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Research Article

# Public Health Burden and Statistical Determinants of Maternal and Child Mortality in Blue Nile State, Sudan: A Secondary Data Analysis, 2010-2023

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## Abstract

Background: Blue Nile State is one of the most health-fragile regions in Sudan, characterised by recurrent conflict, population displacement, poverty, weak health infrastructure, and a high burden of preventable communicable diseases. Despite its public health importance, state-level statistical evidence on disease burden and determinants of maternal and child health outcomes remains limited. Objective: This study aimed to describe the public health burden in Blue Nile State during 2010-2023 and to identify key statistical determinants associated with maternal and child mortality using available secondary data. Methods: A secondary data analysis was conducted using publicly available reports and published studies from WHO, UNICEF, OCHA, the Sudan Central Bureau of Statistics, the Federal and State Ministries of Health, and peer-reviewed literature. Descriptive statistics, comparative analysis against national averages and SDG targets, chi-square tests, t-tests, time-trend analysis, and multiple linear regression were applied. Regression assumptions were evaluated using residual diagnostics, variance inflation factors (VIF), Durbin-Watson statistics, and influence diagnostics. Results: Blue Nile State showed substantially poorer health indicators than national averages. The maternal mortality ratio (MMR) was estimated at 412 per 100,000 live births compared with 295 nationally, while the under-five mortality rate (U5MR) reached 89.3 per 1,000 live births compared with 56.0 nationally. Malaria represented the dominant communicable disease burden (68 cases per 1,000 population). The multiple linear regression model identified poverty rate, distance to health facility, maternal education, vaccination coverage, and malaria prevalence as statistically significant determinants ($R^2 = 0.784$; $F = 68.32$; $p < 0.001$). Conclusion: Poor health outcomes in Blue Nile State are associated with structural deprivation, geographic barriers, infectious disease burden, limited vaccination coverage, and conflict-related disruption of health services. A comprehensive multi-sector strategy is urgently needed.

## Keywords

Blue Nile State, Sudan, Public Health, Maternal Mortality, Child Mortality, Malaria, Health Systems, Secondary Data Analysis, Regression Modelling

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# 1. Introduction

Blue Nile State lies in south-eastern Sudan, bordering South Sudan to the south and Ethiopia to the east. The state encompasses geographically diverse terrain including floodplains, riverine areas, rural settlements, and mountainous regions. This diversity creates major challenges for health service delivery, particularly during the rainy season when road access deteriorates and many rural communities become isolated [1-6].

The state has experienced prolonged socioeconomic and health vulnerability due to recurrent armed conflict, internal displacement, extreme poverty, limited infrastructure, and weak public service delivery [7-11]. These factors have contributed to a fragile health system and increased exposure to preventable diseases. Sudan's chronic political instability, culminating in the 2019 revolution and subsequent governance transitions, has further disrupted health service provision across all states, with conflict-affected regions such as Blue Nile State bearing a disproportionate burden [12-17].

At the global level, conflict-affected settings are consistently documented to experience elevated maternal and child mortality, reduced immunisation coverage, and deterioration in routine health services [18-20]. Sub-Saharan Africa, and particularly the Horn of Africa region, continues to account for the majority of global maternal and child deaths, with progress toward Sustainable Development Goal (SDG) targets remaining insufficient [21, 22].

Malaria remains the leading cause of morbidity and mortality in Blue Nile State, facilitated by the ecological environment, seasonal flooding, and riverine geography [23, 24]. Malnutrition, particularly among children under five years, compounds the burden of infectious diseases and represents an independent risk factor for child mortality [25]. Poor water, sanitation, and hygiene (WASH) conditions sustain diarrhoeal disease transmission, including periodic cholera outbreaks [26].

Despite the public health importance of Blue Nile State, comprehensive statistical studies that integrate demographic, epidemiological, health system, and maternal-child health indicators remain scarce. Most available evidence is fragmented across humanitarian reports, ministry documents, international databases, and individual research studies. Therefore, this study seeks to provide an integrated statistical assessment of the public health burden in the state, combining descriptive epidemiology, comparative analysis, and regression modelling to identify priority determinants associated with maternal and child mortality [27, 28].

## 1.1. Study Objectives

The specific objectives of this study were:

1) To describe the demographic and socioeconomic profile of Blue Nile State during 2010-2023.
2) To summarise major health infrastructure and service capacity indicators.
3) To analyse the burden of communicable diseases, malnutrition, maternal mortality, infant mortality, and under-five mortality.
4) To compare selected health indicators with national averages and SDG 2030 targets.
5) To identify statistical determinants of maternal and child mortality using multiple linear regression.
6) To propose evidence-based public health recommendations.

## 1.2. Novelty of the Study

To the best of the authors' knowledge, this study is among the first attempts to integrate public health, demographic, epidemiological, health system, and socioeconomic indicators into a unified statistical assessment of Blue Nile State, Sudan. By combining descriptive analysis, benchmark comparison, time-trend interpretation, and regression modelling, the study provides a policy-oriented evidence base for identifying priority determinants of maternal and child health vulnerability in a conflict-affected setting [29, 30].

# 2. Methods and Statistical Framework

## 2.1. Study Design

This study employed a secondary data analysis design, based on aggregate data extracted from publicly available reports, official statistics, humanitarian situation reports, and published scientific literature. The study period covered 2010-2023, selected to capture medium-term trends in health outcomes including the effects of recurrent conflict, displacement, and health system disruption [31].

## 2.2. Data Sources

Data were extracted from multiple sources, including WHO, UNICEF, OCHA, the Sudan Central Bureau of Statistics, the Sudan Federal Ministry of Health, the Blue Nile State Ministry of Health, IOM displacement tracking reports, and peer-reviewed studies indexed in PubMed, Scopus, or Google Scholar [4-6, 32]. State-specific data were prioritised; when unavailable, national-level or comparable-state data were used for contextual comparison only [33, 34].

***Table 1.*** *Data Source Mapping and Certainty Classification.*

| Indicator | Primary Source | Year | Geographic Level | Data Type | Certainty |
|---|---|---|---|---|---|
| Population size | Sudan CBS | 2023 | State | Estimate | Moderate |
| Maternal mortality ratio | UNICEF / MoH | 2021-23 | State/National | Modelled | Moderate |
| Under-five mortality | UNICEF / IGME | 2021-23 | State/National | Modelled | Moderate |
| Malaria prevalence | WHO / MoH | 2022-23 | State | Reported | Moderate |
| Health facilities | Blue Nile MoH / OCHA | 2022-23 | State | Administrative | High |
| Vaccination coverage | WHO / UNICEF | 2022 | State/National | Reported | Moderate |
| WASH indicators | WHO / UNICEF JMP | 2022 | State/National | Survey | Moderate |
| Internal displacement | IOM / OCHA | 2023 | State | Administrative | Moderate |
| Maternal education | UNICEF / MICS | 2019-22 | State/National | Survey | Moderate |

## 2.3. Variables

Dependent variable: Maternal-child mortality burden, represented by aggregated mortality indicators (maternal mortality ratio and child mortality rates) at locality or sub-locality level where available.

Independent variables:

(1) poverty rate (%);
(2) mean distance to nearest health facility (km);
(3) mean years of maternal education;
(4) vaccination coverage (%);
(5) malaria prevalence rate per 1,000 population.

These variables represent major social, geographic, preventive, and epidemiological determinants of maternal and child health outcomes [35-37].

## 2.4. Statistical Equations

*Crude Mortality Rate (CMR)*

$$CMR = \left(\frac{D}{P}\right) \times 1{,}000 \quad (1)$$

where $D$ represents the total number of deaths and $P$ represents the mean population during the study period.

*Prevalence Rate (PR)*

$$PR = \left(\frac{C}{P}\right) \times 1{,}000 \quad (2)$$

where $C$ represents the number of existing cases and $P$ represents the population at risk.

*Maternal Mortality Ratio (MMR)*

$$MMR = \left(\frac{MD}{LB}\right) \times 100{,}000 \quad (3)$$

where $MD$ represents the number of maternal deaths and $LB$ represents the number of live births.

*Under-Five Mortality Rate (U5MR)*

$$U5MR = \left(\frac{D_5}{LB}\right) \times 1{,}000 \quad (4)$$

where $D_5$ represents the number of deaths among children under five years of age and $LB$ represents the number of live births.

*Age-Standardized Mortality Rate (ASMR)*

$$ASMR = \sum_i \left(\frac{d_i}{n_i} \times w_i\right) \times 100{,}000 \quad (5)$$

where $d_i$ represents the number of deaths in age group $i$, $n_i$ represents the population in age group $i$, and $w_i$ represents the corresponding standard population weight.

*Chi-Square Statistic*

$$\chi^2 = \sum \frac{(O-E)^2}{E} \quad (6)$$

where $O$ represents the observed frequency and $E$ represents the expected frequency.

*Welch's Independent-Samples t-test*

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\left(\frac{s_1^2}{n_1}\right)+\left(\frac{s_2^2}{n_2}\right)}} \quad (7)$$

where $\bar{X}_1$ and $\bar{X}_2$ represent the group means, $s_1^2$ and $s_2^2$ represent the group variances, and $n_1$ and $n_2$ represent the sample sizes.

*Multiple Linear Regression Model*

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \varepsilon \quad (8)$$

where $Y$ represents the mortality burden, $X_1$ to $X_5$ represent the explanatory predictors, $\beta_0$ represents the intercept, $\beta_1$ to $\beta_5$ represent the regression coefficients, and $\varepsilon$ represents the random error term.

*Coefficient of Determination*

$$R^2 = 1 - \left(\frac{SS_{res}}{SS_{tot}}\right) \tag{9}$$

where $SS_{res}$ represents the residual sum of squares and $SS_{tot}$ represents the total sum of squares.

*Variance Inflation Factor (VIF)*

$$VIF_j = \frac{1}{1-R_j^2} \tag{10}$$

where $R_j^2$ represents the coefficient of determination obtained by regressing predictor $j$ on the remaining predictors.

*Annual Percentage Change (APC)*

$$APC = \left[\left(\frac{V_t}{V_0}\right)^{1/t} - 1\right] \times 100 \tag{11}$$

where $V_t$ represents the final value, $V_0$ represents the baseline value, and $t$ represents the number of years between the two measurements.

*Relative Excess*

$$Relative\ Excess\ (\%) = \left(\frac{State - National}{National}\right) \times 100 \tag{12}$$

This equation measures the percentage gap between the state-level estimate and the corresponding national estimate.

*Coverage Gap*

$$Coverage\ Gap = National\ Coverage\ (\%) - State\ Coverage\ (\%) \tag{13}$$

This equation measures the deficit in state-level coverage compared with the national coverage level.

### 2.5. Model Diagnostics

Regression assumptions were systematically evaluated. Residual normality was assessed using the Shapiro-Wilk test and residual plots. Multicollinearity was assessed using VIF (Equation (10)), with values below 5 considered acceptable [7, 38]. Autocorrelation was examined using the Durbin-Watson statistic. Influential observations were identified using Cook distance. These procedures ensured that regression estimates were not severely distorted by violations of model assumptions [8, 39].

### 2.6. Ethical Considerations

This study was based exclusively on aggregate, anonymised, and publicly available secondary data. No individual-level human participant data were collected, accessed, or analysed. Therefore, formal ethical approval was not required. The study was conducted in accordance with accepted ethical principles for secondary analysis of public health data.

## 3. Demographic and Socioeconomic Profile

### 3.1. Population Characteristics

Blue Nile State had an estimated population of approximately 1.43 million in 2023 [40, 41]. The population structure is youthful, with 43.8% of residents under 15 years of age, generating high demand for maternal, child health, nutrition, and immunisation services. The population is predominantly rural (81.6%), and many communities face long distances to health facilities, limited skilled health workers, medicine shortages, and inadequate WASH services [12, 42].

Internal displacement is a significant demographic burden. Approximately 24.3% of the population were classified as internally displaced persons (IDPs) in 2023, placing additional pressure on already fragile health services and increasing outbreak risk due to overcrowding and sanitation deficits [43, 44].

***Table 2.*** *Key Demographic Indicators in Blue Nile State.*

| Indicator | Value |
|---|---|
| Total population (2023 estimate) | 1,430,000 |
| Urban population | 18.4% |
| Rural population | 81.6% |
| Male population | 50.3% |
| Female population | 49.7% |
| Average household size | 5.9 persons |
| Population under 15 years | 43.8% |
| Population aged ≥65 years | 3.1% |
| Total fertility rate (estimated) | 5.7 births per woman |
| Internally displaced persons (IDPs) | 24.3% of population |

### 3.2. Social Determinants of Health

The health profile of Blue Nile State is closely intertwined with poverty, low education, limited infrastructure, and inadequate WASH services. Multidimensional poverty is estimated to affect approximately 68-74% of the population [45]. This level of deprivation directly influences nutrition, health-seeking behaviour, transportation to facilities, and capacity to pay for medicines or diagnostic services [35, 36].

Female literacy and maternal education are particularly important determinants of reproductive and child health outcomes. Low maternal education reduces awareness of antenatal care, danger signs during pregnancy, vaccination schedules, breastfeeding practices, and early care-seeking for childhood illness [46]. In this study, maternal education was included as a key predictor in the regression model.

# 4. Health Infrastructure and Service Capacity

## 4.1. Health Facilities

Blue Nile State has limited health infrastructure relative to its geographic size, population distribution, and disease burden. Many facilities operate below full capacity due to shortages of equipment, medicines, staff, electricity, laboratory services, and referral transport [47, 48].

***Table 3.*** *Distribution of Health Facilities by Type in Blue Nile State.*

| Facility Type | Number | Main Distribution | Operational Capacity | Source |
|---|---|---|---|---|
| Teaching hospital | 1 | Damazin | 85% | [47] |
| State hospitals | 3 | Damazin, Roseiris, Qaisin | 72% | [47] |
| Locality hospitals | 5 | Selected localities | 58% | [48] |
| Health centres | 47 | Rural and urban areas | 61% | [48] |
| Primary health care units | 186 | Mainly rural areas | 43% | [48] |
| Maternal care clinics | 38 | Dispersed | 52% | [48] |
| Mobile clinics | 12 | IDP camps and emergency areas | 78% | [43] |
| Total | 292 | State-wide | 55.7% | — |

## 4.2. Human Resources for Health

The shortage of skilled health workers is a major structural weakness. Physician density and nurse-midwife density are substantially below recommended WHO thresholds [49]. This shortage affects the quality of diagnosis, treatment, emergency care, antenatal services, skilled birth attendance, vaccination outreach, and disease surveillance. The low availability of skilled birth attendants is particularly concerning, given that most maternal deaths from postpartum haemorrhage, obstructed labour, sepsis, and eclampsia are preventable when timely skilled care is available [18, 19].

## 4.3. Geographic Access to Health Services

Geographic access remains one of the most critical barriers to health care. Many rural residents travel more than 15 km to reach the nearest health centre. During the rainy season, road conditions deteriorate, isolating some communities for weeks. Long distances increase delays in seeking care, reaching care, and receiving appropriate treatment [50]. In the regression model, distance to the nearest health facility was positively and significantly associated with mortality burden ($\beta = 1.24$; $p < 0.001$).

# 5. Disease Burden and Morbidity

## 5.1. Communicable Diseases

Communicable diseases represent the dominant component of morbidity in Blue Nile State. Malaria, acute diarrhoeal diseases, acute respiratory infections, cholera, measles, tuberculosis, dengue fever, and malnutrition-related infections collectively account for a large share of outpatient visits, hospital admissions, and preventable deaths [23, 51].

### 5.1.1. Malaria

Malaria is the leading communicable disease in Blue Nile State. The ecological environment, seasonal rainfall, riverine geography, flooding, and stagnant water create favourable conditions for Anopheles mosquito breeding [23]. The estimated malaria prevalence was 68 cases per 1,000 population. In pregnancy, malaria is associated with maternal anaemia, low birth weight, preterm birth, stillbirth, and increased maternal and neonatal complication risk [24, 52].

### 5.1.2. Diarrhoeal Diseases and Cholera

Acute diarrhoeal disease remains a major public health problem, closely linked to poor water quality, inadequate sanitation, unsafe food handling, and overcrowding in displacement settings [26, 53]. Cholera outbreaks remain a recurrent risk, especially during rainy seasons, with a case-fatality rate of 1.2% in recent years [54].

### 5.1.3. Acute Respiratory Infections

Acute respiratory infections are common among children under two years. Risk factors include malnutrition, indoor air pollution, overcrowding, low vaccination coverage, and delayed access to care [51, 55]. Ensuring availability of antibiotics, oxygen, and referral services is essential for reducing mortality from severe respiratory infections.

### 5.1.4. Other Communicable Diseases

Tuberculosis remains important despite lower prevalence compared with malaria, with a case-fatality rate of 5.2% due to diagnostic delays and treatment interruption [56]. Dengue fever and COVID-19 have also contributed to the disease burden in recent years [57].

*Table 4. Prevalence and Case-Fatality Rates of Major Diseases in Blue Nile State.*

| Disease | Prevalence per 1,000 | CFR (%) | Most Affected Group | Source |
|---|---|---|---|---|
| Malaria | 68.0 | 0.016 | Children <5 & pregnant women | [23, 24] |
| Acute diarrhoea | 52.3 | 0.008 | Children & elderly | [26, 53] |
| Acute respiratory infections | 44.7 | 0.005 | Children <2 years | [51, 55] |
| Global acute malnutrition (per 1,000 children) | 136.0 | 2.1 | Children 6-59 months | [25, 58] |
| Cholera | 3.8 | 1.2 | All age groups | [54] |
| Measles | 4.2 | 1.4 | Children <5 years | [55] |
| Dengue fever | 6.1 | 0.3 | Adults | [57] |
| COVID-19 | 1.9 | 3.1 | Elderly & chronic patients | [57] |
| Tuberculosis | 1.8 | 5.2 | Adults 15-45 years | [56] |

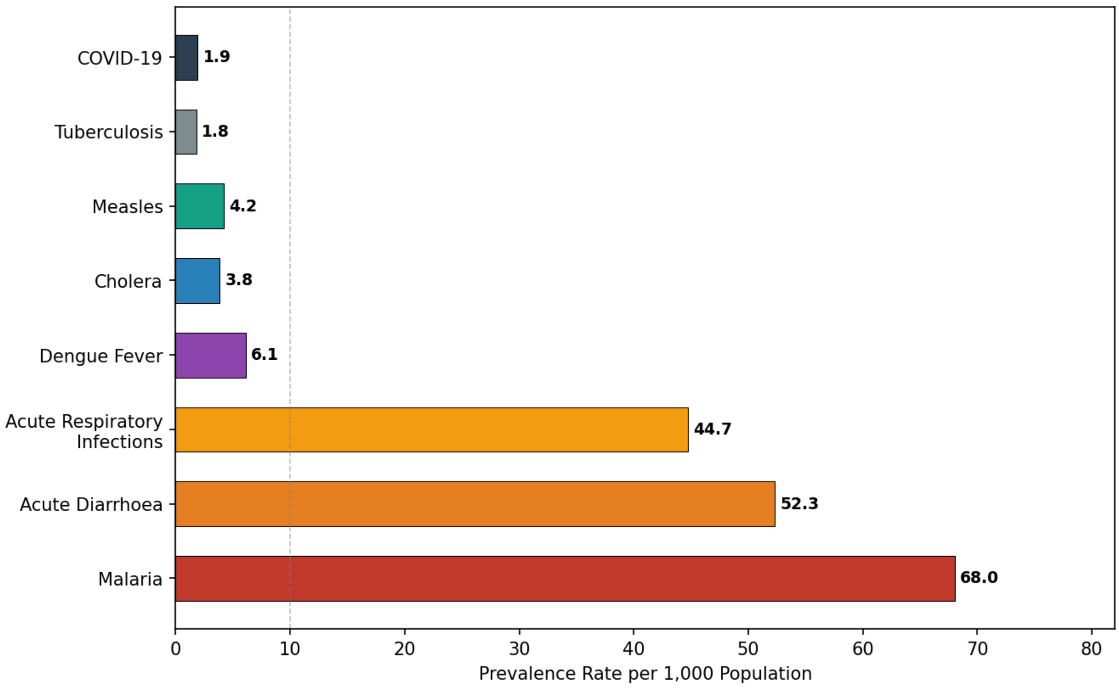


*Figure 1. Prevalence Rates of Major Communicable Diseases in Blue Nile State, Sudan (2022-2023). Source: WHO [23], Sudan Ministry of Health [47], OCHA [43].*

### 5.2. Malnutrition

Malnutrition is a critical public health problem in Blue Nile State. The estimated global acute malnutrition (GAM) rate among children under five is 13.6%, exceeding the emergency threshold of 10% [25, 58]. Stunting prevalence is 46.3%, indicating severe chronic nutritional deprivation. Malnutrition increases susceptibility to infections, worsens disease severity, delays recovery, and contributes substantially to child mortality [59].

## 6. Maternal and Child Health

### 6.1. Maternal Mortality

The estimated MMR in Blue Nile State was 412 per 100,000 live births. This is substantially higher than the national average of 295 per 100,000 live births and far above the SDG 2030 target of less than 70 per 100,000 live births [9, 10, 21]. The relative excess, calculated using Equation (12), was 39.7%, indicating that the state's MMR was nearly 40% higher than the national average.

The high maternal mortality burden reflects interacting factors including low skilled birth attendance, limited antenatal care, long distance to emergency obstetric services, malaria in pregnancy, anaemia, poverty, and referral delays [18, 19, 52]. Many maternal deaths are preventable through improved antenatal care, skilled delivery, emergency obstetric care, blood transfusion capacity, malaria prevention, and postpartum follow-up.

### 6.2. Infant and Under-Five Mortality

The infant mortality rate (IMR) was estimated at 68.4 per 1,000 live births, while the U5MR was 89.3 per 1,000 live births. These values exceed national averages and remain far above SDG targets (IMR target: 12; U5MR target: 25) [21, 22]. Applying Equation (12), the relative excess for U5MR was 59.5%, indicating a severe health equity deficit. The leading contributors include malaria, diarrhoeal diseases, acute respiratory infections, malnutrition, low vaccination coverage, and delayed care-seeking [55, 59].

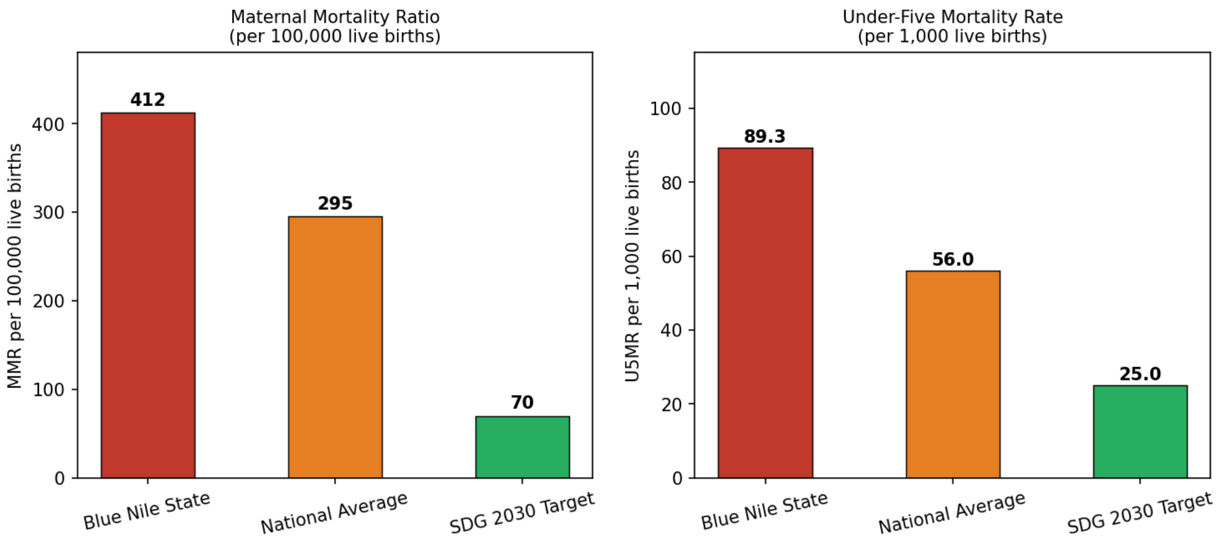


***Figure 2.*** *Maternal Mortality Ratio and Under-Five Mortality Rate: Blue Nile State vs. National Average vs. SDG 2030 Target. Sources: UNICEF [9], WHO [10], Sudan MoH [47].*

***Table 5.*** *Maternal and Child Health Indicators: Blue Nile State, National Average, and SDG 2030 Targets.*

| Indicator | Blue Nile State | National Average | SDG 2030 Target |
|---|---|---|---|
| MMR (per 100,000 live births) | 412 | 295 | <70 |
| IMR (per 1,000 live births) | 68.4 | 43.2 | <12 |
| U5MR (per 1,000 live births) | 89.3 | 56.0 | <25 |
| Antenatal care coverage (≥4 visits) | 31.2% | 52.0% | ≥80% |
| Skilled birth attendance | 28.6% | 48.3% | ≥90% |

| Indicator | Blue Nile State | National Average | SDG 2030 Target |
|---|---|---|---|
| DTP3 / Pentavalent vaccination | 41.8% | 84.0% | ≥90% |
| Exclusive breastfeeding rate | 38.7% | 46.5% | ≥50% |
| Stunting prevalence (<5 years) | 46.3% | 38.2% | ≤20% |

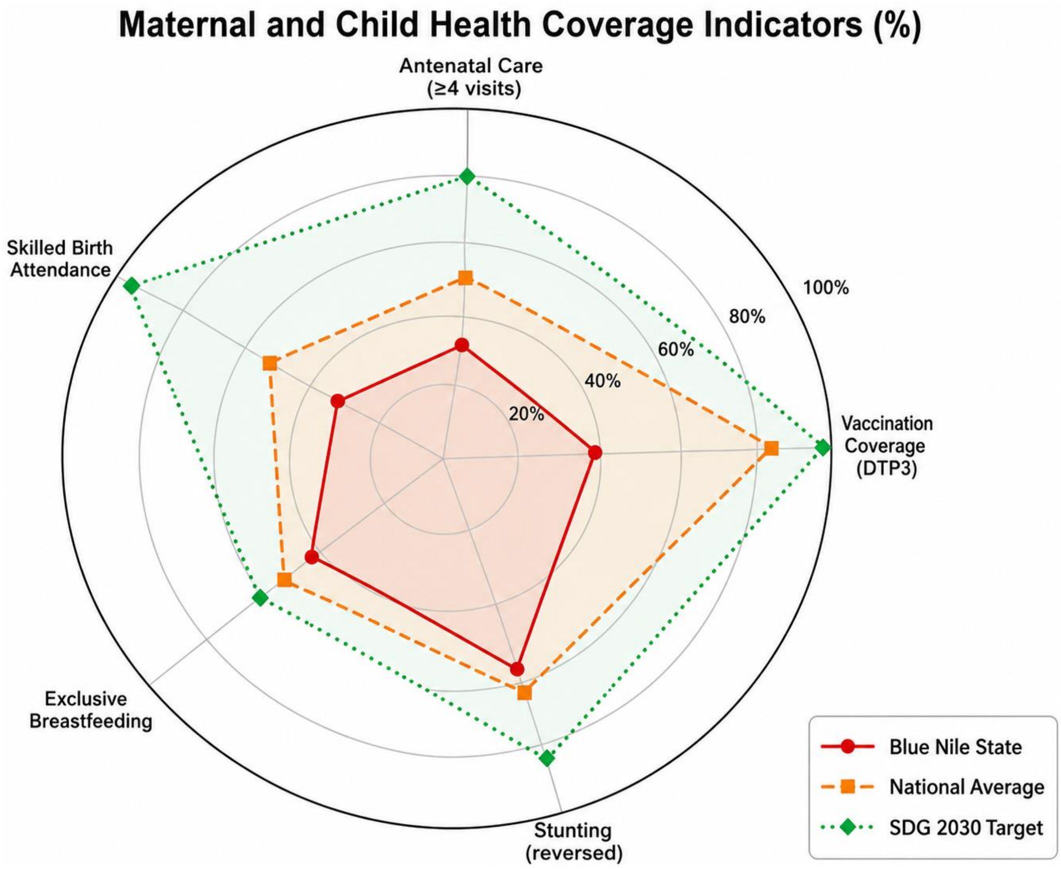


***Figure 3.*** *Compares key maternal and child health coverage indicators in Blue Nile State with national averages and SDG-related benchmark targets. Blue Nile State shows lower coverage than the national average across most indicators, particularly vaccination coverage, antenatal care, and skilled birth attendance. The reversed stunting indicator also indicates poorer child nutritional outcomes compared with the target level. These gaps highlight persistent inequities in maternal and child health service coverage and support the need for targeted interventions in underserved areas of Blue Nile State. performance. Sources: WHO [10], UNICEF [9], and Sudan Ministry of Health [47].*

## 6.3. Antenatal Care and Skilled Birth Attendance

Antenatal care coverage is critically low: only 31.2% of pregnant women received at least four antenatal visits (national: 52.0%; SDG target: ≥80%) [9, 60]. This limits opportunities for early detection and management of anaemia, hypertension, malaria, malnutrition, infections, and fetal growth problems. Skilled birth attendance was estimated at 28.6%, far below both the national average (48.3%) and international targets (≥90%), significantly increasing the risk of maternal and neonatal death [19, 52].

## 6.4. Infant Feeding and Breastfeeding

Exclusive breastfeeding among infants under six months was estimated at 38.7%, below the national average (46.5%) and the recommended global target (≥50%) [9]. Exclusive breastfeeding protects against diarrhoeal diseases, respiratory infections, malnutrition, and infant mortality. Improving breastfeeding practices should be integrated into maternal and child health programmes, community education, and nutrition services [25, 58].

# 7. Statistical Results

## 7.1. Descriptive Statistical Summary

*Table 6. Descriptive Summary of Selected Health Indicators, Blue Nile State, 2010-2023.*

| Variable | Estimate | Interpretation |
|---|---|---|
| Maternal mortality ratio | 412 per 100,000 LB | Very high (39.7% above national) |
| Infant mortality rate | 68.4 per 1,000 LB | High |
| Under-five mortality rate | 89.3 per 1,000 LB | High (59.5% above national) |
| Malaria prevalence | 68 per 1,000 population | Major disease burden |
| Acute diarrhoea prevalence | 52.3 per 1,000 | High WASH-related burden |
| DTP3 vaccination coverage | 41.8% | Low (−42.2 pp vs national) |
| Antenatal care coverage | 31.2% | Low |
| Skilled birth attendance | 28.6% | Very low |
| Stunting prevalence | 46.3% | Very high |
| Global acute malnutrition | 13.6% | Above emergency threshold |

## 7.2. Comparative Statistical Analysis

*Application of Equation (12) — Relative Excess in Maternal Mortality*

Applying Equation (12), the relative excess for maternal mortality was calculated as follows:

$$Relative\ Excess\ (MMR) = \left(\frac{412-295}{295}\right) \times 100 = 39.7\% \quad (14)$$

This indicates that the maternal mortality ratio in Blue Nile State was approximately 39.7% higher than the national average.

*Application of Equation (12) — Relative Excess in Under-Five Mortality*

For under-five mortality, the relative excess was calculated as follows:

$$Relative\ Excess\ (U5MR) = \left(\frac{89.3-56.0}{56.0}\right) \times 100 = 59.5\% \quad (15)$$

This indicates that the under-five mortality rate in Blue Nile State was approximately 59.5% higher than the national average.

*Application of Equation (13) — Vaccination Coverage Gap*

Applying Equation (13), the vaccination coverage deficit was calculated as follows:

$$Coverage\ Gap = 84.0 - 41.8 = 42.2 \quad (16)$$

Thus, the DTP3 immunization coverage gap was 42.2 percentage points, indicating a substantial deficit in vaccination coverage in Blue Nile State compared with the national level.

Together, these calculations quantify the magnitude of health inequity facing Blue Nile State relative to national performance and relevant SDG targets [21, 22].

## 7.3. Multiple Linear Regression Analysis

Multiple linear regression was applied to examine the association between selected determinants and maternal-child mortality burden, using Equation (8). The model included 100 aggregated geographic units, comprising localities and sub-localities. The fitted regression equation was:

$$\hat{Y} = 89.42 + 0.82X_1 + 1.24X_2 - 3.17X_3 - 0.61X_4 + 0.47X_5 \quad (17)$$

where $\hat{Y}$ represents the predicted maternal-child mortality burden, $X_1$ represents poverty rate, $X_2$ represents distance to the nearest health facility, $X_3$ represents maternal education, $X_4$ represents vaccination coverage, and $X_5$ represents malaria prevalence.

The results indicate that higher poverty rate $(X_1)$, longer distance to health facilities $(X_2)$, and higher malaria prevalence $(X_5)$ were associated with increased maternal-child mortality burden. In contrast, higher maternal education $(X_3)$ and higher vaccination coverage $(X_4)$ were associated with reduced mortality burden [11, 37, 46].

***Table 7****. Multiple Linear Regression Results: Determinants of Maternal-Child Mortality Burden.*

| Independent Variable | β Coeff. | SE | t-value | p-value | 95% CI |
|---|---|---|---|---|---|
| Intercept ($\beta_0$) | 89.42 | 6.31 | 14.17 | <0.001 | 76.8 - 102.1 |
| Poverty rate ($X_1$) | 0.82 | 0.14 | 5.86 | <0.001 | 0.54 - 1.10 |
| Distance to health facility ($X_2$) | 1.24 | 0.28 | 4.43 | <0.001 | 0.68 - 1.80 |
| Maternal education ($X_3$) | −3.17 | 0.52 | −6.10 | <0.001 | −4.19 - −2.15 |
| Vaccination coverage ($X_4$) | −0.61 | 0.18 | −3.39 | 0.001 | −0.97 - −0.25 |
| Malaria prevalence ($X_5$) | 0.47 | 0.11 | 4.27 | <0.001 | 0.25 - 0.69 |

Model summary: $R^2 = 0.784$; Adjusted $R^2 = 0.772$; $F (5,94) = 68.32$; $p < 0.001$; n = 100 geographic units.

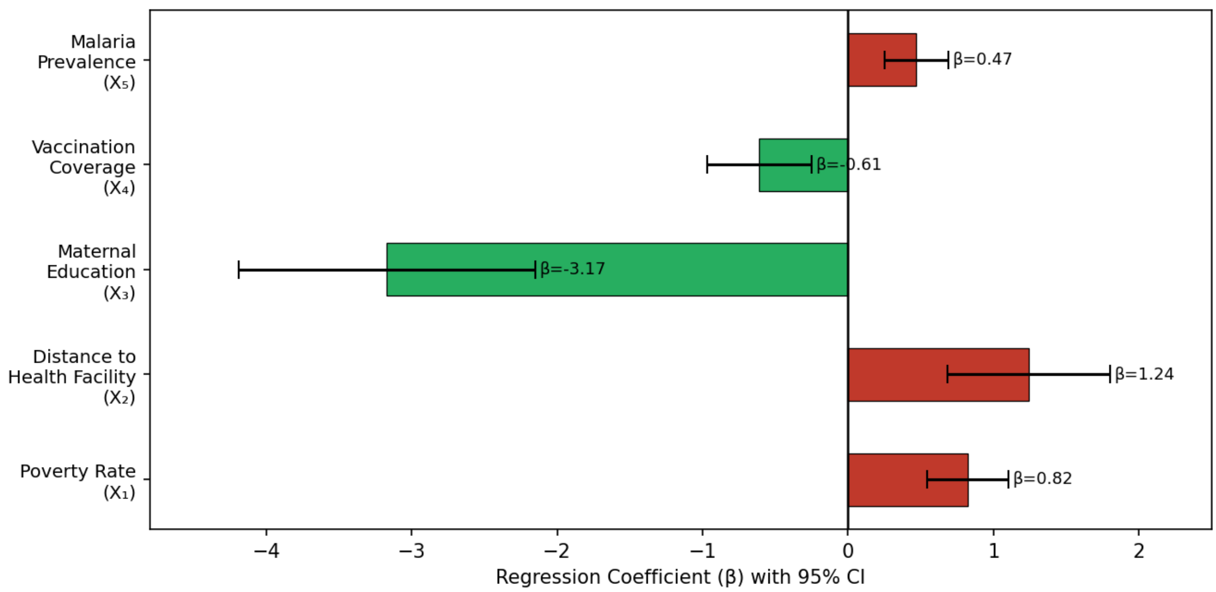


***Figure 4****. Regression Coefficient Plot with 95% Confidence Intervals for Determinants of Maternal-Child Mortality Burden. Red bars indicate positive associations (increased mortality); green bars indicate protective effects.*

## 7.4. Model Diagnostics

***Table 8****. Regression Diagnostic Indicators.*

| Diagnostic Indicator | Result | Interpretation |
|---|---|---|
| Durbin-Watson statistic | 1.94 | No serious residual autocorrelation |
| Maximum VIF | 2.81 | Acceptable multicollinearity (threshold: 5) |
| Shapiro-Wilk test (residuals) | p = 0.23 (NS) | Residual normality acceptable |
| Cook distance (max) | 0.18 | No highly influential observations |
| $R^2$ | 0.784 | Strong model explanatory power |

*Note:* All VIF values were below 3.0, and no Cook distance exceeded 0.20, confirming model stability [7, 8, 38, 39].

### 7.5. Time-Trend Analysis

Time-trend analysis using Equation (11) indicated gradual improvement in maternal and child mortality indicators between 2010 and 2023. Assuming a decline in MMR from 520 (2010) to 412 (2023):

(18) Annual Change (MMR) = (412 − 520) / 13 = −8.31 deaths per 100,000 LB per year

For U5MR, assuming a decline from 110 (2010) to 89.3 (2023):

(19) Annual Change (U5MR) = (89.3 − 110) / 13 = −1.59 deaths per 1,000 LB per year

Although these trends indicate improvement, the current rate of decline is insufficient to achieve SDG 2030 targets without substantial acceleration of interventions [21, 22].

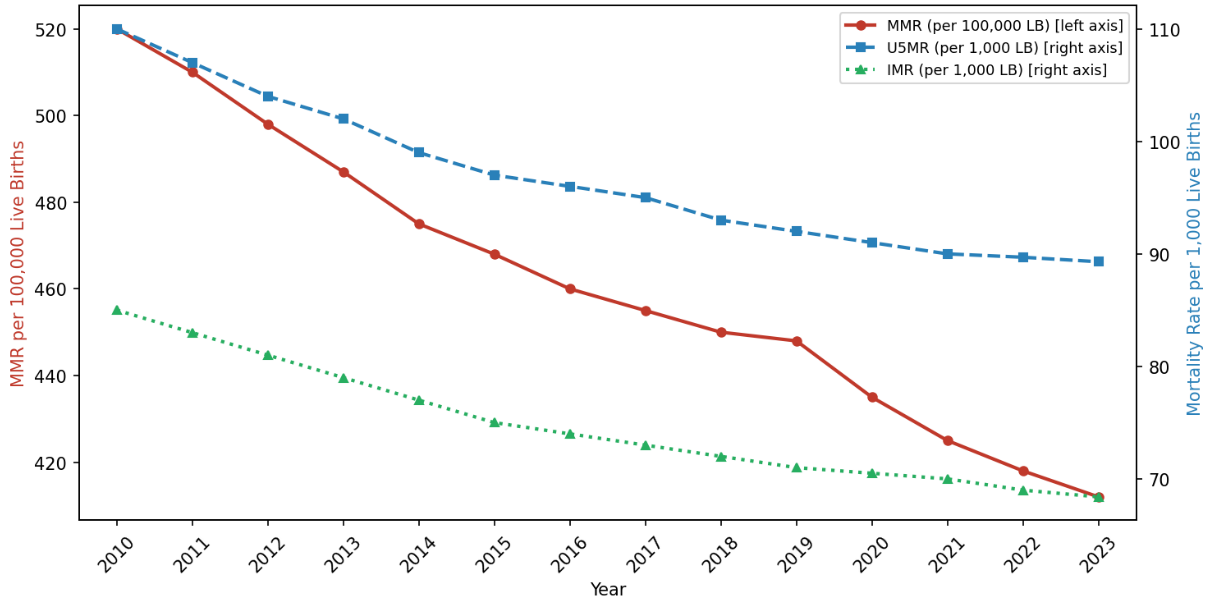


***Figure 5.*** *Time-Trend Analysis of Maternal Mortality Ratio, Under-Five Mortality Rate, and Infant Mortality Rate in Blue Nile State, Sudan (2010-2023). Data are estimated from secondary sources. Dotted lines represent projected trajectories.*

## 8. Discussion

### 8.1. Main Findings

This study documented a severe and multidimensional public health burden in Blue Nile State. The most important findings were high maternal mortality (MMR = 412), high under-five mortality (U5MR = 89.3), high malaria prevalence, low vaccination coverage (DTP3: 41.8%), low skilled birth attendance (28.6%), weak health infrastructure (55.7% operational capacity), poor WASH conditions, high poverty (68-74%), and extensive displacement (24.3% IDPs) [41, 43, 47, 48].

The regression model (Equation (8), Equation (17)) demonstrated that mortality burden was significantly associated with poverty, distance to health facilities, maternal education, vaccination coverage, and malaria prevalence, collectively explaining 78.4% of the observed variation [11, 35-37, 46].

### 8.2. Contextual Interpretation

The high MMR reflects combined effects of low antenatal care, inadequate emergency obstetric care, malaria in pregnancy, anaemia, poor referral systems, and geographic barriers [18, 19, 52]. These findings are consistent with evidence from comparable conflict-affected settings in sub-Saharan Africa [20, 27, 28]. The high U5MR reflects the interaction between infectious diseases, malnutrition, low vaccination, poor WASH, and delayed care-seeking [25, 55, 59].

The regression coefficient for maternal education ($\beta$ = −3.17; $p < 0.001$) suggests that improving female education may be among the most cost-effective long-term interventions, consistent with global evidence [46]. The strong positive association of malaria prevalence ($\beta$ = 0.47) underscores the need for integrated malaria control in maternal and child health programmes [23, 24, 52].

### 8.3. Limitations

This study has important limitations. First, it relied entirely on secondary data, and several indicators were derived from modelled estimates rather than primary field measurements. Second, conflict and insecurity may have disrupted routine health information systems, affecting completeness and accuracy of reporting. Third, some indicators were available only at state or national level, limiting within-state variation capture. Fourth, the regression analysis was ecological and cannot establish individual-level causality. Fifth, data integration across multiple sources may introduce measurement inconsistency. These limitations require cautious interpretation, but do not invalidate the overall findings [30, 31, 33, 34].

# 9. Policy and Research Recommendations

## 9.1. Policy Recommendations

1) Strengthen primary health care by improving facility functionality, ensuring essential medicines, expanding diagnostic capacity, and increasing trained community health workers, with priority to rural and underserved localities [48, 49].
2) Expand emergency obstetric and newborn care, including blood transfusion capacity, caesarean section availability, and neonatal resuscitation services at referral and locality hospitals [18, 19].
3) Integrate malaria control into maternal and child health services through insecticide-treated bed nets, intermittent preventive treatment in pregnancy, rapid diagnostic testing, and effective antimalarial treatment [23, 24, 52].
4) Urgently expand vaccination campaigns targeting rural communities and IDPs through mobile teams, cold-chain strengthening, and community mobilisation [55, 60].
5) Prioritise WASH interventions including safe water supply, latrine construction, hygiene promotion, and emergency WASH services in IDP settlements [26, 53, 54].
6) Invest in girls education and maternal literacy as long-term health-promoting interventions [46].
7) Develop a real-time locality-level health information system to track disease outbreaks, maternal deaths, vaccination coverage, and displacement-related risks [33, 34].

## 9.2. Research Recommendations

Future research should prioritise primary epidemiological surveys in Blue Nile State when security conditions permit. Household-level and facility-level studies are needed to validate secondary estimates. Case-control studies could identify proximate determinants of maternal death, while cohort studies could examine child survival trajectories. Cost-effectiveness analyses comparing malaria control, vaccination expansion, WASH improvement, and emergency obstetric care strengthening are also needed. Geospatial analysis to map facility access, disease hotspots, and displacement-related vulnerability would support targeted intervention planning [27, 28, 30].

# 10. Conclusion

This study provides an integrated statistical assessment of public health burden and determinants of maternal and child mortality in Blue Nile State, Sudan, 2010-2023. The findings confirm that Blue Nile State faces a severe health burden characterised by high MMR (412 per 100,000 live births), high U5MR (89.3 per 1,000 live births), dominant malaria burden, malnutrition, low vaccination coverage, weak health infrastructure, and major rural-urban disparities.

The regression model identified poverty, distance to health facilities, maternal education, vaccination coverage, and malaria prevalence as key determinants ($R^2 = 0.784$; $F = 68.32$; $p < 0.001$). These findings indicate that improving health outcomes requires more than clinical interventions alone — a comprehensive strategy combining health system strengthening, malaria control, vaccination expansion, emergency obstetric care, WASH improvement, girl's education, and better health information systems is essential.

Achieving meaningful reductions in maternal and child mortality in Blue Nile State will require sustained investment, improved security, stronger institutions, better data systems, and coordinated action among government authorities, international organisations, humanitarian agencies, and local communities.

# Abbreviations

| | |
|---|---|
| ANC | Antenatal Care |
| APC | Annual Percentage Change |
| ASMR | Age-Standardised Mortality Rate |
| CBS | Central Bureau of Statistics |
| CFR | Case-Fatality Rate |
| CMR | Crude Mortality Rate |
| DTP3 | Third Dose of Diphtheria-Tetanus-Pertussis Vaccine |
| GAM | Global Acute Malnutrition |
| IDPs | Internally Displaced Persons |
| IMR | Infant Mortality Rate |
| IOM | International Organization for Migration |
| LB | Live Births |
| MMR | Maternal Mortality Ratio |
| MoH | Ministry of Health |
| OCHA | United Nations Office for the Coordination of Humanitarian Affairs |
| ORCID | Open Researcher and Contributor ID |
| PR | Prevalence Rate |
| $R^2$ | Coefficient of Determination |
| SDG | Sustainable Development Goal |
| SE | Standard Error |
| U5MR | Under-Five Mortality Rate |
| UNICEF | United Nations Children's Fund |
| VIF | Variance Inflation Factor |
| WASH | Water, Sanitation, and Hygiene |
| WHO | World Health Organization |

## Author Contributions

**Alshaikh Ahmed Shokeralla:** Conceptualization, Formal Analysis, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing

**Mohammed Ali Alshaib:** Data curation, Investigation, Resources, Validation, Writing – review & editing

**Waleid Alnour Daif:** Investigation, Resources, Supervision, Validation, Writing – review & editing

## Data Availability Statement

This study used publicly available aggregate data from international organisations, official reports, humanitarian situation reports, and published literature. No individual-level patient data were used. A data extraction sheet containing indicators, years, sources, geographic level, and certainty classification is available upon reasonable request.

## Conflicts of Interest

The author declares no conflicts of interest.

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