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A decade of change: maternal mortality trends in Sudan, 2009–2019

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Abstract

Background Unacceptably high levels of preventable maternal deaths persist across sub-Saharan Africa. Due to limited research on maternal mortality in Sudan, a thorough examination is crucial to develop effective reduction strategies. This study aims to analyze maternal mortality trends at national and subnational levels in Sudan from 2009 to 2019.

Methods In this retrospective-comparative study, the researchers reviewed mortality data covering 2009 to 2019 from the reports issued by the national maternal death surveillance and response. The maternal mortality ratios for the national and state levels were adjusted based on the population of women of reproductive age. The trends were assessed for statistical significance using the Mann–Kendall test, implemented in Python (version 3.12). The cut-off *p*-value for significance was taken as < 0.05.

Results The national maternal mortality ratio declined significantly by nearly 60% from 2009 to 2019 ($S = -53$, $p < 0.001$). The states of Kassala ($S = -51$, $p < 0.001$), Gadarif ($S = -43$, $p < 0.001$), Gezira ($S = -41$, $p = 0.002$), White Nile ($S = -41$, $p = 0.002$), Blue Nile ($S = -39$, $p = 0.003$), Red Sea ($S = -39$, $p = 0.003$), Khartoum ($S = -39$, $p = 0.003$), Northern State ($S = -27$, $p = 0.043$), River Nile ($S = -27$, $p = 0.043$), and Sinnar ($S = -27$, $p = 0.043$) showed significant declining trends. Blue Nile state recorded the highest average maternal mortality ratio in the study period (339.76), while Southern Darfur (66.46) and River Nile (89.59) recorded the lowest ratios. Major causes of maternal death include Obstetric hemorrhage (45.5%), hypertensive disorders (16%), and sepsis (12.6%). Important characteristics of pregnancy-related death include condition at admission, gestational age, antenatal care, mode of delivery, and areas of delay.

Conclusions The national maternal mortality ratio significantly declined between 2009 and 2019, with wide regional disparities. Direct causes of maternal death remain a critical challenge. Effective strategies or frameworks focused on reducing maternal mortality ratios in Sudan are strongly solicited.

Keywords Maternal death, Maternal mortality ratio, Maternal death surveillance and response, Sudan

Background

The International Classification of Disease (ICD- 11) defines maternal death as "the death of a woman while pregnant or within 42 days of termination of pregnancy, irrespective of the duration and site of the pregnancy, from any cause related to or aggravated by the pregnancy or its management but not from unintentional or incidental causes" [1]. Maternal deaths are further classified into direct and indirect, where direct maternal deaths are those "resulting from obstetric complications of the pregnant state (pregnancy, labor and puerperium), and from

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interventions, omissions, incorrect treatment, or from a chain of events resulting from any of the above". Examples include obstetric hemorrhage, hypertensive disorders in pregnancy, and complications of anesthesia or cesarean section. The indirect maternal deaths are those "resulting from previous existing disease, or disease that developed during pregnancy, and that were not due to direct obstetric causes but were aggravated by the physiologic effects of pregnancy." The Maternal mortality ratio (MMR) is the global epidemiological indicator that measures maternal mortality and reflects the risk of death associated with a single pregnancy or live birth [2].

In September 2000, the United Nations issued eight Millennium Development Goals (MDGs) to be achieved by 2015 [3]. MDG 5 aimed to improve maternal health, with the target of reducing the MMR by three quarters. Since 1990, the global MMR has decreased by 45%, and by 49% in sub-Saharan Africa [4]. The Sustainable Development Goals (SDGs) commenced in 2016, aimed at ending preventable maternal mortality, explicitly in SDG 3.1: By 2030, to reduce the global MMR to less than 70 per 100,000 live births. As such, the African Union developed "agenda 2063", a strategic framework aimed to achieve inclusive and sustainable development across the continent [5]. Commenced in 2013, the overall performance in achieving Goal 3 of Agenda 2063 (Healthy and well-nourished citizens) was satisfactory, scoring 77% in 2023 [6].

In 2020, an estimated 287,000 women (MMR: 223 per 100,000 live births) died from maternal causes worldwide; and in sub-Saharan Africa the MMR was 545 per 100,000 live births [7]. Several African countries like, Kenya, Nigeria, Democratic Republic of Congo, and South Africa, have seen good progress towards reduction of maternal mortality as they all seen a significant decline in the MMR [7]. Other African countries, especially in the sub-Saharan region, face challenges hindering their progress in reducing maternal death, these are strongly linked to limited resources for quality maternal healthcare, and patient-related factors such as acceptability and affordability of maternal health services [8]. In Sudan, due to the lack of proper civil registration systems, the MMR was estimated through national surveys and surveillance systems such as the maternal death review (MDR). Established in 2009 by a ministerial decree from the minister of health, the MDR evolved into the maternal death surveillance and response (MDSR) system in 2012. The MDSR structures consist of a higher MDSR committee and a technical MDSR committee at national and state levels. Maternal death reviews occur at facility, community, district, and state levels. At the facility level, a focal person must notify the MDSR Registrar and Reproductive Health (RH) Coordinator within 24 h of confirming a death. In the community, a designated focal person notifies the locality midwifery supervisor within 24 h, who then informs the RH Coordinator. The MDSR Registrar and RH Coordinator are required to investigate all reported deaths from facilities within 48 h and from the community within 2 weeks. The investigation team completes review forms and submits them to the state technical committee, which reports monthly to the State Higher Committee. The State Higher Committee then reports to the National Technical MDSR Committee and the National Higher MDSR Committee, responsible for reviewing maternal mortality reports, developing national response plans, and oversee implementation, monitoring, and evaluation (Federal Ministry of Health of the Republic of Sudan, Directorate General of Primary Health Care, Directorate of Mother and Child Health, National Reproductive Health Program, Maternal Death Surveillance and Response in Sudan, unpublished). During 2010–2015, MMR was 164 per 100,000 live births, with variations between the Sudanese states [9]. Direct obstetric causes of maternal death constituted 62.6%, mainly from hemorrhage (31.1%), whereas indirect causes were 27.6%, mainly from hepatitis 10.9%. The national MMR estimate for the period 2014–2017 was 127 per100000 live births, with variations between states and years [10]. Direct maternal deaths were 72.9%, of which hemorrhage constituted 32.6%, whereas the indirect maternal deaths were 27.1%.

There is a notable lack of research specifically examining maternal mortality trends at both national and subnational levels using data from the MDSR system in Sudan. This type of analysis is essential for comprehending the context of maternal mortality and developing tailored interventions. This study aims to analyze maternal mortality trends at national and subnational levels in Sudan from 2009 to 2019. The findings of the study are expected to provide valuable insights from Sudan to guide progress in reducing maternal mortality and inform policy decisions for achieving the SDG 3.1 target.

Methods

Study design, setting and population

This retrospective-comparative study was conducted in Sudan, an African country that occupies a total area of 1,886,068 square kilometers, and the capital is Khartoum. Sudan is divided into 18 states which are in turn subdivided into 189 districts. The estimated population of Sudan in 2024 was 50,448,963, with a population growth rate of 0.81%, a fertility rate of 4.26 and a life expectancy of 66.52 years [11]. Percentage of female population aged 15–49 was 24.8% in 2023 [12]. The researchers reviewed mortality data covering 2009 to 2019 from the annual reports issued by the national MDSR unit based in the Federal Ministry of Health (FMOH) and published in collaboration with the World Health Organization (WHO), World Bank, United Nations Population Fund, and United

Nations Children's Fund. The MDSR processes involve the daily notification of maternal deaths (including zero reporting), by appointed focal persons, from the facility and the community in each district to the State Maternal Death Review Committee (SMDRC). Maternal death data were collected by trained resident registrars in obstetrics and gynecology. The SMDRC reviews the collected data using ICD- 11 structured formats to determine the causes of death, categorize them into avoidable and unavoidable, and generate response recommendations. The SMDRC reports the forms and live births electronically to the National Maternal Death Review Committee (NMDRC) on a regular basis. The forms are edited, reviewed by the authors, and analyzed using Statistical Package for the Social Sciences (SPSS) software, and national reports are generated [10].

Data collection and analysis

The researchers adapted extraction forms to extract the required data from the reports. The target data and variables were the maternal death numbers, the estimates of live births, population projections of women of reproductive age (WRA), and the causes of maternal death. Summary of important characteristics of women who died as a result of pregnancy-related conditions (age, stage of pregnancy, antenatal care (ANC), mode of delivery, birth attendance, and areas of delay) were also included to support better understanding. We excluded Central Darfur, Eastern Darfur, and Western Kurdofan from the study due to severe data gaps. Data were entered into Microsoft Excel, cleaned, tabulated, and analyzed. The national and state MMRs for 2009–2019 were calculated using the standard formula:

$$\textit{number of maternal deaths in the period} / \textit{number of live births in the same period} * 100000.$$

Researchers used direct standardization to adjust national and subnational MMRs based on WRA population. The 2009–2019 national WRA population was obtained from the United Nations Populations Division data portal [13]. For year-to-year comparability, we adjusted national MMRs using the national WRA population for each year with the following formula:

$$\textit{Adjusted MMRyear} = \textit{MMRyear } x \textit{ (standard WRA population)} / (\textit{WRA population in year})$$

The standard WRA population is the average across 2009–2019. To compare subnational MMRs, we adjusted them using estimates of subnational WRA populations for each year. Due to unavailable data, we used the FMOH's method by applying a 24% proportional allocation to states' total populations from 2009 to 2018, sourced from the central bureau of statistics [14]. For 2019, we estimated the state's total population based on 2018 proportions. The formula used to adjust states'MMRs was:

$$\textit{Adjusted MMRState, Year} = (\textit{number of maternal deaths})/(\textit{number of live births}) \; x \; (\textit{national WRA population})/(\textit{state WRA population}) * 100000$$

The adjusted subnational MMRs for 2019 were further refined through the application of Polynomial Random Sample Consensus (RANSAC), which was employed to eliminate outliers and improve the robustness of the predicted values. The national and subnational MMR trends were subsequently evaluated for statistical significance using the Mann–Kendall non-parametric test, with a significance threshold set at a p-value of <0.05. The Mann–Kendall test was used because it does not assume normal distribution of data. It is robust to outliers and missing data observed in the study, and it provides the direction and significance (tau coefficient and p-values respectively) of the trend. This makes it suitable for assessing whether MMR is increasing, decreasing, or stable across different states. We computed the average MMRs for each state from 2009 to 2019. Based on the WHO's maternal mortality report [15], we classified states into three categories: low (20–99 MMR), moderate (100–299 MMR), and high (300–499 MMR). A detailed analysis was performed for 2019, the most recent year included in the study, to provide valuable insights and guidance for the present and future periods. The characteristics of women who died from pregnancy-related conditions during the reference period were summarized in a frequency table and analyzed using the Chi-square test of independence, with significance determined at p-values <0.05. The statistical analyses and visualizations were conducted using Python 3.12, with Pandas 2.2.2, Geopandas 1.0.1, numpy 1.26.4, and Matplotlib 3.9.2 libraries. Figures illustrating the causes of maternal death were prepared using Microsoft Excel. The Python scripts and Excel sheets are provided in a Supplementary file.

Results

A total of 11,327 maternal deaths were notified to the national MDSR system from 2009 to 2019, of which 98.70% underwent review. Reasons for excluding some

files from the review process include incomplete or lost files. Other reasons are related to logistic insufficiency such as transport difficulties, fax or internet connectivity issues. The variation between the notified and the reviewed cases ranged from 2 to 59 cases and were skewed towards notification. The national MMR tremendously reduced by nearly 60%, from 224.20 in 2009 to 90.33 maternal deaths per 100,000 live births in 2019 ($S = -53$, $p < 0.001$) as shown in Fig. 1 below and Table 2 in the Appendix. There was a steep decline with an annual reduction rate (ARR) of approximately 8.7% over the reference period. The highest MMR was recorded in 2010 (234.28 per 100,000 live births) which coincided with the secession of South Sudan. Six months after voting to secede from the Republic of Sudan in January 2011, South Sudan gained its independence on July 9, 2011, with subsequent political and social ramifications [16].

At the sub-national level, the Mann–Kendall test revealed significant decreasing MMR trends ($p < 0.05$) in ten of the fifteen analyzed states: Kassala ($S = -51$, $p < 0.001$), Gadarif ($S = -43$, $p < 0.001$), Gezira ($S = -41$, $p = 0.002$), White Nile ($S = -41$, $p = 0.002$), Blue Nile ($S = -39$, $p = 0.003$), Red Sea ($S = -39$, $p = 0.003$), Khartoum ($S = -39$, $p = 0.003$), Northern State ($S = -27$, $p = 0.043$), River Nile ($S = -27$, $p = 0.043$), and Sinnar ($S = -27$, $p = 0.043$). The remaining states were not statistically significant, showing no clear trends: Southern Darfur ($S = 25$, $p = 0.062$), Southern Kurdofan ($S = -23$, $p = 0.087$), Northern Darfur ($S = -15$, $p = 0.276$), Western Darfur ($S = 9$, $p = 0.474$), and Northern Kurdofan ($S = -9$, $p = 0.533$).

Figure 2 demonstrates the substantial regional disparities in average MMR across states during the reference period. Based on the WHO maternal mortality report 2025 [15], the states of Southern Darfur (MMR:66.46) and River Nile (MMR:89.59) qualified as having low MMR (10–99 maternal deaths per 100,000 live births) Moderate MMRs (100–299 maternal deaths per 100,000 live births) were observed in Northern State (MMR: 131.27), Khartoum (MMR:137.66), Gezira (MMR:148.04), White Nile (MMR:154.07), Northern Kurdofan (MMR:156.12), Sinnar (MMR:165.85), Northern Darfur (MMR:166.38), Western Darfur (MMR:169.53), Southern Kurdofan (MMR:184.41), Gadarif (MMR:189.97), Kassala (MMR:205.21), and Red Sea (MMR:227.71). The only state with High MMR (300–499 maternal deaths per 100,000 live births) was Blue Nile (MMR:339.76).

In 2019, 96.28% of notified maternal deaths underwent review (N = 1155). The national MMR was estimated at 90.33 maternal deaths per 100,000 live births (95% CI:85.27–95.69). The lowest MMRs were recorded in White Nile (MMR:38.7, 95% CI:28.6 – 52.37), Kassala (MMR:68.48, 95% CI:51.3—91.43), and Red Sea (MMR:70.02, 95% CI:52.28—93.78).

The highest MMRs were observed in Darfur States, namely Southern (MMR:221.29, 95% CI: 178.46–274.41), Northern (MMR:217.46, 95% CI:180.4–262.15), and Western Darfur (MMR: 217.73, 95% CI: 169.41–279.84) as demonstrated in Fig. 3 and Table 3 in the Appendix.

Direct-cause maternal deaths were more comprehensively recorded than indirect-cause deaths. From 2009 to 2019, direct-cause deaths accounted for 80.25%, while indirect-cause deaths were 19.75% of the total (N = 9058). Direct maternal deaths escalated to 900 cases in 2018, then fell to 778 in 2019 (Fig. 4a). Indirect maternal deaths

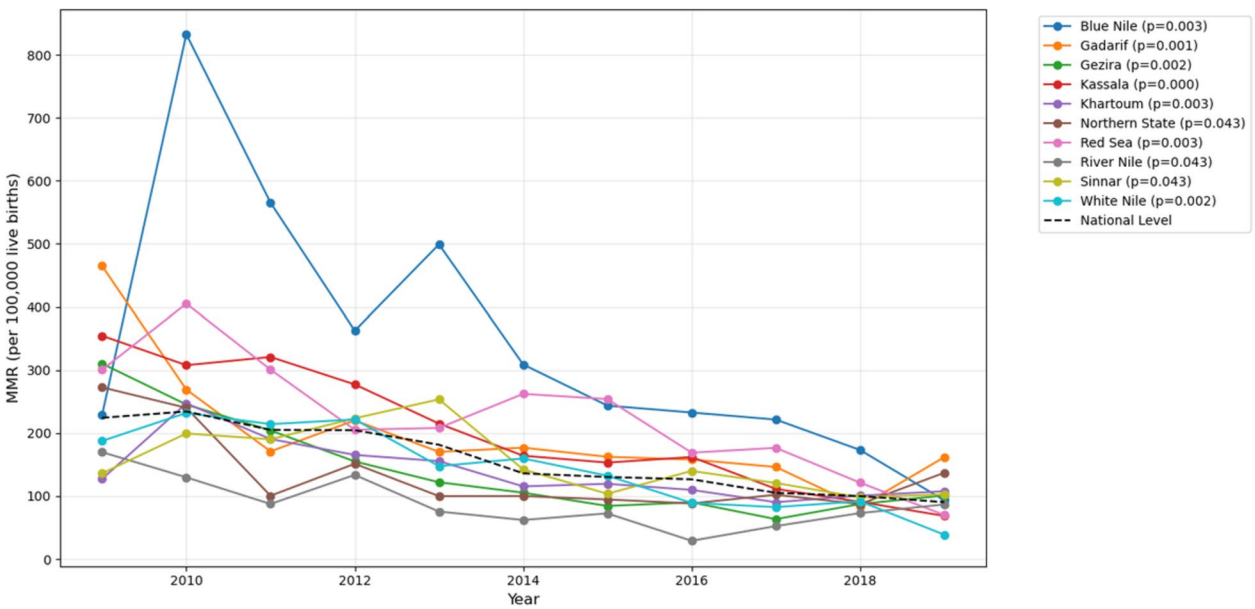

Fig. 1 Statistically significant trends in maternal mortality ratio (MMR), 2009–2019

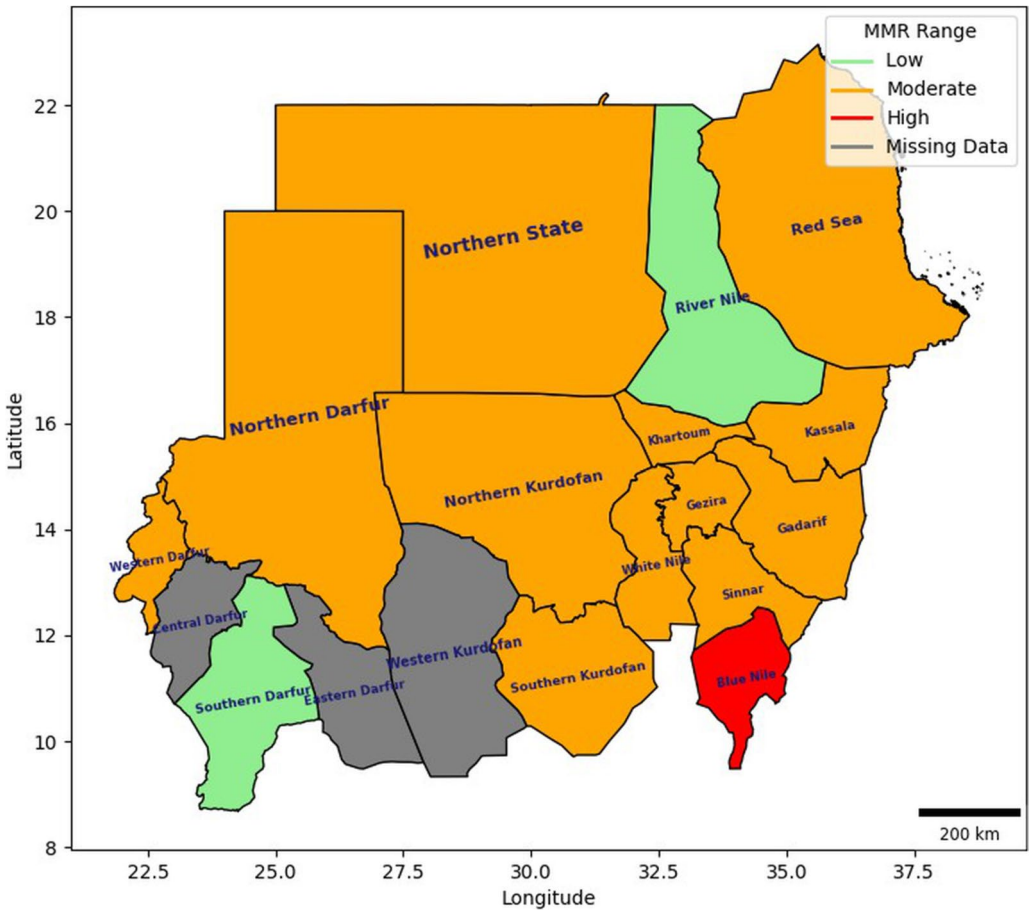

Fig. 2 Regional distribution of maternal mortality ratio (maternal death per 100,000 live births) across the Sudanese states, 2009–2019

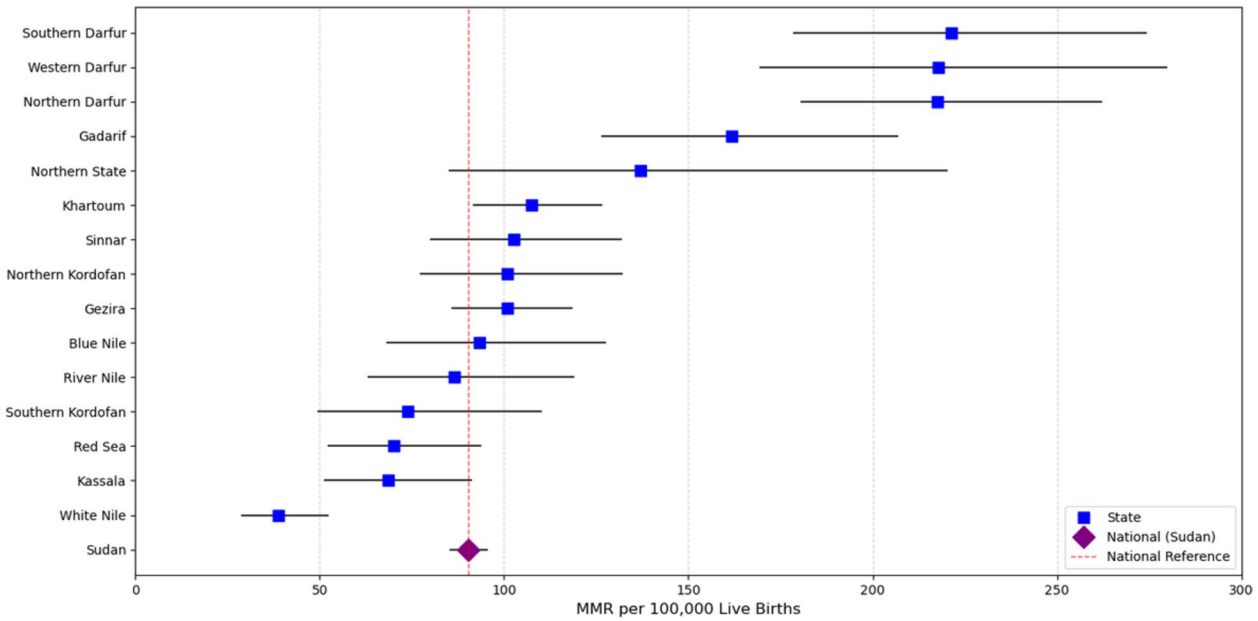

Fig. 3 Trends in maternal mortality ratio in Sudan, 2019

peaked at 320 in 2013, with data gaps affecting trends from 2014–2018.

In 2019, direct obstetric causes of maternal death constituted 78.74%, while indirect causes presented 21.26%. Obstetric hemorrhage was the leading cause of death, accounting for 45.45%. Hypertensive disorders constituted 16.09%, followed by sepsis (12.55%), and abortion

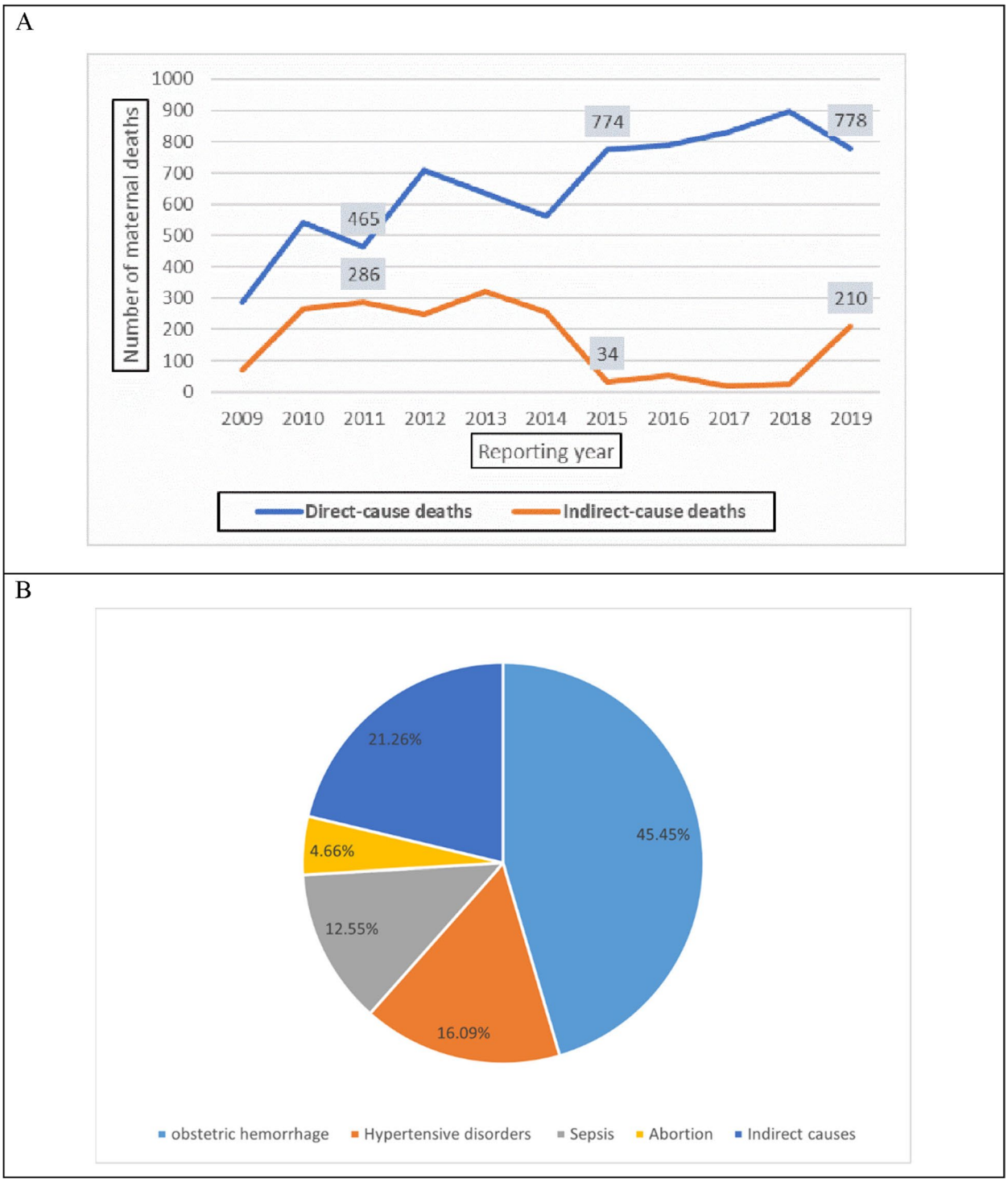

Fig. 4 Demonstrates maternal death causes, **A** displays the changing trends of direct and indirect causes of maternal deaths over time during the study period. **B** reflects the causes of maternal deaths in 2019 (*N* = 988)

(4.66%). Maternal deaths from indirect causes represented 21.26% (Fig. 4b).

Table 1 shows the counts and percentages of deceased women across three time periods, evaluated by Chi-Square test of independence. Most women arrived in critical condition with significant increased counts as well as deceased patients ($\chi^2 = 32.1$, df $= 4$, $p < 0.001$). Also, most women died from obstetric hemorrhage which markedly increased over time. Deaths from hypertensive disorders (eclampsia) and sepsis also increased, but abortion deaths slightly decreased ($\chi^2 = 40.77$, df $= 6$, $p < 0.001$). There was no statistically significant difference in age distribution across the time periods ($\chi^2 = 11.87$, df $= 6$, $p = 0.065$), however deaths among women aged 21–30 years remained high. The majority of fatalities were recorded from 37 weeks of gestation through childbirth, with a significant rise in maternal deaths over time ($\chi^2 = 223.84$, df $= 12$, $p < 0.001$). We observed a significant difference in ANC utilization, with most women not receiving ANC, showing an increasing trend overtime ($\chi^2 = 13.65$, df $= 2$, $p = 0.0011$).

Maternal deaths with spontaneous vaginal delivery remained high and even increased in number as well as deaths from Cesarean sections. Deaths with instrumental vaginal delivery, however, decreased over time ($\chi^2 = 56.95$, df $= 8$, $p < 0.001$). From 2013 to 2016, 47% of pregnancy-related deaths were attended by registrars in obstetrics and gynecology. Medical officers attended 18% of deaths, obstetricians attended 17%, midwives 8.2%, and house officers 1.5% (n = 3209). Maternal deaths categorized by the three delays model significantly increased over time, more pronounced in the delay at home and the delay in reaching health care ($\chi^2 = 82.64$, df $= 6$, $p < 0.001$). Institutional maternal deaths remained elevated without significant change over time ($\chi^2 = 5.1$, df $= 2$, $p = 0.0779$).

Discussion

The situation of maternal mortality in the past decade has improved tremendously, however, this pace of progress (ARR≈ 8.7%) might be insufficient to achieve the SDG target by 2030 as denoted by the SDGs report 2024 which stipulated an ARR of 11.6% between 2021 and 2030 [17]. The year 2010 witnessed the highest national MMR over the study period (234.28 per 100,000 live births); that year was characterized by armed conflicts and widespread political instability affecting the entire country. We observed regional variations in MMR trends over the reference period, with significant declining trends in Kassala, Gadarif, Gezira, White Nile, Blue Nile, Red Sea, Khartoum, Northern State, River Nile and Sinnar. The MMR trends of the West states, i.e. Darfur and Kurdofan, were not statistically significant, showing no trend directions. The states of Blue Nile, Red Sea and

Table 1 Characteristics of pregnancy-related deaths in Sudan, 2009–2019

Characteristic	Description	2009–2012 n (%)	2013–2016 n (%)	2017–2019 n (%)	Chi-Square ($p < 0.05$)
Condition at admission	Arrived dead	97(0.11)	92(2.47)	107(3.51)	[1]$\chi^2 = 32.1$, [2]df $= 4$, $p < 0.001$
	Critically ill	2208(76.19)	2819(75.74)	2428(79.63)	
	Stable	593(20.46)	811(21.79)	514(16.86)	
Common causes of maternal death	Obstetric hemorrhage	842(42.06)	1353(48.99)	1325(52.89)	$\chi^2 = 40.77$, df $= 6$, $p < 0.001$
	Hypertensive disorders (eclampsia)	431(21.53)	589(21.33)	587(23.43)	
	Sepsis	383(19.13)	518(18.75)	443(17.68)	
	Abortion	183(9.14)	189(6.84)	150(5.99)	
Age at death	</= 20	515(15.83)	693(16.05)	603(16.71)	$\chi^2 = 11.87$, df $= 6$, $p = 0.065$
	21–30	1568(48.2)	2175(50.36)	1749(48.48)	
	31–40	1085(33.35)	1377(31.88)	1172(32.48)	
	> 40	85(2.61)	74(1.71)	84(2.33)	
Gestational age (weeks)	< 28	27(6.85)	493(15.36)	505(14)	$\chi^2 = 223.84$, df $= 12$, $p < 0.001$
	28–36	49(12.44)	524(16.33)	684(18.96)	
	=/> 37 (including childbirth)	307(77.92)	1380(43)	1474(40.85)	
	puerperium	11(2.79)	812(25.3)	945(26.19)	
Antenatal care	no antenatal care	2100(64.56)	2623(68.11)	2464(68.29)	$\chi^2 = 13.65$, df $= 2$, $p = 0.0011$
	with antenatal care	1153(35.44)	1228(31.89)	1144(31.71)	
Mode of delivery	Not delivered	1100(33.81)	1355(31.37)	1032(28.6)	$\chi^2 = 56.95$, df $= 8$, $p < 0.001$
	Spontaneous Vaginal delivery	1286(39.53)	1802(41.72)	1616(44.79)	
	instrumental vaginal delivery	90(2.77)	64(1.48)	44(1.22)	
	Elective C/S	126(3.87)	155(3.59)	129(3.58)	
	Emergency C/S	651(20.01)	943(21.83)	787(21.81)	
Birth attendance	Obstetrician	-	548(17.08)	-	
	Registrar	-	1528(47.62)	-	
	Medical Officer	-	578(18.01)	-	
	House Officer	-	48(1.5)	-	
	Midwife	-	264(8.23)	-	
	Others	-	243(7.57)	-	
Areas of delay	No delay	117(28.61)	441(13.74)	616(17.07)	$\chi^2 = 82.64$, df $= 6$, $p < 0.001$
	Delay at home	206(50.37)	2187(68.15)	2309(64)	
	Delay in reaching hospital	52(12.71)	286(8.91)	390(10.81)	
	Delay in receiving medical care	34(8.31)	295(9.19)	293(8.12)	
Place of death	Hospital	1966(86.46)	3722(85.9)	3049(84.51)	$\chi^2 = 5.1$, df $= 2$, $p = 0.0779$
	Home	308(13.54)	611(14.1)	559(15.49)	

[1] χ^2 = Chi-Square statistics

[2] df = degrees of freedom

Kassala performed less than the national MMR decreasing trend, possibly most affected with the country-wide instability that ensued in 2010. The River Nile, Northern State, Gezira, and Khartoum MMR trends persistently outpaced the national trend, whereas trends of White Nile, Sinnar and Gadarif closely aligned with the national trajectory.

We observed regional variations in the distribution of average MMR in the reference period with the lowest figures observed in River Nile and Southern Darfur. This may be explained by the size of WRA population, or the quality and access to maternal health services. In River Nile, the WRA population represented only 3% of the total national WRA population over the 11-yaer period. This state had the highest proportion of emergency obstetric and neonatal care (EmONC) facilities (98%) and an institutional birth reaching 46% [18]. In Southern Darfur, although 76% of facilities provided comprehensive emergency obstetric care, only 2% of births took place in these facilities in 2017, suggesting a potential underutilization of health services or barriers to accessing healthcare. In both states, the low average MMRs could have resulted from statistical outliers, since most years had low MMR values (see Table 2 in the Appendix). This issue stems from poor data quality, influenced by underreporting or misclassification of maternal deaths. Generally, most states suffered severe gaps in EmONC facilities against the recommended numbers, in addition to inadequate infrastructure to support health services. Blue Nile and the Darfur states saw prolonged conflicts and instability that further disrupted health systems and exacerbated the already fragile situation [19]. The surveillance system reported 551 maternal deaths from viral hepatitis between 2011 and 2014. The outbreaks struck the Red Sea, Northern Kurdofan and Blue Nile states and most cases were caused by Hepatitis B virus. In 2017, the Red Sea state reported the highest proportion of maternal deaths from indirect causes nationwide (59%) [18]. All these challenges emphasize the need for robust data collection and surveillance systems for rapid response and effective decision making.

In 2019, although the national MMR was the lowest recorded since 2009, ten states exhibited MMRs exceeding the national level, with notable variations across states as demonstrated in Fig. 3. The Darfur states, Gadarif, and Northern State recorded the highest MMRs with apparently wide confidence intervals flagging uncertainty and precision issues with MMR estimates. The whole country was affected by the global crisis of COVID- 19, which increased the risks of pregnancy-related maternal deaths and burdened the health system. The whole country experienced significant political instability across the nation due to the Sudanese revolution, which reignited armed conflicts and unrest in areas already affected by conflict, such as the Darfur region, Southern Kordofan, and Blue Nile. A mix of Intercommunal violence between ethnic groups and attacks by armed groups and militias led to displacement of civilians and humanitarian crises. Khartoum also saw significant violence as well as other states, which interrupted access to obstetric care. We observed an increasing trend in maternal deaths from direct causes over the study period, with the sudden drop in 2019, which is likely attributed to underreporting, given the political context. Indirect causes peaked at 320 cases in 2013, predominantly viral hepatitis that accounted for 56.88% (Fig. 4a).

Maternal deaths from direct causes were higher than those from indirect causes, with obstetric hemorrhage being the leading cause of maternal death, followed by hypertensive disorders and abortion. These results are consistent with recent studies conducted in sub-Saharan Africa [8].

Analyzing the characteristics of women who died from pregnancy-related conditions between 2009 and 2019, we observed a significant rise in maternal deaths arriving critically ill or dead at health facilities, denoting areas of delay, particularly the first and second delays that remained a significant challenge yet to be addressed. Maternal deaths from obstetric hemorrhage remained high and showed an upward trend, suggesting persistent challenges in managing the issue. Factors may include poor adherence to treatment protocols, unavailability of equipment and supplies, and inadequate infrastructure to support EmONC [10]. The EmONC survey reported 47% of health facilities lacked Magnesium sulphate for treating hypertensive disorders, and 35% reported stock out or never had Oxytocin for treating obstetric hemorrhage in the last three months prior to the assessment [18].

The number of women aged 21–30 years who died from pregnancy-related conditions has remained high suggesting the involvement of a social factor such as early marriage or female genital cutting (FGC). The Multiple Indicator Cluster Survey conducted in 2014 reported 21.5% of women aged 20–24 had at least one live birth before turning 18 [20]. The prevalence of FGC among women aged 15–49 was reported at 86.6% nationwide, reaching 99% in the Northern State. The number of women who died from 37 weeks of pregnancy through childbirth, in addition to those without antenatal care and those delivering vaginally or by caesarean section were growing over time. These upward trends underscore the need to leverage ANC and emergency obstetric services. In the 2013–2016 period, nearly half maternal deaths (47%) were attended by registrars, suggesting they are the front-line providers of obstetric care. Dominance of registrars may reflect shortage of fully qualified specialists, or

reliance on trainees to fill gaps. The under documentation of birth attendants in the study period might indicate fear of blame and litigation. Cultivating a culture of cooperation and transparency among obstetric workforce in documenting and investigating maternal deaths is essential for enhancing the quality of mortality data.

This study presented insights into maternal mortality trends in Sudan but faced challenges with adjusting subnational MMRs based on WRA population. Due to the lack of state-level WRA data, it was assumed to be 24% of the total population, with 2019 populations estimated from 2018 figures. Outliers (some >1000) appeared in 2019 figures and were cleaned using Polynomial RANSAC. Information on region-specific maternal mortality interventions was unavailable. We recommend improving data collection and health information systems for better maternal mortality data quality.

Conclusions

The national maternal mortality ratio significantly declined from 2009 to 2019. However, intensified efforts are needed to achieve the SDG target by 2030. Regional disparities in maternal mortality ratios persist, and maternal death from direct causes remain a critical challenge. Policy makers should focus on implementing effective strategies and interventions to reduce maternal mortality ratios and regional disparities in Sudan. To this end, strengthening health information and surveillance systems is invaluable for evidence-based decision making.

Table 3 Number of maternal deaths, live births, and maternal mortality ratio, 2019

No	State	Maternal deaths	Live births	Crude MMR	Adjusted MMR	95% Confidence Interval
1	Khartoum	146	197,651	73.87	107.59	91.48-126.54
2	Gezira	110	48,541	226.61	100.85	85.75-118.62
3	River Nile	38	43,731	86.89	86.63	63.03-119.05
4	Gadarif	63	57,189	110.16	161.66	126.29-206.94
5	Northern State	17	24,313	69.92	136.94	85.13-220.28
6	Sinnar	61	43,128	141.44	102.69	79.9-131.99
7	Kassala	46	73,639	62.47	68.48	51.3-91.43
8	White Nile	42	66,966	62.72	38.7	28.6-52.37
9	Blue Nile	39	47,075	82.85	93.33	68.19-127.75
10	Southern Darfur	83	159,947	51.89	221.29	178.46-274.41
11	Red Sea	45	19,229	234.02	70.02	52.28-93.78
12	Northern Kurdofan	53	28,980	182.88	101.01	77.17-132.22
13	Northern Darfur	110	33,830	325.16	217.46	180.4-262.15
14	Southern Kurdofan	24	37,066	64.75	73.9	49.53-110.25
15	Western Darfur	61	52,519	116.15	217.73	169.41-279.84
19	Sudan	1155	1,083,917	106.56	90.33	85.27-95.69

Appendix

Table 2 Trends in maternal mortality, 2009–2019

State	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	[3] *p*-value
Blue Nile	228.94	832.38	565.15	362.26	499.07	308.84	243.56	232.62	221.39	173.16	93.33	0.003*
Gadarif	464.61	268.96	170.89	220.10	170.22	176.80	162.29	157.98	146.18	83.21	161.66	0.001*
Gezira	310.16	245.27	204.11	154.96	121.93	105.34	84.31	89.99	63.38	87.33	100.85	0.002*
Kassala	354.39	307.69	320.73	277.20	214.97	164.00	153.12	161.97	111.41	90.78	68.48	0.000*
Khartoum	127.21	247.04	190.51	165.29	155.48	115.34	119.46	109.76	90.21	100.64	107.59	0.003*
Northern Darfur	347.46	182.28	136.90	216.08	218.57	136.24	105.59	135.29	91.84	186.02	217.46	0.276
Northern Kordofan	85.51	103.56	239.30	212.30	249.32	127.62	135.02	137.87	114.19	91.35	101.01	0.533
Northern State	272.51	240.04	100.47	151.25	99.89	100.02	94.56	88.27	102.10	87.23	136.94	0.043*
Red Sea	300.42	405.06	300.64	205.24	208.11	262.18	253.92	168.89	176.47	121.24	70.02	0.003*
River Nile	169.66	129.73	87.43	133.59	75.39	62.06	72.48	29.00	52.34	72.95	86.63	0.043*
Sinnar	136.16	199.37	190.14	223.38	253.49	142.25	103.59	139.88	120.73	97.90	102.69	0.043*
Southern Darfur	3.33	53.57	108.72	45.29	69.16	39.22	44.43	85.08	104.88	90.78	221.29	0.062
Southern Kordofan	52.68	346.84	221.10	303.89	285.20	187.82	77.09	120.72	106.97	108.50	73.9	0.087
Western Darfur	-	160.99	106.88	520.83	155.61	105.93	97.20	167.73	157.50	183.95	217.73	0.474
White Nile	187.52	231.92	214.16	221.55	147.47	159.66	132.27	89.16	82.44	91.70	38.7	0.002*
National Level	224.20	234.28	205.01	204.57	181.46	136.06	130.24	126.61	105.13	99.97	90.33	0.000*

[3] Significant *p*-value < 0.05

Abbreviations

ANC	Antenatal care
ARR	Annual reduction rate
CI	Confidence Interval
COVID- 19	Corona virus disease of 2019
EmONC	Emergency Obstetric and Neonatal Care
FGC	Female Genital Cutting
FMOH	Federal Ministry of Health
ICD- 11	The International Classification of Disease-eleventh revision
MDG	Millennium Development Goal
MDR	Maternal death review
MDSR	Maternal death surveillance and response
MMR	Maternal mortality ratio
NMDRC	National Maternal Death Review Committee
P value	Probability value
RANSAC	Random Sample Consensus
RH	Reproductive Health
S	Sen's Slope
SDG	Sustainable Development Goal
SMDRC	State Maternal Death Review Committee
SPSS	Statistical Package for Social Sciences
WHO	World Health Organization
WRA	Women of reproductive age

Supplementary Information

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Supplementary Material 1.

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Authors' contributions
ST: Compiled and reviewed the data, designed the study, created Figs. 1, 2, 3, interpreted the results, and wrote the main manuscript text. NA: Supervised the study and revised the manuscript for scientific excellence. AI: Assisted in revising the manuscript and created Fig. 4. AM: performed statistical analyses and prepared Tables 1 to 3. All authors read and approved the final manuscript.

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Data availability
The datasets supporting the conclusions of this article are included within the article and its additional file.

Declarations

Ethics approval and consent to participate
The data used was secondary data that did not include any personal information. The data was provided after obtaining ethical approval from the institutional review board at al- Neelain University, as well as permission from the Directorate of Mother and Child Health in the Federal Ministry of Health.

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