Underreporting of Epidemic Rebound and Resurgent Malaria in Nine African Countries

by

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This project focuses on the underreporting of epidemic rebound and resurgent malaria in nine African countries—The Gambia, Ghana, Kenya, Malawi, Nigeria, Sierra Leone, Uganda, Zanzibar and Zimbabwe—over the span of a century. There is a history of undercounting and underreporting of Malaria resurgence and rebound, the return of the disease in a region after successful control, on the African continent. This thesis attempts to account for these gaps and patterns by providing an overview and analysis of malaria prevalence from 1920-2020 through the documentation of unreported cases of malaria resurgence. Historical epidemiological data of malaria prevalence and control measures were collected, organized, and analyzed to compile a longer frame, essentially creating a new panel dataset, to illustrate longer trends in time and identify instances of rebound. Initial findings show multiple unreported cases of malaria rebound in the nine African countries. The results of this research add to the field of malaria research and have implications on the nature of data collection methodology and its presentation on a global scale. It provides a framework for how accounting for how accounting for social, political, and cultural contexts, WHO and other public health organizations can more accurately and fully determine and present cases of resurgent malaria and epidemiological data.

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Definitions and Abbreviations

WHO	World Health Organization
GMEP	Global Malaria Eradication Programme (1955-1969)
RBM	Roll Back Malaria Initiative—created by the WHO (1998-Present)
ACT	Artemisinin Combination Therapy, current first-line drug against malaria
IRS	Indoor-residual spraying
ITN	Insecticide-treated nets
LLIN	Long-lasting insecticide-treated nets
Chemoprophylaxis	The use of medication as a form of malaria control

CHAPTER 1: INTRODUCTION

This project focuses on the underreporting of epidemic rebound malaria in nine Anglophone African countries—The Gambia, Ghana, Kenya, Malawi, Nigeria, Sierra Leone, Uganda, Zanzibar and Zimbabwe—over the span of a century. The underreporting malaria resurgence, particularly on the African continent, can be partially attributed to issues of data collection methodology and presentation. This project will begin to fill in and explain these ruptures in data by providing an overview and analysis of malaria prevalence in these countries and its resurgence during two separate time periods: 1920-1955, the British colonial era, and 1980-2020, post African independence.

The thesis asks and interrogates the following questions:

1) What trends will be uncovered when mapping out malaria prevalence over the course of 100 years instead of the shorter time range that is typically used by public health organizations?
2) Are there unreported cases of epidemic rebound malaria in The Gambia, Ghana, Kenya, Malawi, Nigeria, Sierra Leone, Uganda, Zanzibar and Zimbabwe?

The initial hypothesis is that there are cases of unreported rebound malaria recorded within existing public health data, and graphing malaria prevalence data over the span of 100 years will uncover these events and indicate an underreporting of rebound and resurgent malaria. Because the standard presentation of data only accounts for a 12-month period on the smaller end, and as high as 10-15 years, rebound events, which occur over a longer span of time, would not be captured in the frame. Data collection

norms, analysis, and presentation prevent the identification of more cases of epidemic rebound malaria, which partially accounts for the underreporting of resurgence on the African continent.

This research does not collect any new data, but it looks at existing data from colonial medical reports, WHO reports and UN population data through a new temporal lens, allowing us to uncover and extrapolate on unreported cases of rebound malaria that are already within existing public health records. Currently, most agencies only provide funding for short-term malaria control, which obfuscates the long-term trends and prevalence rates of the disease. Many public health organizations like WHO report malaria prevalence data in the span of 12 months and 10-15 years at most which provides an incomplete picture of resurgence events.

This research has discovered a total of 36 resurgence events—20 in the colonial era and 16 in the independence era—of which 35 have not been previously reported on: clear evidence of underreporting of epidemic rebound malaria events in published literature and in the associated epidemic curves. In addition, eight out of the nine African countries follow similar patterns of malaria prevalence over the century, with as much as a 6x increase in prevalence from 1920-1955 to 1980-2020— a finding that was neither in the original hypothesis, nor expected. These near-identical trends raise questions about the historical factors and social conditions that may have contributed to these reporting patterns.

This number was gathered for each country through calculating the average prevalence within each timeframe (colonial and post-), then dividing by one another to determine the amount for each country. While this calculation is only an estimation of

the difference in prevalence between the two timeframes, it is important to note that this value is overestimating the difference between the colonial and post-colonial era. The reported prevalence rates during the colonial era were vast underestimations of malaria within these countries, due to many factors related to how and where data collection occurred. Thus, even if malaria rates are higher during the modern era, it is not to the extent listed above.

In line with the original hypothesis, these findings reveal a stark difference in existing malaria rebound and resurgence data and the malaria resurgence events determined through the panel dataset and epidemic curves generated in this research. This research compels us to take a closer look at the efficacy of short-term control interventions, challenge the norms of data collection and presentation, and interrogate the ethics of data collection on the African continent.

Because malaria control and elimination requires sustained time and effort, it is critical that funding and resources provided are being used in the most efficient manner. This funding must also allow for a larger-framed presentation of malaria prevalence data ensuring maximum effectiveness of any ordained control and elimination measures.

The rest of this chapter will provide an overview of the technical biology of malaria and defining rebound and resurgent malaria. It will also explore the historical backgrounds of the nine African countries from 1920-2020. To conclude, the chapter will describe the research methodology, its limitations, and a literature review related to malaria prevalence, control interventions and the ethnographies of data collection.

Chapters two and three will contain a robust discussion on the generated epidemic curves, explain trends in the data and explicitly state resurgence dates based on control information and whether it has been reported on before. Chapter two will focus on countries located in Western Africa (Gambia, Ghana, Nigeria and Sierra Leone), whereas Chapter 3 will provide an analysis on the countries located in Eastern Africa (Kenya, Malawi, Uganda, Zanzibar and Zimbabwe).

Chapter four will substantiate the argument that WHO's presentation of global health data prevents instances of rebound malaria from being uncovered. This is made clear by comparing the epidemic curves generated for this research and existing WHO figures. The conclusion will reflect on the data, propose potential steps for public health organizations and malaria researchers to identify and report epidemiological data and epidemic rebound malaria, and examine both the short- and long-term implications of this research.

Overview of Malaria

While malaria is a preventable and curable disease that has been eliminated in over 40 countries (WHO, 2022), it still remains endemic across many regions in the global South and can be life-threatening if left untreated. The populations most at-risk of contracting malaria are pregnant women, migrant populations and children under the age of five; this age group makes up 80% of all malaria deaths in Africa. (WHO, 2021).

Since 2016, almost half of the world's population— about 3.2 billion people— are still at risk of contracting malaria (WHO, 2021). The African continent carries a disproportionate amount of this global malaria burden, accounting for 95% of all cases in 2020 (WHO, 2022). In the past two decades, renewed and considerable efforts have

been made in lowering malaria morbidity and mortality rates across the world, leading to a 45% reduction in malaria rates since 2002 (Global Funds, 2021). These global malaria trends do not accurately portray the condition of malaria in Africa. While malaria rates have decreased in the region, it has only decreased about 34% since early 2000s (Our World in Data, 2021). The disproportionate impact of malaria on the African continent, and the distance between continental trends and global trends, illustrates a severe inequity in the transmission and disease burden of malaria. Only 13% of the countries that have successfully eliminated are on the African continent, including: Algeria, Lesotho, Mauritius, La Reunion, and Seychelles (RBM, 2021; WHO, 2021).

From 2016 onwards, there is an increase in malaria case numbers across the globe, with conditions being exacerbated by the economic and healthcare instability following the onset of COVID-19 (Global Fund, 2021). Due to the global pandemic and arising safety concerns, national governments and international agencies suspended many operative malaria control programs. An estimated two-thirds of all deaths reported globally in 2020 are due to disruptions caused by COVID-19. While it is impossible to know definitively what the pandemic's long-term impact on malaria prevalence will be, there are already reported increases in malaria rates across many countries in 2020 (WHO, 2022).

Technical Biology and Ecology of Malaria

Malaria is a parasitic disease of the genus *Plasmodium*, and is transmitted through a bite from a female *Anopheles* mosquito. Female mosquitos require blood meals for egg production, and these meals are how the parasite is able to go from the

mosquito host, to the human, and back to the mosquito. Infected *Anopheles* mosquitos are able to transmit the disease over to humans by releasing sporozoites into the bloodstream when taking a blood meal, thus acting as the vector. Uninfected *Anopheles* mosquitos can also get the disease through a blood meal from a human infected with the *Plasmodium* parasite. While human hosts are affected by the presence of the parasites in their system, mosquito vectors are not. This lifecycle of malaria can clearly be seen in Figure 1 below:

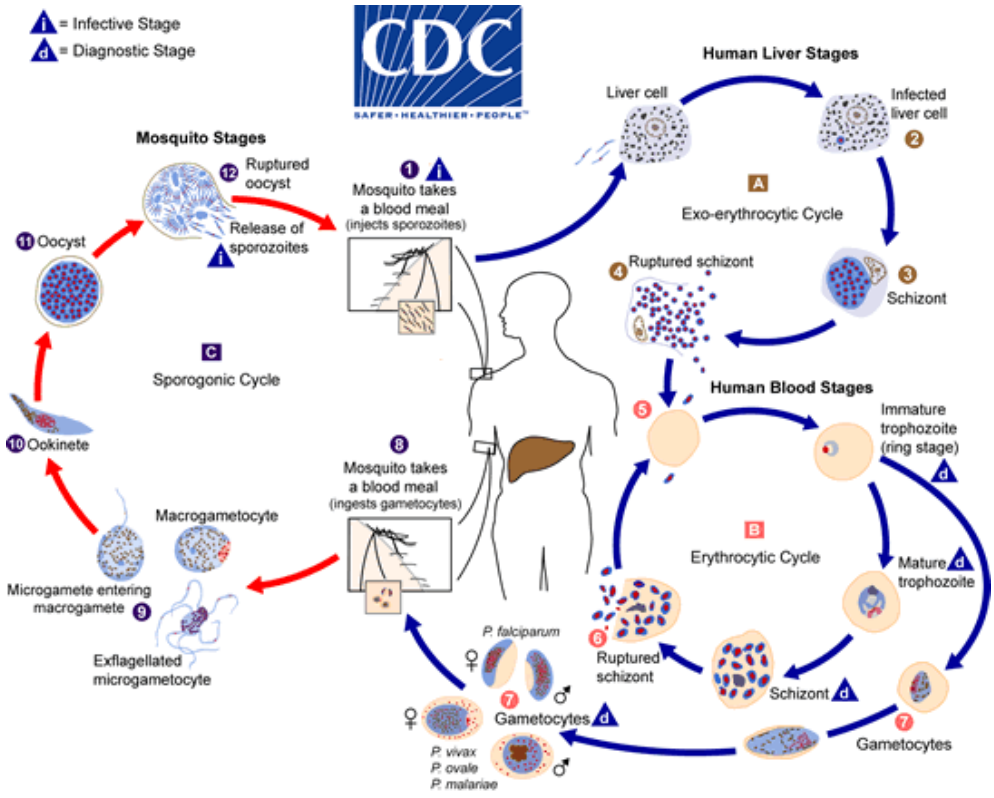


Figure 1: Malaria Biology and Life Cycle. Image sourced from the Centers for Disease Control and Prevention.

While there are hundreds of *Plasmodium* parasites, only four species of *Plasmodium* are able to infect humans: *P. falciparum*, *P. vivax*, *P. ovale,* and *P. malariae*. The most

prevalent in the African continent is *P. falciparum*, followed by *P. vivax* and *P. ovale*. *P. falciparum* can also cause the most severe malaria because the parasite multiplies rapidly in the blood, leading to anemia and severe blood loss (CDC, 2022).

Malaria transmission relies heavily on the climate, and can only occur in areas where the conditions will allow the parasite to multiply within its mosquito vector and for the vector itself to survive. Specifically, *Anopheles* mosquitoes require warm, humid climates and sufficient rainfall in order to survive and multiply, and *P. falciparum* parasites require warmer climates to complete their growth cycle in the mosquito (CDC, 2022). Because of this, malaria transmission is more intense in warm and humid areas, and only possible in temperate regions during summer and fall months.

Anopheles mosquitoes and *P. falciparum* parasites thrive in tropical and subtropical climates. This partially explains why malaria is so prevalent and endemic in sub-Saharan Africa, and why it is has been challenging to fully eliminate malaria from this region. The CDC defines endemic as "the amount of a disease that's usually present in a community," and defines epidemic as "an often-sudden increase in the number of cases of a disease above what is normally expected in that population in a specific area" (CDC, 2021). Malaria is endemic across many countries in sub-Saharan Africa, meaning that the disease is present at all times in the region, even if it is at lower levels.

Public health measures often grapple with the role of acquired immunity on malaria control in endemic countries. Acquired immunity refers to the body's antibody reserve of the malaria disease after multiple infections. These antibodies provide a physiological protection to a person that did not necessarily prevent infection but greatly limited the severity of the disease (Packard, 2021). WHO researchers have been

aware of acquired immunity, and have debated its risks and benefits as early as the 1930s (Graboyes and Meta, in press). Not much is known about how long acquired immunity may last in a person, or what the threshold is for reaching immunity in a given geographical area. Research shows it is somewhat effective in protecting people from contracting the disease (CDC, 2022). Children under five, too young to form a resistance to the disease, remain susceptible to contracting malaria—part of the reason why this age group is most at-risk. Also, in places where higher malaria transmission levels occur seasonally, acquired immunity is much less developed across the population, with all age ranges susceptible to the disease (Packard, 2021).

Rebound epidemics is closely tied to, and reliant on the loss of acquired immunity. Malaria rebound occurs most often in endemic countries, but a country does not have to be malaria-endemic in order to experience an epidemic rebound event. Normally, with strong control interventions focused on both human hosts and mosquito vectors, acquired immunity will naturally decrease in a population since it is reliant on consistent infections. In countries with lower levels of malaria prevalence due to effective control interventions, the lack of acquired immunity does not impact transmission levels. In instances where there are weakened control measures, malaria case rates increase due to the lack of acquired immunity within the community. This increase in case rates in relation to control measures is what is referred to as a malaria rebound event.

Overview of Rebound and Resurgent Malaria

Definition and Characterization of Rebound Malaria

While the definition of rebound malaria has been debated in existing literature, for the purpose of this thesis, rebound will be defined as any kind of increase in malaria prevalence or case numbers following the cessation or weakening of control measures (Adapted from Cohen et. al, 2012). While this thesis builds off of the work of Cohen et al., there will not be a differentiation between "resurgence" and "rebound." While Cohen's team chose to separate the definitions of "resurgence" and "rebound," no other reports or researchers make that distinction between the two terms, not in its usage or definition. As such, this research will follow the majority of those within the field of malaria research and won't separate the terms' definitions, instead using both interchangeably.

As an improvement to past definitions of rebound and resurgence, this thesis offers three dates for determining rebound epidemic events: the start date, which marks the initial rise in prevalence; the peak date, or the highest the prevalence gets during the rebound event; and the plateau date, which marks the leveling out of prevalence / case numbers for more than one year due to reinstated control measures.

An increase in prevalence, which characterizes the beginning of a rebound event, is most commonly caused by a weakening in the malaria program which can be attributed to political instability, insecticide / drug resistance, or funding decreases for malaria control. The loss of those measures within a population without acquired immunity causes an increase in case rates. Once control measures are reimplemented, prevalence rates markedly decrease. With previous definitions, the end of a resurgence

event is classified graphically when prevalence rates return back to pre-resurgence rates. As with many diseases, there is not always a clean bell curve with a return to initial prevalence rates. Instead, we see the formation of a new equilibrium, often at a different level than where the resurgence event started. Equilibrium refers to the base level of malaria in a country with no ongoing epidemic. This new characterization is different than the normal "start and stop" dates that have been collected in the past for resurgence events. The inclusion of a "peak" and "plateau" date in the collection allows for consideration and establishment of a new malaria equilibrium and the start of a 2-year plateau after the end of a resurgence event.

Resurgence and Rebound in Past Literature

Malariologist LJ Bruce-Chwatt was the first to provide an explicit definition for resurgent malaria in 1972. After the rise in cases following the end of the Global Malaria Eradication Program (GMEP), he suggested the term "resurgence" to refer to "the reappearance of new infections in significant numbers after malaria has subsided owing to the measures applied to reduce or interrupt its transmission" (Chwatt, 1982). While Chwatt's definition provided the groundwork for Cohen et al's definition, his definition only touched upon resurgence events in relation to control interventions.

In 1998, Jose Najera and his team wrote an article for the WHO titled "Malaria epidemics detection and control, forecasting and prevention," which detailed best practices for malaria epidemic detections, surveillance, forecasting and prevention. The article says a malaria epidemic may be caused by an "interruptions of antimalarial measures which have kept malaria under control, but in an unstable equilibrium, in an area with all epidemiological characteristics of high endemicity. The resulting

epidemics are the true resurgences or failures of control" (Najera et al, 1998). Their definition differs from Chwatt's as Najera's team explicitly mention equilibrium as a descriptor of a resurgence event. Najera et al. still fail to delve into equilibrium or intrinsic risk, and how these different concepts play a role in a resurgent event.

Justin Cohen et al. published a systematic review investigating and assessing the causes of epidemic rebound malaria because "understand[ing] where and why resurgence has occurred historically can help current and future malaria control programs avoid the mistakes of the past" (Cohen et al, 2012). This groundbreaking systematic review was the first report to quantify and collect cases of resurgent malaria. It identified a total 75 resurgence events in 61 countries across the globe, from the 1930s through the 2000s. The results of the review established the connection between weakening control measures and the resurgence of malaria cases in a region. Whenever an intervention is weakened in a malaria-endemic area, the likelihood of a resurgent event is exponentially higher since malaria prevalence is likely to return to its baseline (Cohen et al., 2012).

Cohen et al. defines resurgence as "a return towards a baseline level of malaria." The team also differentiates between the terms 'resurgence' and 'rebound,' referring to rebound as an "overshoot past the baseline" (Cohen et al., 2012)." This distinction is not established within the field of malaria research as of yet. Their definition also fails to engage with the concept of equilibrium, nor does it take into account the role of immunity in resurgence events.

Overview of Colonial and African Independence Eras

Colonial Era

The nine African countries chosen for this research (The Gambia, Ghana, Kenya, Malawi, Nigeria, Sierra Leone, Uganda, Zanzibar, and Zimbabwe) are spread across the east and west coasts of the continent, seen in the map below. Although they may not have too many geographical similarities, and vary in their geographic and population sizes, these countries have a shared colonial history. All nine countries were colonized by the British Empire for a large period of time: The Gambia was a colony from 1765 to 1965; Ghana from 1874 to 1957; Kenya from 1895 to 1963; Malawi from 1891 to 1964, Nigeria from 1900-1960, Sierra Leone from 1808 to 1961; Uganda from 1894 to 1962; Zanzibar from 1890 to 1963; and Zimbabwe from 1890 to 1980.

Figure 2: Map of Africa with Nine Researched Countries Highlighted, adapted from the Free World Maps

This colonial history is crucial to understanding the record of malaria control in these countries from 1920-1955. As British colonies, their governments and health infrastructure were under the control of the United Kingdom. All malaria control efforts occurring in these regions were run by the British colonial government, and as such, some of the health and medical records for the nine African countries are accessible online. The accessibility of this archival material were why these nine countries were selected, and why they were a great study for an in-depth malaria analysis.

The use and reliance on data retrieved from colonial sources requires thoughtful and critical interpretation. As stated in the *1924 Medical and Sanitary Report of Kenya*, "the problem of colonization **is** the problem of malaria". The epidemiological data that

the British colonial government collected as well as the control interventions they implemented were both operating and functioning as colonialism does: by protecting and safeguarding the interests of European settlers over the captive African population. From the 1920s through African independence, the bulk of control interventions focused heavily on the health and wellbeing of European settlers, despite the data in the colonial Medical and Sanitary Reports showing Africans were contracting malaria at higher rates. This reflects one of the shortcomings of this data—the information collected is not 100% accurate to malaria during these decades. This may have been partially influenced by the epidemiological portrayal of malaria at the time. Many believed that Africans were immune to infection and asymptomatic carriers of malaria, a belief that directly impacted the implementation of control measures (Snow et al., 2012).

Control measures during the colonial era mainly occurred in urban settings, excluding large swaths of the country and large segments of the African population. The case numbers collected in the medical reports only come from hospitals, located in urban city centers, where there were more British settlers than indigenous people. As such, the epidemiological data collected in the *Medical and Sanitary Reports* do not provide a complete or accurate assessment of the local malaria condition. The numbers reported within these medical reports are vast underestimations of what malaria was in these countries since majority of the population were not included in the data collection. In addition, the annual population numbers are vague estimates at best since census data was not routinely taken. It is near impossible to accurately assess malaria rates throughout these countries from 1920-1955.

African Independence and WHO Era

Following the end of World War II, the rise of African nationalism was met with the desperation of European colonial empires' attempts to hold onto their waning influence on the continent (Jones, 2016; Myrice, 2015; Webb, 2009). Both of these forces were at odds. African nations began to unify, many embracing Marxist and pan-African ideologies, and waging wars of liberation from European imperialism and colonialism. Because World War II led to a weakening of British political and economic systems and power, many of these colonizing nations could not afford to fight the rise of revolutionary moments across the continent even if they wanted to. "The British won the war, but had to fight for their victory to the last man and the last penny. They came out of the war much poorer than before" (Davidson, 1994) The post-World War II era set the stage for successful national liberation projects across the continent, and with that many colonial medical programs were disregarded (Webb, 2009).

The World Health Organization was formed April of 1948 in order to coordinate health affairs across countries, to be responsible for public health in the international community, and to lead partners in global health responses. When the WHO officially launched, much of sub-Saharan Africa was still under colonial control. Due to the perceived political instability of these countries during this time period, WHO worked closely with colonial governments, relying on their medical reports and country data throughout the 1950s (Jones, 2016).

In 1955 WHO launched their first malaria program, the Global Malaria Eradication Programme, or the GMEP. The program's goal was to eradicate malaria from the globe and permanently reduce every country's prevalence

rate to zero through insecticides and chloroquine drugs. The African continent was not a benefactory of this program. Most existing literature claim that "sub-Saharan Africa was not equipped for elimination or eradication programs" and attribute this exclusion to inadequate health infrastructures (Snow, 2012). However, reports from WHO from 1955 to 1968 show that there were pilot malaria control programs taking place in a majority of sub-Saharan Africa but they "were not counted as formal parts of the eradication attempt" (Graboyes & Alidina, 2021). No comprehensive information is given within WHO malaria reports on the scale and size of the pilot programs and their relative successes or failures. The GMEP was eventually ended in the 1960s, and eradication was deemed unachievable in many tropical and sub-tropical countries.

With the end of the GMEP in 1969, little malaria prevalence and control data is recorded as newly independent African countries implement their own systems of governance. In the 1960s, the collection of epidemiological and entomological data is no longer the responsibility of the former British colonial government, but that of individual African governments. Many countries reject WHO's malaria pre-eradication efforts, choosing to focus their scarce resources on other health concerns instead of prioritizing programs that were colonial relics (Packard, 2008; Webb, 2009). The only exceptions are Zimbabwe, which did not gain its independence until 1980 and had limited control measures throughout this time, and Zanzibar, which had active programs and control interventions during this time implemented by the new African government.

According to the WHO, there is a large resurgence in African malaria prevalence from the 1970s through the early 1990s due to drastic rises in chloroquine and insecticide resistance and minimal malaria funding (Webb, 2009; Spracklen, 1984).

In 1998, the WHO launched the "Roll Back Malaria" initiative alongside UNICEF and the World Bank to provide a coordinated global response to malaria, and provide guidance to African countries in its control. RBM implemented new control measures at the turn of the century, and with the President's Malaria Initiative created in 2005, its funding helped implement control measures on a larger scale. With these new initiatives at work, malaria prevalence decreased across the globe.

There is no doubt that *who* collects malaria control and prevalence data and *how* they collect it, impacts its presentation, interpretation, and analysis. An understanding of colonial health infrastructures and the construction of post-colonial health infrastructures is vital for this project and its data analysis.

Methods

The quantitative information collected included information from WHO on country population data, malaria case numbers and prevalence rates on an annual basis, as well as resurgence dates and years. The qualitative data collected was the country-specific control measures that were implemented, and the descriptions of the types of control used. After compiling all the existing quantitative information, a new panel dataset of historical epidemiological data of malaria prevalence for each country over the timeframe was assembled. This was then overlaid with the annual qualitative information to determine potential and confirmed cases of rebound malaria on these epidemic curves. A comparison was done afterwards searching within published literature to see if confirmed cases of rebound had been previously reported.

Sources of Data

The data came from primary and secondary sources. The primary sources include malaria prevalence data from national governments, and colonial medical and sanitary reports from the British Online Archives and UN population data. Much of the archival primary source documents were found through digitized records in the British Archives and UN census databases. Since a great deal of the archival information collected did not include data past the 1950s, this research involved the collection of "grey literature," such as recent reports and articles through Google and database-specific searches. These sources include annual malaria reports by the WHO, reports from the President's Malaria Initiative, USAID, and the Global Fund to Fight AIDS, Tuberculosis and Malaria, UN annual reports and historical sources, and recent records documenting control efforts and cases of malaria rebound epidemics.

The contemporary and historical secondary reports were found through keyword searches on JSTOR, WorldCat, PubMed, Library of Congress, WHO IRIS, Wellcome Library, Hathi Trust, UN Digital Library and Biodiversity Library. A combination of keywords including country names, "malaria", "elimination", "eradication", "control", "rebound" and "resurgence" led to a total of 2488 articles, which was then narrowed down to 226 through a close reading of the abstract and titles of the articles. Those final articles specifically pertained to the project at hand, and were deemed the most likely to provide the type of information needed for this research.

This research project also collected information related to rebound and resurgent malaria from a related research project replicating Cohen et al's research and conducting a systemic review of resurgent malaria. Through this process, the team

searched through numerous databases, identified more than 10, 000 articles of import, then systematically and methodically organized and reviewed them to find reported instances of malaria resurgence. This work involved collecting information concerning reported malaria resurgences in the nine African countries, which was then used to determine the unreported malaria resurgences in these countries.

Quantitative and Qualitative Data

The quantitative data—which includes the prevalence rates, case numbers, population data and control measure data, has been organized and cleaned using Excel. The qualitative data, which includes the control measures descriptions, were entered into Scrivener and organized by time and location. The annual malaria case numbers were taken, divided by the standard population and then multiplied by 1000 to calculate the prevalence rate for each year. Rates were used instead of the raw case numbers because the rates allowed for a thoughtful comparison between the nine African countries and their relative levels of malaria.

Once the quantitative data was cleaned up in Excel and the qualitative information was entered into Scrivener, an epi curve was created for each country over the ten-decade period with the help of other research assistants. After that was completed, the epidemiological data was overlaid with all of the qualitative control measure data, and the characteristic peaks associated with epidemic rebound malaria were identified. That information was compared to published events of epidemic rebound malaria to officially determine what events constituted as “new” and never before reported in published literature.

Interruptions in Data Collection

From 1955 to 1980s, there was a large interruption in data collection in all nine countries, which is displayed through gaps on the epidemic curves. Some missing prevalence information was filled in with outside sources or estimated based on case numbers and approximate population data. These data points are displayed graphically with blue dots. The gaps in data are due to multiple factors. On a local level, there were many anti-colonial liberation movements occurring within these countries. While the exact dates differ country to country, the vast majority occurred during these three decades. During this time, information on control measures and case numbers were not recorded.

On a global scale, WHO implemented the GMEP from 1955-1969 with multiple pilot programs in Africa (Graboyes & Alidina, 2021). While the increased use of spraying with DDT and prophylaxis helped eliminate malaria in many countries during this period in time, it was decided that efforts in sub-Saharan Africa should be focused on controlling malaria in the region, instead of its eradication (WHO, 2021; Snow, 2009). Many newly independent African countries, including eight of the nine countries focused on in this project, did not agree with WHO's pre-eradication efforts and began to focus their limited resources towards other pertinent public health concerns (Webb, 2009). Because of these factors, there is no control information from the 1970s and 80s, and reported instances of large, global malaria resurgences on the African continent (Webb, 2009; Packard, 2008).

Limitations

The most significant limitation of this thesis is the quality of the data collected and the political and historical context in which it was gathered. The data that is

available is not fully representative of the malaria situation in these African countries. it is very important to note that much of the epidemiological data from the nine countries are underestimations of malaria of varying degrees. The colonial era in particular is a vast underestimation of the data, only reporting data from European settlers and African government officials and leaving out the larger African population in their data collection. The more recent time period, from 1980-2020, is an underestimation as well, but to a lesser degree. This data is more representative of the African population but only collects data from urban areas of the country.

In addition, since the control information collected is limited to what was found in published literature, there is no comprehensive information of all control measures taking place in all nine countries. Because of this there are some cases of epidemic rebound malaria that cannot be officially confirmed. There is also a large gap in data from 1955 to 1980. This thesis can only posit hypotheses for this time period based on information from outside sources.

Lastly, the malaria prevalence data collected in this research are all national-level data. This differs greatly from many published instances of resurgence events in literature, since those are most often reported on a local level. Because of this difference in scale and scope, reported instances of local malaria rebound events may not be reflected in the national-level data this research worked with and vice versa. These challenges mean that rebound dates in recorded literature do not always align with the national level rebound events in the generated epidemic curves. This limitation did not prevent researchers from uncovering numerous cases of epidemic rebound malaria that had previously been unreported.

Literature Review

Malaria Prevalence

Jim Webb, author of *Humanity's Burden: A Global History of Malaria* (2016) and *The Long Struggle Against Malaria in Tropical Africa* (2009), provides a broad history of the global prevalence of malaria, tracing the disease from its roots from tropical Africa, to Asia, to the Americas and back. Webb considers how environmental, social, biological, and ecological forces impact the transmission of malaria in tropical Africa. Webb includes a chapter in *Humanity's Burden* specifically touching on resurgent malaria. He states that "following two decades out of the spotlight, malaria begins to reemerge as a global health concern…", he continues: "the data gathered by the WHO indicates a dramatic increase in African malaria." He later refers to this increase as a as a resurgent event (179). Webb fortifies his findings through carefully collected data, including annual WHO case numbers, to historicize malaria resurgence.

This thesis will build on Webb's work and research on resurgent malaria. Webb does not provide his own definition for resurgence in either of these books, neither does he attribute resurgent events to anything other than climate. This thesis differs will delve into what other factors, including but not limited to climate, that may contribute to a resurgent event. It will also provide a more rigorous analysis of case numbers, control measures that occurred during the time periods this research looks at. Webb's chapter regarding resurgent malaria and collection of WHO data, as well as his detailed research into malaria control in tropical Africa, are one of the many foundations upon which this research is built.

In the book *The Making of a Tropical Disease: A Short History of Malaria* (2009), Randy Packard provides an in-depth analysis of malaria control and eradication efforts on the African continent. Informed by his time working at a clinic in Uganda, he provides a detailed record of the history of malaria from its earliest occurrences in Africa and southeast Asia through the present. He posits that malaria policy "needs to be informed by history", and a connection must be established between current biomedical control measures and the social and economic condition that influence malaria transmission (4).

This thesis relies on and builds upon Packard's argument that building a historical narrative of malaria is critical for researchers studying the disease in Africa. Like Webb, Packard does not define malaria rebound or resurgence, only mentioning that the global resurgence of malaria in the 1970s was "driven by a combination of malaria control program failures, the declining efficacy of the first line pesticide and antimalarial drugs, misguided development policies, armed conflicts, population displacements, the AIDS pandemic, growing debt burdens, collapsing health systems, and rising poverty" (216). This thesis will provide a more wholistic analysis of these patterns of rebound and resurgence that both Webb and Packard allude to.

Robert Snow et al. provides a comprehensive and necessary historical analysis of control measures on the African continent in *The Changing Limits and Incidence of Malaria in Africa: 1939– 2009* (2012). It dives into the historical misperception and epidemiological portrayal of malaria at the time: Africans were considered "immune" to the disease. This misperception had enormous consequences on the strengthening and worsening of control measures over the years. It also contextualized individual country

control measures within global and regional malaria control campaigns, with mentions of how certain countries were implementing campaign goals to reduce their country's malaria prevalence.

Snow et al.'s article is the largest compiled dataset of malaria control measures and prevalence in the African continent. Those datasets were critical in the creation of the ones that are contained in this research. This project attempts to buoy this existing panel datasets alongside that by providing individual datasets for each of the nine African countries instead of collating them into one. In addition, this project's findings and Snow et al. have similar understandings of control information, and both document a shared instance of malaria resurgence. The two works differ in the scope of data collected on individual country control measures and resurgence data. While Snow et al. did not provide an in-depth look at the efficacy of control measures, this thesis provides a more rigorous assessment of malaria control measures, prevalence and resurgence.

Lastly, in *Malaria resurgence: a systematic review and assessment of its causes* (2012), Justin Cohen and his team of researchers systematically investigated and assessed the causes of rebound malaria epidemics. Their work collected a total of 75 resurgent malaria events in 61 countries which revolutionized discussions on rebound and resurgence malaria. The research presented in this thesis builds off of the work of Cohen's team and applies a historical analysis to both the general framing of malaria and the discussion of control measures. In addition, this research uncovers previously unreported instances of resurgent malaria in African countries that Cohen's team were not able to capture in the scope of their work.

Control, Elimination, and Eradication

When public health organizations are in the process of implementing malaria control programs, they decide to either *control* malaria in a region, *eliminate* malaria from a region, or *eradicate* malaria from the globe. *Controlling* malaria is an effort to reduce the prevalence, incidence, morbidity, or mortality a significant amount, and is often due to deliberate national or international efforts (WHO, 2016). These efforts must occur continuously in order for the region to maintain control of malaria. While malaria elimination in Africa may have been a previous WHO goal, the endemicity of malaria in sub-Saharan Africa means many campaigns in the region are focused on controlling the disease.

Eliminating malaria, often confused with eradication, involves reducing malaria prevalence to a zero in a specific geographic region. Similar to *controlling* malaria, *elimination* also requires continued efforts in order to prevent the reintroduction of the disease (WHO, 2016). Across the globe, there are currently 40 countries and territories that have received a "malaria-free certification" from the WHO. They present these malaria-free certifications to countries that have "demonstrated that the chain of indigenous malaria transmission by Anopheles mosquitoes has been interrupted nationwide for at least the past three consecutive years" and "demonstrate the capacity to prevent the re-establishment of transmission" (WHO, 2021).

Eradication is the permanent reduction of malaria case numbers to zero through national and international efforts (WHO, 2016). *Eradication* differs greatly from *elimination* and *control*, and is very difficult to achieve as it must happen on a global scale. The world has only successfully eradicated two diseases: smallpox and

rinderpest. The largest difference between eradication and elimination/control is that when eradication is achieved, there is no need for further control measures or interventions. Elimination and control interventions requires consistent and continued efforts in order to maintain their specified level of prevalence.

Malaria Treatment and Control Interventions

Similar to the distinctions between different types of control strategies, there are also a range of options when it comes to forms of malaria testing, treatment and interventions. All of the methods mentioned before have all been used to different lengths and with varying degrees of success in the past century, and some are used currently to test and treat malarial infections. The different forms of control interventions and treatments will be grouped under different categories that correlate with the epidemic curves in Chapters Two and Three.

Vector Control

Vector control aims to limit malaria transmission through the reduction and elimination of human contact with the mosquito vector. Different vector control measures taken in the nine African countries were various environmental measures, insecticide-treated nets (ITN), and long-lasting insecticide nets (LLINs), and spraying.

Environmental measures refer to measures that destroy the breeding sites of mosquitoes. The most common environmental measures used during the early 20th century were draining swamp areas, clearing out bushes and ditches, pouring oil in standing water, and cleaning out mosquito-breeding places.

ITNs and LLINs are two different types of insecticide-treated nets. These are one of the most effective ways to prevent malaria since they form both a physical and

chemical barrier against mosquitoes, blocking them with the netting and killing them with the insecticide coating. Studies have shown that insecticide-treated nets are proven to reduce malaria illness and death in malaria-endemic regions (UNICEF, 2022). The most significant difference between ITNs and LLINs is that LLINs are able to maintain effective levels of insecticide for a minimum of 3 years.

Spraying is a control measure that was popularized in the 1940s and 50s, and involves coating the walls and all other surfaces of a house and outdoor surfaces with an insecticide. Indoor residual spraying (IRS) specifically refers to the spraying of insecticides indoors. Some mosquito vectors rest inside houses after taking a blood meal, which is why they are the best target for this treatment. Spraying can also be done outdoors (outdoor-residual spraying) to specifically target and kill mosquitoes in their natural habitats (Zhu et. al, 2017). The most common insecticides used for spraying by the British colonial government were Paris Green and DDT. Paris Green was an extremely toxic compound found in the 1870s and was used briefly in some countries during the 1940s as an insecticide for outdoor spraying before DDT was popularized (Maggio et al, 2005). DDT was discovered during World War II and was used as an insecticide for indoor spraying through the end of the GMEP program in 1969, proving to be very successful in eliminating malaria in some countries (WHO, 2021; EPA, 2016). Decrease in DDT use was due in part to increased resistance and growing concern of its adverse environmental impacts (EPA, 2016). Currently, other insecticides are used in IRS treatment that are slightly more expensive but less harmful to the environment.

Antimalarial Medication

The most common forms of antimalarial medication mentioned throughout the thesis are quinine, chloroquine, and artemisinin-based therapies (ACTs). Quinine was the first antimalarial drug discovered in Peru in 1820. This drug is typically used to treat acute cases of severe P. Falciparum, and is often used in regions that have higher levels of resistance to chloroquine and other antimalarial drugs (Achan et al., 2011). Chloroquine was first developed in the 1940s and used to prevent and treat susceptible cases of malaria. This drug used to be the first line of treatment across the world (and still remains the first line of treatment in sub-Saharan Africa) until resistance to chloroquine became widespread (Lowe, 2020; MMV, 2022). This led to a decline in its treatment of *P. Falciparum*, although it remains relatively effective for treatment of *P. ovale*, *P. malariae*, and, in most regions, *P. vivax* (WHO, 2022). Lastly, artemisinin-based therapies (ACTs) are when two or more antimalarial drugs are used in combination with one another to treat malaria and better prevent chances of drug resistance. Currently, ACTs have become standardized for malaria treatment across the world and serve as a first-line antimalarial drug, but its deployment across many countries in the global South have been particularly slow due to costs and limited knowledge on combination therapy (CT) (Wang et al., 2019; Malaria Consortium, 2022; Travassos & Laufer, 2022).

Vaccine

In November 2021, the WHO endorsed and recommended the use of a malaria vaccine, but has yet to be rolled out for widespread use across the African continent. This four-dose immunization, better known by its brand name Mosquirix, is a

significant milestone in the scientific community that has taken decades of work. The vaccine has been shown to significantly reduce malaria, especially among young children, and has proven to be most effective when used with other malaria treatment methods, such as ITNs and ACTs. (WHO, 2022).

Ethnographies of Data

All data, even that which is considered "clean" or "raw", or "purely numbers", are influenced by the cultural and social constructs that shape the knowledge production process. As such, the data collected over the course of this research may not necessarily be reflective of the world we live in, but a snapshot of the world that was measured. Ethnographies of data explore this phenomenon and investigate how data collection and compilation are both a technical and political form of knowledge production. In *Cooking Data: Culture and Politics in An African Research World*, an ethnographic account of research on the HIV/AID epidemic in Malawi, Cal Biruk illustrates how data ends up "cooked" through its collection, interpretation and production process. Biruk shows how the data collection can "not only produce numbers but shape personhood, sociality, and truth claims" (4).

In *The Seductions of Quantification,* Sally Engle Merry investigates the disparities between local knowledge production systems and more globally quantified systems, specifically touching on the production of data around human rights and sex trafficking. Merry talks about the varied ways data and information are documented and produced, arguing that these processes of measurement cannot be unlinked from larger systems of power. Data collection is shaped by the assumptions and agendas of the institutions and actors responsible for its compilation, and their perspectives shape the

presentation of the data. As Merry says, "how such numerical assessments are created, produced, cast into the world, and used has significant implications for the way the world is understood" (5). Because of this, the data becomes separated from the local systems of meaning. Instead of interpreting data from our world, we are essentially creating a new one. This has tremendous ethical implications for researchers, particularly those working in a cultural context outside their own.

With *Metrics: What Counts in Global Health* (200.), Vincanne Adams and other contributors look the successes and limitations of global health metrics, and raise important questions about how different metrics can solve or hinder global health issues. Metrics, similar in definition to indicators, have been shaped by the politics of knowledge. Global knowledge and global health metrics often reproduce the same issues of inclusion and exclusion—of data and of people—that were seen in the era of colonialism. The writers investigate how to transcend the national and political interests of countries, and the economic and social divide between poor and wealthy nations, when thinking of issues pertaining to global health. Ultimately, the volume hopes to "think about the architectures of global health in terms of who benefits and who does not" within countries across the global South (17).

In *Poor Numbers: How We Are Misled by African Development Statistics and What to Do About It*, Morten Jerven provides the first analysis on the production and interpretation of African economic development statistics. He delves into the origins of these statistics with his research, discovering that not only is the economic data inaccurate, but "the arbitrariness of the quantification process produces observations with very large errors and levels of uncertainty" (xi). These errors in the data lead to

inaccurate results which then contribute to the misinterpretation of metric values. This is one of Jerven's chief concerns: the misinterpretation of metric values could lead to government misallocation of important resources and funding.

The works of Adams, Merry, Biruk and Jerven look at data collection and the cultural, social, political and technical aspects that influence this knowledge production process. Their work has allowed for a reflection on how this thesis and project fit into this larger framing. This research involves data collected from, among other outside sources, the British Online Archives and the World Health Organization. That recognition comes with the awareness that the data collected is not an accurate representation of malaria prevalence in the nine African countries. For example, there are multiple instances throughout the medical reports where a colonial government states that their case numbers are severe underestimates of malaria cases in the region. While the WHO collects their prevalence data from the countries themselves, this ethnography indicates that the process and approach towards data collection and production can shift data value and, ultimately, truths. Because that knowledge informed data analysis and interpretation, this means that the resurgences discovered during the colonial time period is based on, and ultimately reflective of, limited data and information.

CHAPTER 2: MALARIA CONTROL AND RESURGENCE IN WEST AFRICA

The next two chapters present a brief but detailed history of malaria control data and compiled list of resurgence events from 1920-2020 in the nine African countries. Chapter 2 will provide an in-depth discussion of the countries located in West Africa—Gambia, Ghana, Nigeria and Sierra Leone.

Malaria Control in The Gambia, 1920-2020

Control in The Gambia in the 1920s and 1930s were characterized by the use of general environmental control measures to control the vector, home and town inspections for mosquito larvae throughout the larger cities in the country, and the beginning uses of medication. During this period of time there was emphasis given to mosquito-proofing European homes and hospitals, of which they began to get careless with in the late 1920s. Eventually from 1928-1931, no control measures were being implemented year-to-year with the public health department questioning whether much more could be done "to control malaria in the region" since "no advancements were being made year-to-year" (Gambia Medical and Sanitary Report, 1929; Gambia Medical and Sanitary Report, 1930). There is a pattern during the first two decades with control measures being implemented for a couple of years, then completely stopped, then started again, then stopped again. Malaria was very endemic to The Gambia during this time, which explains why there were multiple periods during the control efforts where the public health departments reassessed and reimplemented different control strategies. In this case, prevalence levels remained relatively low so by 1932, the

government continued their control efforts with the filling in, and draining of, mosquito breeding areas. In 1937 and 1938, quinine use became popularized and began to be administered. However, at this time the drug was only accessible to European the settlers and not available to the greater population of Gambia.

With World War II, control measures were not being reported nor implemented from the late 1930s to the early 1940s, with the government explicitly reporting that control measures were extremely insufficient (Gambia Medical and Sanitary Report, 1942). During this time, there were drastic increase in prevalence levels. In 1943, the colonial government officially established an anti-malarial team to determine best methods to decreasing prevalence. Environmental measures were brought back, alongside the use of suppressive drugs and spraying with DDT. C.F. Mackay, the Assistant Director of Medical Services at the time, conducted research into malaria distribution and incidence in order to "fill certain important gaps in the accumulating records of information", before an "adequate program could be established" (Mackay, 1947). He conducted house by house surveys, and determined that the species of parasite was *P. falciparum* and that parasite rates were higher than initially thought or suspected, especially among younger children. With this information, the government began to implement and greatly encourage the use of prophylaxis throughout hospitals and clinics. In the 1950s, it was believed that control had reached its maximum efficiency, and no new measures were implemented year-to-year. They maintained environmental control efforts, and continued the use of spraying with DDT and prophylaxis among European settlers (Gambia Medical and Sanitary Report, 1953; Gambia Medical and Sanitary Report 1955). The end of this period of time was

characterized by the conducting of research and surveys into malaria transmission and outdoor spraying with Paris Green.

No prevalence or control information is available from The Gambia throughout the 1960s and 1970s, and very little information is available during the 1980s and 1990s. There is a marked increase in prevalence rates during this time period, which is believed to be a result of rising insecticide and drug resistance, and lasting impacts of the GMEP (Spracklen, 1984). In the late 1990s, the Roll Back Malaria initiative was launched, with their program focusing on protecting and treating at least 60% of at-risk populations in high burden countries (Snow, 2012). Through the 2000s, new efforts and control measures are being introduced with varying levels of success. There were reported active control measures in the Gambia from as early as 2003 through 2009 (Ceesay et al., 2011). In 2004, the Gambia adapted and began to scale up home management of malaria into their national control strategies. In the late 2000s, there is a drastic increase in the amount of LLINs distributed annually, going from 77,163 in 2007 to nearly 300,000 in 2008 (WMR, 2009). With ITN usage, there was a marked decrease in ITNs reported in households in 2006 and 2007, with nets covering less than 20% of the population at risk during this timeframe (WMR, 2008). There were also some changes in first-line antimalarial therapy, with the increased use of ACTs over chloroquine, and Global Fund support for malaria control (Ceesay et al., 2011).

The 2010s started out with the continuation of control measures, in addition to research being conducted into different mosquito vectors. In 2013, a malaria program review was conducted and seasonal malaria chemoprophylaxis was implemented as a tool for control in the Gambia (…) This period of time is characterized with overall

decreases in malaria prevalence. ITNs and LLINs were distributed free of charge to all age populations from 2015 through 2019, covering close to 80% of the entire population (WMR, 2016; WMR, 2018; WMR 2020).

Malaria Resurgence in The Gambia, 1920-2020

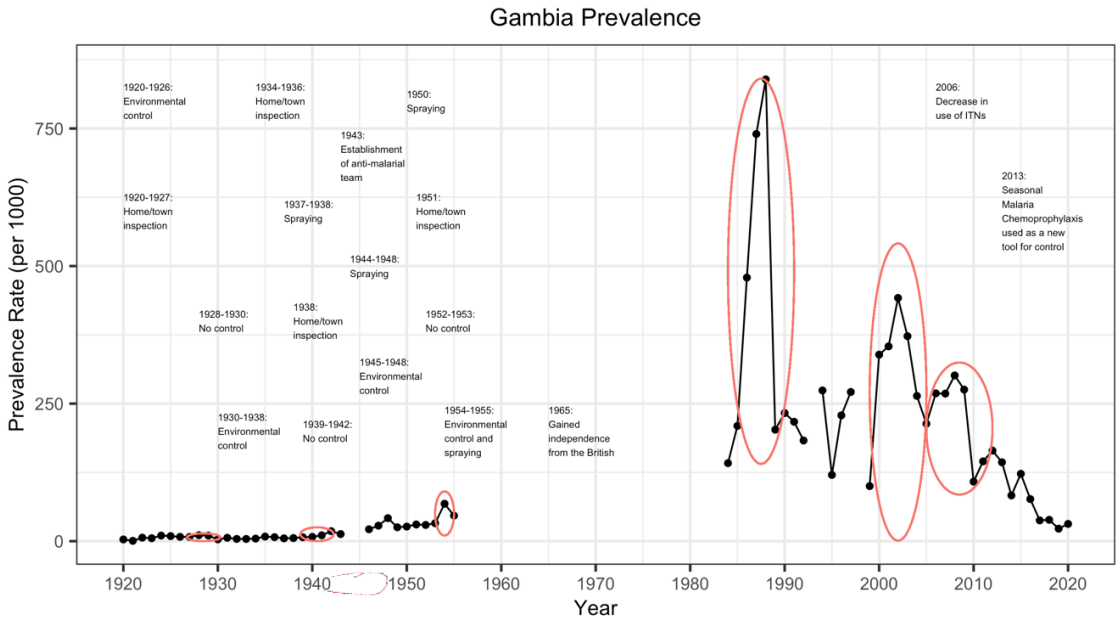


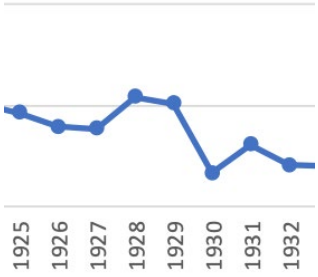
Figure 3: Standardized Malaria Prevalence Rates (per 1000) in The Gambia, 1920-2020 [1]

[1] Adapted from *Colony of the Gambia Annual Medical Report.* (1920-1955). British Online Archives; *WHO Annual World Malaria Report*. (2005). World Health Organization; *WHO World Malaria Report*. (2008-2021). World Health Organization; *WHO Weekly Epidemiological Record*. (1999). World Health Organization.

Start Date	Peak Date	End Date	Previously reported?
1927	1928	1932	No
1939	1949	1948	No
1952	1954	Not Known	No
1984	1988	1990	No
1999	2003	2005	No
2005	2008	2011	No

Table 1: Events of Rebound and Resurgent Malaria in The Gambia, 1920-2020

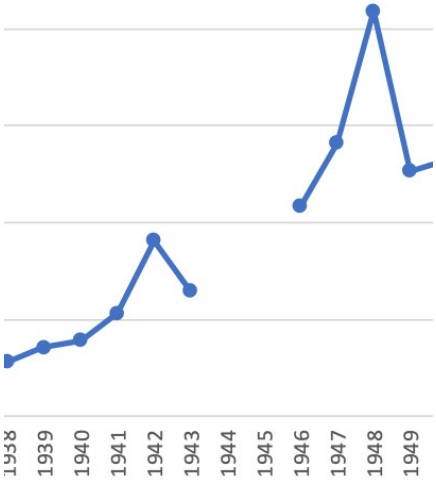
In The Gambia, there are a total of six rebound events discovered in the generated epidemic curves, all of which have not previously reported upon. The first two are not immediately obvious due to the scaling of the graph, so a zoomed-in portion of the graph will be displayed while discussing those instances of rebound malaria in The Gambia, followed by a narrative discussion on the last three resurgence events.



A portion of Figure 3 has been zoomed in to easily showcase occurrence of malaria rebound and resurgence from 1927-1932.

The first rebound event is from 1927-1932, with a peak in 1928. Surrounding questions on the efficacy and feasibility of current control measures in The Gambia and reductions in quality of malaria control through middle-to-late 1920s, control interventions were halted with a subsequent reassessment and reorganization of

antimalarial measures. This is visible in Figure 3 with the rise in prevalence during that period of time. Eventually, new measures were reinstated in the early 1930s which led to decreases in prevalence rates, shown in the zoomed-in figure above.



A portion of Figure 3 has been zoomed in to easily showcase occurrence of malaria rebound and resurgence from 1939-1949.

The next event of rebound malaria occurs from 1939 to 1949, with a peak in prevalence in 1948. With World War II, control measures were not implemented nor reported upon from the late 1930s through the early 1940s. With no active control measures, increases in prevalence are visible through 1948, reflected in the graph above. The establishment of an antimalarial team and assessment of control measures from 1943-1946 led to increases and renewed energy spent towards chemoprophylaxis, environmental control and IRS with DDT (Colony of the Gambia Annual Medical Report, 1946); these efforts led to a decrease in prevalence in 1949 where we mark the end of the event.

The third event of rebound malaria starts in 1952, with an observed peak in prevalence in 1954. Due to interruptions in data collection, there is no confirmed end date to this resurgent event. The beginning of the 1950s had a decrease in control

measures, with the belief that maximum efficiency had been reached. While spraying with DDT and environmental measures were maintained, malaria transmission increased. There is a decrease in prevalence in 1955, but whether the prevalence plateaued after 1955 remains unknown.

The fourth rebound event occurs from 1984-1991, with a peak in prevalence in 1988. During the 1980s, there were large increases in drug- and insecticide-resistant *P. falciparum*. This, coupled alongside the lasting impacts of the GMEP led to increases in prevalence visible in the epidemic curve (Figure 3; Spracklen, 1984). There are decreases in prevalence from 1989-1991, but due to the limited control information available, it is unknown what contributed to this decrease in prevalence rates.

The fifth rebound malaria start in 1999-2005, with a peak in prevalence in 2003. Once again, due to limited control information available, it is unknown what caused the malaria resurgence in 1999. However, the launch of the Roll Back Malaria initiative led to reported increases in ITN, LLIN and ACT distribution and usage (Ceesay et al., 2011; WMR, 2008, WMR, 2009); and these control measures led to a decrease in prevalence from 2003 to the end of the event in 2005.

Lastly, the sixth rebound event takes place from 2005-2012 with a peak in 2008. While there were active increases in ITN usage in the early 2000s, this number decreased from 2006-2007 with less than 20% of households having access to at least one net (WMR, 2008). This change in ITN usage is what led to an increase in prevalence from 2006-2008. Malaria control funding from the Global Fund increased in the late 2000s, which led to the expansion of control measures and research. These

factors led to a decrease in prevalence from 2009-2011, which signifies the end of the rebound event.

Malaria Control in Ghana, 1920-2020

Limited information was recorded for malaria control in Ghana for the first couple of decades. In addition, data collection from 1922 through 1934 were collected from April of one year to March of the subsequent year, which differs from the rest of the years that go from January to December. This made it a little difficult in displaying and analyzing this information graphically; however, it did not impact analysis since the prevalence data was still being reported in 12-month frames annually. Throughout the 1920s and 1930s, the majority of control measures implemented by the British were home and town inspections, some forms of environmental measures—such as oiling standing water and cutting trees—and different types of personal prophylaxis, such as quinine, being administered. There was also research conducted during this period on the malarial parasite and at-risk populations. Dr. J. M. O'Brien, Senior Medical Officer in Koforidua, noted that "every individual of the local population over a few weeks of age, and with rare exceptions, is infected frequently with malaria", and specifically noting that about 24% of malaria infections were children under the age of 5 (Report on the Medical and Sanitary Department, 1926-1927). Because of this, there was a shift in focus in the 1930s for control measures, specifically aiming to treat and prevent malaria within school-age children. A focus was also made on educative propaganda within schools and among younger children.

The beginning of the 1940s there is also limited information on control measures. Town inspections were somewhat conducted during this period, but it was

noted that the lack of financial support and staffing meant that their control efforts did not reach the entire country, only areas where there were trained staff (Report on the Medical and Sanitary Department, 1941). There was also a large discussion in the reports on lack of financial support, and whether the Public Health department could afford to keep on conducting these relatively expensive anti-malaria schemes. Eventually in 1945, there was a dismantling of the Anti-Malarial Board established and a noted decrease in staffing. In 1946, there was a halt in control measures, stating that "a shortage of senior staff and of material has prevented progress being made" (Report on the Medical and Sanitary Department, 1946). From this time until 1950, it was only noted that "routine anti-mosquito measures were continued" and "existing standards… were maintained" and would remain so until a malariologist was appointed with sufficient staffing, funding, and equipment (Report on the Medical and Sanitary Department, 1947; Report on the Medical and Sanitary Department 1949). While DDT began to be used in some areas of Ghana, it did little to reduce the prevalence of malaria at the time.

From 1950-1952, there is this same trend. Minimal and routine measures were being implemented, which consisted of limited spraying with DDT, maintenance of drains and surveys in selected areas (Report on the Medical and Sanitary Department, 1950). It must be noted that the routine measures being implemented were strictly anti-mosquito measures, and not antimalarial in nature. In 1953, a Chief Medical Officer and entomologist were appointed and began investigations into malaria problems, stating that they hoped to take notes from the WHO's efforts in malaria control in other countries (Report on the Medical and Sanitary Department, 1953). In their research,

they saw that there was a "considerable degree of underdiagnosis by Medical Field Units" that were examining blood films for malarial parasites. This was suspected to be due to lack of specialized training and the conditions in which the blood slides were inspected under (Report on the Medical and Sanitary Department, 1953). During this period, there was also a large discussion on how population movements, inherited immunity and racial identity impact malaria transmission and what that meant for malaria control. It was decided that a focus would need to shift to vector control, residual insecticides, and suppressive drugs only among at-risk populations, and that these controls "would be necessary for eradication" and "should be capable of extension to cover the whole country (Report on the Medical and Sanitary Department, 1955).

Once again, from the 1960s to the 1980s, there is little to no information on control measures or prevalence. There were reports of limited IRS spraying from 1970 through the 1980s, and of resurgences and resistance to insecticides and drugs up until early 1990s (Spracklen, 1984; Snow, 2012). In 1993-1997, there was a Malaria Action Plan implemented in the region, with a goal of reducing morbidity and mortality rates (Malm et al., 2013). As stated in an epidemiological profile provided by health programs in Ghana, the Malaria Action Plan approaches were as followed:

> "…increasing the knowledge and skills of health workers on malaria, strengthen capacities of health services to diagnose and treat malaria, increase community awareness and participation in malaria activities within primary care, make antimalarial drugs available and affordable to the general population, establish surveillance systems and determine the pattern and extent of malaria transmission in the country" (MoH, 1991; Malm et al., 2013).

Shortly after this program ended, an aggressive Roll Back Malaria initiative was launched and partnerships were established between the government of Ghana and

various international funding agencies. Control measures implemented in 2000s were characterized by an increase in freely available malaria treatment and prevention strategies. From 2001 to 2004, there were programs that distributed free ITNs across different regions and sectors within Ghana with reported increases in ITNs availability in households from 2003 to 2006 (WMR, 2005; WMR, 2008). ACTs became the first line of antimalarial drugs in 2007, although making it widely accessible to the larger population proved difficult throughout the 2010s (WHO, 2008; Malm et al., 2013). The 2010s in control are defined by an increase in prevalence levels and decreases in control measures used. ITN distribution began to decrease in 2014, with only about 10% of at-risk populations having access to it. In 2019, parts of Ghana alongside Malawi and Kenya underwent a pilot introduction of the RTS,S vaccine and as of 2020, about 500,000 children have received their first dose of the vaccine (WMR, 2020; WMR, 2021). Currently, Ghana is one of ten countries that account for 70% of the global malaria burden and current and future goals for malaria control involve increased surveillance and assessments, nationally integrated malaria databases, and five-year subnational malaria control plans (WMR, 2020).

Malaria Resurgence in Ghana, 1920-2020

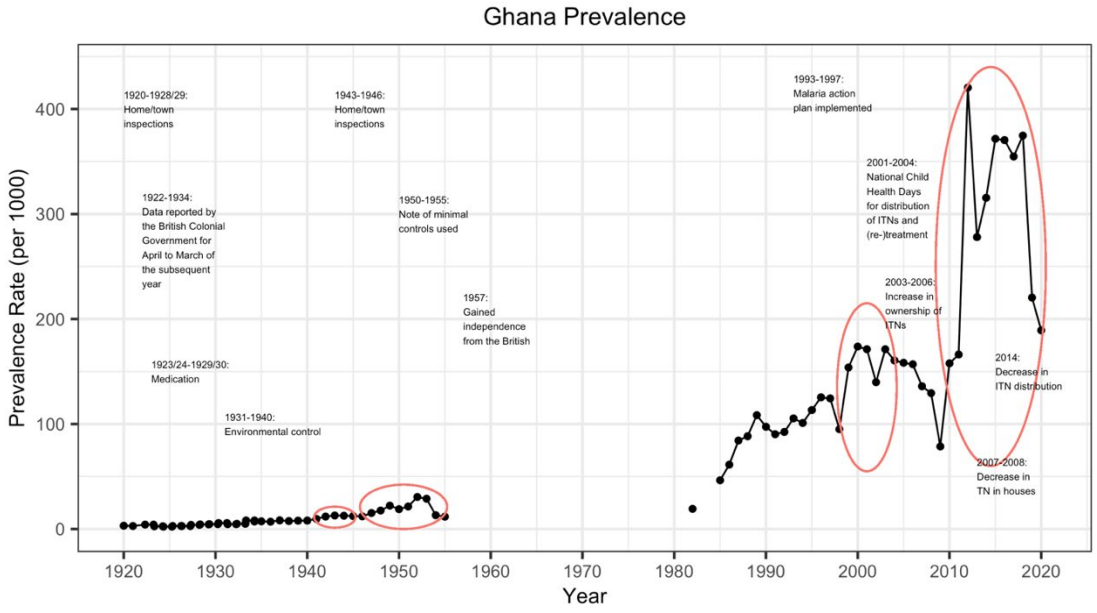


Figure 4: Standardized Malaria Prevalence Rates (per 1000) in Ghana, 1920-2020 [2]

[2] Adapted from *Gold Coast Colony Report on the Medical Department.* (1920-1955). British Online Archives; *WHO Annual World Malaria Report*. (2005). World Health Organization; *WHO World Malaria Report*. (2008-2021). World Health Organization; *WHO Weekly Epidemiological Record*. (1999). World Health Organization.

Start Date	Peak Date	End Date	Previously reported?
1940	1943	1945	No
1945	1952	1955	No
1998	2000	2004	No
2009	2012	Ongoing	No

Table 2: Events of Rebound and Resurgent Malaria in Ghana, 1920-2020

There are a total of four events of rebound and resurgent malaria in Ghana found in the epidemic curves, with none having appeared in reported literature before. Due to the scaling of the graph, a zoomed-in portion of the first rebound event will be provided alongside the narrative.

A portion of Figure 4 has been zoomed in to easily showcase occurrence of malaria rebound and resurgence from 1940-1945.

The first rebound event is from 1940 to 1945, with a prevalence peak in 1943. Once again, with World War II there were little recorded control information on malaria. However, there were discussions surrounding the lack of financial support for

antimalarial measures in 1940, with resulting decreases in control interventions (Report on the Medical and Sanitary Department, 1943). With those reductions in control, malaria transmission increases from 1940-1943. In 1943, control measures were reinstated, consisting of home and town inspections for mosquito larvae. This environmental control leveled out the prevalence in 1945, where the rebound event ends.

The second event occurs from 1945-1955, with a peak in 1952. In 1945, the Anti-Malarial Board was disbanded and in 1946, there was a halt in control measures due to shortages in funding and staffing. Limited routine measures were maintained through early 1950s, but malaria prevalence still increased through 1952. In 1953, staffing increased and new control measures were restarted in the region which caused a decrease in prevalence through 1955.

The third rebound event takes place from 1998-2004, with a prevalence peak in 2000. From 1993 to 1997, the government of Ghana implemented a Malaria Action Plan, ending due to funding concerns. There is a substantial increase in prevalence afterwards, with it peaking in 2000. However, with the RBM Initiative, more aggressive forms of malaria control were launched with ITN and LLIN expansions—leading to a decrease in prevalence through 2004.

Shortly afterwards is the last rebound event, from 2009-present, with a peak in 2012. Much of the 2010s are defined by decreases in control. Starting from 2007 through 2014, ITN distribution and administration decreases—contributing to the large increases in prevalence during that time. Prevalence begins to decrease in 2018, with the prevalence rate reaching around 200 per 1000 total population in 2020.

Malaria Control in Nigeria, 1920-2020

In the 1920s, there were a lot of scientific advancements. Anopheles mosquitos were recognized as the carriers of malaria and the need for vector control was noted. Testing also increased in the region, and in Lagos, 95% of children were diagnosed with malaria through blood examinations. It was also stated that medical energy was too focused on European welfare that there was nothing spared to be focused on other purposes. Europeans can't be the only people considered when looking at the incidence and prevalence of a disease because "they are a treated community, while the bulk of the people are not" (Annual Medical and Sanitary Report, 1924). Control measures in Nigeria during this period of time were largely environmental measures and use of prophylaxis—quinine to be specific. While quinine was highly popularized in Nigeria during this time, there were large debates on its effectiveness in reducing morbidity rates in urbans areas of the country and was eventually stopped in 1924. There were notably less measures from 1926 through 1930, and towards the end of the decade, some town inspections were conducted to find places of mosquito breeding.

The 1930s involved the continuation of usual anti-malarial measures—including environmental measures and spraying with Paris Green—and the conducting of research with funding from the Rockefeller Center. Among other findings, Dr. M. A. Barber of the Rockefeller Center discovered important information on the nature of the *Anopheles* mosquito and information on its transmission, noting that one; the mosquito larvae survive mainly in freshwater, in water containing less than 60% of salt within it and in any body of water exposed to the sun, and two; *Anopheles* mosquitos can disperse more than a half mile away from their breeding places (Annual Medical and Sanitary Report,

1930). There was also a large focus during this period on expanding control measures beyond the town of Lagos, with environmental control measures conducted in Northern and Western provinces of Nigeria. The majority of control measures done during this decade were environmental measures and occasional quinine distribution. From 1933 through 1939, there was a staffing and funding shortage, which greatly impacted the level and quality of environmental measures in the region, specifically stating that "mosquito control by larvicides and insecticides has been continued within the very restricted limits possible with limited funds and staff available" (Annual Medical and Sanitary Report, 1939).

The 1940s and 1950s involved the revamping of different environmental measures and the creation of new antimalarial services, including programs from the WHO towards the beginning of the 1950s. While there was still prophylaxis taken by European settlers in the beginning of 1940s, the focus shifted more towards vector control and destroying places of mosquito breeding by the end of the decade. In 1949, malaria control pilot schemes began, with residual spraying with DDT in certain regions in Ghana, field research on different insecticides as forms of malaria control and an establishment of a malaria bulletin to report “summarized information on problems of malaria research and control” across West Africa (Annual Medical and Sanitary Report, 1953). Initial reports from the Medical and Sanitary reports spoke on the fruitfulness of the schemes, and the hopes to extend it across a much larger population of 100,000 people in the near future (Annual Medical and Sanitary Report, 1954). However, they also stated their doubtfulness on urban control schemes and whether they “have much

effect on the incidence of malaria, though they do something to mitigate the mosquito nuisance" (Annual Medical and Sanitary Report, 1954).

While there was little control information from 1955 to the 1980s, some control programs were implemented. From 1969 to 1976, a study was conducted, co-funded by the WHO and the Nigerian government. Called the Garki project, the researchers aimed to measure the effects of different control measures—such as IRS and MDA—and to attempt to construct a mathematical model for malaria transmission (Molineaux and Gramiccia, 1980). This project found that the insecticides were very effective against the mosquito vectors, but a limited impact on malaria transmission. Similarly, it also found that the use of MDA "reduced malaria to a very low level, [but] failed to interrupt transmission" (Molineaux and Gramiccia, 1980; Packard, 2008). On the other hand, the mathematical model created was able to provide a realistic stimulation of the epidemiology of malaria and planned to be used for future malaria control efforts. From the 1980s to the early 1990s, efforts to control malaria were impacted by decreased funding and support, and increasing resistance to insecticides.

In the 2000s, we see an influx of control measures implemented with the RBM initiative. From 2001 to 2004, there was an increase the accessibility of ITNs and LLINs, distributed for free at antenatal clinics across the country, and made available to the rest of the population in 2009 (WMR, 2005; WMR, 2010; Amzat, 2011). Other control measures used during this period included widespread use of IRS since 2007, and ACTs in 2006 (WMR, 2007; WMR, 2008, Amzat, 2011). Although these control measures were in place, the size and scale of these programs do not cover the entire population—which poses a large question of the utility and usefulness of control

measures when they only reach a small portion of the population. While funding for malaria control increased from $17 million (US) in 2005 to $80 million in 2008, this amount was still not enough to provide control measures and treatment for Nigeria's rising population (WMR, 2009). As such, the control measures did not do much to reduce the transmission of malaria in the country. In 2005, one-third of children were unable to receive prophylaxis to treat their malaria, 17% of households had access to at least one mosquito net and even less slept under the nets at night (NDHS, 2008; WHO, 2009).

Currently, Nigeria holds the largest malaria burden in the world with one-third of global malaria mortality occurring in the country (World Bank, 2022; WHO, 2022). While Nigeria has a large budget dedicated for malaria control, substantial decreases in funding and very low coverage rates of control interventions led to increases in malaria transmission throughout the 2010s (Amzat, 2011; WMR, 2011-2019). In the past couple of years, there has been a large focus and goal in reducing prevalence, morbidity and mortality rates in Nigeria through the tailoring of control interventions in different regions of the country (WMR, 2020).

Malaria Resurgence in Nigeria, 1920-2020

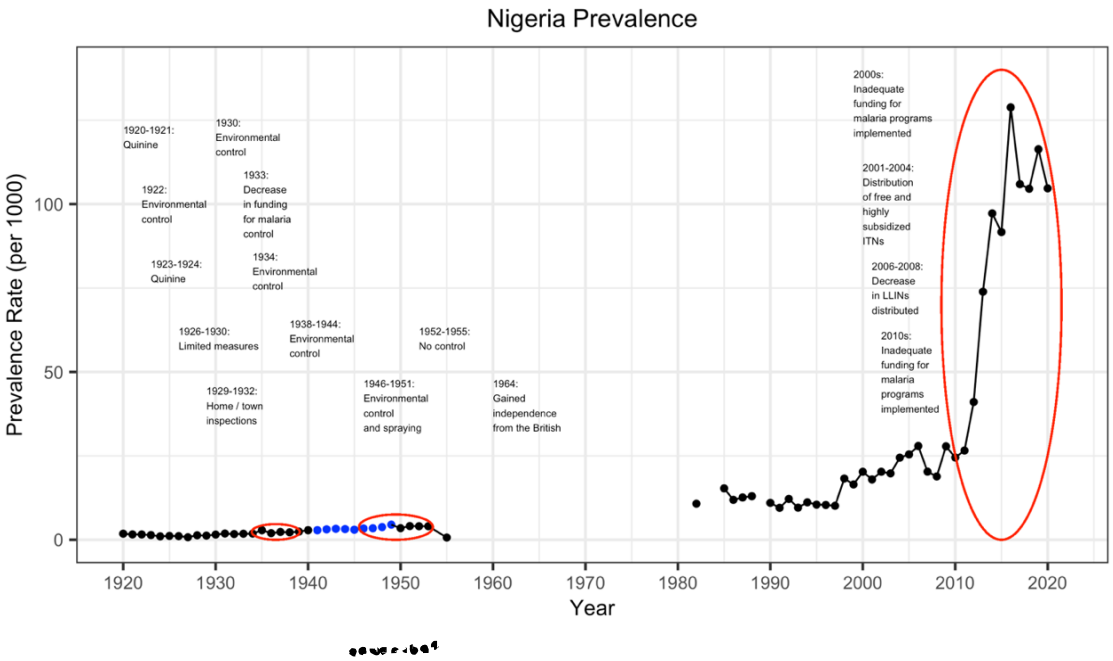


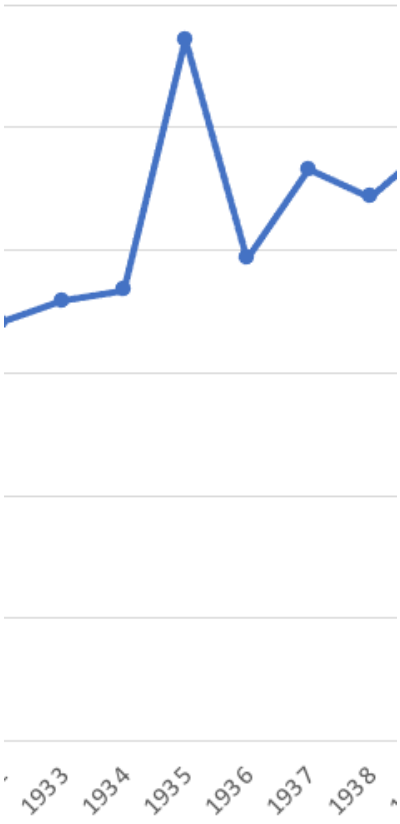
Figure 5: Standardized Malaria Prevalence Rates (per 1000) in Nigeria, 1920-2020 [3]

[3] Adapted from *Nigeria Annual Medical and Sanitary Report.* (1920-1955). British Online Archives; *WHO Annual World Malaria Report*. (2005). World Health Organization; *WHO World Malaria Report*. (2008-2021). World Health Organization; *WHO Weekly Epidemiological Record*. (1999). World Health Organization.

Start Date	Peak Date	End Date	Previously reported?
1933	1935	1938	No
1945	1949	1953	No
2008	2016	Ongoing	No

Table 3: Events of Rebound and Resurgent Malaria in Nigeria, 1920-2020

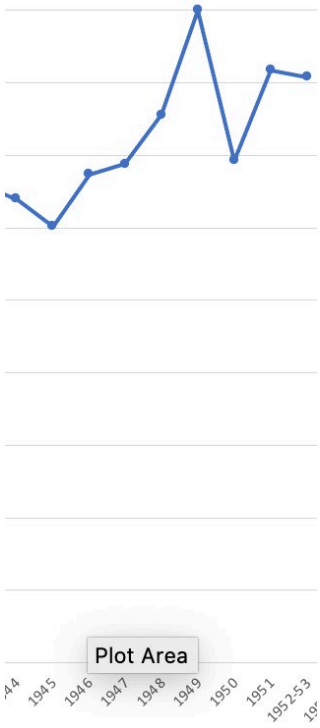
There are three instances of malaria rebound in Nigeria found in the epidemic curves. A zoomed-in portion of the first two events will be presented below alongside the narrative.



A portion of Figure 5 has been zoomed in to easily showcase occurrence of malaria rebound and resurgence from 1933-1938.

The first event of malaria rebound takes place from 1933-1938, with a recorded peak in 1935. From 1933 through the end of the 1930s, there were staffing and funding

shortages, which decreased quantity and quality of control measures in the region at the time. This led to increases in prevalence through 1935, seen in the figure above. In 1936, quinine administered increased in the townships and in 1937, environmental measures were reconstructed and reimplemented in Nigeria (Annual Medical and Sanitary Report, 1936; Annual Medical and Sanitary Report, 1937). These factors led to a decrease in malaria transmission, with the prevalence rates levelling out in 1938 (Figure 5).



A portion of Figure 5 has been zoomed in to easily showcase occurrence of malaria rebound and resurgence from 1945-1955.

The second rebound event occurs from 1945-1953, with a peak in prevalence in 1949. World War II interrupted data collection and malaria control execution. The lack of control measures led to increases in prevalence levels through 1949 (Annual Medical and Sanitary Report, 1945; Figure 5). With the reorganization and restructuring of

antimalarial measures, including the introduction of IRS with DDT, came a decrease in prevalence in 1950 until levelling out in 1953.

The last event of rebound malaria goes from 2008 to the present, with a peak noted in 2016. While Nigeria had a large increase in malaria funding, substantial decreases and lower coverage rates of ITNs and IRS led to increases in malaria transmission throughout the 2010s. This event does not have a confirmed end date since the prevalence has yet to reach a plateau.

Malaria Control in Sierra Leone, 1920-2020

Sierra Leone was the first country in the African continent to have malaria control interventions. Ronald Ross initially made the connection between malaria and mosquitos in 1897 while conducting research in Sierra Leone, and helped lead initial antimalarial schemes in the region (Snow et al., 2012; Alilio et al., 2004; Ross, 1901). Control in the 1920s and 1930s for Sierra Leone were characterized by intensive environmental measures, including but not limited to: canalization of streams, oiling of pools and gutters, chipping and filling trees, inspection of boats and canoes, clearing bushes and street drainage (Sierra Leone Annual Medical and Sanitary Report, 1921-1936; Snow et al., 2012). Quinine was also used a couple years during this period as a personal prophylaxis, but the focus of control measures at the time were on vector control. These intensive measures were very effective and led to reductions in vector transmissions by the 1940s (Snow et al., 2012).

In the 1940s and early 1950s, there was a stall in the intensiveness of control measures and a shift in focus from environmental measures to spraying. In 1939, tests were conducted to see the effectiveness of spraying with insecticides, and was

conducted indoors and outdoors in 1942 using DDT and pyrethrum in kerosene (Sierra Leone Annual Medical and Sanitary Report, 1939; Sierra Leone Annual Medical and Sanitary Report, 1942). From 1946 to 1948, there is a reported decrease in malaria funding from £22,000 to £16,928 and no possibility to "proceed with any permanent work owing to the absence of engineering assistance" (Sierra Leone Annual Medical and Sanitary Report, 1944; Sierra Leone Annual Medical and Sanitary Report, 1946-1947). Through the late 1940s and early 1950s, spraying remained the most prevalent control intervention, environmental measures were reinstated—specifically the canalization of streams and swamp drainage—and trials on different types of larvicides were performed (Sierra Leone Annual Medical and Sanitary Report, 1949-1955).

The next 50 years, there are little to no control measures and prevalence information due to malaria resurgences and rising insecticide / drug resistance from the 1960s through the 1980s, and political instability from the 1990s to early 2000s. Following the end of a civil war in Sierra Leone in 2002, the IMF, British government and World Bank provided Sierra Leone five million pounds in 2000-2001 to help stabilize the economy (Bulletin of the WHO, 2010). Because of the destruction of economic and healthcare systems, the next five to ten years following the war were spent rebuilding the country. During this time, almost 60–70% of healthcare was delivered with support from donors, including the WHO and UNICEF (Bulletin of the WHO, 2010).

The 2000s had limited control information, only stating notable decreases in ITN and LLIN distribution and less than 20% of the population covered with nets of any kind (WMR, 2005; WMR, 2008-2010). However, with the 2010s came a renewal in

malaria control efforts. From 2010 to 2015, a new national strategic plan was prepared for malaria control. With this strategy, there are considerably advancements in ITN and ACT accessibility (Sierra Leone MoH, 2010; WMR, 2011-2016). Unfortunately, after this program ended, there was a reduction in malaria funding noted from 2017 through 2020, and natural emergencies from 2018-2020 that impacted control measures in the region, including the onset of COVID-19 (WMR, 2019; WMR, 2020; WMR, 2021).

Malaria Resurgence in Sierra Leone, 1920-2020

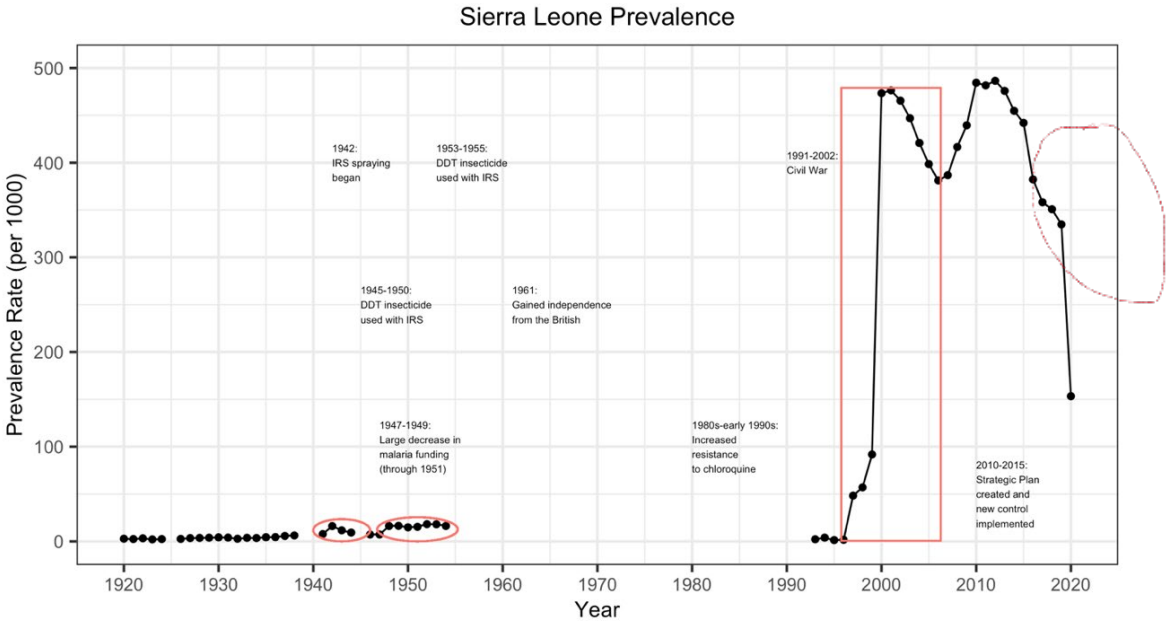


Figure 6: Standardized Malaria Prevalence Rates (per 1000) in Sierra Leone, 1920-2020 [4]

[4] Adapted from *Sierra Leone Annual Medical and Sanitary Report.* (1920-1955). British Online Archives; *WHO Annual World Malaria Report*. (2005). World Health Organization; *WHO World Malaria Report*. (2008-2021). World Health Organization; *WHO Weekly Epidemiological Record*. (1999). World Health Organization.

Start Date	Peak Date	End Date	Previously reported?
1940	1942	1946	No
1947	1952	Not Known	No
1997	2001	2006	No
2007	2010	2017	No

Table 4: Events of Rebound and Resurgent Malaria in Sierra Leone, 1920-2020

There are a total of four events in Sierra Leone, and none have been previously reported on. The first rebound event occurs from 1940 to 1946, with a peak in 1942. This period of time in Sierra Leone consisted of decreases in quality of control measures due to World War II, which led to the subsequent increases in prevalence witnessed in the graph (Figure 6). With DDT spraying beginning in 1942, there is a decrease in prevalence that levels out in 1946 (Figure 6; Annual Medical and Sanitary Report, 1942).

The second event occurs right after, starting in 1947 with a peak in 1952. In 1947, there was a reported loss of 5000 pounds in malaria funding that year. These decreases in financial support, and control measures as a result, continue through 1949. However, with the canalization of streams and swamp drainage in 1951, prevalence rates are seen decreasing through 1955 (Figure 6). An ending date to this rebound event cannot be determined due to interruptions in data collection after 1955.

The third rebound event takes place from 1997-2006, with a peak in 2001. This event is due to multiple compounding factors, including political unrest and instability as well as lack of control measures through the mid-1990s. All of these contributed to the large increase in prevalence seen in the late 1990s (Figure 6). With the launch of

RBM initiatives in Sierra Leone alongside the end of the war came a steady decrease in prevalence through 2006. The fourth resurgence happens right after, from 2007-2017 with a peak in 2010. From 2006 to 2008, there were noticeable decreases in ITN and LLINs distributed across the country, which caused the prevalence to increase to levels seen in 2000. The turn of the decade brought about a renewal in malaria control, with new control plans implemented and coverage increased, leading to a steady decrease in prevalence through 2020, with a plateau in 2017.

CHAPTER 3: MALARIA CONTROL AND RESURGENCE IN EAST AFRICA

This chapter will conclude the analysis of each country's control data and resurgence events. I will focus my discussion for this chapter on the countries located in East Africa (Kenya, Malawi, Uganda, Zanzibar and Zimbabwe).

Malaria Control in Kenya, 1920-2020

Malaria control in Kenya in the 1920s consisted largely of vector control, with home and town inspections and minimal environmental measures aimed towards destroying mosquito breeding areas. These measures were noted as being more passive in nature, with "no organized antimalarial campaigns" occurring during the time (Kenya Annual Medical Report, 1927). However, with two malaria epidemics in 1926 and 1928—impacting both local Africans and European settlers—malaria control efforts were renewed as the disease began to be treated more seriously (Snow et al., 2012; Kenya Annual Medical Report, 1928). More medical units and hospitals for natives were established, propaganda related to improving housing conditions was distributed to houses, more facilities for entomological research were created, and medication use was popularized as a direct form of control (Kenya Annual Medical Report, 1928; Kenya Annual Medical Report, 1929). There were also multiple surveys, studies and investigations conducted on how best to reduce malaria levels and focus future research throughout the early 1930s—including testing Paris Green as a potential insecticide and looking at different anti-malarial oils' ability to disrupt mosquito breeding areas. These measures were successful in reducing malaria transmissions until a recorded epidemic

in 1937; however, it was noted that less staff and heavy rains led to the outbreak that year and not a lack of control measures (Kenya Annual Medical Report, 1937). Malaria transmission remaining level confirms what Snow suggests on malaria in Kenya during this period; that malaria control was "successful in reducing vector breeding and locally acquired disease incidence" (Snow et al., 2012).

There were limited control information and epidemics recorded during the 1940s, in part due to World War II. While the government stated that the epidemics were not due to the war nor the migration of troops, there is a notable decrease in control measures maintained, and unspecified strategies being used (Kenya Annual Medical Report, 1940).

As a way to re-establish control measures in Kenya and lower the case rate, the government began to perform rounds of spraying with insecticides, but it did little to interrupt malaria transmission (Kenya Annual Medical Report, 1945; Kenya Annual Medical Report, 1946). Eventually in 1951, there was a large reorganization of all antimalaria measures and restructuring of the antimalarial team (Kenya Annual Medical Report, 1951). Medication use was emphasized once again as a treatment and prevention method—with quinine being made available at postal offices as well as hospitals and clinics (Kenya Annual Medical Report, 1950; Kenya Annual Medical Report, 1952). In the 1950s, WHO pilot programs also began and specifically focused on IRS spraying with dieldrin and DDT across rural regions of the country. All of these control measures proved to be successful—medical reports noted case numbers being "substantially lower" than in years before (Kenya Annual Medical Report, 1954; Kenya Annual Medical Report, 1955; Gray, 1956). One of the WHO IRS pilot programs in

Kenya was a part of the Pare-Taveta Malaria Scheme, an elimination program from 1955-1959 involving the Pare district of Tanganyika (now known as Tanzania) and the Taveta district of Kenya. The program was successful in its goals, almost eliminating malaria in the district and greatly reducing malaria transmission levels. However, the program was ended in 1959, and the return of the mosquito vectors following the lack of active control measures coupled with the loss of acquired immunity by the people of Pare and Taveta led to a steady increase in malaria case rates (Graboyes, 2014). This brought up ethical concerns and questions of what responsibility do researchers and medical officers hold to the population they are working within, and the role the program played into the eventual increase in case numbers.

Following this program, there is limited malaria control information available in Kenya for the next 30 years. In the 1970s, there were reports of the use of chloroquine and other medication as a form of malaria control (Snow et al., 2012); in the 1980s and 1990s, there were increasing drug and insecticide resistances. Control measures were not reported upon annually until the 2000s.

At the turn of the century, a national malaria strategy was brought together by the Kenyan government and the WHO with goals to reduce malaria transmission and introduce the use of integrated malaria management (IMM). The strategy had four goals: “access to prompt and effective treatment; management and prevention of malaria during pregnancy; use of ITNs and other vector control methods; and epidemic preparedness and response in 16 epidemic-prone districts” (WMR, 2005). With this strategy, the government began a campaign to expand ITN coverage in Kenya and increase the availability of antimalarial medication in 2004. As a result, there were

increases in ITN and LLIN acquisition and distribution as well as chemoprophylaxis availability and accessibility through 2007, and a "steady reduction of malaria deaths and infection" (Ceesay et al., 2011; WMR, 2005; WMR, 2008). In 2007, there were decreases in LLINs distributed but the numbers picked back up again in 2010 (WMR, 2009; WMR, 2011).

In the 2010s, ITN and LLIN distribution increased from about 1 million in 2013 to over 10 million in 2015, and over 80% of households reported to have at least one ITN in 2017 (WMR, 2016; WMR, 2018) However, from 2018 through 2020, there were significant decreases in funding for malaria control from UNICEF and World Bank, which is expected to decrease through 2021 with the impact of COVID-19 (WMR, 2020).

Malaria Resurgence in Kenya, 1920-2020

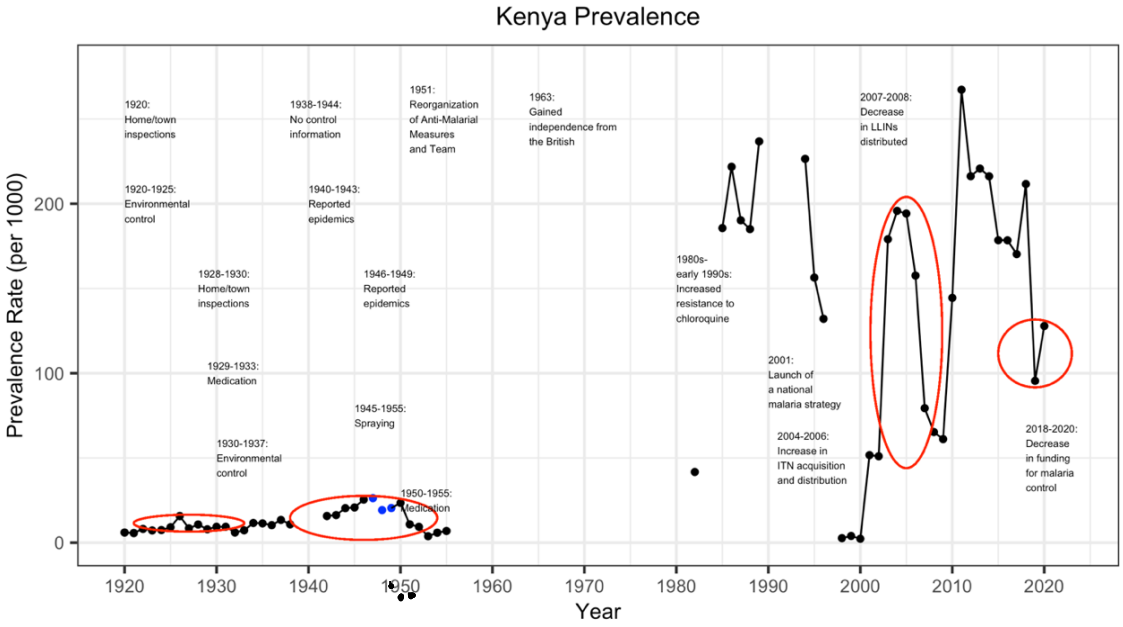


Figure 7: Standardized Malaria Prevalence Rates (per 1000) in Kenya, 1920-2020 [5]

[5] Adapted from *Colony and Protectorate of Kenya Annual Medical Report.* (1920-1955). British Online Archives; *WHO Annual World Malaria Report*. (2005). World Health Organization; *WHO World Malaria Report*. (2008-2021). World Health Organization; *WHO Weekly Epidemiological Record*. (1999). World Health Organization.

Start Date	Peak Date	End Date	Previously reported?
1924	1926	1930	No
1938	1947	1955	No
2002	2004	2008	No
2009	2011	2013	No
2019	2020	Ongoing	No

Table 5: Events of Rebound and Resurgent Malaria in Kenya, 1920-2020

There are five discovered instances of malaria rebound in Kenya, which have not been reported in existing literature. The first event is from 1924-1930, with a peak in 1926. Environmental control measures were halted in 1925, with reported epidemics in 1926 and 1928 (Annual Medical Report, 1928). Malaria was taken more seriously in the region afterwards, and control efforts were reinstated in 1929. The prevalence decreases as a result, with the event ending in 1930.

The second instance of malaria rebound occurs form 1938-1955, with a peak in 1947. From 1938 to 1944, there ws no reported information on control measures in Kenya, due to World War II. Because of the cessation of control measures during this time, prevalence rate increased to a significant amount (Figure 6). The British government reported two epidemics during this period, one from 1940-1943 and one from 1946-1949. While control measures were reinstated in 1945, prevalence does not decrease. Eventually, antimalarial measures were reorganized and reconstructed in order to decrease the prevalence—which it was able to do with prevalence rates levelling out in 1955.

The third event occurs form 2002-2008, with a prevalence peak in 2004. From 2001, a malaria control program occurred for a short period of time, with goals in reducing malaria transmission; however, it ended due to funding concerns. With the end of this program, there was a rise in cases through 2005 with a peak in 2004 (Figure 7). In 2004 to 2006, there was an increase in ITN distribution, and with this we see a fall in cases through 2007. The fourth event occurs right after, from 2009-2013 with a peak in 2011. LLIN distribution decreases starting in 2007, and the early 2010s were reporting on low coverage with ITN and IRS. This led to a sharp increase in prevalence from 2009-2011. With the increase in ITN and LLIN administration in 2011 came a decrease in prevalence through 2013, where this event ends.

The last event starts in 2019, with a current peak in 2020. From 2018-2020, there were significant decreases—almost 50%—in malaria funding that led to an increase in cases starting in 2019. An end date cannot be confirmed at this time since this is an ongoing event.

Malaria Control in Malawi, 1920-2020

The first four decades of malaria control were greatly impacted by lack of funding and staffing. Control consisted of environmental measures and some home inspections, but were sporadic and inconsistent from as early as 1920 through 1939. In 1935 and 1936, efforts were taken to renew malaria control in Malawi with the reorganization of control efforts, and the reimplementation of environmental measures alongside net and quinine distribution (Nyasaland Protectorate Annual Medical and Sanitary Report, 1935; Nyasaland Protectorate Annual Medical and Sanitary Report, 1936). However, these efforts were short-lived. With World War II, staffing and

funding decreased and there were only reports of restricted quinine distribution and routine measures throughout the 1940s. It wasn't until the 1950s that efforts were reinvigorated, with forms of environmental measures and spraying with insecticide occurring in the region (Nyasaland Protectorate Annual Medical and Sanitary Report, 1953). From 1954 to around 1963, Malawi (Nyasaland), along with Zimbabwe (Southern Rhodesia) and Zambia (Northern Rhodesia) formed a semi-autonomous state and began to report medical information across all three countries in concise medical reports. Reported resistance to chloroquine was reported upon during the 1970s and 1980s, but no other information on antimalarial measures were given during this period in time (Spracklen, 1984).

The Combatting Childhood Communicable Diseases (CCCD) project was launched in Malawi from 1984 to 1988, and their support of malaria control research activities continued through 1992. Their work provided key assistance on the following: surveillance on the incidence of malaria and drug sensitivity; assessment of clinical and community-level treatment practices; and development of national treatment and prophylaxis policies" (USAID, n.d.). A number of studies were conducted on the effectiveness of various antimalarial drugs with specific focus on chloroquine, and findings showed that chloroquine was inadequate in treating clinical malaria in young children (Spracklen, 1984; USAID, n.d.). Based on these results, the Malawi Ministry of Health shifted its policy and replaced chloroquine with sulfadoxin-pyrimethamine drug combination (SP) as the first-line antimalarial drug in 1992. In addition, following reports of a resurgence in "a particularly virulent strain of malaria", the CDC worked

alongside the Vector Biology and Control in developing a national malaria control plan from 1990-1994 (USAID, 1993).

With the support of the Roll Back Malaria initiative, President's Malaria Initiative and the Global Fund, control interventions were widely scaled up throughout the country in the 2000s. ACT were adopted as the recommended malaria treatment in 2007, and work was put in to make it freely accessible to the larger Malawi population. ITN administration and distribution also greatly increased from less than 6% in 2002 to over 35% in 2006, and LLINS were distributed on a large scale in 2007 (WMR, 2008; Roca-Feltrer et al., 2012). However, IRS coverage remained less than 10% across the country despite increased efforts in expansion (Roca-Feltrer et al., 2012). From 2010 to 2015, there was a 21% decline in malaria transmission with LLINs and IRS as the main methods of malaria control that continued through 2018, and a decrease in malaria funding in 2019 (WHO Malawi Annual Report, 2015; Malawi Priorities Project, 2021). Future goals for malaria control in Malawi consist of increasing care-seeking behaviors and combatting insecticide resistance.

Malaria Resurgence in Malawi, 1920-2020

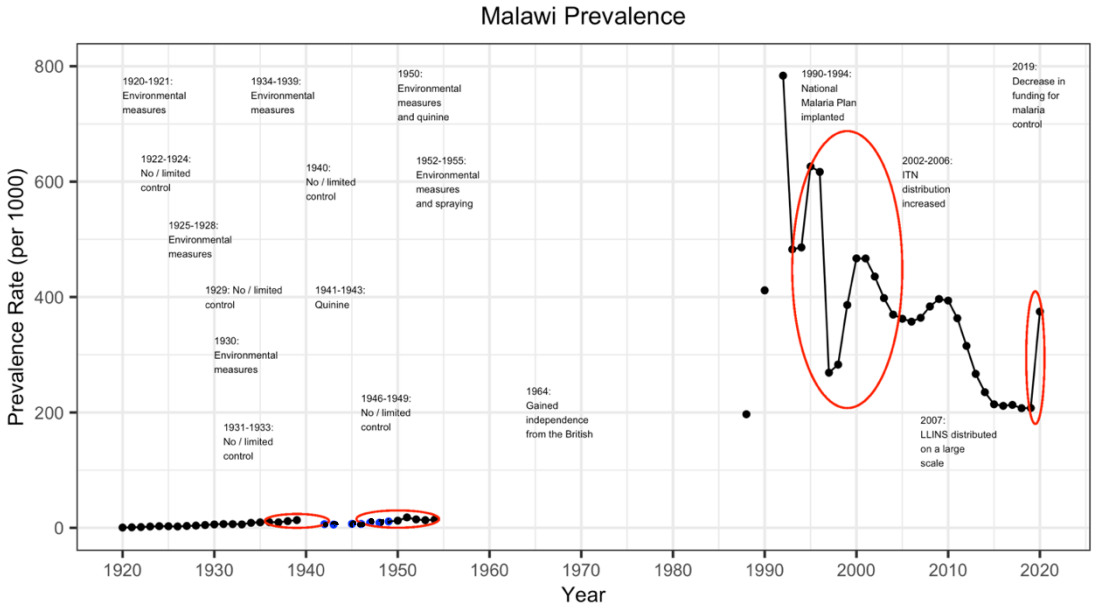


Figure 8: Standardized Malaria Prevalence Rates (per 1000) in Malawi, 1920-2020 [6]

[6] Adapted from *Nyasaland Protectorate Annual Medical and Sanitary Report.* (1920-1955). British Online Archives; *WHO Annual World Malaria Report*. (2005). World Health Organization; *WHO World Malaria Report*. (2008-2021). World Health Organization; *WHO Weekly Epidemiological Record*. (1999). World Health Organization.

Start Date	Peak Date	End Date	Previously reported?
1937	UNK	1945	No
1946	1951	1954	No
1994	1995	2004	No
2019	2020	Ongoing	No

Table 6: Events of Rebound and Resurgent Malaria in Malawi, 1920-2020

There are a total of four events of rebound malaria in Malawi. A zoomed-in portion of the first resurgence event will be provided below alongside the narrative.

A portion of Figure 8 has been zoomed in to easily showcase occurrence of malaria rebound and resurgence from 1937-1945.

The first rebound event takes place from 1937-1945, with a peak occurring sometime between 1939 and 1942. There is no prevalence information from 1940-1941 and 1944. However, based on control measures provided in the medical and sanitary reports, malaria transmission levels increase until at least 1941 before decreasing in 1942. With

World War II, there were gradual decreases in reported control measures starting in the late 1930s. In 1942, quinine distribution was increased alongside other forms of environmental control. Prevalence eventually plateaus in 1945, which marks the end of that rebound event.

The next event occurs right afterwards from 1946-1954 with a peak in 1951. Quinine usage went down, and only "routine measures" were occurring in the region (Annual Medical and Sanitary Report, 1947). With restricted control measures, malaria prevalence steadily increased (Figure 8). In 1950, there are further control restrictions due to funding concerns, and it is not until 1952 that we see control measures renewed though 1955, with the prevalence levelling out by 1954.

The third rebound event takes place from 1994-2004, with a peak in 1995. With more control information, this event could start as early as 1988. With increasing resistance to insecticides and drugs, malaria case rates were relatively high during this time (Spracklen, 1984). From 1990-1994, Malawi implemented a malaria control plan, shifting from chloroquine as the first-line antimalarial drug. In addition, from 2000, control interventions were widely scaled up across the country, all of which eventually led to a decrease in prevalence through 2004.

The last malaria rebound event starts in 2019, with a current peak in 2020. With increases in insecticide resistance and decreases in malaria control funding, prevalence increased on a large scale in 2020 (Malawi Priorities Project, 2021; Figure 8).

Malaria Control in Uganda, 1920-2020

The 1920s and 1930s malaria control in Uganda largely consist of environmental measures—including but not limited to: drainage and control of swamps,

use of oil and larvicides in standing water, bush clearing, and canalization of streams. While they are increases in case numbers from 1926, this is strictly due to improvements in diagnosis. Quinine was also administered during this period but was "undoubtedly amongst Europeans… carried out more thoroughly" (Uganda Annual Medical and Sanitary Report, 1925). A shift was made in 1927 on the format of control measures, with regular inspections taken of malaria conditions and action only taken when necessary. With this change in control implementation, sparse control efforts were recorded during the 1930s. Control measures were recorded from 1934-1937, with experiments conducted on larvicides, environmental measures focused on vector control and quinine administration with a focus on the European settler population. After research and studies were conducted, mepacrine took the place of quinine as first-line antimalarial drug in 1939 (Uganda Annual Medical and Sanitary Report, 1939).

The 1940s and 1950s brought about the fruition of new control measures. While vector control through environmental measures remained a focus on malaria control schemes, indoor spraying began with DDT, and nets were more widely distributed. The largest problem remained that control was only restricted to larger urban areas of the country, which meant a great majority of the Ugandan population were left out of control measures and schemes. It was stated that "personal measures of prophylaxis by mosquito-proofing houses, insecticidal spraying, the use of mosquito nets and chemoprophylactic drugs are at present beyond the reach of the mass of the population" (Uganda Annual Medical and Sanitary Report, 1949). There were also discussions on malaria eradication in Uganda—specifically on whether it was feasible for malaria to be eradicated in a hyperendemic country through only residual spraying and other forms of

vector control. It was also brought up that disturbance of the host-parasite connection "would carry serious risks if eradication was not complete and permanent" (Uganda Annual Medical and Sanitary Report, 1950; Uganda Annual Medical and Sanitary Report, 1951).

With Ugandan independence from the British, public health focus shifted away from malaria as the country worked to reestablish and rebuild itself. The conflict did not allow for the construction of WHO pilot schemes or large-scale malaria programs since the environment and political landscape was too unstable (Alilio et. al, 2004). The next couple of decades did not have reported control information, only statements on increasing resistance to chloroquine and other insecticides until as late as 1999. Afterwards, in conjunction with WHO, RBM launched a strategic plan to guide malaria control activities from 2001-2005. Its main goals included effective treatment, vector control and epidemic preparedness (WMR, 2005). In addition, IRS was reincluded in control measure efforts after over 40 years of it not being used in the country. Despite these measures, there were reports of high malaria transmission through the 2000s in Uganda with the clinical burden in hospitals and clinics increasing (Snow et al., 2012). Use of ITNs and ACT were increased throughout the 2010s due to increasing in financial support.

Uganda Ministry of Health's current National Malaria Control Program hopes to "provide quality assured services for malaria prevention and treatment" and includes the following goals:

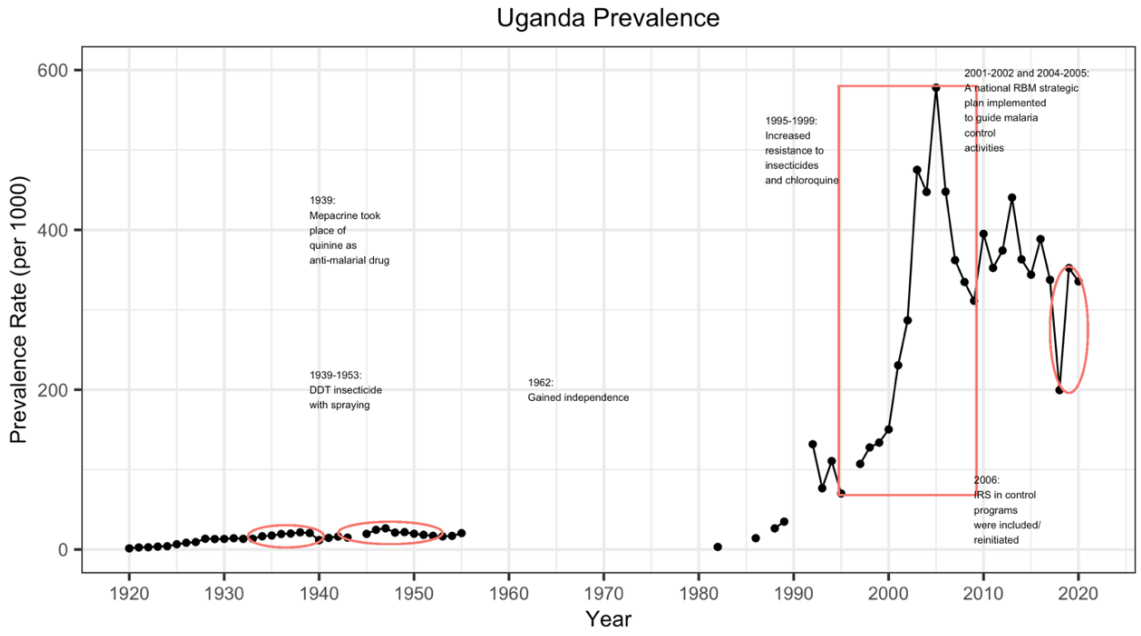
> "By 2020, reduce annual Malaria deaths from the 2013 levels to near zero (Near zero implies less than 1 death per 100,000 population); by 2020, reduce malaria morbidity to 30 cases per 1000 population (That is 80% reduction from the 2013 levels of 150 confirmed malaria cases per

> 1000 population); and lastly, by 2020, reduce the malaria parasite prevalence to less than 7% (Over 85% reduction in malaria parasite prevalence from a baseline of 45% in 2010) (Uganda MoH, 1970).

While much of these goals were not reached, this plan highlights the importance of a multisectoral approach towards malaria control programs, and in trying to use different areas for control interventions can have a farther reach.

Malaria Rebound and Resurgence in Uganda, 1920-2020

Figure 9: Standardized Malaria Prevalence Rates (per 1000) in Uganda, 1920-2020[7]



[7] Adapted from *Uganda Protectorate Annual Report of the Medical Department.* (1920-1955). British Online Archives; *WHO Annual World Malaria Report*. (2005). World Health Organization; *WHO World Malaria Report*. (2008-2021). World Health Organization; *WHO Weekly Epidemiological Record*. (1999). World Health Organization.

Start Date	Peak Date	End Date	Previously reported?
1933	1938	1940	No
1940	1947	1953	No
2000	2005	2011	No
2018	2019	Ongoing	No

Table 7: Events of Rebound and Resurgent Malaria in Uganda, 1920-2020

The first event is from 1933 to 1940, with a peak in 1938. While the reasons were not explicitly stated in the Medical Report, there was a decrease in control measures being implemented year to year starting in 1931, with only routine control information being reported from 1933-1937. This gradual decrease in control measures led to an increase

in prevalence starting in 1933. DDT use became popularized in 1938 again, and a new antimalarial drug taking place of quinine in 1939. With these two control measures reimplemented, we see a decrease in prevalence through the end of the 1930s.

The second event takes place from 1942 to 1953 with a peak in 1947. With World War II, there was very little information on control measures in Uganda during the 1940s. With the lack of control measures, prevalence in the region increased until IRS with DDT became a new measure for control, noting its effectiveness in lowering prevalence rates (1948). Following this, we see a relative decrease in the rate from 1948 through 1953, where the event officially ends.

The third instance goes from 1995 to 2011, with a peak in 2005. Due to increasing resistance to insecticide use from 1995-1999, there is an increase in prevalence through 2005 (Figure 9; Spracklen, 1984). A national RBM strategic plan was implemented from 2004 to 2005 with funding to help guide malaria control activities in Uganda. In addition, IRS was reinitiated in Uganda in 2006 after over 40 years of not being used. Both of these measures together led to a decrease in rates through 2009, with prevalence eventually levelling out in 2011 (WMR, 2008).

The last case starts in 2018. According to the Ugandan government, there had been an unprecedented increase in prevalence from 2017 to the present (WMR, 2020). They cite the reasons for the increases in prevalence to be due to climate change and a failure by the public to properly use insecticide treated bed nets (Yeka et al., 2013).

Malaria Control in Zanzibar, 1920-2020

Malaria control in the first two decades largely consisted of environmental control to destroy areas of mosquito breeding. A mosquito brigade was established in

the early 1920s to conduct antimalarial work in what was considered the native part of town. There were also advancements in malarial control; Paris Green was also introduced as an insecticide during this time and quinine was delivered during some years as a form of chemoprophylaxis. While control efforts were made, malaria was highly endemic to the region which meant malaria transmission was at an increase. There were also multiple moments during this time that control had to be stopped due to a lack of finances or resources, with reports in 1927, 1934 and 1935 stating that antimalarial work was not conducted "owing to the financial stringency" (Zanzibar Protectorate Annual Medical and Sanitary Report, 1927; Zanzibar Protectorate Annual Medical and Sanitary Report, 1935). The end of the 1930s were dedicated to research and surveys in order to determine best next steps in malaria control.

During the 1940s, environmental control was continued with oiling standing water, home and town inspections and swamp drainage. Alongside environmental control measures were the first uses of DDT as an insecticide for residual spraying, which proved to be successful in lowering malaria transmission. However, it was only used free of charge in government employee households and in private residential areas at a cost (Zanzibar Protectorate Annual Medical and Sanitary Report, 1947; Snow et al., 2012). In the early 1950s before the start of the GMEP, the only control measures were larvicides and occasional use of Paris Green.

With the launching of the GMEP came renewed efforts in control that was prevalent on the island. It was determined that indoor residual spraying (IRS) would be the best method for eliminating malaria on the island. WHO began a control program in 1957, which shifted into an eradication program in 1961 (USAID, 1985; Snow et al.,

2012). The WHO ran biannual cycles of spraying with DDT alongside drug administration. These both proved to be very successful, reducing prevalence to 0.8% in 1967 (Snow et al., 2012). However, since transmission was not completely interrupted and prevalence rates did not hit zero, the program was deemed unsuccessful. Control efforts formally ended in 1968, and with that ending came the resurgence of malaria on the island.

Efforts were revived in the 1980s with the creation of the Zanzibar Malaria Control Project (ZMCP). Funded by USAID, the goal of the program was to reduce malaria transmission "to a level which no longer constitutes a major public health problem" (USAID, 1985). This second attempt in malaria control consisted of two rounds of residual spraying with DDT and increased administration of chloroquine but "failed to show any perceptible change", bringing about its ending in 1989 (Snow et al., 2012)

Malaria control did not begin again until early 2000s. With rising resistance to chloroquine, ACT became widely available and administered. In addition, ITN, LLIN and IRS coverage were greatly expanded, all of which led to a large decline in malaria prevalence and transmission from 2004 onwards (Snow et al., 2012). From 2008, there remained a low level of malaria prevalence in the country with community-based malaria prevalence in regions of Zanzibar presenting as less than 1% and 98% of children under five receiving either ITN or IRS coverage (Snow et al., 2012; Björkman, et al., 2017). From this time onward, Zanzibar entered a state of pre-elimination malaria control, which meant that efforts have shifted from control to elimination.

The Zanzibar Malaria Elimination Program (ZAMEP) was created in 2013 to reflect the country's shift to elimination, with initial goals to eliminate malaria from the region by 2018 (Khandekar et al., 2019). The program maintained ITN and IRS usage throughout the past decade. In addition, there were advancements in malaria surveillance technology with case notifications delivered via mobile applications and a testing of all members of a household with a positive case of malaria (Björkman, et al., 2017; Khandekar et al., 2019).

Malaria Rebound and Resurgence in Zanzibar, 1920-2020

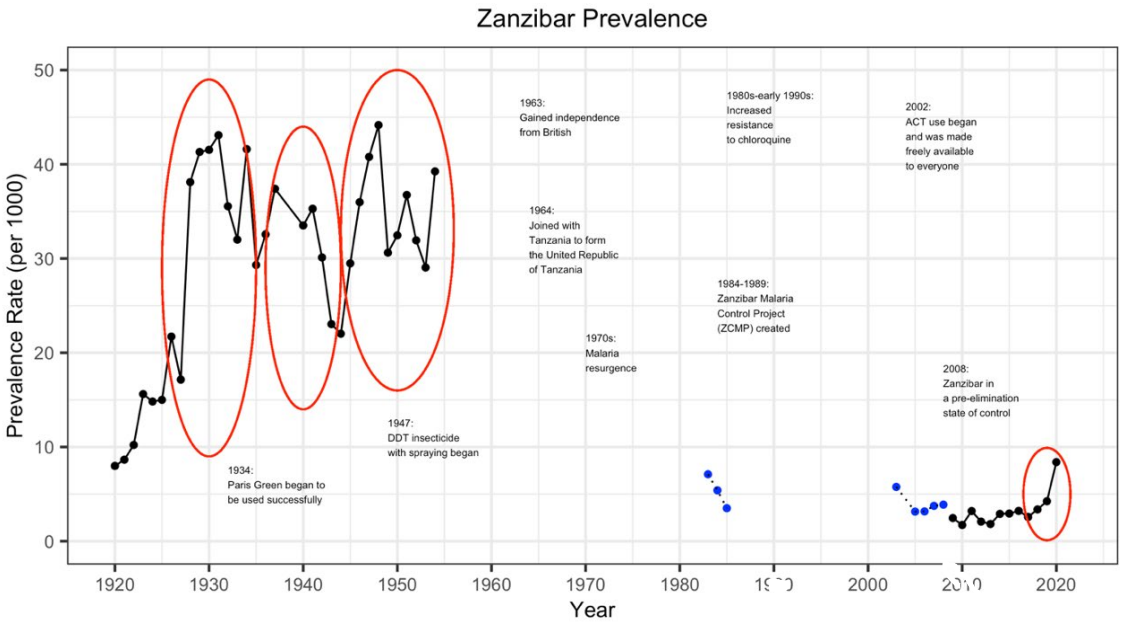


Figure 10: Standardized Malaria Prevalence Rates (per 1000) in Zanzibar, 1920-2020[8]

[8] Adapted from *Zanzibar Protectorate Annual Medical and Sanitary Report.* (1920-1955). British Online Archives; *WHO Annual World Malaria Report*. (2005). World Health Organization; *WHO World Malaria Report*. (2008-2021). World Health Organization; *WHO Weekly Epidemiological Record*. (1999). World Health Organization.

Start Date	Peak Date	End Date	Previously reported?
1925	1931	1935	No
1935	1937	1943	No
1944	1948	1955	No
2017	2020	Ongoing	No

Table 8: Events of Rebound and Resurgent Malaria in Zanzibar, 1920-2020

The first event occurs from 1925-1935, with a peak in 1931. In 1926, there was a reorganization of the healthcare infrastructure in Zanzibar and medical officers in 1927 emphasizing the need for increased funding for malaria control. A lack of funding, combined with the endemicity of Zanzibar at this time, led to a large increase in prevalence with a peak in 1931. Recognizing the need for increased controls, the government implement house and town inspections into their control measures in 1931, and Paris Green as an insecticide in 1934. With both of these, we see a decrease in control measures through 1935.

The second event we see is right afterwards, from 1936-1944, with a presumed peak in 1939. Once again, in 1936 there are visible decreases in control measures taking place in Zanzibar. There are no control measures reported on throughout the end of the 1930s due to World War II. In 1945, the Annual Medical Reports stated that control

measures were very stunted throughout the beginning of the 1940s (Zanzibar Medical and Sanitary Report, 1943). However, more funding was made available in 1940 for control, and with the increases in control measures was a subsequent decrease in prevalence through 1944.

Lastly, the third event we see follows right afterwards, starting in 1944vwith peak in 1948. A combination of political instability and decreases in control interventions led to an increase in malaria transmissions through 1948. In 1946, IRS with DDT became popularized, leading to an overall decrease in prevalence. An end date cannot be determined at this time due to interruptions in data collection.

The last event begins in 2017. There is a slight increase in prevalence through 2020; however, control information does not explain what this increase is due to. Until more information is received, this will remain only a case of potential rebound.

Malaria Control in Zimbabwe, 1920-2020

Malaria control and prevalence is not reported on consistently in Zimbabwe until 1930, stating usage of environmental control—specifically draining pools and swamps and oiling of standing water—and chemoprophylaxis to maintain malaria control in the region. However, malaria was highly endemic in the country at the time, and so the 1930s also brought about malaria epidemics, starting in 1931 and occurring through 1935 (Southern Rhodesia Annual Report of the Public Health, 1931; Southern Rhodesia Annual Report of the Public Health, 1933; Southern Rhodesia Annual Report of the Public Health, 1935). The 1930s also brought biomedical advancements with the replacements of quinine with mepacrine in 1939 (Southern Rhodesia Annual Report of the Public Health, 1939).

Control is not believed to have begun in earnest until the 1940s (Snow et al., 2012). DDT is introduced into the region, and is used for residual spraying through the decade. Control interventions were also expanded, with over 200,000 people covered by IRS by the early 1950s and different forms of chemoprophylaxis more widely used and available (Snow et al., 2012; Southern Rhodesia Annual Report of the Public Health, 1941; Southern Rhodesia Annual Report of the Public Health, 1949). These efforts are reflected in the numbers; malaria hospital admissions decreased from 10% to 0.3% by 1962 (Snow et al., 2012; Taylor and Mutambu, 1986). Little control information is available in Zimbabwe during the 1960s and 1970s in part due to the country's political instability, and the 1980s and 1990s consisted of rising insecticide and drug resistance, and malaria epidemics of differing frequencies (Snow et al., 2012). With continued political wrought and unrest throughout the 1990s, prevalence rates drastically increased (Figure 11).

Advancements and shifts were made in malaria control in the 2000s. The first-line treatment changed from chloroquine to a combination of chloroquine and sulphadoxine-pyrimethamine in 2004, then ACTs in 2006; IRS with DDT was reintroduced in 2004 and; ITN coverage increased to 42% in 2008 (Snow et al., 2012; WMR 2005; WMR, 2008; WMR, 2010). However, despite these advancements, prevalence remained very high throughout the 2000s, eventually decreasing in 2006 and reaching lower prevalence levels in 2012 (Figure 11). These control measures were maintained throughout the 2010s, with greater financial support from PMI starting in 2011 (WMR, 2012; WMR, 2021).

Malaria Rebound and Resurgence in Zimbabwe, 1920-2020

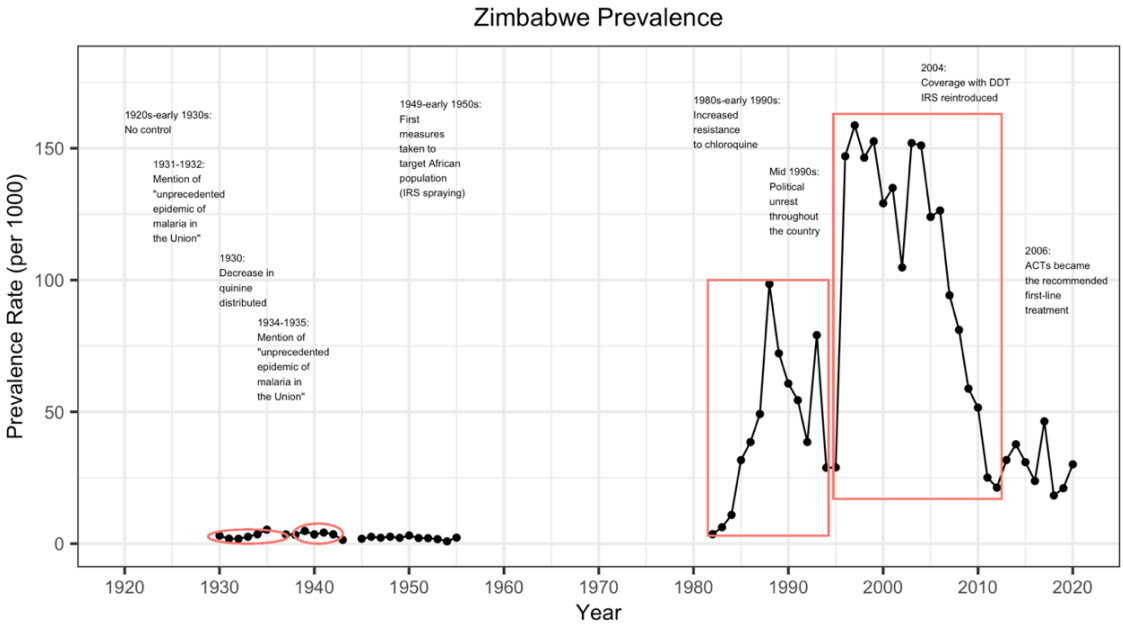
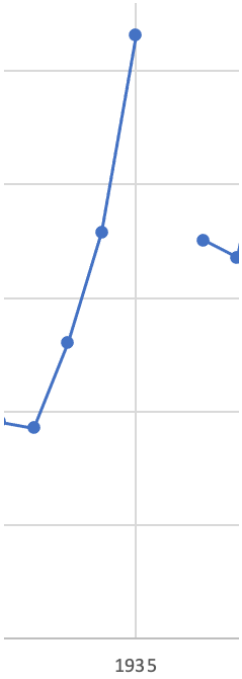


Figure 11: Standardized Malaria Prevalence Rates (per 1000) in Zimbabwe, 1920-2020 [9]

[9] Adapted from *Southern Rhodesia Report on the Public Health.* (1920-1955). British Online Archives; *WHO Annual World Malaria Report*. (2005). World Health Organization; *WHO World Malaria Report*. (2008-2021). World Health Organization; *WHO Weekly Epidemiological Record*. (1999). World Health Organization

Start Date	Peak Date	End Date	Previously reported?
1932	Not Known	1937	No
1938	1939	1951	No
1984	1988	1994	No
1995	1997	2011	Yes

Table 9: Events of Rebound and Resurgent Malaria in Zimbabwe, 1920-2020



A portion of Figure 11 has been zoomed in to easily showcase occurrence of malaria rebound and resurgence from 1932-1937.

There are a total of four events of rebound and resurgent malaria in Zimbabwe. The first rebound event occurs from 1932-1937, with a presumed peak during that time frame. Medical reports indicated a decrease in quinine distributed in 1930, with plans to conduct research into feasible and quality control to implement in Zimbabwe. Reports also mentioned an "unprecedented epidemic of malaria in the Union" in 1931-1932 and 1934-1935, and noted from 1930 to 1935 the need for further measures for the

prevention and control of malaria in Zimbabwe (Report on the Public Health, 1931; Report on the Public Health, 1932; Report on the Public Health, 1934; Report on the Public Health, 1935). These different factors laid the groundwork for a rebound event to occur. Control measures were reimplemented in 1935, with reported decrease in prevalence the following years.

A portion of Figure 11 has been zoomed in to easily showcase occurrence of malaria rebound and resurgence from 1938-1951.

The second event of rebound takes place from 1938-1951, with a peak in 1939. As been stated for other countries, there was very little control information from 1938 through early 1940s due to World War II. However, there are reports on decreases in funding provided and control measures being exercised at the end of the 1930s and early 1940s, and a renewal in control efforts beginning in 1945 (Report on the Public Health, 1941; Report on the Public Health, 1945). With this, it's clear that while control decreased the prevalence rate, it did not level it out until 1951 (Figure 11).

The third event takes place from 1982-1994, with a peak in 1988. In Zimbabwe, there was increasing chloroquine resistance starting in the 1980s until early 90s, with increases in prevalence through early 1990s. We eventually see the prevalence rate reach a plateau in 1995. Snow et al. note these increases in prevalence in their work, stating that "the country witnessed a number of severe epidemics of increasing frequency from the mid-1980s with the most widespread and severe epidemics in 1988 and 1993" (25).

The last instance of rebound malaria from 1995-2012, with peaks in 1997. There was continued disruption within the health sector brought about by political unrest in the region and with the country nearing the brink of war, coupled with rising insecticide and drugs resistance as well as other financial concerns, there is an exponential rise in malaria prevalence. Prevalence does not begin to decrease until 2006 with the implementation of ACTs as the new first-line antimalarial drug. The prevalence continues to decrease until it plateaus in 2012. Cohen et al. note this resurgence in their work, similarly citing drug resistance and resource constraints as the two main causes of the event (Cohen et al., 2012).

Results

Country Name	Events captured in Thesis	Events captured by Cohen
The Gambia	1927-1932 1939-1948 1952-Not Known 1984-1990 1999-2005 2005-2011	N/A
Ghana	1940-1945 1945-1955 1998-2004 2009-Ongoing	N/A
Kenya	1924-1930 1938-1955 2002-2008 2009-2013 2019-Ongoing	1956-1961 (Regional: Highlands) 1959-1962 (Regional: Pare-Taveta) 1977-UNK (Regional: Kisumu) 1990-1998 (Regional: Highlands)
Malawi	1936-1945 1946-1954 1994-2004 2019-Ongoing	N/A
Nigeria	1933-1938 1945-1953 2008-Ongoing	N/A
Sierra Leone	1935-1946 1947-Not Known 1997-2006 2007-2017	N/A

Uganda	1933-1940 1940-1953 2000-2011 2018-Ongoing	1990-1994 (Regional: Highlands)
Zanzibar	1925-1935 1935-1943 1944-1955 2017-Ongoing	1967-1983 1989-1997
Zimbabwe	1932-1937 1938-1951 1984-1994 **1995-2011**	**1995-2007**
Total Events	36	8

Table 10: Total Events of Malaria Rebound and Resurgence, compared to Cohen et al.

My findings have revealed a total of 36 cases of rebound malaria across nine African countries. In comparison, Cohen and his team identified only eight events in four of the listed African countries. In the table, the side-by-side comparison shows that there is only one event of resurgence on my epidemic graphs that's been reported before—in Zimbabwe from 1995-2012. This means that this thesis has identified 35 cases of rebound and resurgent malaria that has never before been reported anywhere else. Part of the reasons there could be such a difference in total events captured is the timeframe. Cohen et al.'s work only went from 1930s to the 2000s; whereas this research collected data from 1920s to 2010s, collecting two decades of prevalence data and control that Cohen's team did not.

Despite that, these results are very significant. For one, it is clear that malaria rebound and resurgence are underreported, and what has been reported fails to include much representation from the African continent—which could be due to a number of factors, including shortcomings in data collection and research publication norms. In addition, these findings also reveal a dichotomy between data collection methodology and presentation, as well as data analysis norms and practices. With new methods of presentation, new insights and cases were revealed. This emphasizes the need for the WHO and other public health agencies to continue to share annual malaria data, but shift the lens used to present it.

This work also challenges the ethics of data collection methodologies. Data from the WHO is used by other global health partners and agencies to determine where malaria funding is most needed. Without the full context, these organizations are not able to make a well-informed decision, which could lead to consequences and harm brought upon these African countries. As leaders in the world of public health, the WHO— alongside other organizations— hold a responsibility to ensure that their data is presented in a form that is most useful to all stakeholders involved, recognize their role in creating the conditions necessary for rebound and resurgence and provide the appropriate response in order to minimize that harm done.

CONCLUSION

Malaria resurgence is a phenomenon across the African continent, and the underreporting of this phenomenon can be attributed to the ways in which the World Health Organization and other public health institutions collect and present data. Through the creation of a panel dataset based on data collected from annual WHO reports and the British Online Archive, this research project aims to account for and fill in the ruptures in existing data to determine whether there are unreported cases of epidemic rebound malaria in The Gambia, Ghana, Kenya, Malawi, Nigeria, Sierra Leone, Uganda, Zanzibar and Zimbabwe.

The findings have revealed 35 cases of rebound and resurgent malaria that have never been reported in existing literature. These results support my hypothesis that there are numerous instances of rebound malaria "hiding in plain sight," events that, due to the nature of malaria transmission, are impossible to capture in datasets with a narrower timeframe. While the WHO graphs often span multiple years, the manner in which their data is presented obfuscates these patterns of rebound and resurgence which our research was able to uncover. This research provides a thorough analysis of a century's worth of malaria prevalence and control measures in nine African countries, information that has been notably absent from the archives and the literature.

The implications of this research are far-reaching, impacting the field of malaria research, and raising valuable questions about the norms and ethics of data collection and presentation. These results show enormous discrepancies between malaria rebound and resurgence events in existing literature and as seen through the generated epidemic curves. These discrepancies have enormous consequences for the field of global public

health and on the lives and wellbeing of the African people whose bear the impact of the collection, interpretation, and misinterpretation, of this data. While this research only includes nine African countries, it's highly probable that there are more instances of resurgent malaria recorded in other databases that have yet to be classified as rebound events. Africa carries the highest malaria burden in the world yet lacks access to the funding and resources other continents do. This reality cannot be decontextualized from the centuries of colonial rule that shaped the relationship between African countries and their former colonizers, a relationship which still shapes the economic and political landscape of our world. Because proper malaria control and elimination measures take dedicated time and effort, it is imperative that the limited funding and resources provided to African states are utilized in the most efficient manner possible. It is impossible to make an accurate assessment of control efforts without an understanding of the current and past condition of malaria transmission in the region. The presentation of WHO data forecloses the possibility of accurately assessing the efficacy of control efforts and undermines any potential mitigation of malaria transmission in these 9 countries.

This work raises important questions about the causes, prevention, and responsible responses to rebound and resurgent malaria. Malaria rebound and resurgence impact and shift epidemiological patterns of malaria in a country. National trends in malaria prevalence are not necessarily representative of local and regional trends and patterns. Because of the differences in malaria transmission and the environmental impact on transmission in different regions of a country, a reported local rebound event may not be classified as such in the national trends. This means that the

quantification of past and current resurgence events is vital to the prevention of future resurgences. Having a more whole understanding of past resurgence events in any given country allows the appropriate public health response and intervention when the need arises.

On a larger scale, this research has serious implications for best practices when it comes to data collection and challenges the way WHO and other public health organizations present epidemiological data. The fact that a change in the presentation of the data was enough to reveal unreported instances of resurgent malaria makes a case for the interrogation of the norms of data collection and presentation. Current methods of data collection provide an inaccurate picture, preventing international public health organizations and national governments from accurately assessing the risk of malaria, the frequency of rebound epidemics, and the barriers towards accessing malaria control measures and treatments. It is the people of the countries that bear the greatest malaria burden who suffer from these oversights, and who are unable to get the support they need. The WHO, in addition to other public health organizations, must reconsider their current methods of data collection. Based on this research, reporting out epidemiological data over the span of short years showed not nearly as much in malaria trends nor patterns, while extending that timeframe over decades lend itself to new discoveries being made.

Additionally, the research raises questions on the near identical trends in prevalence across eight of the nine studied African countries that hasn't been accounted for in existing literature: What factors are contributing to the drastic increases in prevalence from 1920-1955 and from 1980-2020? What do these findings reveal about

malaria prevalence on a broader scale, and the methods and metrics of data collection and presentation? This finding was not part of the original hypothesis and requires closer examination to determine what socio-political, environmental, or other forces may account for these trends.

This research illustrates the necessity of quantifying resurgence events in order to accurately evaluate the efficacy of control measures in a region and prevent future instances of resurgent malaria. It is my hope that this research will prompt public health organizations and funding agencies to reconsider and shift their current methods of data collection and presentation to portray a more accurate sense of the conditions of malaria in any given country, ultimately resulting in more effective and efficient malaria control efforts, and better public health outcomes for the people of the African continent.

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