Impact of the 2023 Armed Conflict of Sudan on Routine Malaria Data Reporting:

Trend Analysis of Three Key Impact Indicators (January 2020- March 2025)

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by

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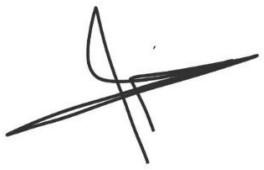
The thesis Impact of the 2023 Armed Conflict of Sudan on Routine Malaria Data Reporting: Trend Analysis of Three Key Impact Indicators (January 2020- March 2025) is my own work.

Signature: 

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Abstract:

Background:
Malaria remains a leading cause of morbidity and mortality in Sudan, accounting for most outpatient visits and hospital admissions in 80% of the states. The health system, already fragile, was further destabilized by the April 2023 conflict, which severely undermined health surveillance infrastructure and triggered a major displacement crisis. No prior study has investigated the conflict's impact on routine malaria surveillance data reported to DHIS2.

Methods:
This study analyzed quarterly malaria impact indicators from DHIS2 for 17 states (excluding Khartoum) from January 2020 to March 2025. A mixed-methods approach was adopted. Quantitative analysis included time trend comparisons pre- and post-conflict, and interrupted time series analysis (ITSA) for 11 states with complete post-conflict data. Qualitative data were gathered through key informant interviews, using a semi-structured format and deductive framework analysis guided by questionnaire themes.

Results:
Significant variation of the indicators was observed across states. Darfur, South, and West Kordofan states showed persistent missing data post-conflict, whereas northern and eastern states continued consistent reporting, corroborated by qualitative findings of improved reporting in these areas. ITSA revealed a significant immediate decline in reported malaria cases per 100,000 population during the conflict quarter, with no further significant changes thereafter. Key challenges identified included destruction of health infrastructure, staffing shortages, unpaid salaries, and communication breakdowns.

Discussion:
Disparities in surveillance and reporting are largely attributable to preexisting infrastructure and personnel differences, compounded by conflict intensity. Strengthening surveillance, innovative outreach to inaccessible populations, and a unified malaria data system are recommended to improve monitoring and response.

Keywords: Malaria surveillance, conflict affected settings, Sudan DHIS2, malaria impact indicators, mixed methods

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List of Abbreviations:

DHIS2	**Digital Health Information System 2**
EMRO	**WHO Eastern Mediterranean Region**
EWARS	**Early Warning, Alert and Response System**
FMOH	**Federal Ministry of Health**
GDP	**Gross Domestic Product**
HBHI	**High Burden High Impact**
HEEC	**Health Emergency and Epidemic Control**
HIS	**Health Information System**
HMIS	**Health Management Information System**
IDP	**Internally Discpalced Person**
IDSR	**Integrated Disease Surveillance and Response**
ITSA	**Interrupted Time Series Analysis**
IVM	**Integrated Vector Management**
KI	**Key Informant**
KII	**Key Informant Interview**
M&E	**Monitoring and Evaluation**
MNAR	**Missing Not at Random**
NGO	**Non Governmental Organization**
NMCP	**National Malaria Control Program**
PHC	**Primary Health Care**
PUDR	**Performance Data and Disbursement Request**
RDT	**Rapid Diagnostic Test**
RSF	**Rapid Support Forces**
SAF	**Sudan Armed Forces**
SMOH	**State Ministry of Health**
WHO	**World Health Organization**

Glossary:

Internally Displaced Person (IDP): "is someone who has been compelled to leave their home due to conflict, violence, persecution, or natural disasters but has not crossed international borders and remains within their own country(1)."

Incidence rate: "defined as the rate of new malaria cases over a specified period of time within the population at risk (2)"

Mesoendemic: "whether a disease occurs with low frequency" (3)

Hypoendemic: "A disease that is constantly present at a low incidence or prevalence and affects a small proportion of individuals in the area"(2,4)

The surveillance system: It is defined as a systematic, continuous collection of data, analysis, and interpretations to detect the disease burden through data management and prioritize prevention and control activities in a timely fashion (5).

Introduction: -

I am a preventive medicine resident who worked at Sudan's National Malaria Control Program as a case management officer, before and during the conflict. Following my displacement, I continued serving with the state malaria program where I was displaced. Through these experiences, I witnessed the profound impact of armed conflict on health systems, especially the critical need for evidence-based decision-making amidst severely limited resources.

The main challenge I faced was assessing health needs and program performance when routine data collection systems were either compromised or had collapsed entirely. This fundamental problem—how to reliably measure and respond to public health needs when surveillance infrastructure is disrupted—was the driving force behind choosing this research topic. My work seeks to document the effect of the 2023 conflict on selected malaria program impact indicators and to systematically explore the challenges encountered in data collection and health system operation during such a crisis.

By undertaking this thesis, my aim is to provide robust evidence for stakeholders about Sudan's urgent need for international and national support, particularly in restoring and strengthening surveillance capacity. I also hope this work will highlight the scale of the data and operational challenges facing Sudan's health system after the conflict and contribute to developing innovative solutions that can help surpass these obstacles in similar settings.

CHAPTER 1: BACKGROUND INFORMATION

1.1. Country profile: -

Sudan is a northeastern African country. The country is administratively divided into 18 states, each of which is further subdivided into localities, resulting in a total of 189 localities across the country (6). Khartoum state is the capital that hosts the national government. Each state has its local governmental unit. Sudan's population is estimated to be 50,448,963 in 2024 with an annual growth rate of 2.53% (7) (6) . This population is spread across 1,886,068 square kilometers, positioning Sudan as the third-largest nation in Africa by area(8). The Country shares borders with seven nations: the Central African Republic, Chad, Egypt, Eritrea, Ethiopia, Libya, and South Sudan (9). Notably, five of these neighboring countries are malaria endemic (10).

1.2. Demographics: -

Sudan is characterized by a predominantly young demographic, with 50.6% of the population under 18. Most of the population resides in rural areas, representing 55% of the population, while 33% live in urban areas. Nomads, internally displaced populations (IDP), and refugees constitute the rest of the population(6). Life expectancy at birth is 66 years (11).

1.3. Geography: -

Sudan is characterized by considerable environmental heterogeneity, shaped largely by the north-to-south variation in annual rainfall. This climatic variation dictates the duration of the rainy season, ranging from approximately three months (July to September) in the northern regions to six months (June to November) in states such as South Kordofan, Blue Nile, and South Darfur(6).

This diverse environmental landscape encompasses deserts in the far north, semi-desert zones extending into northern central areas, low rainfall savannahs in central regions, high rainfall savannahs in the south, and isolated pockets of mountain vegetation (12). This environmental heterogeneity, therefore, directly influences the variable dynamics of malaria transmission and endemicity across Sudan. Levels of endemicity, ranging from mesoendemic to hyperendemic, are closely linked to seasonal rainfall patterns and vector densities (13).

Consequently, the northern states are predominantly hypo-endemic, except areas such as Port Sudan and El-Fasher, whereas the eastern, southern, and western regions experience higher transmission intensities (13). Furthermore, the development of large-scale irrigation schemes in certain areas has facilitated recurring malaria transmission, even outside the typical rainy season (6).

1.4. Economy and political situation: -

Sudan is classified as a low-income country contends with a considerable national debt (14), and widespread poverty, reaching a rate of 66.1% in 2022 (6). Its economic fragility is further evidenced by a low gross domestic product (GDP) per capita, estimated at approximately $751.82 in 2021. This economic landscape translates into severely constrained health expenditures; in 2019, annual per capita health spending was only 4.6% of the national GDP (6).

Consequently, health financing is heavily reliant on out-of-pocket payments, which accounts for 69% of health spending in 2018. With health insurance contributing to overall health expenditure by only 6.7% in 2018 (6). Beyond these economic challenges, Sudan's development is profoundly hampered by prolonged political instability, critically exacerbated by the outbreak of conflict in April 2023, which has led to dramatic economic contraction and soaring inflation (14).

1.5. Health system: -

Sudan's health system operates under a decentralized model, with responsibilities distributed across federal, state, and locality levels. The Federal Ministry of Health (FMOH) serves as the national authority, driving the development of strategic health plans and overseeing state-level implementation. State Ministries of Health (SMOHs) are responsible for adapting these plans to local contexts and ensuring their execution, while locality governments manage the actual delivery of health services at the locality level, all under the supervision of SMOHs(6).

Malaria control is led by the National Malaria Control Program (NMCP), which is situated under the Directorate of Communicable Disease Control, part of the Directorate General of Primary Health Care (PHC) at the FMOH. The NMCP's core function is to coordinate nationwide malaria control efforts; however, its operational reach is somewhat constrained.

Essential malaria-related activities are managed by separate departments (15),for instance, integrated vector control is overseen by the Integrated Vector Management (IVM) Department. Surveillance, epidemic preparedness, and data collection for malaria fall under the mandate of the Health Emergency and Epidemic Control (HEEC) General Directorate, rather than the NMCP itself. Similarly, procurement and supply management of malaria commodities is handled by the National Medical Supplies Fund. This fragmented structure leads to coordination challenges and highlights the program's need for strengthened cross-departmental collaboration (15).

NMCP is composed of two primary units: the Case Management Unit, which is responsible for updating and disseminating national malaria case management policies, treatment guidelines, and diagnostic protocols; and the Surveillance and Monitoring & Evaluation (M&E) Unit, which oversees the development of M&E guidelines and tracks epidemiological indicators ,though much of the data collection and analysis from localities and states is managed by other directorates (15).The latest national malaria 2023 protocol emphasizes the importance of laboratory confirmation, abolishing clinical diagnosis in favor of microscopy or rapid diagnostic tests (RDTs) for all suspected cases (16).

1.6. Health Information System: -

A health information system (HIS) is a foundational component of any health system (17). Effective malaria surveillance enables timely planning and resource mobilization, especially when rising trends suggest impending outbreaks. By continuously monitoring impact indicators, this system acts as an early warning tool and supports data-driven, strategic decision-making at the national level (6).

Malaria data is collected from three main sources: the Health Management Information System (HMIS), the Weekly Disease Surveillance System, and regular monitoring surveys. HMIS collects monthly program data through the District Health Information System 2 (DHIS2) for malaria control program planning purposes through reports designed by the program and obtains program impact indicators (15).

The DHIS2 is an open-source, web-based platform designed to streamline the collection, validation, and analysis of health data(18). DHIS2 has been progressively rolled out, reaching 144 of 189 localities; nevertheless, data are collected from all the levels, primary, secondary, and tertiary healthcare facilities, to localities, across all states, aggregated at the national level, and stored in a structured database(15). (Figure 1)

For malaria outbreak detection, weekly aggregate surveillance data are collected from selected sentinel sites through the Integrated Disease Surveillance and Response (IDSR) system managed by the General Directorate of HEEC. Weekly data is shared with the NMCP and the IVM department to join efforts in managing the outbreaks (15). For regular monitoring, surveys conducted using surveillance data are also used to assess malaria-related threats, such as drug resistance and emerging vectors, as well as the quality of care (15). Currently, malaria-related data remain fragmented across multiple sources and are not integrated into a single comprehensive reporting system, resulting in suboptimal utilization for decision-making (15).

Data completeness remains a challenge, with health facility reporting for key program indicators averaging only 64% in 2020(19). Barriers to timely and complete malaria reporting include inadequate infrastructure, such as unreliable electricity and internet access, and a shortage of computers in many health facilities according to 2020 HIS assessment report . The scarcity of trained statisticians further impedes effective data management, while the persistence of parallel reporting systems contributes to fragmentation and undermines data consistency. At the national level, inconsistent data quality checks and a lack of standardized

reporting guidelines further limit the system's reliability and comparability across states and facilities(19).

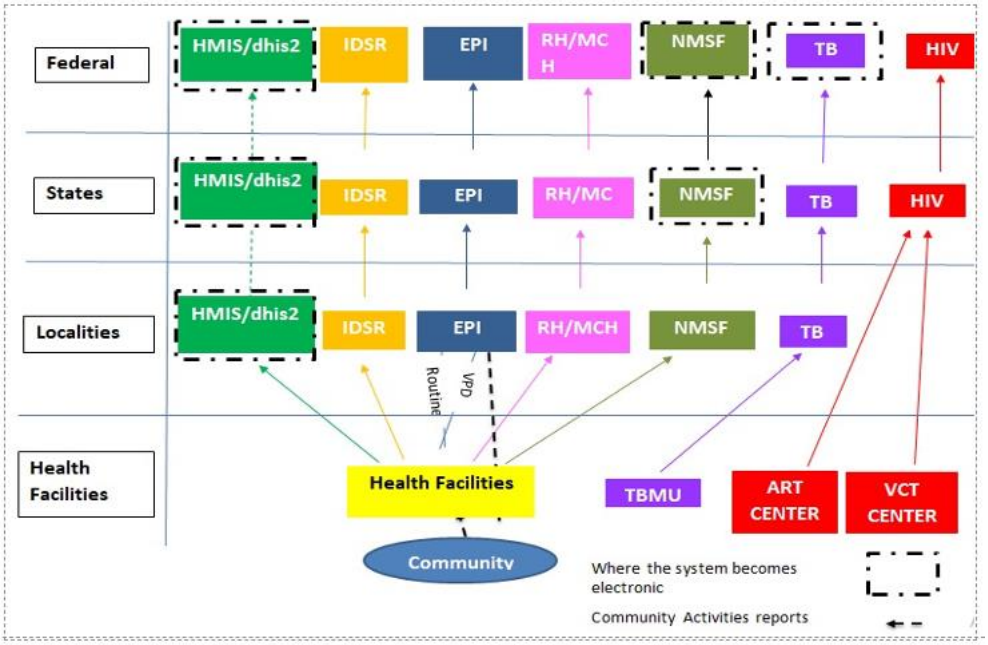

Figure 1Routine facility reporting systems: overview of HIS data flow across administrative levels "ART: antiretroviral treatment; EPI: Expanded Programme on Immunization; IDSR: Integrated Disease Surveillance and Response, NMSF: National Medical Supplies Fund; RH/MCH: reproductive health/maternal and child health; TBMU: tuberculosis management unit; VCT: voluntary counselling and testing."(19).

CHAPTER 2: PROBLEM STATEMENT, JUSTIFICATION, and OBJECTIVES: -

2.1. Problem Statement: -

According to the World Malaria Report 2024, Sudan reported the second highest number of malaria cases within the World Health Organization Eastern Mediterranean Region (EMRO) (10). In 2023, Sudan accounted for approximately 41% of all malaria cases and 49% of malaria-related deaths in EMRO, making it the largest contributor to the regional malaria burden (20).

Malaria is a significant public health burden in Sudan, persistently ranking as the most treated and deadliest disease across the country (21). According to the 2021 Annual Health Statistical Report, malaria accounted for 17% of all outpatient cases and was the leading cause of outpatient visits in 15 out of 18 states (21). The disease had the highest prevalence rate among the top ten outpatient conditions, reaching 83.5 cases per 1,000 population. Among children under five, malaria was responsible for 20% of outpatient visits and 21.8% of inpatient admissions. Despite being preventable and treatable, malaria was the second leading cause of hospital admissions (14.7%) and the sixth leading cause of hospital deaths among children under five (5.8%). Furthermore, it contributed to 8.4% of all hospital deaths across all age groups (21).

The weak health system and infrastructure are a result of a long history of ongoing conflicts and political instability (22). This fragility was further exacerbated by the April 2023 conflict that emerged from the capital to other states between the Sudanese Armed Forces (SAF) and the Rapid Support Forces militia (RSF). However, different states were attacked at different times, such as Jazeera and Sennar were attacked by the militia five and thirteen months after the assault on the capital, respectively.

The conflict resulted in the severe destruction of the country's infrastructure, healthcare facilities, the disintegration of the health ministries, and disruption of disease control programs, and the health information system. The national medical supply fund and vaccine stocks were inaccessible (23–25).
The conflict shifted the central supply chain from Khartoum to Port Sudan, significantly increasing transportation distances for delivering malaria commodities (see Figure 2) (26). For example, the distance from Khartoum to Blue Nile state was 540 kilometers pre-conflict, but from Port Sudan to Blue Nile it is approximately 1,350 kilometers. This logistical complexity worsened following attacks on Jazeera and Sennar states, isolating several areas from supply routes (Figure 7).

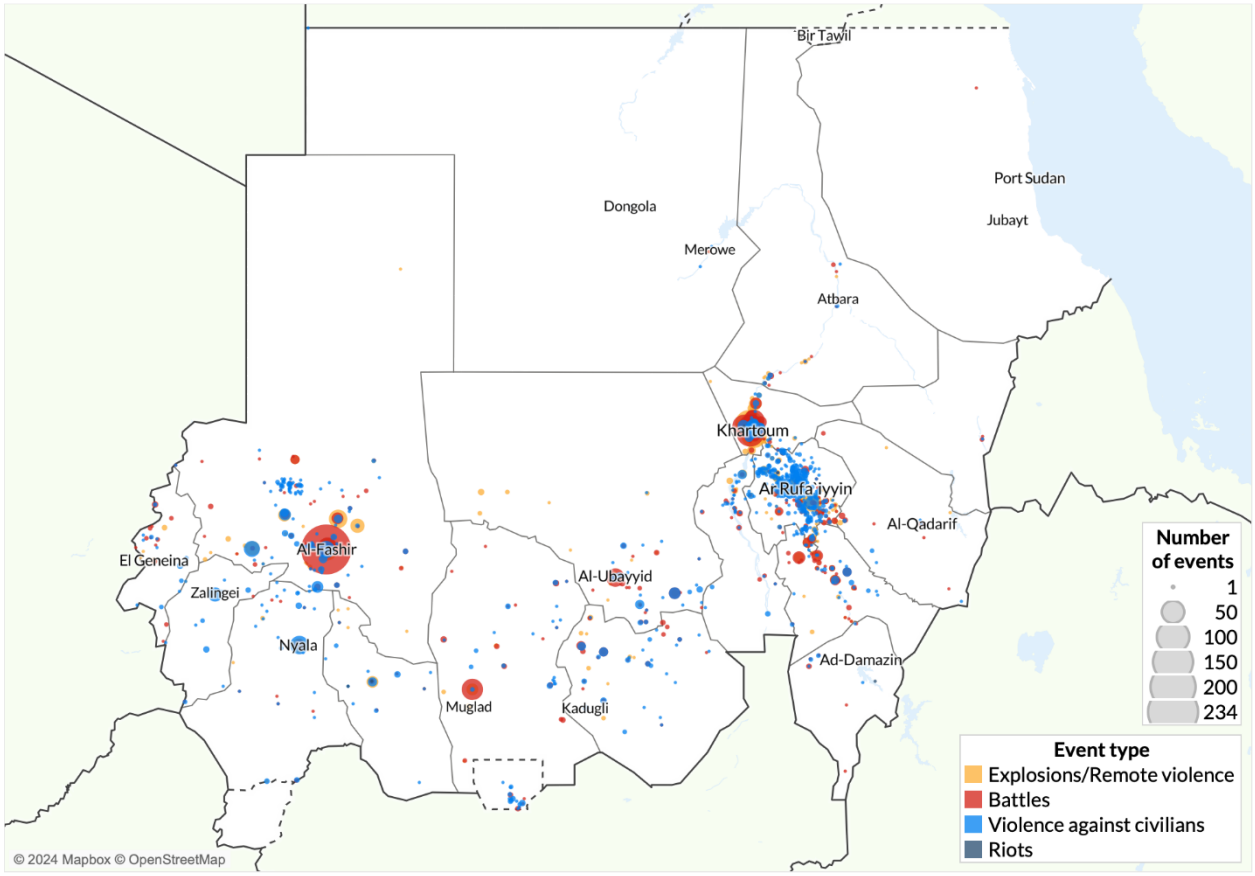

Figure 2: Political Violence in Sudan 1 January -29 November 2024 (27)

The conflict led to the largest IDP crisis in the world, estimated at10,065,329 million (28). The IDPs were predominantly from Khartoum (30%), South Darfur (21%), and North Darfur (20%). Khartoum-originating IDPs relocated mainly to the River Nile, the White Nile, and Northern states, while IDPS from Darfur and Kordofan states were displaced within the same states (29).

Before the onset of the conflict, Sudan faced a substantial burden of infectious diseases. The critical humanitarian and health situation was further aggravated by outbreaks of deadly infectious diseases, including malaria(30). Due to the current conflict context, the real estimates of malaria burden and deaths are underreported (31).

2.2. Justification:

Malaria surveillance is a core intervention under the Global Technical Strategy for Malaria 2016–2030 (32). Despite the adoption of DHIS2, persistent challenges continue to undermine the effectiveness of disease monitoring, with the 2023 conflict exacerbating the already existing challenges.

Notably, there is a significant gap in recent comprehensive studies exploring malaria surveillance data to understand how the ongoing 2023 conflict has affected malaria trends and their dynamics across Sudan's diverse states.

Addressing this gap is critical, as malaria data are essential for informed decision-making and implementing targeted control interventions. This research aims to describe three key malaria impact indicators from the NMCP's latest strategic plan of 2021-2026(6).

By conducting this research, evidence-based recommendations will be provided necessary to strengthen malaria control efforts in conflict-affected settings and to improve the resilience of HIS in Sudan. According to the national strategic plan, the program has one strategic goal: to reduce the baseline of mortality and morbidity by 25%, taking 2021 as a baseline.

To measure progress toward this goal, the strategic plan identifies seven impact indicators. These indicators are prioritized because they reflect program performance and are used for outcome and impact evaluation.
Of the seven impact indicators, two (under-five mortality rate per 1,000 live births and malaria prevalence) are not part of routine surveillance and are collected through periodic national surveys. Therefore, they fall outside the scope of this study, which targets routinely collected data from DHIS2. Of the remaining indicators, five are reported regularly to DHIS2, three were selected for analysis.
The selection was based on relevance and the aim to avoid redundancy. “Inpatient malaria deaths per 100,000 population” were chosen as the key mortality indicator, given its inclusion in the Global Fund’s Performance Data and Disbursement Request (PUDR) reporting (33). The alternative indicator,” Inpatient malaria deaths/ total inpatient deaths”, was excluded due to its conceptual overlap with the first indicator.
Similarly, “Reported malaria cases (presumed plus confirmed)” was selected over “Confirmed malaria cases per 1,000 population”, as it encompasses the latter in its numerator and is more representative of overall case reporting. Finally, malaria” Test positivity rate (microscopy plus RDT)” was included as it reflects diagnostic coverage and transmission trends.

These three indicators: “Inpatient malaria deaths per 100,000 population”, “Reported malaria cases (presumed and confirmed)”, and “Test (RDT + microscopy) positivity rate”, were selected for analysis based on their strategic relevance, routine availability in DHIS2, and alignment with both national and international monitoring frameworks.

2.3. Objectives: -

2.3.1. General Objective: -

To assess the impact of the 2023 conflict on the routine malaria surveillance data by analyzing the temporal trends of three key malaria impact indicators, as prioritized in Sudan’s Malaria Strategic Plan (2021–2026), using DHIS2 data with a focus on changes observed before and after the onset of the April 2023 conflict.

2.3.2. Specific Objectives: -

1. To describe temporal changes for three key malaria impact indicators across Sudan’s 17 states, measured quarterly from January 2020 to March 2025.
2. To assess whether the trend of a “reported malaria cases (presumed and confirmed) per 100000 “significantly changed following the start of the April 2023 conflict, using interrupted time series analysis (ITSA) across 11 states.

3. To explore perceived changes in malaria surveillance data collection and reporting across Sudan's states following the 2023 conflict, and to contextualize the underlying reasons for these shifts by conducting key informant interviews.
4. Provide recommendations based on quantitative and qualitative results to the NMCP to address the current challenges and make evidence-based decisions for future program interventions.

CHAPTER 3: METHODOLOGY

This study adopted a mixed-methods research design, integrating both quantitative and qualitative approaches to comprehensively address the research objectives.

3.1 Quantitative Analysis: -

3.1.1 Study Area

The study covers 17out of 18 states that report malaria surveillance data to the national DHIS2 platform. Khartoum is excluded due to its reporting to a separate surveillance system. The methodology involves two distinct analyses: a descriptive analysis encompassing 17 states and an analytic analysis limited to 11 states.

3.1.2 Study Design:

The quantitative component comprises descriptive and analytic secondary data analyses. For the descriptive analysis, a longitudinal trend analysis was conducted using three key malaria impact indicators extracted from DHIS2 at the state level and then calculated. This enabled the examination of temporal variations across states in malaria indicators.
For the analytic analysis, the “reported malaria cases (presumed and confirmed) per 100000” indicator was assessed to determine the impact of conflict on malaria trends by modeling changes before and after conflict using Interrupted Time Series Analysis (ITSA). DHIS2 was chosen as the primary data source because it functions as the national routine surveillance platform for the NMCP.

3.1.3 Study Population

The study population includes all individuals reported as a malaria case as documented in the DHIS2 platform who attended health facilities in any of the 17 states during the study period. This population encompasses all laboratory-confirmed and clinically diagnosed malaria cases.

3.1.4 Sample Size: -

The analytic part did not involve any sampling; instead, it utilized the complete datasets of malaria indicators reported in DHIS2 from all states during the selected study period that met the inclusion criteria. All data were collected on 5 July 2023 from the national DHIS2 website.

3.1.5 Inclusion and Exclusion Criteria:

The analysis primarily included states that typically rely on DHIS2 for data submission, regardless of their data completeness, from January 2020 to March 2025. However, the presence of considerable missing data in some states necessitated their partial exclusion from ITSA analyses.
Conversely, Khartoum State was specifically excluded due to its reliance on a parallel surveillance system, distinct from the DHIS2 platform utilized by the included states.

Data collected before January 2020 were excluded as they fell outside the study's timeframe, and data after the first quarter of 2025 were excluded due to incompleteness at the time of analysis.

3.1.6 Study Variables

The quantitative analysis was underpinned by several key variables. Temporal variables encompassed the Year and Quarterly period (three-month intervals) to track changes over time. Contextual variables included the state name and its associated state population, essential for standardizing the indicators. The primary study outcome variables selected were "Inpatient malaria deaths per 100,000 population", providing insight into mortality, and "Total reported malaria cases (presumed plus confirmed) per 100,000 population", reflecting overall morbidity. Additionally, the Test positivity rate, incorporating both microscopy and RDT findings, served as a crucial indicator of infection burden.

Table 1 :Study Variables and Corresponding Definitions

Variable	Definition
period	a categorical variable representing three-month intervals. Data were downloaded quarterly and organized chronologically, spanning from January 2020 to March 2025, resulting in 21 distinct time points.
State name	A categorical variable identifies the administrative states.
State Population	A count variable represents the state-level population count per study year
Inpatient malaria deaths per 100,000 population(6) (34)	A rate variable, the numerator is the crude number of in-patient malaria deaths, and the denominator is the state population at risk (number of people living in the state where malaria transmission occurs) multiplied by 100000 This variable provides insight into malaria mortality within healthcare facilities and acts as a proxy for overall population-level malaria deaths. It additionally highlights the efficacy of malaria case management, encompassing prompt diagnosis and treatment (35).
Reported malaria cases (presumed and confirmed) per 100000 population	It is a rate variable. The nominator is crude in the number of reported malaria cases (confirmed and presumed) (6) (34) , divided by State population at risk multiplied by 100000 “This indicator enables assessing the reported malaria caseload in the general population.”(35) . “Presumed cases are cases suspected of being malaria that are not confirmed by a diagnostic test. Confirmed cases are malaria cases in which the parasite has been detected in a diagnostic test, i.e., microscopy or RDT”(36).
Test (RDT + microscopy) positivity rate (6) (34)	It is a percentage variable. The numerator is the number of confirmed malaria cases (by microscopy or RDT) (6), and the dominator is the number of patients who received a parasitological test. It is calculated by dividing the numerator, the number of malaria cases confirmed by microscopy, by the denominator: the number of patients who received a parasitological test by microscopy. And calculating the number of malaria cases confirmed by RDT over the denominator: the number of patients who received a parasitological test by RDT. For symptomatic individuals suspected of malaria, the indicator offers a proxy indication of the actual infection rate (35).

3.1.7. Data Management: -

Six years of malaria surveillance data were extracted from the DHIS2 platform by selecting the three study indicators, downloaded into an Excel file. The data included malaria indicators across 17 states, structured into quarters (three-month intervals) from January 2020 to March 2025. The data are not disaggregated by age and gender.

The two indicators, "Inpatient malaria deaths per 100,000 population" and "Reported malaria cases (presumed and confirmed) per 100000" were downloaded as crude counts from DHIS2. To allow comparability between the different states, the absolute count indicators were standardized to states' population by dividing the count by the state population and multiplying by 100000.

The equation used to calculate the inpatient malaria death per 100000 population =

(Number of inpatient malaria deaths/ State population per 2020-2025 year) × 100,000 (35)

Similarly, the equation used to calculate reported malaria cases (presumed and confirmed) per 100000 =

(total reported malaria cases (presumed and confirmed) / State population per 2020-2025 year) × 100,000

The total population data for each state for the different years was sourced from the Expanded Immunization Program records. However, the dataset did not contain population figures for 2020 and 2023. Missing data on state population counts were estimated by applying an annual growth rate of 2.53%. This calculation was performed using the latest population figure available from the immunization program record taking year 2022 as a baseline (6).

The malaria test positivity rate (Microscopy + RDT) indicator was obtained as a percentage (not a crude count) for each state from DHIS2 and thus did not require standardization.

The start of the conflict period was considered April to June 2023 quarter, allowing the data to be categorized into two distinct phases, pre-conflict and after the start of the conflict quarters (24). Data were managed and processed using the R program version R 4.5.0 in RStudio. The dataset was inspected for blank entries and outliers.

The data was chronologically ordered. Blank entries after the conflict quarter were considered Missing Not at Random (MNAR) due to their direct association with conflict-related events. To avoid introducing bias through imputation and to maintain the authenticity of the observed trends, descriptive linear plots were developed using only available data without imputation. All blank entries were recorded as "non-available" before data analysis. and flagged as missing data and carefully considered in both the analysis and interpretation.

3.1.8. Data Analysis:

Descriptive time trend analysis was conducted to examine the first objective of the study. Each state's data were analyzed and visualized using time series plots, stratified by both state and malaria indicator. This allowed for an assessment of temporal trends and interstate disparities in the selected malaria indicators across the country, with special attention to the pre- and during conflict period.

To address the second objective, an ITSA was conducted on the "reported malaria cases (presumed and confirmed) per 100000". The indicator was selected because of its strategic importance to the program. Six states with missing data post-conflict period were excluded from the analysis, which were South Darfur, Central Darfur, South Kordofan, North Darfur, West Darfur, and West Kordofan. A total of 11 states were included in the ITSA analysis.

3.1.9. Ethical considerations:

The DHIS2 data is anonymized, and access was requested and obtained from NMCP.

3.2 Qualitative Component: -

Objective three was addressed through the integration of a qualitative phase, designed to complement and provide triangulation with quantitative results, to enhance the robustness of the results during a period of significant disruption.

3.2.1 Conceptual Framework:

A semi-structured interview guide was used to conduct the key informant interviews (KIIs) with questions tailored to the professional roles of each informant.

The interview guide was developed from the Conceptual Framework for Public Health Surveillance in Armed Conflicts. Data collection was performed using a semi-structured questionnaire drawn from the instrument detailed in Wiesen's (2020) doctoral dissertation (37). The design and application of this instrument have undergone peer review through its subsequent publication in *Conflict and Health* (Wiesen et al., 2022) (Figure 3) (38).

The framework was adapted to the Sudan context and the specific objectives of this study, which directly address the operational and systemic challenges of conducting surveillance in conflict-affected areas for an infectious disease.

Core thematic domains adopted from the framework included the context of the country and the selected states, surveillance challenges, success stories that probe for the enabling factors, and innovative adaptations of surveillance after the conflict. These domains were structured into the interview questionnaire to ensure systematic exploration of malaria surveillance during conflict.

Questions probed the challenges of conducting surveillance amid widespread insecurity, including inaccessibility, population displacement, damage to health infrastructure, and disruptions to communication and supply chains.
My understanding of themes related to inter-state variations was significantly informed by insights derived from the qualitative component of the mixed-method study by Yenew, Mulatu, and Alamneh (2021), which focused on malaria trends within the Amhara Regional State, Ethiopia (39). Further questions were asked to elaborate on the contextual factors behind these patterns.

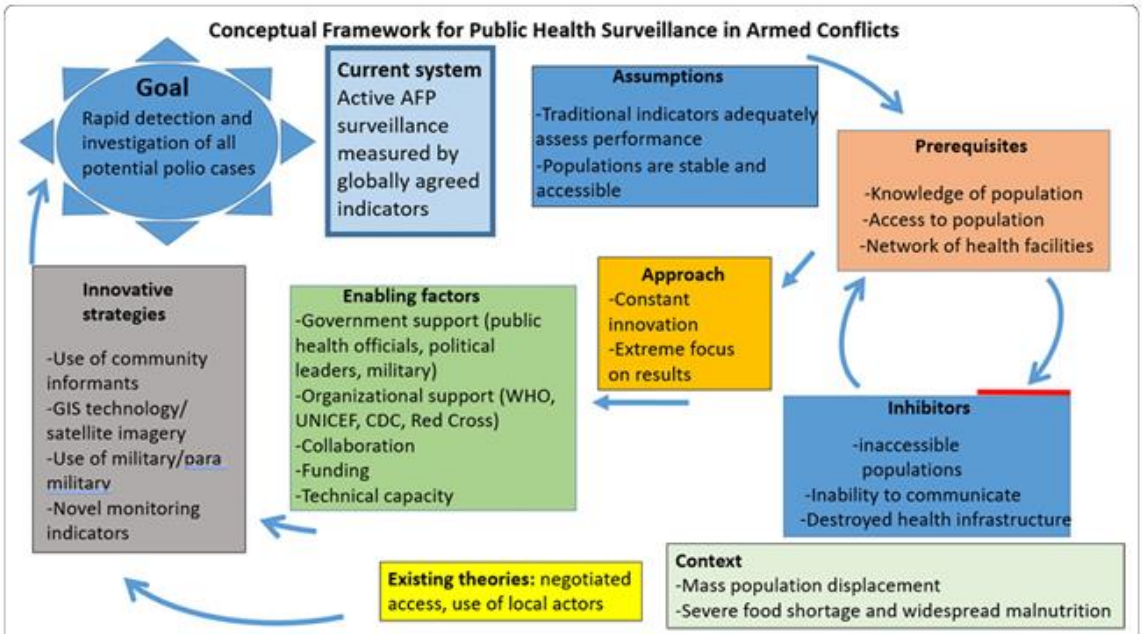

Figure 3 Conceptual Framework for Public Health Surveillance in Armed Conflicts (38)

3.2.2 Study Sampling:

To achieve the study's objectives, key informants (KIs) were selected using a purposeful sampling strategy. Three KIIs were subsequently conducted. This involved interviewing the senior malaria surveillance manager from the NMCP to gain a broad perspective on malaria surveillance at the national level . For detailed insights into thematic areas, one state-level malaria manager and one state-level M&E manager were interviewed. These two state-level interviews were conducted in states purposively chosen to represent differing levels of conflict

impact: one directly affected by the conflict and the other indirectly affected. State names are withheld to maintain confidentiality. Despite efforts to broaden the sample of conflict-affected areas, the final selection of states was limited to those with reliable communication due to connectivity issues.

3.2.3 Data collection and data management:

The utilized semi-structured interview guide was first translated into Arabic by the author. Interviews were conducted in Arabic by the corresponding author via recorded Google Meet sessions. The resulting audio recordings were then transcribed using the TurboScribe online site (40), manually proofread, and subsequently translated into English.

3.2.4. Data Analysis: -

A coding framework was deductively developed using the established themes from the framework described in section 3.2.1. The interview data were then manually organized and analyzed according to these pre-defined themes and their corresponding codes to identify emerging patterns. To safeguard participant anonymity, all identifying information was pseudonymized by assigning identifier codes to each key informant. In adherence to ethical guidelines, all collected data will be securely destroyed once the study's objectives have been fulfilled.

3.2.5. Ethical Consideration:

Recorded verbal consent was obtained from participants. The consent was translated into Arabic, and all aspects of the research process, including participants' rights to withdraw or decline participation at any time, were explained.

Chapter 4: Results: -

4.1. Quantitative Results:

4.1.1. Descriptive analysis:

This section presents descriptive time trends for three key malaria impact indicators across 17 states of Sudan from January 2020 to March 2025, with data collected at 21 quarter intervals. The indicators are: (1) Inpatient malaria deaths/ 100,000 population, (2) Reported malaria cases (presumed and confirmed)/ 100,000 population, (3) Malaria Test (slide + microscopy) positivity rate. For each indicator, time trends are displayed for each state using line graphs

Quarters with data appeared as blank entries were observed in some states across all indicators. No zero value was reported in the dataset. Based on contextual knowledge from the NMCP, unavailable data after the second quarter of 2023 were attributed to conflict-related disruptions rather than actual program performance.

Non-available data points are marked with red dots as zero values on the graphs. Axes and legends are labeled to facilitate interpretation. To emphasize fluctuations within each state, the y-axis scales were adjusted independently across facets. This approach ensures that meaningful changes, particularly in states with low indicator rates, are not visually compressed.

Each graph displays the indicator value on the x-axis and the quarters chronologically on the y-axis, with the state name labeled above each graph.

To calculate the percentage of missing data for each indicator, I divided the data into three periods: before, during, and after the start of the conflict. Since the number of reporting quarters differs across these periods, 13 data points before the conflict, one data point during, and 7 points after the conflict. The percentage of missing data was calculated by dividing the number of missing values by the total number of values for each period.

4.1.1.1. Inpatient malaria deaths per 100,000 population:

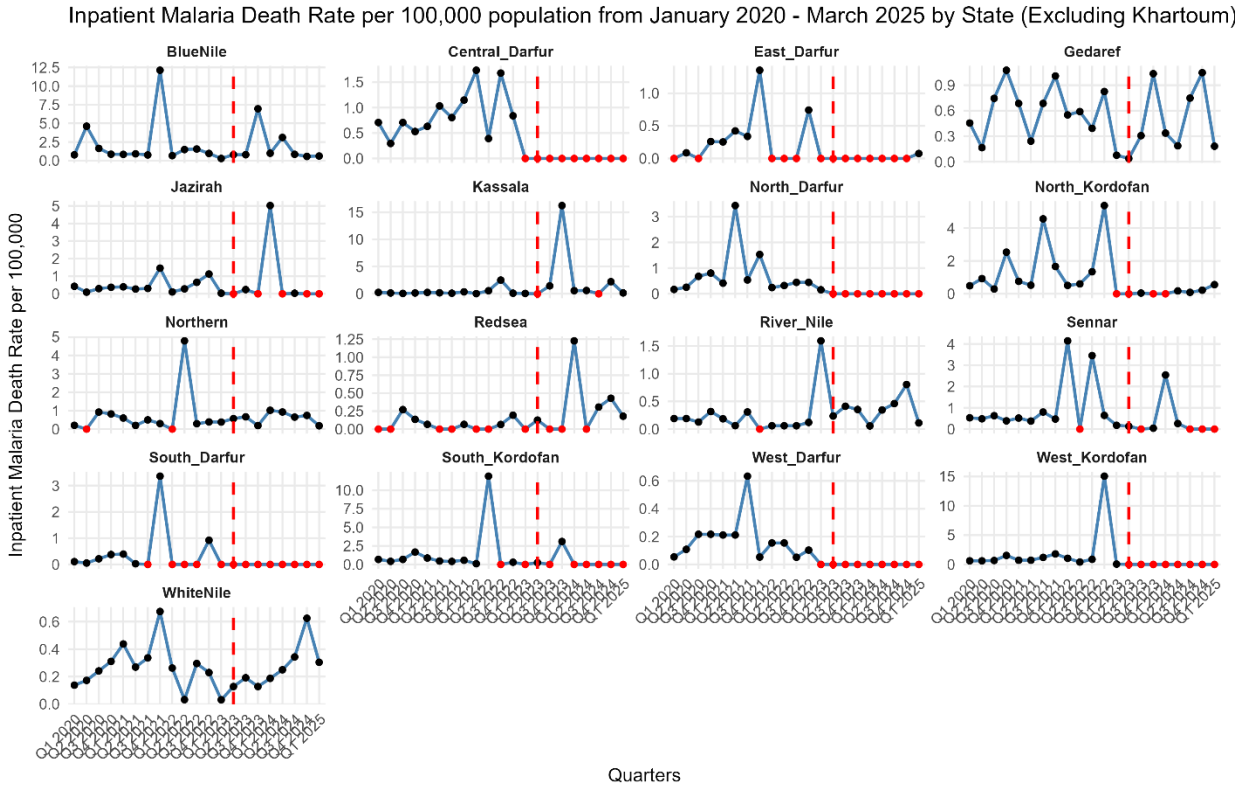

Figure 4 Time trend Graphs of Inpatient Malaria Death Rate per 100000 Indicator of Sudan States (except Khartoum) from January 2020 to March 2025

Note: Q1 = January–March, Q2 = April–June, Q3 = July–September, Q4 = October–December. The red dashed line indicates the start of the conflict.

This section presents the trends of "in inpatient malaria deaths per 100,000 population" across 17 Sudanese states, covering the period from January 2020 to March 2025.

Throughout the study period, the collective graph of the indicator visually illustrates considerable differences in patterns across states (Figure 4). Notably, clear shifts in these trends were apparent when comparing the periods before and after the onset of the conflict.

The inpatient malaria death rate (per 100,000 population) had the highest amount of missing data among all the indicators, both before and after the conflict began. As shown in Table 2, the state-level percentage of missing data was substantially higher during and after the conflict compared to the pre-conflict period.

Table 2 : Nationwide Malaria Inpatient Death Rate Missing Data percentage before, during and after the start of the 2023 Conflict

Period	Number of present data quarters	Number of missing data quarters	Total number of quarters per state per period	Missing percentage
Before the conflict	194	40	234	17.1%
During the conflict quarter	8	10	18	55.6%
After the conflict	63	63	126	50%

A notable observation in the post-conflict period was the comprehensive absence of data for the five Darfur states - North, East, West, South, and Central Darfur - on this indicator. A two-decade history of conflict characterizes this region.

Beyond Darfur states, a similar pattern of data absence post-conflict was evident across the three Kordofan states (Figure 4). An exception was North Kordofan, which reported some values post-conflict; however, these figures remained near zero (e.g., 0.05 inpatient deaths per 100,000 in Q3 2023, reaching a maximum of 0.56 in Q1 2025) and notably failed to reflect the prominent seasonal peaks characteristic of the pre-conflict period (Figure 4) (see Table A2 in Annex). Conflict-related disruptions to data reporting impacted the southern states bordering South Sudan, a region historically marked by instability (41)

Prior to the conflict's onset, individual states where data was available exhibited diverse trends in inpatient malaria deaths per 100,000 population (Figure 4). Central Darfur State, for instance, displayed an increasing trend, peaking at 1.74 and 1.68 cases per 100,000 in Q1 and Q3 2022, respectively, before a sharp decline was observed in Q3 2022. West Darfur showed an otherwise irregular trend, marked by a prominent peak in Q3 2021.

In the Kordofan region, West Kordofan maintained relatively stable and low malaria death rates, typically below one death per quarter throughout the pre-conflict period, save for a sharp peak of 15 deaths per 100,000 in Q4 2022. South Kordofan demonstrated a comparable pattern, experiencing a peak of 11.89 cases per 100,000 in Q2 2022, contrasting with generally less than one death case per quarter throughout the rest of its pre-conflict period. North Kordofan, distinctively, consistently exhibited a clear seasonal pattern in malaria deaths.

Blue Nile state's death rate remained stable near one case per quarter for most of the pre-conflict period, though interrupted by a single peak of 12.14 cases per 100,000 in Q4 2021. Following the onset of the conflict, Blue Nile state's mortality rates displayed two subsequent peaks, reaching 6.97 and 3.11 cases per 100,000 in 2023 and 2024, respectively (Figure 4).

Trends in Northern and Eastern States:

In the Northern State, inpatient malaria deaths per 100,000 population remained consistently low throughout the entire study period, typically below one case per quarter, observed both before and after the onset of the conflict (Figure 4). The River Nile State, however, experienced an increase in its malaria death rate following the conflict's start. Before the conflict, its maximum quarterly death rate was 4.8 cases per 100,000 in Q2 2022. Post-conflict, subsequent low trend was observed, reaching a maximum of 1 case per 100,000 in Q1 2024 (Figure 4) (see Table A2 in Annex).

Among the eastern states, Gedaref's trend remained consistent before and after the conflict, characterized by clear seasonality and recurring peaks. However, the lowest documented values for Gedaref were observed in the first two quarters of 2023, coinciding with the conflict period (Figure 4). Kassala State exhibited a noticeable surge in inpatient malaria deaths during the conflict, peaking at 16 cases per 100,000 in Q4 2023. This contrasted sharply with its relatively stable and low rate, typically less than one case per quarter, both before and after this specific conflict-period peak. Finally, White Nile State demonstrated a seasonal pattern of malaria deaths, with a gradual increase in the malaria death rate post-conflict. Despite this increase, rates consistently did not exceed one case per quarter throughout the entire study period (Figure 4) (see Table A2 in Annex).

4.1.1.2. Reported malaria cases (presumed and confirmed) per 100,000 population:

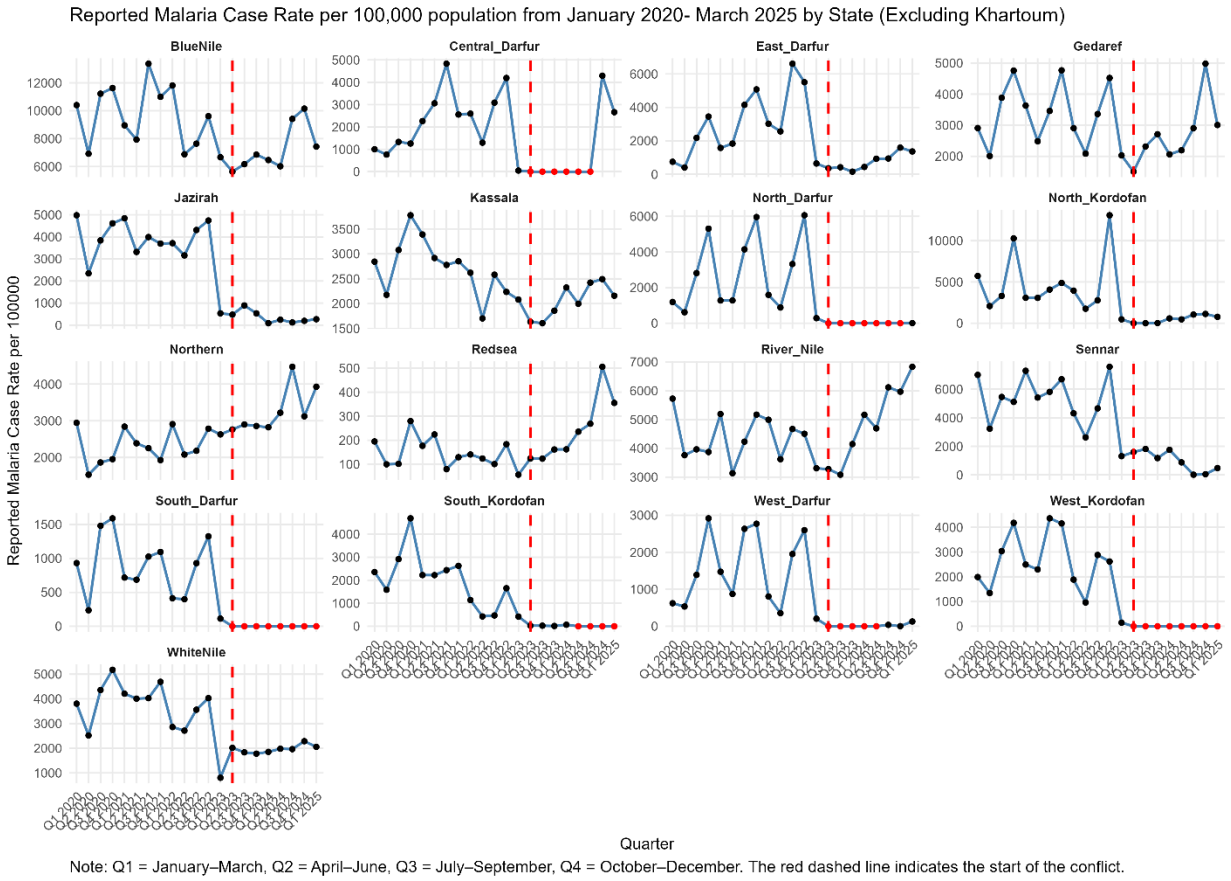

Figure 5 : Time trend Graphs of Reported Malaria Case Rate per 100000 Indicator of Sudan States (except Khartoum) from January 2020 to March 2025

Note: Q1 = January–March, Q2 = April–June, Q3 = July–September, Q4 = October–December. The red dashed line indicates the start of the conflict.

This section presents the trends in reported malaria cases (presumed and confirmed) per 100,000 population across 17 Sudanese states, from January 2020 to March 2025.

As shown in Figure 5, the indicator displayed substantial variation among states throughout the study period, with clear shifts in trends observed before and after the April 2023 conflict.

As shown in Table 3, collectively, the percentage of missing data was substantially higher during and after the conflict compared to the period before the conflict.

Table 3 Nationwide Reported Malaria Cases Rate, Missing Data Percentage, Before, During and After the Start of the 2023 Conflict

Period	Number of present data quarters	Number of missing data quarters	Total number of quarters per state per period	Missing percentage
Before the conflict	222	12	234	5.31%
During the conflict quarter	12	6	18	33.3%
After the conflict	92	34	126	27%

Trends in Darfur and Kordofan States:

Following the conflict, a significant trend emerged in all Darfur states and West Kordofan, which experienced a complete cessation of data reporting for most of the post-conflict period. Similarly, South Kordofan reported no data for three of the seven post-conflict quarters. It is worth noting, however, that limited data reporting resumed in Central and West Darfur during the final two quarters of the study.

In contrast, North Kordofan continued to report data post-conflict, but with significantly lower figures. The state's highest pre-conflict value was recorded in the last quarter of 2022, with 13,091.8 reported malaria cases. This plummeted to 468.6 cases in the subsequent quarter and dropped even further to just 1.7 and 2.6 cases in the second and third quarters of 2023, respectively. (Figure 5) Before the conflict, these states were characterized by a noticeable seasonal pattern, which aligns with their high malaria endemicity.

Trends in Jazirah and Sennar States

Following the onset of the conflict, both Al Jazirah and Sennar states continued to report malaria cases, despite experiencing militia attacks in the fourth quarter of 2023 and the third quarter of 2024, respectively. However, a significant drop in reported cases is evident in their post-conflict trends (Figure 5).

After the second quarter of 2023, reported cases plummeted, especially when compared to the same high-transmission quarters of previous years. For instance, in the fourth quarter of 2024, Jazirah state reported a low of 193.7 cases, a sharp decline from the 4742 cases reported during the same quarter of 2022, just before the conflict. Similarly, Sennar state saw a dramatic drop from 7571.8 cases in the fourth quarter of 2022 to only 43 cases in the fourth quarter of 2024 (see Table A3 in Annex).

Unlike the complete cessation of data reporting observed in the Darfur states, these states maintained some level of reporting throughout the period. Before the conflict, both states displayed a clear seasonal trend in malaria cases, which has been severely disrupted.

Trends in the Northern and Eastern States:

In the low-malaria-transmission regions of Northern State, River Nile, and Red Sea, the post-conflict period saw a notable increase in reported malaria cases per 100,000 population (Figure 5). This upward trend is likely a direct result of the large-scale population displacement into these states. All three states reached their maximum reported values after the conflict began: Northern State reached 4471.6 cases, River Nile hit 6832 cases, and Red Sea recorded 505.7 cases. Prior to the conflict, these states had shown a seasonal trend in malaria cases (see Table A3 in Annex).

Trends in Gedaref and Blue Nile States:

The Gedaref and Blue Nile states experienced a significant drop in reported cases from the second quarter of 2023 to the first quarter of 2024. After this decline, both states appeared to resume the pre-conflict trend of reported cases. The overall pattern suggests seasonal variation with intermittent spikes and drops, though the impact of the conflict is visible in the data gap.

Trends in White Nile State:

The White Nile State also saw a noticeable drop in reported cases immediately following the conflict. However, the state's reporting did not recover to its pre-conflict trend. A comparison of the last quarter of each year highlights this decline: reported cases dropped from 4689.9 in 2021 to 4030 in 2022, and then to just 1778.7 in 2023. This state also demonstrated a clear seasonal pattern before the conflict began.

4.1.1.3. Malaria Test (RDT + microscopy) positivity rate: -

This section presents the trends in malaria test (RDT+ microscopy) positivity rate across 17 Sudanese states, from January 2020 to March 2025. The April 2023 conflict caused clear shifts in the indicator, as shown by the substantial variation among states throughout the study period (Figure 6).

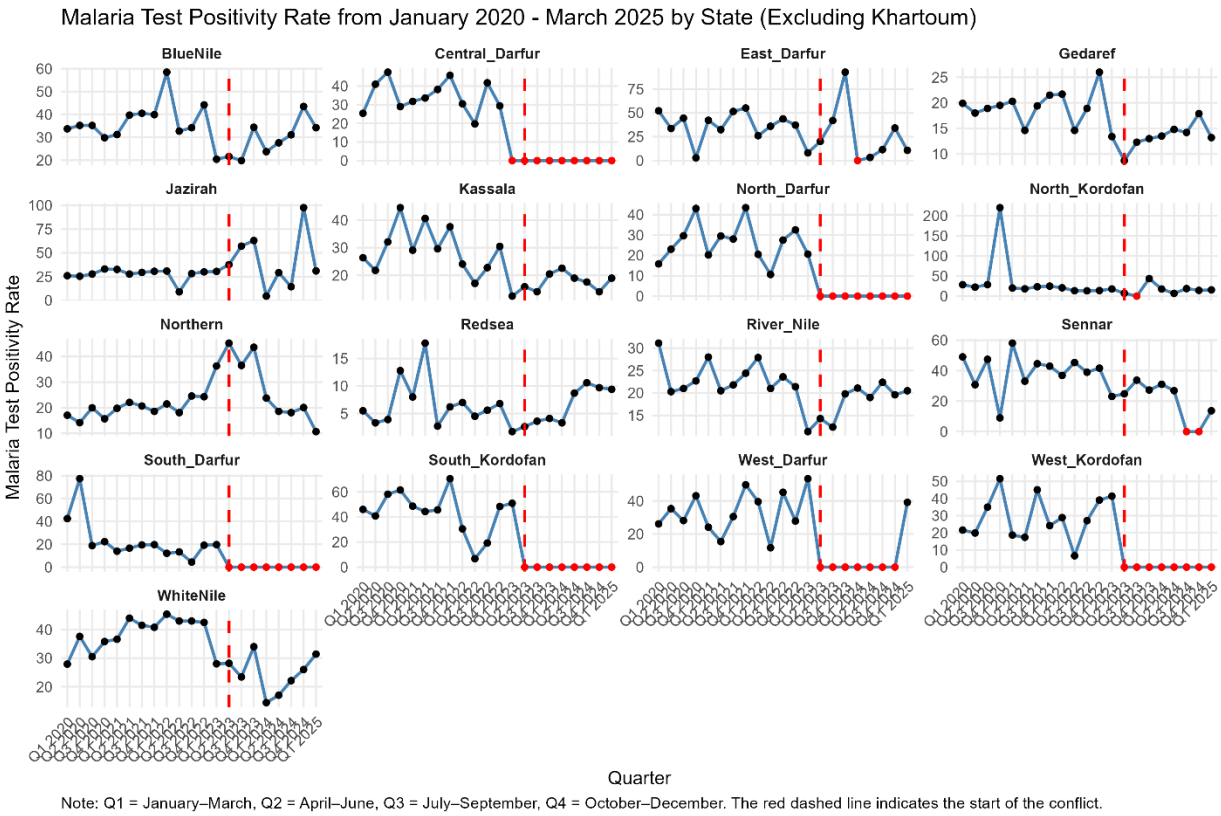

Figure 6 : Time trend Graphs of Malaria Test Positivity Rate Indicator of Sudan States (except Khartoum) from January 2020 to March 2025

Note: Q1 = January–March, Q2 = April–June, Q3 = July–September, Q4 = October–December. The red dashed line indicates the start of the conflict.

As shown in Table 4, the state-level percentage of missing data was substantially higher during and after the conflict compared to the period before the conflict.

Table 4 : Nationwide Malaria Test Positivity Rate, Missing Data Percentage Before, During and After the Start of the 2023 Conflict

Period	Number of present data quarters	Number of missing data quarters	Total number of quarters per state per period	Missing percentage
Before the conflict	220	14	243	5.98%
During the conflict quarter	11	7	18	38.9%
After the conflict	80	46	126	36.5%

Following the conflict, a significant trend of missing data was observed across the Darfur and Kordofan states. All Darfur states, except East Darfur, experienced a complete cessation of reporting. Similarly, West and South Kordofan states provided no data for the indicator. These regions had previously shown a distinct seasonal pattern in their pre-conflict data.

Meanwhile, North Kordofan's malaria positivity rate remained relatively stable in post-conflict, though with a notable surge in the last quarter of 2023. The percentage of cases testing positive for malaria jumped to 43.6% in Q4 2023, a sharp increase from 13.8% during the same quarter of 2022 (see Table A4 in Annex).

East Darfur’s highest positivity rate was noticed post-conflict, reaching 92.7% in the final quarter of 2023. Before the conflict, this state's data showed a clear seasonal cycle, with peaks suggesting consistent transmission trends influenced by predictable climatic factors (Figure 6).

Northern states: -

Before the conflict, Northern State had a relatively stable malaria positivity rate, averaging around 21%. Following the conflict, this trend sharply increased, peaking at 43.6% in the fourth quarter of 2023 before dropping to 20% in the same quarter of 2024.

The River Nile State saw a drop in its positive rate during the pre-conflict quarter, reaching 11%. However, the trend quickly returned to pre-conflict levels afterward.

Similarly, the Red Sea state demonstrated an increase in its positivity rate following the conflict compared to the pre-conflict period. All three of these states had exhibited a cyclic pattern in their positivity rates before the conflict began (Figure 6).

Central States: -

During the conflict quarter, Jazirah State initially showed a rise in malaria positivity rate, a trend that corresponds with the large influx of IDPs fleeing the capital due to the state's geographical proximity. However, a significant drop in reported cases was observed after the fourth quarter of 2023. This decline coincides with the RSF attack on the state, which disrupted health service delivery reaching the lowest percentage post conflict at Q1 2024 with 4.5% positivity rate compared to 30% in the same quarter the previous pre-conflict year (see Table A4 in Annex).

A subsequent recovery in reported data is visible in the quarters that followed, aligning with a period of relative stability in the central region of the country (42). The remaining states, in contrast, demonstrated an overall decline in malaria positivity during the post-conflict period compared to the period before the conflict began.

4.1.2. Analytic Analysis: -

4.1.2.1. Interrupted Time Series Analysis (ITSA): -

The ITSA was employed to assess the impact of the 2023 conflict, identified as the intervention point, on reported malaria cases (presumed and confirmed) per 100,000 population. Seasonality was carefully considered as a potential confounder in this analysis.

I treated seasonality as a time-varying confounder in the ITS analysis by including it in the regression model (43).

A clear seasonal trend pattern in the reported malaria cases was observed in the ITSA graph (Figure 7) before the onset of the conflict. After the conflict began, the overall trend is demonstrating a notable reduction in case notification rates and loss of seasonal variability compared to the pre-conflict period. This reduction in reported cases is likely attributed to a profound disruption to routine surveillance.

The ITSA results confirmed a statistically significant immediate level change following the start of the conflict (during the conflict quarter). Specifically, the indicator showed a statistically significant immediate drop right after the conflict began, with a p-value of 0.0205, even after adjusting for seasonality ($p = 0.0238$) see Table 5. To adjust for seasonality, I created a categorical variable, “quarter”, representing the four quarters of the year. By including the “factor(quarter)” in my linear model, I effectively stratified the model by calendar quarter, creating distinct strata for each quarter within the year

model_2 <- lm(case_rate ~ time + post + post_time + factor(quarter), data = collapsed_data)

The observed downward trend before the conflict quarter appears consistent with a normal seasonal decline, as similar results were obtained after adjusting for seasonal effects stratified per quarter.

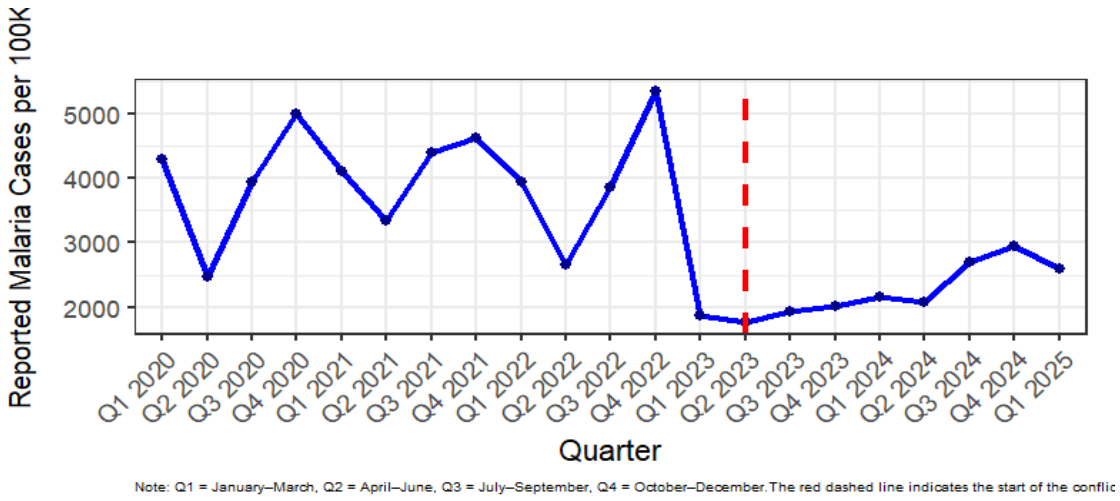

Figure 7 Nationwide Interrupted Time Series Analysis (ITSA) of Reported Malaria Cases (Presumed and Confirmed) per 100,000 Population from January 2020 to March 2025, Including Data from 11 States

Note: Q1 = January–March, Q2 = April–June, Q3 = July–September, Q4 = October–December. The red dashed line indicates the start of the conflict.

Table 5: Nationwide ITSA Coefficients for Reported Malaria Cases per 100,000 (No Seasonality Adjustment)

	Estimate	Std. Error	t value	Pr(>|t|)	Significance
B 0 (Intercept)	4081.8	499.46	8.173	2.73e-07 ***	***
B1: time	-35.79	62.93	-0.569	0.5769	
B2: post	-2037.10	797.20	-2.555	0.0205*	*
B3: post_time	190.27	145.32	1.309	0.2078	

*Note: Significance codes are indicated as follows: *** for p<0.001, and * for p<0.05.*

Table 5 presents the coefficients from the ITSA, illustrating the changes in the indicator across the study period. The intercept (β0) represents the estimated baseline level of the indicator at the start of the time series. The pre-conflict trend (β1=−35.79) showed a non-statistically significant decline (p =0.58). Notably, during the start of the conflict, there was a statistically significant immediate decline in the indicator level, as indicated by the post-intervention level change coefficient (β2=−2037, p = 0.02). This coefficient reflects an estimated drop of approximately 2037 reported cases per 100,000 population immediately following the conflict's onset. The slope change after intervention (β3=190) was positive but not statistically significant (p = 0.20),

suggesting no clear evidence that the change in the indicator trend's slope following the interruption differed significantly from the pre-intervention trend in the long term, beyond the initial sharp decline. Table 6 demonstrates seasonality-adjusted coefficients.

Table 6: Nationwide Interrupted Time Series Coefficients (Seasonality Adjusted) for Reported Malaria Cases per 100,000 Population

Coefficient	Estimate	Std. Error	t value	Pr(>|t|)	Significance
(Intercept)	4059.31	461.56	8.795	4.47e-07	***
time	-60.81	50.28	-1.209	0.2466	
post	-1670.02	658.71	-2.535	0.0238	*
post_time	163.41	118.29	1.381	0.1888	
factor(quarter)2	-518.75	425.57	-1.219	0.2430	
factor(quarter)3	376.32	414.11	0.909	0.3789	
factor(quarter)4	998.93	409.39	2.440	0.0286	*

*Note: Significance codes are indicated as follows: *** for p<0.001, and * for p<0.05.*

4.2. Qualitative Results: -

The following section presents the qualitative findings, organized by key thematic areas that were explained in section 3.2.1. The National M&E Manager will be referred to as N-M&E, the State M&E Manager as S-M&E, and the State Malaria Program Manager as S-MP throughout the section.

4.2.1. Theme 1: Variation of Impact of Conflict Among States:

The N-M&E highlighted the differences in the impact of the conflict across the Sudanese state, as some states suffered direct consequences of the conflict, and others faced the indirect effects on health service delivery and malaria surveillance.

*"Conflict and its consequences are the main reason for the variation among the states" N-*M&E

States such as Darfur faced direct consequences of the conflict, including the destruction of health infrastructure, lack of security, disruption of electricity and internet services, and displacement of health personnel.

"Darfur states were directly affected by the conflict, which resulted in destruction of the infrastructure, electricity, internet, and connection, displacement of the health care providers and malaria program personnel, health care facilities going out of service, and that resulted in complete absence of reporting" reported N-M&E

This near-total collapse of systems in conflict-affected areas led to significant gaps in health service provision and data collection. In contrast, states in Northern and Eastern Sudan did not experience direct conflict but were indirectly affected by large influxes of IDPs seeking safety.

"Other states were indirectly affected by the conflict through the IDP influx to these states."

explained the N-M&E

States such as the River Nile, Kassala, and Gedaref hosted large numbers of IDPs, placing additional strain on already fragile health systems due to the increase in populations

"River Nile state hosted the largest number of IDPs". Reported N-M&E

4.2.2. Theme 2: Post-Conflict Challenges:

One respondent stated that before the conflict, operational issues such as minor staff turnover and occasional delays in obtaining fuel for supervision visits were routine but manageable, with reporting typically maintained weekly and delays not exceeding one week. After the capital was attacked, however, reporting was significantly interrupted and reduced.

Sub-theme 4.2.2.1.: Health System Infrastructure Damage

The conflict caused severe disruptions to essential health infrastructure, rendering many facilities nonfunctional. Key informants identified this as a major obstacle, undermining both routine care and surveillance, which directly impacted effective malaria surveillance.

"Many health centers, serving as primary reporting units, were rendered nonfunctional, with laboratories and essential diagnostic equipment either destroyed or stolen. This loss disrupted routine case detection and confirmation." S-M&E

"Health care facilities went out of service, and that resulted in a complete absence of reporting," noted N-M&E.

The conflict had serious repercussions for health information management. The theft of M&E department computers and the destruction of archived paper-based records resulted in the loss of historical data. Additionally, the routine malaria control activities were halted, likely contributing to a sharp increase in outbreaks and fatalities. However, the collapse of communication and surveillance systems prevented formal documentation of these trends; only informal community reports were available, as government and humanitarian access to the area remained impossible due to insecurity.

Sub-theme 4.2.2.2: Human Resource Challenges

Two KI agreed that a significant loss of trained malaria personnel occurred at all levels of the surveillance system, from data officers at health facilities to program surveillance officers due to the social and economic disruption of the conflict. One informant noted that the high cost of returning to the country continued to discourage the repatriation of experienced professionals, even as security conditions began to be stable.

"Health care facility statisticians and malaria program surveillance officers immigrated from all levels, some of them died during the conflict." N-M&E

Across the states examined, KIs consistently identified insufficiently trained and minimally skilled health personnel as a major challenge after the conflict, due to the mass displacement and immigration. Two respondents highlighted a general shortage of qualified staff, while a third informant from a state hosting large numbers of IDPs specifically noted that recently arrived laboratory personnel lacked training in malaria diagnosis. All the informants noted that the lack of salaries and transportation incentives due to a change in financing priorities to military funding demotivated the remaining workers and led to partial performance as major obstacles:

"Program officers and statisticians did not have the money for transportation to go to work." S-M&E

Sub-theme 4.2.2.3.: Data Collection Constraints:

All key informants agreed that the conflict caused widespread communication network failures, specifically, the disruption of the telephone service and internet previously used by M&E teams. Two informants emphasized that interruptions in electricity, combined with the theft of computers used for data entry, severely limited the ability to digitize and transmit surveillance data. These breakdowns compounded the difficulties in maintaining regular data collection and supervision.

"Surveillance reports are paper-based on the health care service level, then at the locality level, these data are digitized. You need electricity and computers to do so," said N-M&E

"My computer at the state malaria program was stolen" S-M&E

Additionally, the lack of printed surveillance booklets further impeded data collection from the health facility level, as printing had halted with the onset of the conflict. The informant stressed that the documented decline in reporting did not reflect a true reduction in malaria cases but rather the collapse of supportive systems.

"The lack of reporting that is documented is not true; it is not due to decreases in the number of malaria cases but rather population movement, lack of health care providers, and the presence of minimally trained health care providers" N-M&E clarified

In areas such as North Darfur, which have been partially impacted by conflict, only some localities are able to submit reports to the surveillance system regularly. Two KI echoed that reporting timeliness is a major challenge in conflict-affected states.

"We tasked our locality officers with physically collecting reports from sentinel sites and supported them by supplying fuel for transportation. Despite these measures, submitting reports on time was still a major issue." S-MP

Heightened insecurity in localities bordering conflict-affected states led to significant disruptions, resulting in interrupted reporting and supervision activities across several areas.

"One locality saw massive population displacement despite our officers being present, while entering and leaving another locality remained dangerous, though we continued to receive some data, we could not conduct supervision as usual." S-M&E *described*

Sub-theme 4.2.2.4.: Impact of Internal Displacement

The states in question, with their distinct malaria epidemiology, received a large influx of IDPs from areas with varied endemicity. S-M&E and S-MP managers concurred that this convergence significantly altered disease risk and heightened transmission patterns in both displaced and host populations in their states.

While routine health services captured cases among IDPs settled within host communities, those in planned and unplanned camps were initially excluded from formal surveillance because camps were not designated as sentinel sites.

"Many malaria cases went undocumented; they came to our attention when the camp representatives directly requested mosquito nets and residual spraying services from the state malaria program." S-M&E

Sub-theme 4.2.2.5.: Medication Quality During the Conflict:

The central drug stores in the capital were severely impacted by the conflict, resulting in widespread shortages of malaria medications across multiple states. Two key informants highlighted ongoing difficulties in assessing both the quality and availability of these medications during the conflict. Additionally, shortages of essential supplies like RDTs, combined with fuel scarcity, posed significant challenges to malaria control efforts.

"We observed a rise in reported malaria cases in IDP clinics. Upon reviewing patient registers, we noticed repeated names, indicating that some patients sought care multiple times due to treatment failure." S-MP

4.2.3. Theme 3: Success Stories: Enhancement of Malaria Surveillance and Capacity

Several states demonstrated improvements in malaria indicator reporting and program capacity despite the challenges posed by the conflict.

"States hosting offices of the FMOH, notably the River Nile and Red Sea, showed marked enhancement in reporting rates." N-M&E reported

The N-M&E attributed the progress of reporting to the displacement of highly trained federal program personnel into these states, which resulted in increased technical capacity and the provision of continuous, hands-on training for state-level malaria program staff. The FMOH and the SMOH collaborated by sharing resources to achieve their common goals. Despite revealing procurement gaps, supervision visits conducted during the conflict were crucial; they provided on-the-job training at all levels of the malaria program, thereby reinforcing the health system's adaptation and resilience.

4.2.4. Theme 4: Innovative surveillance methods

Despite significant disruptions, malaria surveillance efforts have experienced both persistent challenges and innovations. According to the N-M&E in conflict-affected states, no new surveillance strategies were introduced; as a result, these regions continued to report missing or incomplete data due to ongoing conflict consequences on the health system.

Two respondents reported that in planned (officially recognized) IDP camps, the MOH deployed disease statisticians alongside the healthcare clinics. These teams systematically report notifiable diseases, including malaria, providing a timely and structured flow of data to the national system. Another notable innovation was the development of the "Early Warning, Alert and Response System (EWARS)" by the General Directorate of HEEC.

"Launched after the onset of conflict, this electronic platform is now operational in ten states, enabling collection and direct transmission of data from health facilities to a centralized dashboard for notifiable diseases, malaria, and dengue fever." Respondent N-M&E

Furthermore, monthly online meetings were instituted between federal and state health authorities, including representation from conflict-affected states. These meetings serve as a forum for data review, discussion of challenges, and coordination of corrective actions, aiming to maintain surveillance continuity and quality despite ongoing instability.

Another innovative method used was the S-M&E attempted to integrate IDP camp surveillance data into the official system through regular reports and inter-agency meetings, though ongoing conflict prevented full implementation. In contrast, the S-MP state successfully used a WhatsApp group to facilitate validated malaria data sharing across MOH departments.

4.2.5. Theme 5: Enabling Factors and Collaborative Adaptation

The provision of dedicated, complimentary telephone lines to M&E personnel was described as an enabling factor. This initiative ensured office accessibility and significantly streamlined reporting despite the limited infrastructure.

S-M&E and S-MP echoed that collaboration with non-governmental organizations (NGOs) also emerged as a positive outcome of the crisis.

"Partnerships with NGOs enabled the scale-up of malaria control interventions, such as the supply of RDT and medications, which contributed to reduced transmission in affected areas." S-MP

Chapter 5: Discussion: -

To the author's knowledge, this is the first study that assesses the impact of the 2023 Sudan conflict on malaria program impact indicator data reported through the national DHIS2 platform. While Sudan's history includes recurrent conflicts, the 2023 crisis is distinguished by its extensive scale and heightened violence (44).

Substantial variation in the three selected malaria indicators across Sudan's states before and after the 2023 conflict was evident from quantitative descriptive analysis and strongly supported by qualitative thematic findings. This was particularly clear regarding the varied impact of the conflict among states.

Nationally, these differences were statistically significant for the indicator "reported malaria cases (presumed and confirmed) per 100,000 population". The primary challenges to data reporting from the qualitative results included population displacement, persistent shortages of trained health personnel, the destruction of critical infrastructure, and data collection-related constraints.

5.1. Variation Between States:

Variations in malaria impact indicators among Sudanese states predate the 2023 conflict, a disparity rooted in uneven resource distribution. As Mohamed Ismail (2020) highlighted, northern and central states (such as the Northern River Nile, Red Sea, and Jazirah) have historically been better resourced in terms of health facilities and qualified personnel than those in Darfur and Kordofan states (45).

Pre-existing infrastructure disparities likely explain the observed quantitative variations in malaria trends; a finding echoed in qualitative accounts of disrupted surveillance. Specifically, continuous reporting and an increase in cases were reflected in the northern and central states, while eastern and southern states showed missing data post conflict. This highlights how effective disease reporting relies not only on physical facilities but also on laboratories for case confirmation and trained personnel, including statisticians and malaria program officers proficient in digital platforms (46).

Darfur and Kordofan: Exacerbated Vulnerability:

The disproportionate severity of the 2023 conflict in Darfur states, compounded by their fewer pre-existing health facilities and personnel, rendered them particularly vulnerable to underreporting (47). Even minor disruptions due to conflict could significantly reduce reporting rates, a pattern less evident in better-resourced regions. For instance, as shown in the descriptive graphs (Figures 5 and 6), Jezirah state, despite experiencing RSF attacks, continued reporting during the conflict period, unlike Darfur, where indicators were largely missing. The challenge of violence constraints acting as a barrier to malaria reporting is also documented in Cameroon, where the destruction of health facilities directly led to missing data (48).

The sustained violence in Western and southern states has not only disrupted healthcare facilities but also might have hindered surveillance officers' physical access to data collection sites, likely contributing to the missing data observed in the descriptive analysis and impairing routine malaria surveillance activities (49). This pattern of missing data due to conflict was previously reported in South Kordofan state from June to July 2018 (50).

This pattern is not unique to Sudan; similar dynamics have been documented in other conflict-affected settings, such as Colombia, where protracted violence has been shown to undermine both the availability and continuity of health system activities, including disease surveillance (51).

These western and southern states have undergone a long history of conflict, which hinders the health development programs. Mirroring Sudan's challenges, South Sudan's health system strengthening efforts were severely impacted by conflict, due to widespread insecurity and degradation of healthcare facilities (52).

These findings highlight that the current breakdown in malaria surveillance data might not be attributed merely to a consequence of the 2023 conflict but also the culmination of decades-long systemic inequities. Persistent inequities in social and health sector development, stemming from the colonial-era concentration of political and economic power in Sudan's riverine north, fueled cycles of instability and conflict that further eroded health system capacity in marginalized regions (53)(54).

The conflict's destruction of health systems in these high malaria-endemic regions likely increased malaria outbreak risk (30). Concurrently, our study has documented substantial missing data, which severely compromises the accurate measurement of malaria program impact indicators. Addressing these challenges will require long-term commitments to equitable development and strengthening of health surveillance systems across these states.

Contrasting Case: Northern, Central, and Eastern States:

In contrast to the challenges faced by Darfur and Kordofan states, the northern and eastern regions demonstrated sustained reporting of malaria data. Temporal trend graphs from these states show no missing data; even states like Al Jazirah and Sennar, which were attacked later, continued their reporting. This resilience is largely attributable to a higher number of healthcare facilities and personnel in these areas. This might explain that despite some facilities being out of service, a sufficient network remained operational, and a larger workforce ensured personnel were available for documentation and reporting, even amid displacement. Furthermore, these states experienced less intense and shorter-duration conflicts and have now transitioned into a recovery phase, unlike the western and southern states that remain under direct conflict (55) .

The Role of Decentralization and Governance:

Our qualitative analysis revealed enhanced malaria surveillance rates after the 2023 conflict in the northern and eastern states, particularly the River Nile, Red Sea, Kassala, and Gedaref. This improvement is attributed to the urgent relocation of FMOH departments to SMOH in these areas following the destruction of the capital.

This relocation marked a substantive shift in health system governance, might move beyond mere logistics. With FMOH offices managed by highly skilled displaced federal staff in partnership with state-level MOH, decision-making authority, resource allocation, and accountability mechanisms were probably effectively localized, bypassing previous bureaucratic delays. This enhanced governance model aligns with the framework described by Lewis and Pettersson (56), who identify standards, incentives, information, and accountability as foundational to improved performance. Within these relocated FMOH offices, such elements might be actively cultivated: surveillance standards were clarified through targeted DHIS2 training workshops and on-the-job mentoring; financial and non-financial incentives (including stipends, vehicle access, and direct supervisory feedback) were introduced; and accountability presumably was strengthened as state-level managers assumed greater responsibility for outcomes as reported in the qualitative results.

Thus, the forced relocation of federal institutions most likely effectively actualized Sudan's previously nominal decentralization, directly overcoming the historical concentration of resources in Khartoum that had undermined its implementation.

Population Displacement:

These better-resourced states became destinations for populations displaced from the capital, possibly due to their proximity to the capital and well-developed infrastructure (28).

Where reported malaria cases have increased in northern states (Figure 5), one possible explanation for the apparent increase is likely a reflection of population displacement. Most of the displaced population in these states settled within host communities (28), potentially leading to increased attendance at local primary healthcare facilities. This shift might have resulted in IDPs being captured more consistently in routine surveillance data, thereby contributing to higher reported cases.

Impact of governance disparity:

The variation in malaria indicator reporting across Sudanese states underscores the importance of strong health system governance in sustaining disease surveillance during crises. This finding aligns with evidence from other conflict-affected settings, such as Colombia, where fragmented local governance and institutional weaknesses led to inconsistent health responses (51), and Northern Syria, where access to health services depended heavily on the governing authority in each region (57).

5.2. ITSA Results and Initial Interpretation:

At the national level, the immediate decline in the reported malaria case rate per 100,000 during the conflict quarter was statistically significant, highlighting a measurable impact of the conflict (Table 5 and 6). While this reduction established a lower baseline compared to the pre-conflict period, the subsequent change in the indicator's trend slope in the post-conflict quarter was not statistically significant. This significant, immediate reduction in reported cases across the country is best explained by insight from our qualitative results, particularly within the "surveillance post-conflict challenges" theme, which sheds light on the underlying causes of these observed trends.

surveillance system constraints:

The surveillance system infrastructure experienced significant setbacks. Despite the availability of statisticians in more stable states, according to the qualitative result, financial constraints resulting from national government budget reallocations that led to a lack of salaries might severely limit their ability to collect and report data, particularly due to restricted mobility to data collection points. The collapse of communication networks could further obstruct the timely transmission of data to central authorities, meaning even cases reaching facilities were missed by routine surveillance.

Additionally, the reduced reported cases could be due to a nationwide cessation of printing surveillance registers and the breakdown of supply chains to distribute them to health facilities, potentially hindering accurate record-keeping, likely leading to undocumented malaria cases. Together, these systemic disruptions might undermine malaria surveillance.

Impaired Malaria diagnosis: -

Additionally, the significant reduction in reported malaria cases nationwide can be attributed to a severely diminished capacity for proper diagnosis of malaria cases post-conflict. This diagnostic deficit stems largely from the mass migration of highly skilled healthcare professionals from all states seeking better employment opportunities overseas, leading to a critical shortage of trained providers (58).

Beyond clinical diagnosis, laboratory confirmation of malaria was likely also adversely affected by shortages of diagnostic commodities. Following a major attack on the capital, FMOH stocks were lost, increasing the distance to supply health facilities nationwide from the new national supply warehouse. This depletion possibly impacted the availability of RDTs and microscopy supplies (26) (58) .

In addition to supply challenges, inadequate infrastructure may compromise storage conditions for RDTs, reducing their reliability. This could lead to underdiagnosis and a decrease in reported malaria cases.

Malaria microscopy, a key diagnostic procedure, is reliant on stable electricity and skilled lab personnel. Both prerequisites were severely compromised by the conflict, which likely contributed to reduced confirmed case reporting (59). This lack of malaria diagnostic technologies might misdiagnose the disease with other febrile illness outbreaks like dengue fever, further reducing reported malaria cases.

A critical gap in malaria case reporting, as revealed by our qualitative analysis, stemmed from the substantial IDPs and their elevated risk of disease. Many IDP camps, particularly informal settlements without clinics or preselected PHC facilities, lacked the infrastructure to report malaria cases from the conflict's onset. Consequently, a vast number of cases likely went unrecorded and unreported, which could explain the reduced malaria case reporting observed nationally post-conflict.

Health Seeking Behavior:

The reduction in reported malaria cases documented in this study may be a reflection of a decline in health-seeking behavior. The willingness and ability of individuals to seek malaria management during the conflict were collectively influenced by accessibility factors, namely availability, accommodation, affordability, and acceptability (60). Economic constraints further compounded these access challenges, as evidenced by Kagaba (61). The pervasive lack of salaries, economic stagnation, and rampant inflation conceivably compromised the population's ability to afford basic care services, and the inability to cover transportation costs often restricted physical access to healthcare facilities (62) .This may have resulted in fewer individuals seeking care, leading to the underreporting of cases at health institutions.

Conversely, the observed reduction in reported malaria cases within the selected states could represent a true decline in disease burden, potentially stemming from effective malaria control interventions. This possibility aligns with cases like Sri Lanka, where malaria was eliminated even amidst a protracted civil war, using similar decentralization leadership strategies and stakeholder partnerships (63).

5.3. Limitations: -

The study is subject to several limitations, primarily inherent to conducting research within a conflict-affected setting.
Firstly, data accuracy and completeness were significant challenges. The widespread population displacement across Sudan during the study period compromised the accuracy of state population estimates (the denominator), potentially leading to either overestimation or underestimation of true indicator rates. Similarly, significant damage to health infrastructure likely affected the completeness and accuracy of the study indicators, potentially underestimating actual rates during the conflict.

Consequently, the comparability of data completeness and quality varies across states and reporting periods. Furthermore, the dynamic nature of the DHIS2 online reporting system is a limitation; data might exist in hard copy but not be uploaded or could be updated at any point after the study data collection, potentially affecting the reproducibility of the presented results.

Secondly, our state-level analysis presents a methodological limitation. While Sudan has adopted the High Burden to High Impact (HBHI) strategy(64) , which tailors malaria interventions to local epidemiological contexts (implying distinct performance at the locality level), analyzing such granular data for many localities was beyond the scope of this study. Therefore, the state level was selected as a practical unit of analysis, acknowledging the potential for within-state heterogeneity.

Thirdly, Khartoum state posed unique challenges. As the epicenter of the conflict and home to the largest displaced population, Khartoum operated with a parallel reporting system, thus limiting its comprehensive inclusion.
Fourthly, methodological considerations regarding qualitative data collection and analysis might introduce potential investigator bias. The data collection, translation, and analysis were conducted solely by the primary researcher. To reduce such bias, I engaged in reflexivity, maintaining awareness of personal assumptions and perspectives throughout the research process.
Additionally, the limited number of KIIs may restrict the breadth of qualitative insights.

Finally, ITSA had limitations. A significant confounder is the uncorrected for changing population dynamics within states due to displacement, which could influence reported rates. This study's reliance on a single primary data source for malaria surveillance data analysis, despite the fragmented nature of malaria surveillance across various departments, is also a limitation, as other potential data sources were not explored.

Chapter 6: Conclusion and Recommendations: -

6.1. Conclusion:

This study employed a mixed-methods approach to comprehensively examine the profound impact of the 2023 conflict on selected national malaria control program impact indicators, using DHIS2 data. Our descriptive quantitative analysis revealed significant state-level variations in indicator trends. The analytic quantitative result reveals a significant reduction in the level of the slope immediately after the conflict of the reported malaria cases indicator nationwide following the conflict's onset. These divergent trends and the overall decline are fundamentally attributed to pre-existing disparities in health development and surveillance infrastructure across states, exacerbated by the differential intensity and direct impact of the conflict. Qualitative insights further elucidated these observations, highlighting the widespread destruction of healthcare infrastructure, severe supply chain disruptions, critical human resource challenges, and the unique reporting gaps posed by internally displaced populations.

The observed variation intensifies the urgent need to invest more resources to strengthen the surveillance system and malaria control interventions in states that report persistent missing data after the conflict. Furthermore, it highlights the potential for actual decentralized approach, as the improvements in reporting echoed in our qualitative findings suggest this strategy warrants activation.

The findings underscore that while conflict universally disrupts surveillance health systems, the specific manifestations and outcomes in Sudan are highly localized, crucially dependent on underlying health system resilience, pre-existing infrastructure, and the nature of governance during crisis.

Despite facing limitations inherent to conflict related research, including compromised data quality and the single-author data collection and analysis for the qualitative part, this study provides vital insights into the complex interplay of conflict dynamics and malaria surveillance.

Ultimately, the interruption of malaria surveillance data, as evidenced by our results and discussed challenges, severely limits the accurate measurement of program interventions via the impact indicators and the effective allocation of vital funds. Therefore, there is a pressing need for robust integrated malaria program information system to guide the country's immediate response and long-term recovery efforts, necessitating future research that explores locality-level impacts and integrates all fragmented malaria surveillance data onto a unified platform for more effective program evaluation.

6.2. Recommendations: -

Future research should furthermore aim for a more granular, locality-level examination of malaria indicator trends, rather than solely state-level, to capture more nuanced epidemiological contexts.

Additionally, extending trend analysis to include data beyond the first quarter of 2025 is recommended to assess longer term trends and recovery from conflict direct consequences on the surveillance health system.

Beyond research, urgent policy and programmatic actions are needed, such as integrating Khartoum's malaria reporting into the national DHIS2 system to reduce data fragmentation and improve overall national surveillance accuracy. In addition, the need for an integrated and unified malaria surveillance platform has become more critical than ever. Such a platform would strengthen collaboration between directorates and standardize their efforts. Another key recommendation is to invest in state-level malaria control management, as the forced decentralization caused by the conflict has demonstrated success. More research is needed to determine the main factors behind this success and to explore potential challenges, which would help mitigate future issues in malaria control coordination and data collection for the surveillance system. Concluded from the literature, strategic investment in Community Health Workers is also critical to bridge existing gaps in surveillance and service delivery, particularly in conflict-affected areas.

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Chapter 8: Annex: -

8.1. Annex Tables: -

8.1.1. Table A1 Sudan States Population from 2020 to 2025

State	Sum_pop_2020	Sum_pop_2021	Sum_pop_2022	Sum_pop_2023	Sum_pop_2024	Sum_pop_2025
Jazirah	5403407.16	5543661.81	5687557.00	5831452.19	5978987.93	6130256.33
BlueNile	1277107.54	1310257.04	1344267.00	1378276.96	1413147.36	1448899.99
Central_Darfur	1697249.47	1741304.47	1786503.00	1831701.53	1878043.57	1925558.08
East_Darfur	1153302.39	1183238.32	1213951.29	1244664.26	1276154.26	1308440.97
Gedaref	2418425.85	2481200.22	2545604.00	2610007.78	2676040.98	2743744.81
Kassala	2670986.41	2740316.42	2811446.00	2882575.58	2955504.75	3030279.02
Khartoum	8689248.12	8914792.37	9146191.00	9377589.63	9614842.65	9858098.17
North_Darfur	2357133.07	2418316.47	2481088.00	2543859.53	2608219.17	2674207.12
North_Kordofan	2052538.81	2105815.96	2160476.00	2215136.04	2271178.98	2328639.81
Northern	972075.32	997307.19	1023194.00	1049080.81	1075622.55	1102835.80
Redsea	1472426.28	1510645.62	1549857.00	1589068.38	1629271.81	1670492.39
River_Nile	1569345.57	1610080.61	1651873.00	1693665.39	1736515.12	1780448.95
Sennar	2062406.88	2115940.17	2170863.00	2225785.83	2282098.22	2339835.30
South_Darfur	3716910.25	3813388.99	3912372.00	4011355.01	4112842.29	4216897.20
South_Kordofan	1917144.80	1966907.56	2017962.00	2069016.44	2121362.55	2175033.03
West_Darfur	1843894.81	1891756.24	1940860.00	1989963.76	2040309.84	2091929.68
West_Kordofan	1627857.59	1670111.41	1713462.00	1756812.59	1801259.95	1846831.82
WhiteNile	2894592.60	2969726.68	3046811.00	3123895.32	3202929.87	3283964.00
Grand_Total	45796052.94	46984767.56	48204337.29	49423907.02	50674331.87	51956392.47

Note:Sum_ pop is equivalent to population

8.1.2. Table A2 Inpatient Malaria Death Rate per 100000 from January 2020 to March 2025 Across Sudan States

Row Labels	April_June2020	April_June2021	April_June2022	April_June2023	April_June2024	January_March2020	January_March2021	January_March2022	January_March2023	January_March2024	January_March2025	July_September2020	July_September2021	July_September2022	July_September2023	July_September2024	October_December2020	October_December2021	October_December2022	October_December2023	October_December2024	Grand Total
Blue Nile	4.92	10.92	1.49	0.00	3.11	0.70	0.84	0.67	0.29	0.29	1.54	0.70	1.95	0.00	0.92	0.65	0.96	2.24	0.97	6.97	0.57	47.24
Central Darfur	0.29	1.93	0.39			0.71	0.63	1.74			0.71	0.80	1.98				0.53	1.15	0.86			10.50
East Darfur	0.19	1.42					0.25					0.24			0.08		0.26	1.35	1.74			3.53
Gedaref	0.17	0.24	0.59	0.04	0.19	0.45	0.69	0.55	0.08	0.24	0.74	0.69	0.29	0.31	0.08	0.75	1.08	1.01	0.82	1.93	1.05	11.37
Jazirah	0.19	0.27	0.39			0.49	0.49	0.11	0.03	5.02	0.30	0.31	0.95	0.24	0.03		0.57	1.46	1.19			11.11
Kassala	0.15	0.19	0.57		0.61	0.26	0.26	0.04	0.07	0.58	0.07	0.11	2.29	1.46			0.15	0.85	0.11	16.24	2.23	26.13
Khartoum					0.45					0.00	0.69					0.44					5.57	7.39
North Darfur	0.25	3.49	0.52		0.57	0.49	0.41	0.24	0.45		0.68	0.24	1.44			0.69	1.93	1.59	1.44			9.49
North Kordofan	0.93	0.52	0.69			0.49	0.76	0.51			0.29	4.56	1.39	0.65		2.93	1.46	1.46	3.37		0.22	20.65
Northern		0.20					0.69			1.02	0.98	0.59	0.29	0.67	0.65	0.82	0.39	0.39	0.19	0.74	0.74	14.57
Red Sea							0.07			1.23	0.98	0.27	0.06	0.14	0.31	0.14	0.07		0.19		0.49	3.07
River Nile	0.19	0.06			0.45	0.19	0.19	0.06	1.59	0.06	0.11	0.13	0.06	0.41	0.46	0.52		0.12	0.55	0.93	6.07
Sennar	0.49	0.39			0.13	0.53	0.52	4.75	0.19	2.24		0.63	0.80			0.29	1.47	0.84	0.84			15.50
South Darfur	0.05	0.03				0.11	0.39					0.22				0.38	3.35	0.92				5.95
South Kordofan	0.42	0.46	0.89		0.24	0.68	0.66	0.10	0.45			0.68	0.41			1.67	0.55	0.39	1.99			21.26
West Darfur	0.11	0.21	0.15			0.05	0.21	0.15				0.22	0.63	0.05		0.22	0.05	0.10				2.17
West Kordofan	0.61	0.72	0.41			0.61	0.72	1.45	0.06			0.68	2.20	0.98		1.54	1.90	1.54	15.16			25.32
White Nile	0.17	0.27	0.03	0.13	0.25	0.14	0.44	0.26	0.03			0.24	0.24	0.31		0.21	0.67	0.23			0.92	5.59
Grand Total	9.93	19.35	26.38	2.27	6.49	5.98	8.23	9.92	2.87	13.15	3.98	9.42	13.29	11.59	4.12	3.92	11.26	27.94	28.38	28.05	6.79	266.97

8.1.3. Table A3 Reported Malaria Cases (presumed and confirmed) per 100000 from January 2020 to March 2023 Sudan States

Row Labels	April_June2020	April_June2021	April_June2022	April_June2023	April_June2024	January_March2020	January_March2021	January_March2022	January_March2023	January_March2024	January_March2025
BlueNile	6917.59	7930.96	6878.99	5635.01	6021.10	10406.56	8955.19	11813.58	6666.87	6465.57	7432.81
Central_Darfur	764.24	3060.23	1296.05			1002.15	2263.02	2596.92	47.99		2660.63
East_Darfur	403.88	1835.56	2565.01	358.17	930.45	745.60	1575.17	3024.42	642.18	435.06	1363.68
Gedaref	2008.29	2483.84	2087.52	1506.51	2194.55	2909.00	3630.14	2905.09	2029.15	2062.52	3006.18
Jazirah	2344.34	3316.17	3157.98	475.22	244.89	4980.41	4842.97	3714.02	535.36	88.39	268.90
Kassala	2176.91	2916.05	1703.89	1634.61	1998.34	2843.74	3389.39	2620.61	2082.06	2324.37	2158.84
Khartoum					180.76					99.79	566.71
North_Darfur	613.37	1275.47	879.25			1189.71	1274.03	1589.06	282.56		6.13
North_Kordofan	2073.87	3071.64	1749.06	1.72	463.99	5729.83	3082.23	3944.96	468.59	584.89	770.36
Northern	1531.26	2387.23	2080.06	2764.04	3220.37	2944.73	2842.25	2910.10	2629.92	2823.48	3928.60
Redsea	99.97	224.34	123.95	124.03	235.57	194.98	176.68	140.79	56.57	162.28	355.28
River_Nile	3761.06	3135.74	3622.37	3278.75	4692.90	5726.14	5191.91	4992.94	3307.09	5166.78	6832.55
Sennar	3231.37	5411.97	2622.74	1592.11	875.03	7001.92	7293.07	4309.25	1308.39	1751.33	472.81
South_Darfur	235.79	686.03	397.69			931.18	717.45	412.64	112.63		
South_Kordofan	1588.98	2223.34	426.72	28.32		2357.05	2225.57	1137.93	419.86	66.94	
West_Darfur	533.38	873.05	353.35			622.92	1473.97	806.50	203.82		128.83
West_Kordofan	1340.84	2296.19	957.59			1988.50	2492.35	1883.67	144.86		
WhiteNile	2516.35	4007.91	2711.16	2015.69	1977.60	3804.40	4208.67	2856.82	801.47	1851.46	2054.50
Grand Total	**32141.48**	**47135.72**	**33613.38**	**19414.17**	**23035.54**	**55378.83**	**55634.06**	**51659.30**	**21739.39**	**23882.88**	**32006.83**

Row Labels	July_September2020	July_September2021	July_September2022	July_September2023	July_September2024	October_December2020	October_December2021	October_December2022	October_December2023	October_December2024	Grand Total
BlueNile	11223.49	13375.47	7644.17	6171.55	9419.19	11630.42	11001.12	9615.95	6856.17	10155.84	182217.58
Central_Darfur	1332.27	4832.12	3089.16			1258.27	2555.84	4191.60		4293.51	35244.01
East_Darfur	2178.53	4154.28	6614.68	419.79	941.81	3453.47	5079.45	5510.11	155.46	1593.07	43979.83
Gedaref	3883.35	3459.13	3359.56	2316.70	2904.18	4758.51	4766.04	4519.48	2711.41	4978.85	64479.99
Jazirah	3839.19	3992.27	4310.43	893.43	123.03	4611.74	3695.37	4742.05	534.65	193.69	50904.50
Kassala	3077.40	2777.23	2582.83	1608.08	2422.90	3775.72	2850.88	2235.72	1859.59	2492.60	51531.78
Khartoum		0.40			351.37				3.27	444.20	1646.52
North_Darfur	2810.75	4144.70	3320.64			5306.15	5955.71	6058.83			34706.37
North_Kordofan	3308.54	4077.27	2774.57	2.62	1047.91	10286.38	4886.28	13091.79	17.15	1124.00	62557.65
Northern	1865.18	2254.27	2182.48	2900.16	4471.55	1954.48	1928.89	2785.20	2857.07	3121.54	56382.87
Redsea	101.74	79.57	100.85	123.41	268.65	279.74	129.41	183.57	161.67	505.69	3828.73
River_Nile	3965.28	4231.84	4672.57	3083.43	6118.46	3872.19	5170.55	4505.01	4146.98	5966.14	95440.70
Sennar	5456.83	5812.59	4657.23	1810.73	8.11	5108.59	6699.24	7571.83	1172.08	43.42	74210.64
South_Darfur	1480.88	1026.41	929.46			1590.76	1094.46	1325.08			10940.44
South_Kordofan	2918.51	2440.02	470.38	24.75		4694.17	2628.44	1654.05	11.74		25316.76
West_Darfur	1390.10	2635.28	1953.93		38.62	2919.15	2772.61	2598.44		2.50	19306.44
West_Kordofan	3034.72	4361.09	2880.83			4178.25	4152.60	2617.45			32328.96
WhiteNile	4356.85	4027.37	3559.56	1833.64	1962.95	5173.92	4689.96	4030.38	1778.68	2283.72	62503.06
Grand Total	**56223.61**	**67681.32**	**55103.33**	**21188.27**	**30078.74**	**74851.92**	**70056.86**	**77236.51**	**22265.93**	**37198.78**	**907526.85**

8.1.4. Table A4 Malaria Test Positivity Rate from January 2020 to March 2025 for Sudan States

Row Labels	April_June2020	April_June2021	April_June2022	April_June2023	April_June2024	January_March2020	January_March2021	January_March2022	January_March2023	January_March2024	January_March2025	July_September2020	July_September2021	July_September2022	July_September2023	July_September2024	October_December2020	October_December2021	October_December2022	October_December2023	October_December2024	Grand Total
BlueNile	35.20	39.70	32.70	21.60	27.60	33.70	31.20	58.50	20.40	23.70	34.20	35.20	40.50	34.20	19.80	31.10	29.80	39.90	44.20	34.40	43.50	711.10
Central_Darfur	41.00	33.60	19.70			25.40	31.80	30.50				47.50	38.20	41.80			29.00	45.80	29.40			413.70
East_Darfur	33.70	32.40	36.00	20.20	3.30	52.20	42.30	26.10	8.10		10.80	44.50	51.50	43.70	42.00	11.50	2.90	55.10	37.20	92.70	34.20	680.40
Gedaref	18.00	14.60	14.60	8.70	14.80	19.90	20.30	21.70	13.40	13.50	13.20	18.90	19.40	18.90	12.30	14.20	19.50	21.50	26.00	13.00	17.90	354.30
Jazirah	25.40	27.70	9.00	37.60	29.20	26.00	32.60	30.90	30.50	4.50	31.00	27.70	29.40	28.20	57.10	14.40	33.00	30.60	30.00	63.00	97.60	695.40
Kassala	21.80	40.60	17.10	15.90	19.00	26.40	29.10	24.10	12.50	22.60	19.00	32.10	29.60	22.80	14.10	17.60	44.50	37.60	30.50	20.50	14.10	511.50
Khartoum					12.80					15.30	18.20					22.10				22.60	23.90	114.90
North_Darfur	23.00	29.50	10.60			15.80	20.20	20.50	20.60			29.60	28.00	27.50			43.00	43.40	32.50			344.20
North_Kordofan	22.40	18.20	13.50	7.20	6.90	28.50	20.20	20.70	17.80	17.60	15.60	28.60	23.30	13.20		18.70	220.20	24.90	13.80	43.60	14.30	589.20
Northern	14.20	22.10	18.10	45.20	18.60	17.10	19.80	21.50	36.30	23.80	10.70	20.00	20.70	24.60	36.50	18.10	15.70	18.60	24.30	43.60	20.10	489.60
Redsea	3.30	17.80	4.50	2.60	8.70	5.50	8.00	7.00	1.70	3.30	9.40	3.90	2.70	5.60	3.60	10.60	12.80	6.20	6.80	4.10	9.70	137.80
River_Nile	20.30	20.50	21.00	14.30	19.00	31.10	28.00	27.90	11.40	21.10	20.50	21.00	21.80	23.60	12.40	22.40	22.70	24.40	21.40	19.80	19.60	444.20
Sennar	30.80	33.10	45.40	24.80	26.90	49.10	58.10	36.90	23.10	31.10	13.70	47.50	44.60	39.00	33.80		9.00	43.00	41.70	27.30		658.90
South_Darfur	77.40	16.60	13.30			42.50	13.90	12.10	19.70			18.80	19.40	4.40			22.30	19.70	19.20			299.30
South_Kordofan	40.80	44.30	6.70			46.00	48.60	30.50	50.90			58.10	45.60	19.20			61.50	70.50	48.30			571.00
West_Darfur	35.30	15.40	11.70			26.10	24.10	39.50	53.40		39.10	28.10	30.50	45.20			43.10	49.70	27.80			469.00
West_Kordofan	19.90	17.40	6.60			21.60	18.70	28.90	41.40			35.00	45.10	27.10			51.60	24.20	39.10			376.60
WhiteNile	37.60	44.00	43.00	28.20	17.00	27.90	36.60	45.40	28.00	14.40	31.40	30.50	41.50	43.00	23.40	22.10	35.80	40.80	42.50	34.00	26.00	693.10
Grand Total	**500.10**	**467.50**	**323.50**	**226.30**	**203.80**	**494.80**	**483.50**	**482.70**	**389.20**	**190.90**	**266.80**	**527.00**	**531.80**	**462.00**	**255.00**	**202.80**	**696.40**	**595.90**	**514.70**	**418.60**	**320.90**	**8554.20**

8.2. Annex 2: Informed Consent Form for Key Informants Interviews'

Title of Study:

Impact of the 2023-Armed Conflict of Sudan on Routine Malaria Data Reporting: Trend Analysis of Three Key Impact Indicators (January 2020- March 2025)

Principal Investigator:

KHLOOD FATHI HASSAN ALNAEEM
KIT ROYAL TROPICAL INSTITUTE
Contact: k.alnaeem@studen.kit.nl/ KHLOODALANAAEM@GMAIL.COM

Introduction:

You are being invited to participate in a research interview because of your key role as the [national monitoring and evaluation manager/state M&E/state malaria program manager] of the Sudan National Malaria Control Program. This interview is part of a master's thesis project being conducted to understand how the 2023-armed conflict affected routine surveillance malaria data reporting to the DHIS2 in Sudan.

Purpose of the Study:

The purpose of this study is to assess the impact of the 2023-armed conflict on the routine malaria surveillance data reported through the DHIS2 system. Your insights will help us understand how the conflict influenced data reporting to the DHIS2 and malaria program operations at the [national/state] level pre and post conflict.

Procedures:

• The interview will take approximately 30–45 minutes and I would like to take your permission to records the discussion to ensure accurate transcription.
• Participation is entirely voluntary, and you may choose not to answer any question or stop the interview at any time without consequence.

Risks and Benefits:

• Risks are minimal as no sensitive personal information will be collected. However, your contribution will help improve understanding of impact of conflict on routine malaria surveillance collected through DHIS2 during emergencies and may inform future public health strategies.

Confidentiality:

• Your name and identity will be kept confidential any information you provide will be used only for academic purposes and may be included in the thesis, but your name will not be mentioned.

Voluntary Participation:

Your participation is voluntary. You may decline to participate or withdraw from study at any point without any penalty or loss of benefits.

Consent Statement:

I have read and understood the information provided above. I agree to participate in this interview voluntarily.

☐ Yes, I give permission to be audio recorded.

☐ No, I do not give permission to be audio recorded.

Name of Participant (Printed): _____

Signature: _____ Date: _____

8.3. Annex 3: Questionnaires

Interviewee: Federal Level NMCP Monitoring and Evaluation Manager

Main Question	Probing Questions / Follow-ups
1. Please describe your involvement in malaria surveillance in the states of Sudan	
2. Please describe the general situation of inaccessibility and conflict in Sudan states.	
3. How has surveillance changed before and after the start of the conflict in April 2023?	

4. Can you describe any differences you've noticed in how malaria is reported in different states before and after the start of the ongoing conflict of April 2023?	• What are the main reasons for these differences? • Can you give examples of states where reporting has improved, remained the same, or remains inconsistent? • What factors are most critical in explaining these patterns?
5. Please describe the major challenges to conducting malaria surveillance, data collection, and reporting across different states before and after the start of the conflict in April 2023 in the states of Sudan	•What are the surveillance challenges among the inaccessible populations affected by conflict? •How does the movement of people affect your ability to track malaria cases? •Can you describe how challenges with communication affect your ability to collect, report, or respond to malaria data? •What difficulties have you faced with malaria surveillance because of damage to health facilities, shortages of supplies, or lack of trained staff? •Besides health facilities, how do problems with roads, transportation, electricity, or water supply make it harder to carry out malaria surveillance in your region? Any examples from your experience?
6. Have these issues affected diagnosis, follow-up, or resource allocation?	
7. Are there other factors that are impacting effective malaria surveillance in conflict-affected areas of Sudan states? Please describe.	
8. Can you describe what malaria surveillance successes you've observed in states where reporting	• Especially regarding the availability and use of DHIS2 data for planning

has improved after the start of the 2023 conflict?	
9. What factors do you think are most critical in explaining the improvement in malaria surveillance?	• Can you explain how [factor] led to improvement? • Why did it make a difference? • Examples from specific states/situations?
10. Can you describe the main approaches or strategies currently used for malaria surveillance in Sudan in conflict-affected and stable states?	
11. How is surveillance conducted in conflict areas compared to stable regions?	• If different, what are the main differences?
12. Have any new or innovative methods been introduced to improve malaria surveillance?	• How have these innovations been implemented?
13. How do traditional surveillance methods interact with new technologies or innovations?	• What has worked well? • What challenges have emerged?
14. Are there other opportunities for effective surveillance that we have not discussed?	
15. How can the quality and accuracy of surveillance be assessed in conflict-affected areas compared to stable states?	• For example, the likelihood that a malaria case would be detected and reported
16. What systems are in place to share information and collaborate between agencies involved in the humanitarian response in Sudan?	
17. How might these systems benefit malaria surveillance in the Sudan states?	

Note :topic guide translated from English language to Arabic language by the author

Interviewee: State Malaria Program Manager, Interviewee: State Level MCP Monitoring and Evaluation Manager

Main Question	Probing Questions
1. Please describe your involvement in malaria surveillance in your state.	-
2. Please describe the general situation of how the 2023 conflict affected your state.	-
3. How has malaria surveillance changed before and after the start of the April 2023 conflict in your state?	-
4. Can you describe any differences you've noticed in how malaria is reported in your state before and after the start of the ongoing conflict of April 2023?	*Can you walk me through the main reasons for these differences? *Can you give examples of how reporting improved, remained the same, or was absent or inconsistent? *What factors related to your state do you think are most critical in explaining these patterns?
5. Can you describe what malaria surveillance challenges were before and after the 2023 conflict, particularly concerning the availability and use of DHIS2 data at the state level?	• Inaccessible populations: What are the surveillance challenges among the inaccessible populations affected by conflict? • Can you describe how difficulties in reaching certain communities—such as those in remote areas, conflict zones, or places with poor transportation—affect your ability to detect, report, and respond to malaria cases? Please share specific examples from your experience where access barriers

	have impacted malaria surveillance efforts. • How does the movement of people—such as those displaced by conflict or searching for safety—affect your ability to track malaria cases? • Can you describe how challenges with communication—such as poor phone networks and internet access—affect your ability to collect, report, or respond to malaria data in your area? • What difficulties have you faced with malaria surveillance because of damage to health facilities, shortages of medical supplies, or lack of trained staff? • Besides health facilities, how do problems with roads, transportation, electricity, or water supply make it harder to carry out malaria surveillance in your region?
6. Are there other factors that are impacting effective malaria surveillance in your state? Please describe.	-
7. Can you describe what malaria surveillance successes you've observed in your state where reporting has improved after the start of the 2023 conflict?	-
8. What factors do you think are most critical in explaining the	*You mentioned [factor]. Can you explain *how this has led to better malaria surveillance?

improvement in malaria surveillance?	*Why do you think this [factor] has made such a difference? *Can you give an example of how this played out in your state?
9. Can you describe the approaches or strategies your program has used for malaria surveillance in different areas of your state before and after the conflict?	-
10. Have any new or innovative methods been introduced to improve malaria surveillance in your state?	-
11. How do traditional surveillance methods interact with new technologies or innovations?	-
12. Are there other opportunities for effective surveillance in your state that we have not discussed?	-
13. Can you describe how malaria surveillance is currently assessed and monitored in your state?	-
14. How can the quality and accuracy of surveillance data be assessed in your state?	-
15. What systems are in place to share information and collaborate between your state malaria program and other agencies involved in the humanitarian response?	-
16. How might these systems benefit malaria surveillance in your state?	-

Note: topic guide translated from English language to Arabic language by the author

8.4. Annex 4: AI Declaration

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ANNEX 4

KIT Institute (Masters or Short course) Participants
Declaration for Use of Generative AI (GenAI)

Check the box that applies to your completion of this assignment:

☐ I confirm that **I have not used** any generative AI tools to complete this assignment.

☒ I confirm that **I have used** generative AI tool(s) in accordance with the ***"Guidelines for the use of Generative AI for KIT Institute Master's and Short course participants"***. Below, I have listed the GenAI tools used and for what specific purpose:

Generative AI tool used	Purpose of use
1.Chatgpt	To generate ideas, to search for R program codes, to search for paraphrasing words
2.Grammerly	To check for grammar and spelling
3. Perplexity AI	To search for relative papers, to generate ideas, to paraphrase words, to search for R program codes
4.Gemini	to generate ideas, to paraphrase words
5.SciSpace	To search for relative articles, to explain articles' methodology

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