Anticipated Decline in Malaria-Induced Fatalities Across Africa

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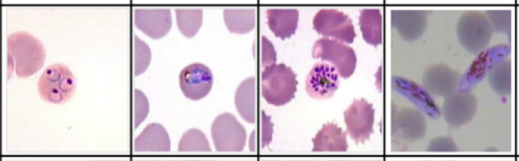
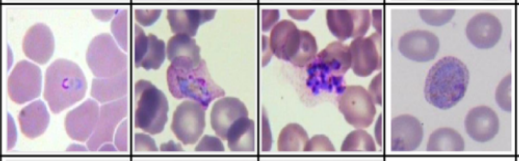
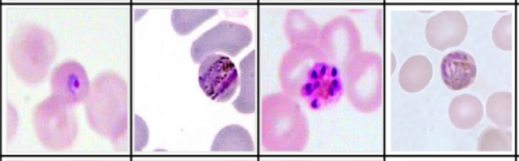
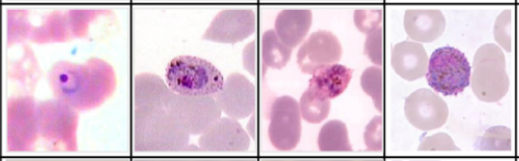
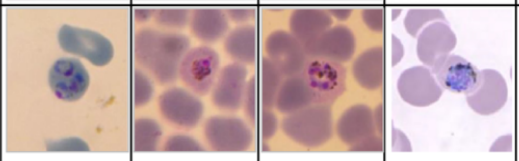
Abstract

Malaria is a preventable and curable disease caused by parasites transmitted to individuals through the bites of infected female Anopheles stephensi mosquitoes. This life-threatening disease is primarily caused by five specific species of the protozoan Plasmodium parasite and is most prominent in Africa. Symptoms vary from nausea to fatigue, vomiting, jaundice, etc., with treatment including antiparasitics and antibiotics, particularly medications such as Malarone, Qualaquin, Oracea, and others. This study aimed to recognize certain trends in malaria throughout the 2000s to guide further prevention and treatment of the disease to minimize its contraction and lower its mortality rate. By plotting data to create graphs, the research team found a remarkable pattern in Africa in which there has been a relative decline in the number of deaths caused by the disease, despite an annual increase in the number of cases. Upon discovering this pattern, the study moved forward with a focus on what factors are decreasing fatalities caused by malaria in Africa, to continue this decline and lead to more efficient treatment of the disease. The study will also determine if a similar trend is seen in other regions of the world, and if not, will provide measures that can be taken to develop the pattern.

The table to the right depicts the life stages of the 5 malaria-causing Plasmodium species.

Human Malaria

Species \ Stages	Ring	Trophozoite	Schizont	Gametocyte	
P. falciparum					• *Parasitised red cells (pRBCs) not enlarged.* • *RBCs containing mature trophozoites sequestered in deep vessels.* • *Total parasite biomass = circulating parasites + sequestered parasites.*
P. vivax					• *Parasites prefer young red cells* • *pRBCs enlarged.* • *Trophozoites are amoeboid in shape.* • *All stages present in peripheral blood.*
P. malariae					• *Parasites prefer old red cells.* • *pRBCs not enlarged.* • *Trophozoites tend to have a band shape.* • *All stages present in peripheral blood*
P. ovale					• *pRBCs slightly enlarged and have an oval shape, with tufted ends.* • *All stages present in peripheral blood.*
P. knowlesi					• *pRBCs not enlarged.* • *Trophozoites, pigment spreads inside cytoplasm, like P. malariae, band form may be seen* • *Multiple invasion & high parasitaemia can be seen like P. falciparum* • *All stages present in peripheral blood.*

Introduction

Background & Origin

Malaria has been a prevalent issue since the ancient world, and was originally thought to be transmitted by vapor for thousands of years until Alphonse Laveran made a discovery in 1880: the malarial parasite (Rajakumar and Weisse). With the use of increasingly sophisticated technology in today's world, it is known that of the 5 Plasmodium species capable of causing malaria, the deadliest are the *Plasmodium falciparum* and *Plasmodium vivax* species, responsible for the most deaths, and being the most widespread, respectively. Furthermore, 17 years after Laveran's discovery marks that of Ronald Ross, an educated doctor in England, who discovered the transmission of these parasites by mosquitoes (Rajakumar and Weisse).

Transmission & Global Health

Although conversations regarding malaria have recently been minimized, the issue it presents is still prominent in today's world. This is partly because transmission of the disease is fostered so well by mosquitoes that can easily bite infected individuals and in turn take in microscopic malarial parasites that mix with the mosquito's saliva which is then injected into another individual, thereby transmitting the parasite and disease to them (CDC). To quantify the ability of the disease to spread and affect others, in 2019 itself, there were about 229 million malaria cases which resulted in 409,000 deaths, the majority of which were in Africa (Menkin-Smith and Winders), with an estimated 247 million cases and 619,000 deaths just last year in the 2022 report (Roychoudhury). Discernibly, there is a significantly consistent rise in malaria cases and deaths, which prompts the need for further research on the life-threatening disease to combat this trend with the proper measures.

Effect on Africa

Of any other region in the world, Africa is the most affected by malaria cases and deaths, which is connected to the role of mosquitoes in the transmission of the disease, and the fact that they are native to the continent. According to the World Health Organization, 95% of malaria cases and 96% of deaths by malaria in 2021 were located in Africa, with approximately 80% of those deaths seen in children below the age of 5. With the magnitude of a hold the disease has on the region, this study aimed to focus on the malaria crisis specific to Africa, to guide future efforts to bring the area to a safer standing when it comes to lowering cases and mortalities caused by the disease.

Recent Innovations & Advancements

While still highly apparent, the conflict has also reached some noteworthy advances, such as GlaxoSmithKline (GSK) and the PATH Malaria Vaccine Initiative developing Mosquirix, the first vaccine for malaria that was backed by the World Health Organization. This vaccine specifically decreased cases in children, who were generally more prone to getting the disease than others. Furthermore, CRISPR-Cas9 gene editing has allowed scientists to alter the genes of mosquitoes carrying malaria parasites; researchers are hoping such genetic modifications will incapacitate mosquitoes from transmitting the disease. As for vector control, ITNs, or insecticide-treated nets, as well as indoor residual spraying (IRS) are prevalent methods of malaria control, with introductions of lasting nets and new, more withstanding insecticides. Additionally, remote sensing, Geographic Information Systems (GIS), and further sophistication in data collection and analysis have allowed for better tracking of malaria transmission, which has enabled the identification of locations in which individuals are more at risk for contracting

the disease, suggesting for certain preventative procedures to be concentrated in such areas to protect those at greater risk.

Proposed Research Methods and Materials

Getting Started

The research team came to the consensus of focusing on a health crisis prior to any further investigation into particular details. Using Kaggle, the largest community in the data science field, the team was able to use various tools made available on the website to find a dataset regarding malaria comprising 3 data tables focused on the estimated number of cases globally, incidence per thousand population at risk, and reported national numbers. After downloading this dataset and changing different factors, such as listing case or death numbers in ascending order, organizing rows by year, etc., the team was able to recognize the potential connection between country and risk for malaria, in terms of the quantifications made in rows specific to the number of cases and number of deaths.

Below a portion of the Estimated Number of Cases table is shown.

Country	Year	No. of cases	No. of deaths	No. of cases_median	No. of cases_min	No. of cases_max	No. of deaths_median	No. of deaths_min	No. of deaths_max	WHO Region
Afghanistan	2017	630308[495000-801000]	298[110-510]	630308	495000	801000	298	110	510	Eastern Mediterranean
Algeria	2017	0	0	0			0			Africa
Angola	2017	4615605[3106000-6661000]	13316[9970-16600]	4615605	3106000	6661000	13316	9970	16600	Africa
Argentina	2017	0	0	0			0			Americas

Armenia	2017	0	0	0			0			Europe
Azerbaijan	2017	0	0	0			0			Europe
Bangladesh	2017	32924[30000-36000]	76[3-130]	32924	30000	36000	76	3	130	South-East Asia
Belize	2017	7	0	7			0			Americas
Benin	2017	4111699[2774000-6552000]	7328[5740-8920]	4111699	2774000	6552000	7328	5740	8920	Africa
Bhutan	2017	11	0	11			0			South-East Asia
Bolivia (Plurinational State of)	2017	6512[4900-8300]	2[0-4]	6512	4900	8300	2	0	4	Americas
Botswana	2017	2989[2300-4200]	7[0-20]	2989	2300	4200	7	0	20	Africa
Brazil	2017	217928[196000-236000]	30	217928	196000	236000	30			Americas
Burkina Faso	2017	7907562[5645000-11330000]	27791[25100-30500]	7907562	5645000	11330000	27791	25100	30500	Africa
Burundi	2017	2113066[1284000-3401000]	5253[4300-6200]	2113066	1284000	3401000	5253	4300	6200	Africa
Cabo Verde	2017	423	1	423			1			Africa
Cambodia	2017	208273[186000-236000]	345[30-590]	208273	186000	236000	345	30	590	Western Pacific

Cameroon	2017	7307515[4704000-11030000]	11566[8900-14200]	7307515	4704000	11030000	11566	8900	14200	Africa
Central African Republic	2017	1804550[777000-3363000]	4804[3980-5640]	1804550	777000	3363000	4804	3980	5640	Africa

Below a portion of the Incidence Per Thousand At Risk table is shown.

Country	Year	No. of cases	No. of deaths	WHO Region
Afghanistan	2017	161778.0	10.0	Eastern Mediterranean
Algeria	2017	0.0	0.0	Africa
Angola	2017	3874892.0	13967.0	Africa
Argentina	2017	0.0	1.0	Americas
Armenia	2017	0.0		Europe
Azerbaijan	2017	0.0		Europe
Bangladesh	2017	4893.0	13.0	South-East Asia
Belize	2017	7.0	0.0	Americas
Benin	2017	1573163.0	2182.0	Africa
Bhutan	2017	24.0	1.0	South-East Asia
Bolivia (Plurinational State of)	2017	4572.0	0.0	Americas
Botswana	2017	1900.0	17.0	Africa
Brazil	2017	189503.0	30.0	Americas
Burkina Faso	2017	10225459.0	4144.0	Africa
Burundi	2017	7670177.0	4414.0	Africa
Cabo Verde	2017	423.0	2.0	Africa
Cambodia	2017	36932.0	1.0	Western Pacific

Cameroon	2017	1191257.0	3195.0	Africa
Central African Republic	2017	383309.0	3689.0	Africa

Feature Engineering

After locating the dataset, the next step taken was to use feature engineering, a way to select and transform specific variables to create a predictive model and allow data to only display desired qualities or properties. By using this method, aspects of the dataset that were unnecessary to the group's focus, such as the minimum, median, or maximum values of the number of cases/deaths for each country were able to be excluded from produced graphs and tables. These rows were kept away from further analysis and manipulation because the *total* values are what held the most importance and raw ability to display important quantifications and trends, rather than the mean or median values. The group also excluded the row depicting specific countries of the dataset, as the "WHO Region" row was decidedly sufficient in providing enough information to link the malaria data values to certain regions, and worked to simplify the dataset by eliminating the large number of countries that would have simply been an excess of information as this research was mainly focused on the *region* of Africa and how it compares to others in regards to malaria cases/deaths.

Using Python & Google Colab

Once the datasets were edited to include only desired factors, the team utilized Python and Pandas (Python's Data Analysis Library) to code in Google Colab, a platform that allows users to run written Python code within an environment much like the Jupyter Notebook. Using this application, the research team was able to formulate graphs using the dataset files and code (shown below). Through a process of trial and error, and with many adjustments made to the code, the desired graphs were put together, and with them, a significant trend was made distinct.

```
[ ]  import pandas as pd
     import numpy as np
     import matplotlib.pyplot as plt
```

```
reported_numbers = pd.read_csv('malaria_data/reported_numbers.csv')
reported_numbers
```

```
region_deaths = reported_numbers[['WHO Region','Year','No. of deaths']]
region_deaths_grouped = region_deaths.groupby(['WHO Region','Year']).sum()
region_deaths_grouped
```

```
df_pivot = pd.pivot_table(
    region_deaths,
    values="No. of deaths",
    index="Year",
    columns="WHO Region",
    aggfunc=np.sum
)


# Plot a bar chart using the DF
ax = df_pivot.plot(kind="bar")
# Get a Matplotlib figure from the axes object for formatting purposes
fig = ax.get_figure()
# Change the plot dimensions (width, height)
fig.set_size_inches(7, 6)
# Change the axes labels
ax.set_xlabel("Years")
ax.set_ylabel("No. of Deaths")
#Give the visual a title
plt.title("No. of Deaths per Region")
```

```
region_deaths_without_Africa = region_deaths[region_deaths["WHO Region"].str.contains("Africa") == False]

region_deaths_without_Africa
```

```
africa_reported_numbers = reported_numbers[reported_numbers["WHO Region"].str.contains("Africa") == True]
africa_reported_numbers_region = africa_reported_numbers[['Year','No. of cases','No. of deaths']]
africa_reported_numbers_group = africa_reported_numbers_region.groupby(['Year']).sum()
africa_reported_numbers_group.reset_index(drop=False, inplace=True)
africa_reported_numbers_group
```

```
#df = africa_reported_numbers.pivot(index='No. of cases', columns='Year', values='No. of deaths')

fig, ax = plt.subplots(figsize=(20,10))

africa_reported_numbers_group.plot(x = 'Year', y = 'No. of cases', ax = ax)
africa_reported_numbers_group.plot(x = 'Year', y = 'No. of deaths', ax = ax, secondary_y = True)
```

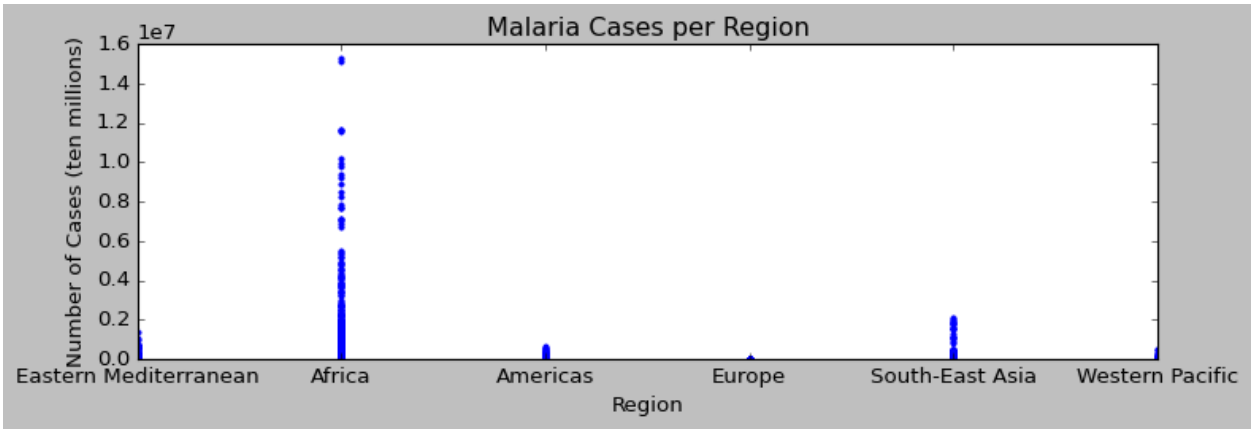
```
[ ]  df_pivot = pd.pivot_table(
         region_deaths_without_Africa,
         values="No. of deaths",
         index="Year",
         columns="WHO Region",
         aggfunc=np.sum
     )

     # Plot a bar chart using the DF
     ax = df_pivot.plot(kind="bar")
     # Get a Matplotlib figure from the axes object for formatting purposes
     fig = ax.get_figure()
     # Change the plot dimensions (width, height)
     fig.set_size_inches(7, 6)
     # Change the axes labels
     ax.set_xlabel("Years")
     ax.set_ylabel("No. of Deaths")
     #Give the visual a title
     plt.title("No. of Deaths per Region w/o Africa")
```

Data Analysis & Results

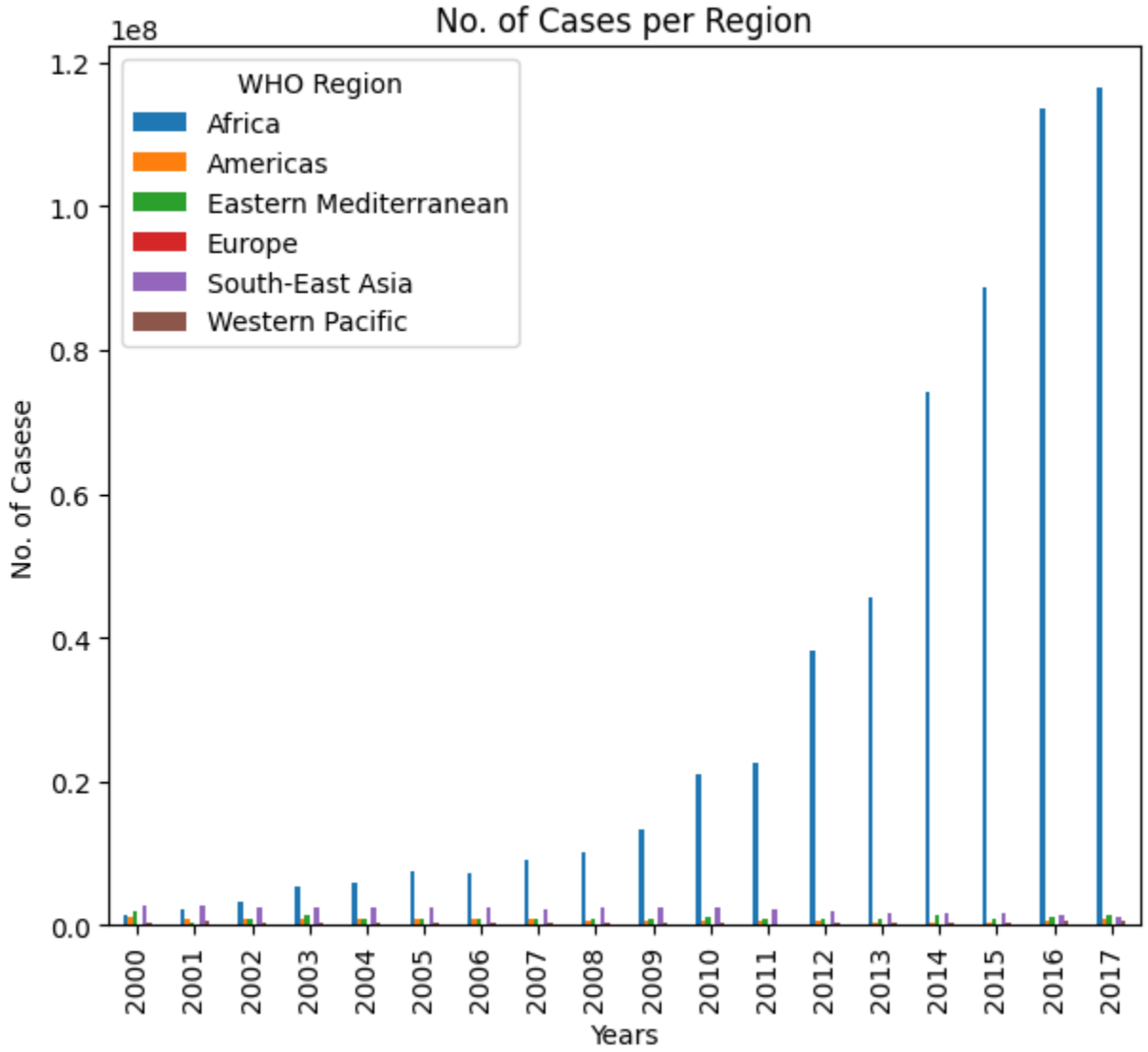
Produced Graphs

Using Python code and Google Colab, the research group was able to produce various graphs & tables and chose 4 that conveyed the purpose of the study. The first graph is shown below, and it serves as a clear visual in terms of comparing the total number of malaria cases within the 6 different WHO Regions. There exists a significant disparity in how Africa has more cases than the 5 other regions *combined*, with South-East Asia having the second-largest number of cases, despite having about an eighth as many cases as Africa. This graph, however, doesn't suggest other trends and was therefore primarily used to provide a basis upon which the study grew. The graph is an appropriate visual to display the *total* impact of malaria cases on Africa, and made it clear to the research team that it is the region most at risk for malaria in comparison to all other regions of the world; this allowed the researchers to move onto the next factor of analysis.

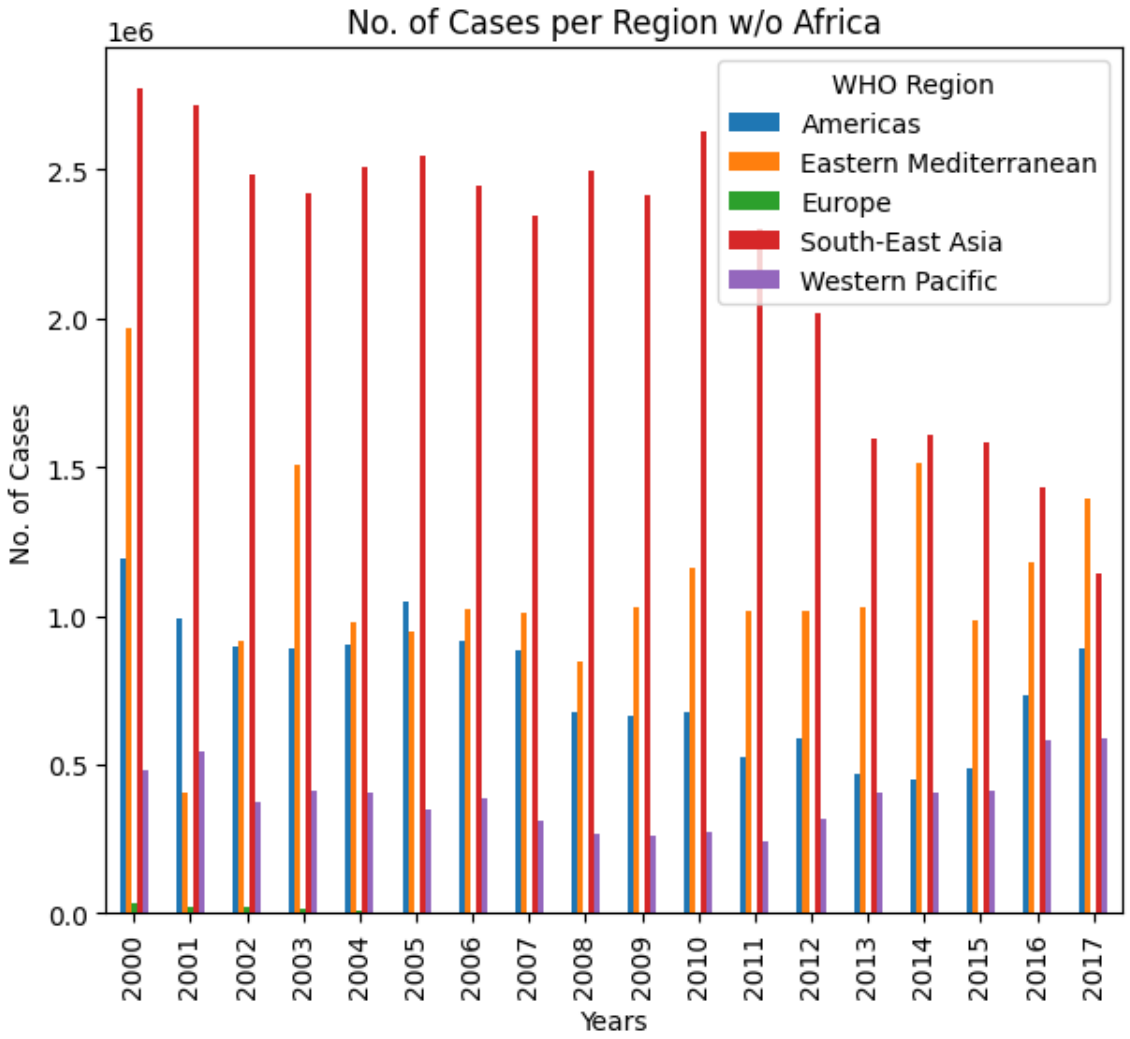


The next graph that was constructed is displayed below; it not only confirms the aforementioned trend of Africa having the largest number of cases but also reveals that case numbers had increased every year (excluding a slight dip seen from 2005-2006). This discovery

further developed the study because of the significance of the fact that despite advancements in technology and medicine over the years, the number of cases in Africa was still increasing annually, however such innovations, like better parasite/infection detection, could've also contributed to the increase in cases. Unlike the previous graph, this bar graph includes time as a factor and shows how the number of cases of malaria changed year by year from 2001 to 2017. The previous graph uses a more straightforward approach to directly display its primary claim that Africa has more malaria cases than any other region in the world, which provides a basic understanding of how the disease affects regions of the world. With the foundation formed by the graph above, this bar graph efficiently builds upon previously laid claims by incorporating time as a factor.



Having 2 graphs that had already supported Africa's significant lead in cases, the research team also wanted to consider the graph without its major outlier; this graph is exhibited below. In this graph, one can see that the other regions don't follow the same pattern of increase in cases as Africa. The region closest to that trend would likely be South-East Asia, however, it would not be matched with the same consistency as the data regarding Africa, as the South-East Asian region had seen a decrease in cases. Due to these findings, the research team was able to infer that an annual increase in cases of malaria is only characteristic of the African region, which then prompted the team to dive into a deeper analysis of Africa and its malaria crisis.

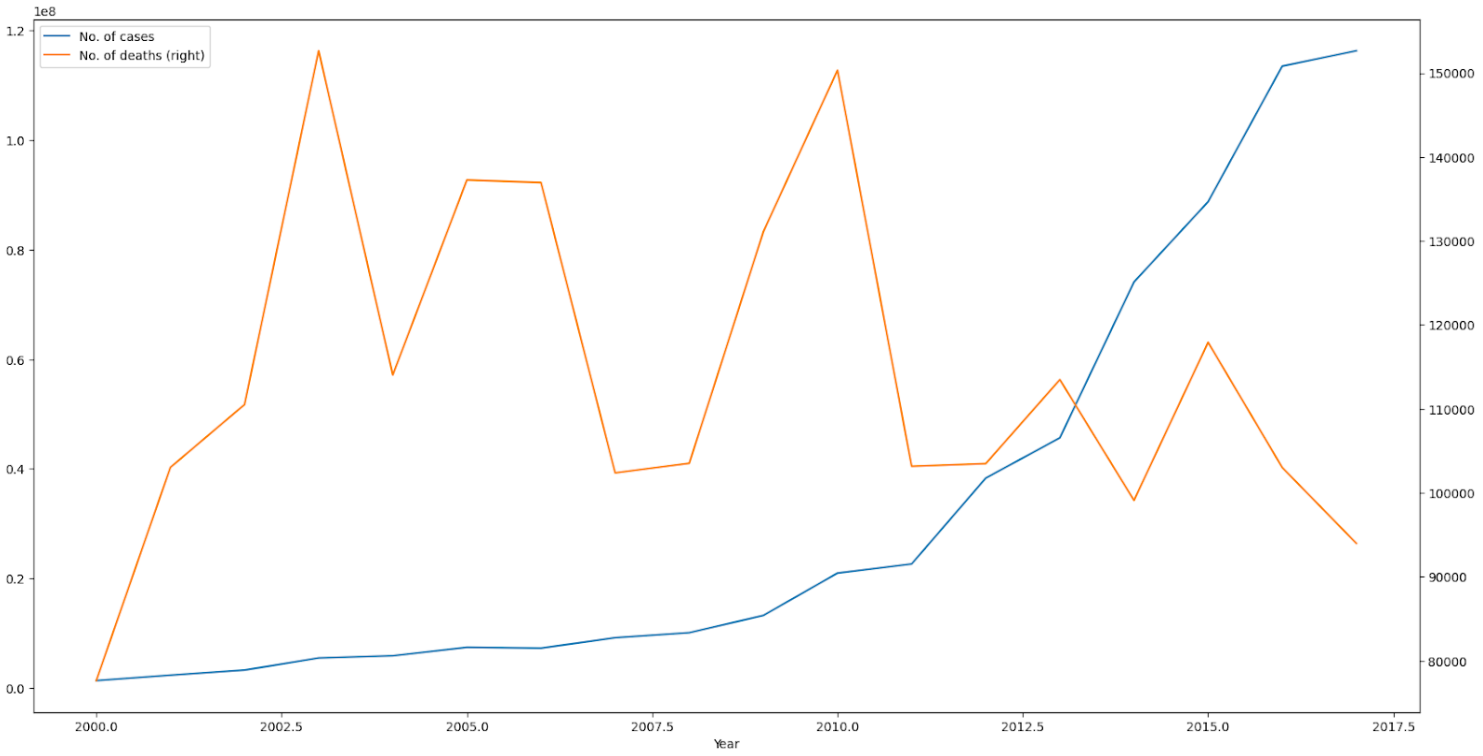


Methods Used in South-East Asia to Overcome Malaria

As discussed, Africa is the only region that has shown consistent increases in the number of malaria cases throughout the past two decades and has the highest number of cases in comparison with other regions. Besides Africa, the next region with the most malaria cases is South-East Asia, and despite having similar environmental factors as Africa, in terms of higher temperatures and more rainfall, the region has been able to decrease its number of malaria cases as time progressed. After this finding, the research team looked into what has helped the South-East Asia region (SEAR) to reduce case rates and found that the region has focused on four main areas of improvement in a "multi-pronged approach": drug resistance, insecticides, vector management, and awareness (Bharati and Ganguly). Drug resistance improvements would allow for anti-malarial drugs and vaccines to become more efficient in actually providing individuals with immunity or allowing them to fully fight off infection. Insecticide advancements also go hand-in-hand with vector management in aiming to control and reduce the number of mosquitoes in the area to provoke a consequent decrease in transmission and case numbers. As for awareness, it is a simple method to educate others at risk of contracting the disease, which will thus allow them to utilize certain measures to avoid infection, such as using insecticide-treated nets, avoiding areas more prone to breeding mosquitoes, etc., as well as taking action if an infection has already occurred. By studying what methods have worked in the SEAR, the team was able to research the use of such strategies in Africa and apply them to the conclusions made in what procedures and practices may aid Africa in overcoming its malaria crisis.

Moreover, the final graph that was produced displayed both the number of malaria cases, as well as the number of malaria-induced mortalities in Africa; it is pictured below. The blue line

shows an increase in the number of cases once again, with additional information on the number of deaths signified by the yellow line. The graph shows an indirect relationship from the year 2010 and onwards; despite the number of cases in Africa increasing, the number of deaths decreased, which was unexpected considering it would be most logical for more cases to result in more deaths. Because of this unusual correlation between deaths due to malaria, and cases of the disease in Africa, the research team aimed to hone in on this discrepancy to figure out what led to a decrease in deaths even with an increase in cases and promote such methods to allow the reduction in deaths to continue.



Leading Causes for an Increase in Malaria Cases in Africa

1. Introducing New Infrastructure & Public Services: The invasive Anopheles stephensi mosquito has spread to various countries in Africa, such as Ethiopia and Sudan in 2016, Somalia in 2019, and Nigeria in 2020 (WHO). “‘Natival [malarial mosquitoes are thought

to breed mainly in rural settings,' notes Dr. Fitsum Tadesse, a lead scientist at the Armauer Hansen Research Institute…'But this new mosquito can breed in water storage containers…These are typically common in rapidly expanding urban settings that have poor infrastructure and sewage systems, where people have to store water…in containers'" (WHO). As Africa introduces new forms of infrastructure and public systems, obstacles form as species of mosquitoes adapt to evolving African countries and gain more options when it comes to breeding and surviving, which includes feeding on individuals, resulting in the spread of malarial parasites/infection and thus more cases.

2. Drug Resistance: The evolution of parasites to become resistant to antibiotics and antiparasitics has been an ongoing conflict in the field of medicine and it has undoubtedly remained unfailing in regards to the malaria crisis. In particular, *P. falciparum*, one of the deadliest malarial parasite species has gained high resistance to chloroquine, an anti-parasitic malarial drug, which "has been a major contributor to the global resurgence of malaria" within previous years (White). As malarial parasites like *P. falciparum* continue to form resistance to drugs used to prevent contraction of the disease, there will undoubtedly be an increase in the number of cases of the illness, as such drugs are administered as a preventative measure and form of protection against malaria.
3. Climate Change: Factors that are often overlooked are the issues of global warming and climate change. Increases in temperature, humidity, and rainfall foster environments for malaria-carrying mosquitoes, causing an increase in transmission of the disease (The United Nations). Putting this information into context with Africa's current situation, as per the World Meteorological Organization, between 1961-1990, Africa faced increases in temperature at 0.2℃ or 32.36℉. This value has only increased between 1991-2021 to

approximately 0.3℃, or 32.54℉. Furthermore, the Intergovernmental Panel on Climate Change (IPCC), assessed that "human-caused climate change has already contributed to an increase in heavy rainfall and flooding across nearly all parts of [Africa]" (Dunne). Evidently, there has not only been an increase in temperature in Africa over the past years but also an increase in rainfall, which certainly enabled further prosperity of mosquitoes carrying the malarial parasite and infecting others, leading to increased cases.

Leading Causes for a Decrease in Malaria Deaths in Africa

1. Increased Treatment Access & International Aid: One major cause for the decrease in deaths caused by malaria in Africa is the increase in access to antimalarial drugs across countries in the continent; this national benefit was aided by international initiatives and funding agencies like the President's Malaria Initiative, UNITAID, the World Bank, and Global Funds (Flegg, Metcalf, et al.). Additionally, as per the Center for Global Development, "[o]ver the past two decades, partnerships between bilateral and multilateral funders, philanthropy, national governments, and the private sector have substantially increased global access to effective malaria treatment". Such forms of aid allow more availability to treatment and in turn, fewer malaria-induced mortalities in Africa, as infected individuals are more likely to receive the treatment they need as other nations, over previous years, started to get involved in Africa's fight against malaria and help with achieving better treatment and care.
2. Effective Preventative Measures: In addition to vaccines and antimalarial drugs, other methods are being taken to combat the malaria crisis. Specifically, anti-mosquito insecticides (DDT, or dichloro-diphenyl-trichloroethane), and insecticide-treated bednets, which have been a highly effective malaria prevention strategy in Africa ever since they

were introduced in the early 1990s (Oria). Such investments and measures are very sufficient in reducing the number of deaths as they prevent the issue of malaria infection from arising in the first place. They also provide more affordable and accessible ways of prevention if antimalarial drugs are unavailable in certain circumstances.

3. Investment in Healthcare System: By properly establishing and prioritizing better healthcare infrastructure and systems, diagnosis, treatment, and care facilities improve and are more equipped and at a better capacity to effectively treat cases of malaria. Improvements that can arise are accurate and timely diagnosis granted by the right equipment to do so, well-trained/educated healthcare workers allowed by proper funding for adequate training programs, and better health facilities, ranging from proper bedding to nutritional food provided at healthcare facilities. Throughout the years, countries all over the globe have bettered their healthcare systems, with Africa being a region that has also followed such enhancements. A flawed system leaves room for errors that can lead to more casualties, however, a successful healthcare system permits patients and individuals to have a much greater chance at proper care & treatment that will better their health.
4. Region-Wide Awareness and Education: Given how prominent the issue of malaria is in Africa, it is imperative that residents of the region are aware of the dangers of the disease, how it is transmitted, and what measures to take. This can only be achieved through proper education and distribution of information regarding the illness. The Malaria Awareness Program is “an interactive malaria education initiative…to improve participant knowledge of malaria as a precursor to increased uptake of malaria control interventions…[and the program’s] effectiveness was measured through pre- and

> post-participation surveys assessing knowledge in malaria transmission, symptoms, prevention, and treatment. …There was a 21.4% and 10.5% increase in the proportion of participants who cited correct malaria transmission and prevention methods, respectively" (Cox, Guidera, et al.). As demonstrated by MAP, educational and awareness initiatives regarding malaria are helpful in allowing individuals to form a better understanding of the disease to allow them to avoid situations in which infection risk is higher, recognize symptoms early on, and familiarize themselves with treatment and preventative methods. With an understanding of the disease, individuals are more likely to prevent or identify infection and receive treatment faster, allowing for efficient care and supporting the trend of decreasing malaria-induced deaths in Africa.

The Future

By using the data and information this study consists of, the research team predicts a continuation of current trends of malaria cases and malaria-induced deaths in Africa. Currently, in Africa, there is an incline in the number of cases of malaria, accompanied by a decrease in the number of deaths caused by the disease. The researchers predict that as healthcare systems in Africa advance, just as that of other regions of the world, more cases will be reported due to the previously mentioned causes for such an increase, but primarily due to the fact that with a better-operated healthcare system comes better diagnosis and thus, the disease will be identified with more ease than it was in earlier years. The researchers also predict a further decrease in the number of mortalities in Africa that are due to malaria mainly for the same reason of better health care, as well as the addition of the aforementioned causes for this decrease. It is also hypothesized that as advancements in malaria vaccines are developed to overcome malarial parasite resistance to antimalarial drugs, more residents of Africa will become immune or at very

low risk of the disease, thus reducing the likelihood of the disease spreading from one person to another, promoting herd immunity to malaria. The researchers predict that this community immunity would be accompanied by a direct relationship between case number and death number in regards to malaria, meaning it would lead to a decrease in both variables, which is inevitably one of, or the best realistic outcome. This can also be achieved by utilizing prediction and classification models that will help identify certain countries/areas in Africa that have the highest numbers of cases. Ideally, a system would be put into place in which such locations get priority in terms of vaccine accessibility and delivery. During the COVID-19 pandemic, vaccination efforts prioritized distribution to people at high risk of the disease, such as the elderly, individuals with asthma, those with heart/lung conditions and immune deficiency issues, etc. This system should be applied to malaria vaccine distribution efforts, with pregnant women, children under the age of 5, infants, and those with HIV/AIDS at higher priority to receive the drug. This method would further promote herd immunity by providing those at higher risk of contracting the disease with a better chance of not being infected, which in turn will lower cases and thus cause transmission of the disease to be more difficult and occur less often.

Conclusion

Malaria has been around since primeval times and still holds an impact on the modern world. More than any other region, Africa has been adversely affected by the disease due to various factors that magnified its effects, including climate change, mosquito population, and more. Nevertheless, the region has made considerable strides in past decades as contemporary advancements in medicine and health technology have shown significant promise in combating the malaria crisis by enabling a decrease in fatalities despite increases in the number of cases, presumably due to better diagnosis and identification of the condition. By following current

methods of treatment and prevention of malaria as well as continuing to invest in the healthcare operating system of Africa, deaths caused by the disease shall decrease, with the potential number of cases experiencing a reduction as well. Evidently, medicine and treatment is an ever-evolving field and will assuredly prove to overcome the malaria crisis in Africa in time.

Works Cited

"Analysis: Africa's Unreported Extreme Weather in 2022 and Climate Change." *PreventionWeb*, 27 Oct. 2022, www.preventionweb.net/news/analysis-africas-unreported-extreme-weather-2022-and-climate-change#:~:text=According%20to%20the%20IPCC's%20most,region%2C%20according%20to%20the%20assessment.

Bharati K, Ganguly NK. Tackling the malaria problem in the South-East Asia Region: need for a change in policy? Indian J Med Res. 2013 Jan;137(1):36-47. PMID: 23481050; PMCID: PMC3657896.

"CDC - Malaria - about Malaria - Faqs." *Centers for Disease Control and Prevention*, 28 June 2023, www.cdc.gov/malaria/about/faqs.html#:~:text=When%20a%20mosquito%20bites%20an,into%20the%20person%20being%20bitten.

"Climate Change and Malaria - a Complex Relationship." *United Nations*, www.un.org/en/chronicle/article/climate-change-and-malaria-complex-relationship#:~:text=An%20increase%20in%20temperature%2C%20rainfall,it%20was%20not%20reported%20earlier. Accessed 26 July 2023.

Five Different Human Malaria Plasmodium Species and Their Life Stages ..., www.researchgate.net/figure/Five-different-human-malaria-Plasmodium-species-and-their-life-stages-in-thin-blood-film_fig2_322459559. Accessed 27 July 2023.

Flegg, Jennifer A, et al. "Trends in Antimalarial Drug Use in Africa." *The American Journal of Tropical Medicine and Hygiene*, Nov. 2013, www.ncbi.nlm.nih.gov/pmc/articles/PMC3820326/#:~:text=Countries%20in%20Africa%20have%20changed,the%20World%20Bank%2C%20and%20UNITAID.

"How to Import Files from Google Drive to Colab." *Saturn Cloud Blog*, 8 June 2023, saturncloud.io/blog/how-to-import-files-from-google-drive-to-colab/#:~:text=Google%20Colaboratory%2C%20or%20Colab%20for,Google%20services%2C%20including%20Google%20Drive.

Interactive Malaria Education Intervention and Its ... - Sage Journals, journals.sagepub.com/doi/abs/10.1177/0272684X17749573. Accessed 27 July 2023.

M;, Rajakumar K;Weisse. "Centennial Year of Ronald Ross' Epic Discovery of Malaria Transmission: An Essay and Tribute." *Southern Medical Journal*, pubmed.ncbi.nlm.nih.gov/10372849/#:~:text=Malaria%20has%20been%20in%20existence,the%20malarial%20parasite%20in%201880. Accessed 26 July 2023.

"Malaria." *Mayo Clinic*,

www.mayoclinic.org/diseases-conditions/malaria/symptoms-causes/syc-20351184. Accessed 26 July 2023.

"Malaria." *World Health Organization*, www.who.int/health-topics/malaria#tab=tab_1. Accessed 26 July 2023.

Menkin-Smith L, Winders WT. Plasmodium vivax Malaria. [Updated 2022 Jul 19]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2023 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK538333/

"Mosquito on the Move." *World Health Organization*, www.who.int/news-room/feature-stories/detail/mosquito-on-the-move. Accessed 26 July 2023.

P., Devakumar K. "Malaria Dataset." *Kaggle*, 1 July 2020, www.kaggle.com/datasets/imdevskp/malaria-dataset?select=reported_numbers.csv.

"Progress Made in Fight against Malaria but Africa Still Has Highest Infection Rates and Deaths." *Alliance for Science*, 24 Apr. 2023, allianceforscience.org/blog/2023/04/progress-made-in-fight-against-malaria-but-africa-still-has-highest-rates-of-infections-and-deaths/#:~:text=These%20include%20antimalarial%20drugs%20(chloroquine,introduction%20in%20the%20early%2090s.

Rosencrance, Linda. “What Is Feature Engineering for Machine Learning?” *Data Management*, 4 Jan. 2021, www.techtarget.com/searchdatamanagement/definition/feature-engineering#:~:text=Feature%20engineering%20is%20the%20process%20of%20selecting%20and%20transforming%20variables,in%20someone%20with%20domain%20expertise.

“State of Climate in Africa Highlights Water Stress and Hazards.” *World Meteorological Organization*, 10 Feb. 2023, public.wmo.int/en/media/press-release/state-of-climate-africa-highlights-water-stress-and-hazards.

Wednesday, and Originally published. “Article.” *Pfizer*, www.pfizer.com/news/articles/from_basic_health_to_herd_immunity_what_is_the_purpose_of_vaccines#:~:text=%E2%80%9CHerd%20immunity%2C%E2%80%9D%20also%20known,from%20one%20person%20to%20another. Accessed 26 July 2023.

White, Nicholas J. “Antimalarial Drug Resistance.” *The Journal of Clinical Investigation*, Apr. 2004, www.ncbi.nlm.nih.gov/pmc/articles/PMC385418/#:~:text=Resistance%20has%20emerged%20to%20all,use%20of%20antimalarial%20drug%20combinations.

“World Malaria Report 2022: The Boat Did Not Tip, but the Storm Is Not over - Blog.”

ISGlobal, 9 Dec. 2022,

www.isglobal.org/en/healthisglobal/-/custom-blog-portlet/world-malaria-report-2022-the-boat-did-not-tip-but-the-storm-is-not-over/10244478/0#:~:text=An%20estimated%2024%20million%20cases,in%202020%2C%20had%20not%20progressed.