-related deaths per age group (Africa)
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Figure 6 shows the malaria-related death distribution per age group in Africa. It is found that young kids, under the age of five (5) years old, are the most affected group, taking about 80% of the overall death toll. Country-wise (for our selected subsample) malaria-related deaths per age group are shown in Figure 7. Kenya is the only country (out of the selected four) that managed to keep the death rate of kids under the age of five (5) years around 70% of the overall associated deaths. For the other three countries, this rate is in the range between 75% and 85%. It is important to note that Africa has suffered the most in terms of reported malaria cases and associated deaths when we compare it with other parts of the globe, as illustrated in Figure 1.

4   Relationship to Finances & Investments

The African continent, as a whole, is experiencing tremendous economic growth over the last few years. Figure 8 shows the top sixteen African countries and their corresponding average Gross Domestic Product (GDP) for the period 2010-2020 [3]. Nigeria and South Africa led the continent with an average GDP of over 350B each.

Fig. 7. Proportion of malaria-related deaths per age group; (top left): Burkina Faso, (top right): Kenya, (bottom left): Nigeria, (bottom right): Uganda

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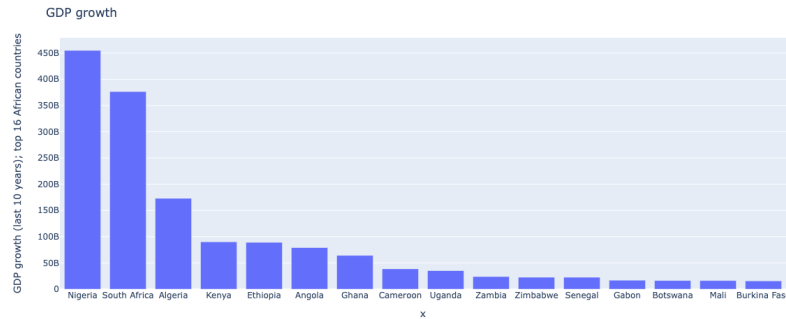
Fig. 8. Average Growth Domestic Product (GDP) of the top sixteen (16) African countries for the period 2010-2020.

Figure 9 shows the average percentage (%) of the GDP expenses in the healthcare sector in Africa for the period 2000-2020. Overall, we see an investment increase in the healthcare sector; however, the pattern is inconsistent, bumpy, and more alarming is the negative trend from 2015. Sadly, this pattern is quite aligned and can be linked to the flat malaria infection and associated death rates for the overlapping period, as reported in Figure 3. Figure 10 shows the overall percentage (%) of the GDP expenses in the healthcare sector by our selected four countries, and we see

% of GDP expebse in health-care
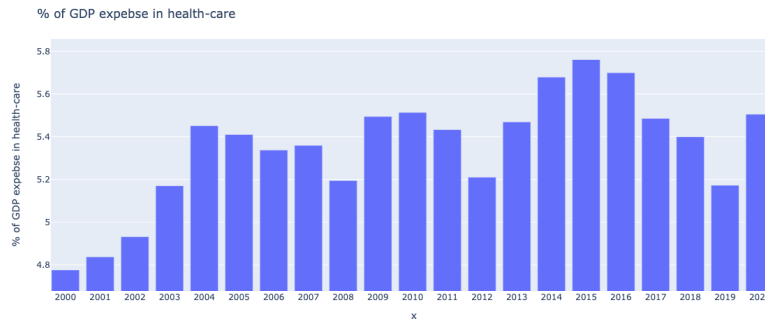
Fig. 9. (%) of GDP expenses over healthcare in Africa for the period 2000-2020.

% of National GDP spent on Healthcare
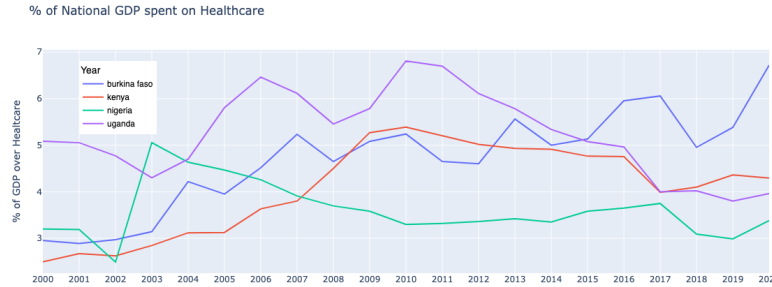
Fig. 10. (%) of GDP expenses over healthcare for the period 2000-2020 (by our selected four countries in Africa).

Burkina Fasos' continuous effort to increase investment in healthcare; the three other countries show either constant or negative investment trends.

It is important to note that none of our sampled four countries have ever spent 7% of their national GDP in healthcare for the specified period (Figure 10). In fact, the average African healthcare expense (as a share of their GDP) was within the range (4.8% - 5.75%) as reported in Figure 9. More alarming is the overall average healthcare spending (as a share of the Gross Domestic Product (GDP)) in Africa is way below the global healthcare spending as reported (5.55% vs 8.5%) in 2000 and (5.18% vs 9.8%) in 2019 by the World Health Organization. This indicates limitations and constrained investments in controlling persistent malaria outbreaks in the region. It is also important to note that Nigeria, the Democratic Republic of the Congo, and Uganda are tropical countries, and the weather is an important factor in helping malaria cases to expedite and death rates to be on the higher end. It is important to pay special attention to them.
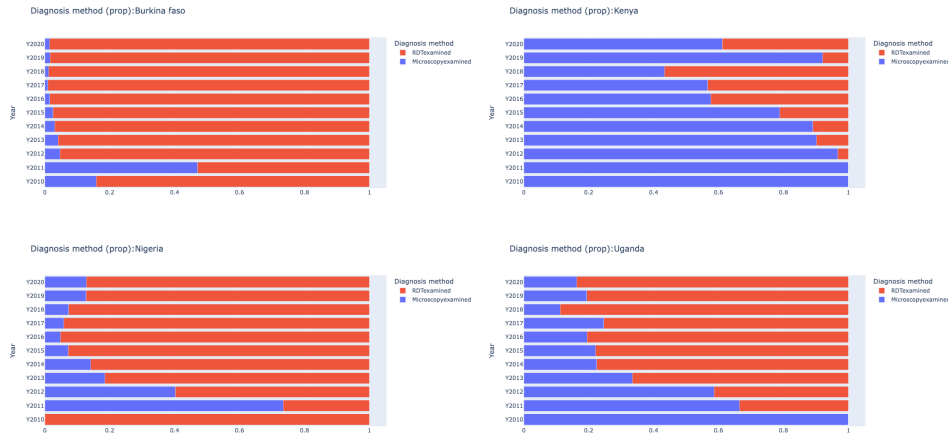
5   Relationship to Diagnosis Methods
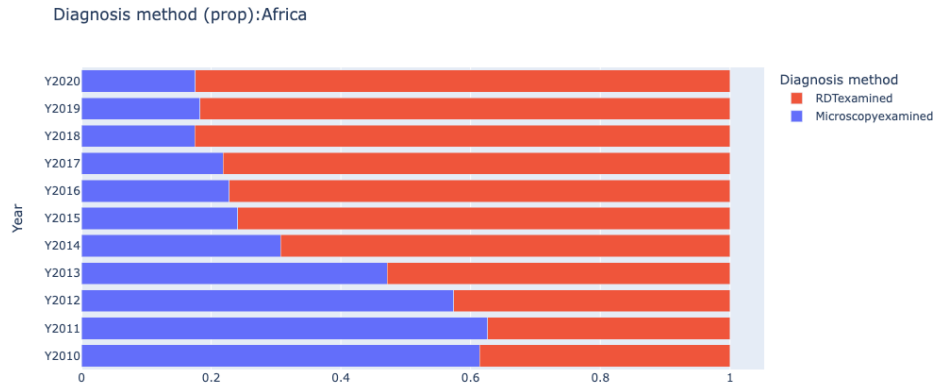
Fig. 11. Relative ratio of the RDTs vs Microscopy diagnosis methods, exercised in Africa, for the period 2010-2020.

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Microscopy and Rapid Diagnostic Tests (RDTs) are two popular malaria diagnosis tests, practiced worldwide [22][32][33]. Microscopy is a relatively thorough test, which is time-consuming, costly, and requires proper clinical expertise. On the other hand, RDT is cheaper, yet faster, easily accessible, and is usually intended for areas where access to well-trained laboratory personnel and proper equipment may be constrained. Compared to RDTs, microscopy allows more accurate quantification of the level of parasites, providing detailed information about the severity of the infection and the state of the disease. This also allows accurate identification of malaria species and choosing the most effective antimalarial treatment. Microscopy is also preferred for research and development purposes where detailed analysis of the disease is necessary along with proper documentation [12][21][22][32]. Figure 11 shows the ratio of these two diagnosis methods, exercised in Africa, for the period 2010-2020. We can see as time passed, we have moved towards choosing a cheaper RDT method over the more accurate and standard microscopy method. This indicates the limitation of the continent's ability, such as sufficient funding and investments, to combat malaria. This may also explain some level of negligence and non-seriousness of understanding the severity of the problem, plus incompetency in handling the scenario.

Looking individually at our sample countries of interest in Figure 12, we can see only Kenya was able to manage a good balance between these two diagnosis

methods. Sadly, Burkina Faso, nowadays, is almost fully relying on the RDT-based diagnosis. Their malaria infection and associated death rates, reported in Figure 5, may have some associations with these cheap and inefficient diagnosis practices. We see similar trends for Nigeria and Uganda as well.

Fig. 12. Relative ratio of the RDTs vs Microscopy diagnosis methods exercised for the period 2010-2020; (top left): Burkina Faso, (top right): Kenya, (bottom left): Nigeria, (bottom right): Uganda.

Our data analysis results show that proper diagnosis is crucial, and possibly one of the most important keys to fight this deadly disease. Kenya can be a role model in this case as we see how they were able to control the outbreaks by executing proper planning including exercising balanced diagnostic practices.

6   Discussion

The analysis of the malaria data from Africa, spanning from 2000 to 2020, reveals an overall decrease in the number of infections, however, we still have considerable places for improvement. The disease affected young children disproportionately when we compare them to other age groups, both in terms of infection rates and associated death rates. Poverty, lack of awareness, constrained investments in the healthcare sector, insufficient infrastructure and precaution measures, weaker policy as well as management, inefficient diagnosis and medication practices remain as significant challenges. Below, we list some other findings:

– In the last twenty years, the African continent managed to reduce malaria infection and associated death rates from 37% to 25% and 0.15% to 0.05% respectively, which indeed is a big achievement. These improvements had been

gradual, but unfortunately, we see a stalled or constant trend for the last few years. To improve conditions further, we must take effective and coordinated efforts to break this static trend.

– The continent has experienced tremendous economic growth over the last few years; however, this didn't translate well into proportional investment in the healthcare sector.

– The overall investment in the healthcare sector in Africa is insufficient and is far below the global investment average (as a share of the corresponding GDP). As reported by the World Health Organization, these numbers are (5.6% vs 8.5%) in 2000 and (5.18% vs 9.8%), when we compare Africa vs the overall global investments. With many other problems, this leads to poor and inaccurate diagnosis of the disease and failure of proper and timely treatment to patients, leading to severe consequences.

– Malaria disproportionately affects vulnerable populations, particularly young children, pregnant women, and others living in poverty or remote areas where access to healthcare facilities is constrained.

– Microscopy is one of the more accurate, clinically practiced, and widely accepted malaria diagnosis methods. RDTs are relatively simple, fast, and low-cost alternatives; however, with limited performance. Some African countries, nowadays, are mainly relying on RDTs over the more standard microscopy diagnosis methods mainly to cope with their constrained healthcare budget. This may have impacted malaria outbreaks and associated death rates negatively.

6.1 Future work

We list below a set of our priorities as future work and direction:

– Building a comprehensive and integrated data pipeline to periodically track the progress of malaria from multiple heterogeneous sources with minimal effort.
– Study some other features such as weather and geospatial location configurations to learn further associative factors related to malaria outbreaks.
– Extend the research area to other parts of the world, especially some similarly affected areas in Asia and Latin America.

7 Conclusion

We have performed a thorough study of malaria infections and associated death rates in Africa for the period 2000-2020. We have also studied independent financial and diagnosis data to learn possible associations among investments in the healthcare sector, diagnosis methods practiced, and the progress we have achieved

so far in combatting this deadly disease. The aim was to analyze data from multiple heterogeneous sources and learn any possible associations.

Looking at these data, it's evident that controlling malaria and associated deaths had some improvement over time; however, we still have space for improvement as the disease is still prevalent in most regions in Africa and some other parts of the world. Vulnerable people such as kids, elderly ones, and pregnant women are the most affected groups as they are easy targets of the carrier agents (mosquitoes). There have been financial improvements in some countries; however, those seem not translated properly to the healthcare sector, especially, in combatting deadly diseases such as malaria. We think it's important to share these findings with health workers, researchers, policymakers, government, and non-government organizations, who are working in this sector. Through a coordinated effort, we can do better at stopping this deadly disease.

In summary, this research provided a comprehensive study of the latest patterns and trends associated with malaria infections and associated deaths in Africa. It also disentangled some concrete associations with finances, investments, and the malaria diagnostics methodologies, adopted and practiced in the region. The project's multifaceted approach contributes to a more subtle understanding of the malaria landscape, aiding in informed decision-making and public health interventions.

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