ORIGINAL RESEARCH ARTICLE

Subnational estimates of maternal mortality in Nigeria: Secondary Data Analysis of female siblings' survivorship histories

DOI: 10.29063/ajrh2023/v27i10.12

Opeyemi O. Babajide[1,2], Joshua O. Akinyemi[1] and Olusola Ayeni[1]*

Department of Epidemiology and Medical Statistics, Faculty of Public Health, University of Ibadan, Ibadan. Oyo State. Nigeria[1]; Dornsife School of Public Health, Drexel University, Philadelphia, PA, United States[2]

***For Correspondence:** Email: *oob26@drexel.edu*

Abstract

High Maternal Mortality (MM) in Nigeria is complicated by the absence of reliable estimates at subnational levels. Obtaining accurate data at the state and geopolitical region levels is crucial for effective policy-making and targeted interventions. This study employs novel small area estimation techniques to derive plausible estimates of Maternal Mortality rates and ratios for Nigerian states and geopolitical regions. Data from 293,769 female siblings, provided by 114,154 women in the Nigeria Demographic and Health Surveys of 2008, 2013, and 2018, are used. Empirical Bayesian technique and the James-Stein estimator are applied to estimate MM Rates and Ratios, respectively. Maternal Mortality Ratio is highest in rural areas, Northern Nigeria states, and regions. While the South West exhibits lower MMRatio, the Northern regions, particularly the North-East, show consistently higher ratios. Mortality trends have decreased in the North West and South East regions but increased in the South West from 2008 to 2018. Addressing these disparities is essential for achieving sustainable development goals and improving maternal health in Nigeria. *(Afr J Reprod Health 2023; 27 [10]: 133-147).*

Keywords: Maternal mortality, sisterhood method, small area estimation, Nigeria, empirical bayesian, siblings'survivorship histories

Résumé

La mortalité maternelle (MM) élevée au Nigeria est compliquée par l'absence d'estimations fiables aux niveaux infranationaux. L'obtention de données précises au niveau des États et des régions géopolitiques est cruciale pour une élaboration de politiques efficaces et des interventions ciblées. Cette étude utilise de nouvelles techniques d'estimation sur petites zones pour dériver des estimations plausibles des taux et ratios de mortalité maternelle pour les États et les régions géopolitiques du Nigeria. Les données de 293 769 frères et sœurs, fournies par 114 154 femmes dans les enquêtes démographiques et sanitaires du Nigeria de 2008, 2013 et 2018, sont utilisées. La technique bayésienne empirique et l'estimateur de James-Stein sont appliqués pour estimer respectivement les taux et les ratios MM. Le taux de mortalité maternelle est le plus élevé dans les zones rurales, dans les États et les régions du nord du Nigéria. Alors que le Sud-Ouest présente un ratio MMR plus faible, les régions du Nord, en particulier le Nord-Est, affichent des ratios systématiquement plus élevés. Les tendances de la mortalité ont diminué dans les régions du Nord-Ouest et du Sud-Est, mais ont augmenté dans le Sud-Ouest de 2008 à 2018. Il est essentiel de remédier à ces disparités pour atteindre les objectifs de développement durable et améliorer la santé maternelle au Nigéria. *(Afr J Reprod Health 2023; 27 [10]: 133-147).*

Mots-clés: Mortalité maternelle, méthode sisterhood, estimation sur petits domaines, Nigeria, Bayésien empirique, histoires de survie des frères et sœurs

Introduction

Elevated levels of maternal mortality are a challenge for population health and development. In 1987, the United Nations launched the Safe motherhood initiative (SMI) in Kenya. This initiative was established to reduce death during pregnancy and after childbirth. The SMI aimed to reduce the MM ratio by 50 percent by the year 2000[1]. Several other initiatives such as the Millennium Development Goals (MDGs) and Sustainable Development Goals (SDGs) introduced various programmes targeted at reducing the global level of MM. Despite these efforts, evidence suggests only a modest reduction in maternal mortality in developing countries[2]. According to the

World Health Organization, 99% of all maternal mortality occurs in LMIC, and it is endemic in rural areas and poor communities[3]. Globally, Nigeria and India rank top on the list of countries with the highest estimated number of maternal deaths according to WHO with an estimate of 67,000 and 35,000 maternal deaths (23% and 12% of global maternal deaths) respectively[2]. Sub-Saharan Africa as a region has a high MMRatio (MMRatio = 542 in 2017). Nigeria with MMRatio = 917, is the most populous country in SSA and as such contributes largely to the burden of MM[2].

While several analyses of MM trends show that Nigeria is making progress in reducing the maternal mortality rate, the pace remains slow as a woman's chance of dying from pregnancy and childbirth is 1 in 13 and more startling is that most of these deaths are preventable[2]. Several doubts have risen about the numbers that have been published as the rates of Maternal Mortality in Nigeria, considering the fluctuation and inconsistency of the figures and the uncertainty of their sources. The difficulty in measurement can be attributed rightly to the inadequate recording of adult deaths, misclassification of maternal death, and the relatively rare nature of maternal deaths[4-7]. Nigeria, as a country, has an inefficient vital/civil registration system, a challenge several developing countries are battling[8,9]. In the absence of a complete vital registration system, which should have been the accurate source of number and causes of deaths, these concerns about the estimates are not outrageous in themselves since estimates are generated by alternate methods based on several assumptions or from health facilities neglecting events that occurred out of the hospitals. Therefore, Nigeria does not only contribute enormously to the high maternal mortality rate in the world but also still has challenges in the measurement of the specific estimates.

Consequently, the various interventions and efforts to reduce maternal deaths and maternal mortality rates cannot be appreciated nor can impact be properly measured, if there are no adequate data and reliable estimates to measure the various performance indicators. Like most LMIC, there are relative inadequacies observed in the information on maternal mortality (MM) in Nigeria. Additionally, without valid estimates for the national and subnational subpopulations, the interventions cannot be targeted accurately to the groups of individuals who need them the most. This can be linked to the recent emphasis on a need to disaggregate data by variables such as socioeconomic status, geographical area, or even sex in the aim to reinforce data monitoring and accountability[10].

The question, therefore, remains, *"what is the magnitude of maternal mortality and how is this burden distributed across different states, to ensure the government appropriates the interventions successfully?"* There are no generally accepted consistent estimates of the maternal mortality rate in Nigeria. There seem to be differences in the estimates produced in various studies and used for various purposes (*Additional Table 1*). Not only are these figures displaying wide variation and disparity, but they concealed the differentials of these estimates within the different regions, states, and socio-economic groups in respective countries.

Several estimates that were provided in the past have been criticized for either being too low or too high[11]. Besides, it has been argued that they do not reflect the impact of several interventions that have been implemented for maternal mortality reduction[12]. Another obvious inadequacy of the existing estimates for Nigeria is that they refer to the country as a whole: there are no differentials such as urban/rural, geopolitical zones, and administrative entities such as states that are necessary for disaggregated planning purposes. Meanwhile, States are semi-autonomous and empowered to design their policies and programmes. It is therefore essential to have subnational estimates of maternal mortality useful for state-level initiates on maternal health indices. Therefore, this study involves a novel adaptation of small area estimation techniques to derive plausible estimates of Maternal Mortality rates and ratios for the thirty-six states, six geo-political regions, rural and urban areas of Nigeria.

Methods

Data source

This study is a demographic and statistical analysis of cross-sectional population-based data obtained from the Nigerian Demographic and Health Surveys of 2008, 2013, and 2018.

For this analysis, the maternal and adult mortality module is also known as the sibling survival module which was added to 2008, 2013, and 2018 Women's Questionnaire was used. The respondents were asked questions about their siblings born to the same biological mother. The name of each of the siblings is provided from the oldest to the youngest, with which the interview proceeds to find more details about each of the siblings. The current age of the siblings is required as well as the marital status, for living siblings. The age at death and year since death is asked for siblings that are reported to be dead. Female siblings who are above the age of 15 are further probed about. The interview asked if the sister died during pregnancy, childbirth, or during the postpartum period. Then MM rates and ratio were derived using the Empirical Bayesian Estimation of MM for states. This method was also adopted by Ahmed & Hill to generate similar estimates for MM in Bangladesh[13]. Selected factors in line with the McCarthy and Maine analytical framework[14] were explored as covariates to get estimates that were being used in the comparison of MM levels across states in Nigeria.

In preparing the data for analysis, the period length is captured by computing reference period which is the seven-year period prior the survey, excluding the month of the interview i.e. 0 - 6 years preceding the survey. The Individual sibling respondent dataset was then reconstructed into panel data (person-years) using the *varstocases* command in SPSS and each reported sibling was counted as an observation and is the unit of analysis from the siblings' history. This reconstructed dataset is labelled as the MM dataset. It has the records of all female siblings reported by the individual women. The data of female siblings who were dead from maternal causes were then used for further analysis. Female siblings who are reported to have died were assumed to be exposed to the risk of dying for 6 months in their year of death and this was considered in calculating the person-years of exposure. For entries with missing value on the survival of the siblings, it was excluded from the analysis. Age was adjusted for all the estimates generated and sampling weight was taken into consideration for all analyses. The dataset was then disaggregated to the various sub-population which include the 36 states and FCT. This was done using the IBM SPSS Syntax in Version 21.0.

Statistical analysis

A direct estimator of MMRate was obtained based on sample weights of the information of maternal deaths from the NDHS.

$$MMRate_{direct} = Y_{direct}$$
$$= \sum \frac{d_i}{N_j} \qquad (1)$$

d_j = the number of deaths in each state
Nj = the number of women in reproductive age in each state
This method is insufficient to obtain the desired parameter in a small area because there might be small areas not represented adequately in the sample size or not large enough to provide a stable and precise estimate.
A synthetic estimate also called an indirect estimate was obtained using the equation:

$$MMRate_{indirect} = Y_{indirect}$$
$$= X'\beta + \epsilon \qquad (2)$$

ε = error term
X' = Vector of covariates, measured at aggregate/mean for every small area. X is a vector of auxiliary variables that are mortality predictors which would be measured as a mean of the values for the sub-national levels. So, the mixed model is optimally based on direct and indirect estimates of Y. This prediction is known as best linear unbiased prediction (BLUP) and is a weighted estimate of the direct and indirect estimators which "borrows strength/information" from related areas and groups. This information provided from other related areas increases the effectiveness of the sample size, and in return, the precision of the estimate derived.
However, the expected value of the $Y_{indirect}$ then ignores the error term

$$E(Y_{Indirect}) = X'\beta \qquad (3)$$

It ignores the diversity (heterogeneity) of all the small areas based on the assumptions of the areas having similar characteristics; it then assumes that the MMRatio is the same.
One of the techniques the small area estimation makes use of is the Random effect model also known as the mixed model. This is different from the generalized linear models as it includes all models in the variance components procedure. MIXED model handles correlated data, unequal

variances and complicated situations in which units are nested in a hierarchy, for example, data obtained from a sample of respondents from a sample of states and political regions in Nigeria, as in the NDHS data.

The mixed model combines the technique of the direct estimator and the indirect estimator to produce what is known as the BEST LINEAR UNBIASED PREDICTION. The Best Linear Unbiased Prediction estimators minimize the Mean Square Error among the other classes of linear unbiased estimators, and it generally does not depend on the normality of the random effects.

$$Y_{mixed} = \bar{X}'\beta + u_j + \varepsilon_{ij} \quad (3)$$

where u_j is the heterogeneity/diversity across the small areas.

$u_j \sim N(0, \sigma_u^2)$

$\varepsilon_j \sim N(0, \sigma_\varepsilon^2)$

$$Y_{mixed} = Y_{jBLUP} = \bar{X}'_j\beta + \gamma(\bar{y}_j - \bar{X}'_j\beta)$$
$$= \bar{X}'_j\beta + \gamma\bar{y}_j - \gamma\bar{X}'_j\beta$$
$$= (\bar{X}'_j\beta - \gamma\bar{X}'_j\beta) + \gamma\bar{y}_j$$
$$= \bar{X}'_j\beta(1-\gamma) + \gamma\bar{y}_j \quad (4)$$

$\bar{X}'_j\beta$=Indirect estimator

γ= Shrinkage factor (SF) for area j.

$$\gamma_j = \frac{\sigma^2}{\sigma_u^2 + \sigma_\varepsilon^2} \quad (5)$$

Hence,

Y_{mixed} = *(SFj)* x *direct estimator* + **(1 —** *SFj)* x *indirect estimator*

The maternal death counts were treated as the response variable, and region of residence, wealth index, religion and level of education were the covariates in the model and an offset variable, the logarithm of the persons-year exposure.

$$\log(y_{ij}) = \beta_o + \beta_1 Religion_j + \beta_2 Region_j + \beta_3 WealthIndex_j + \beta_4 Education_j + \beta_5 Urban/Rural_j + v_j + \log(py).$$

Results

Model-based estimates of maternal mortality rates and ratio

For 2008, the estimates for MMRatio ranged from 280 (95% CI: 172 – 457) maternal deaths per 100,000 live-births in Lagos to 879 (95% CI: 718 – 1075) maternal deaths per 100,000 in Nasarawa State for 2008 (Figure 1) and ranged from 95 (95% CI: 57 – 158) maternal deaths per 100,000 live-births in Lagos state to 1621 (95% CI:1295 – 2029) maternal deaths per 100,000 live-births in Kastina State for 2013 (Figure 2).

Table 1 shows the model-based estimates of MMRatio in the Northern states for 2008. Among all the Northern states, Nasarawa had highest MMRatio of 879 (95% CI: 718 – 1075) maternal deaths per 100,000 live-births. Adamawa state had the highest MMR of 709 (95% CI: 621 – 810) maternal deaths per 100,000 live-births among the North Eastern states and Kebbi state had the highest among the North Western states with MMR of 780 (95% CI; 633 – 962). Table 1 shows the model-based estimates of the Southern states. Among the states in the Southern geopolitical zones, Lagos recorded the lowest MMR of 280 (95% CI: 172 – 457) maternal deaths per 100,000 live-births and Bayelsa State had the highest MMRatio of 832 (95% CI: 671 – 1033) maternal deaths per 100,000. Akwa Ibom State in the South South and Enugu State in the South East also had closely high MMRatio of 762 (95% CI: 666 – 872) maternal deaths per 100,000 live-births and 768 (95% CI:683 – 865) maternal deaths per 100,000 live-births respectively.

Table 2 show the model-based estimates of maternal mortality ratio for the Northern and Southern states for 2013 respectively. Katsina State in North Western part and Benue State in the North Central part of Nigeria had the highest MMRatio of 1621 (95% CI: 1295 – 2029) and 1257 (95% CI: 973 -1625) maternal deaths per 100,000 live-births respectively followed by Bauchi State in the North East with MMRatio of 998 (95% CI: 845 – 1179) maternal deaths per 100,000 live-births. However, states like Kaduna in the North West and Taraba states in the North East had relatively lowered MMRatio of 267 (95% CI: 213 – 334) and 317 (95% CI: 332 -414) maternal deaths per 100,000 live-births.

Figure 1 and 3 gives insight into how each state in the country fared compared to the national estimates of 545 maternal deaths per 100,000 live-births from the NDHS 2008 and 576 maternal deaths per 100,000 live-births. The observation for 2008 is that about half of the 36 states and the FCT falls below and borderline the estimates published by the Nigeria DHS, while the other half of the

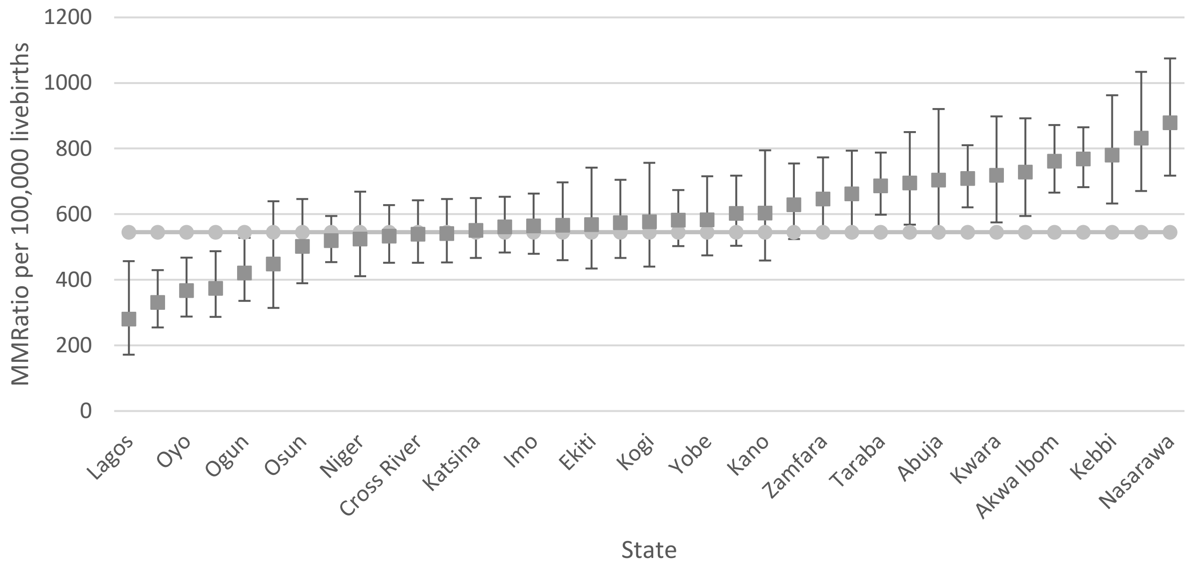

Figure 1: Model-based maternal mortality ratio estimates for all 36 States of Nigeria, 2008

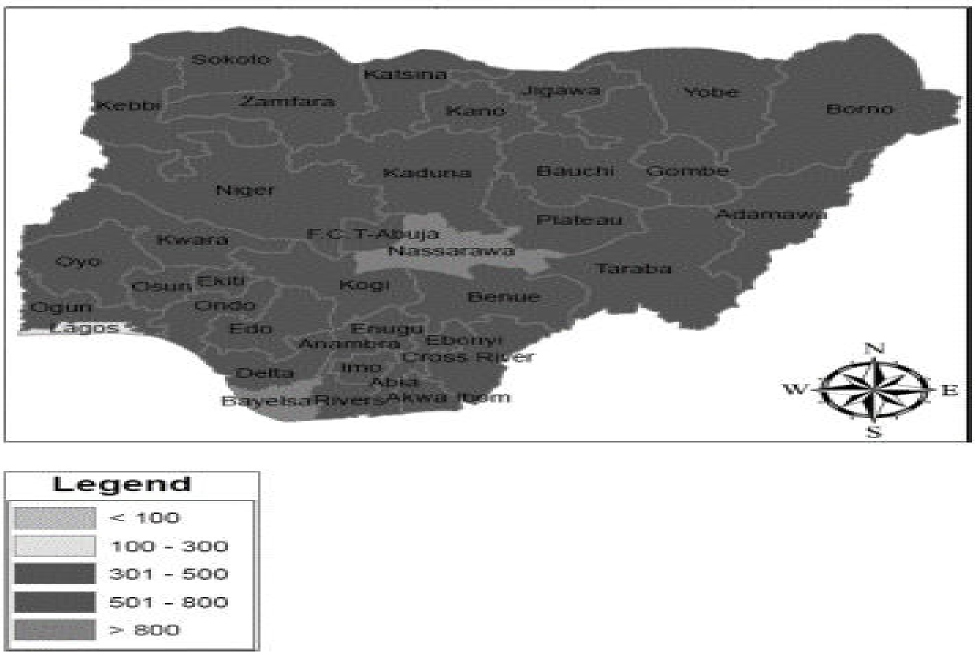

Figure 2: Map showing Model-based subnational maternal mortality ratio (MMRatio) estimates, for 36 states and FCT, Nigerian DHS 2008

Table 1: Model-Based Estimate of maternal mortality rates (MMRates) and Maternal mortality ratio (MMRatio) in All States in Nigeria DHS, 2008

Region	States	MMRate	MMRatio
North Central	Kogi	0.09 (0.07-0.12)	577 (440 – 756)
	Niger	0.13 (0.10 -0.17)	524 (411 – 668)
	Abuja	0.11(0.08 – 0.14)	704 (536 - 920)
	Nasarawa	0.14 (0.12 – 0.18)	879 (718 – 1075)
	Benue	0.09 (0.06 - 0.13)	448 (315 – 640)
	Kwara	0.12 (0.10 -0.16)	718 (575 – 898)
	Plateau	0.11 (0.09 -0.13)	629 (524 – 754)
North East	Yobe	0.15 (0.12-0.19)	583 (475 – 715)
	Borno	0.14 (0.12 -0.16)	520 (454 – 595)
	Adamawa	0.16 (0.14 -0.18)	709 (621 – 810)
	Gombe	0.15 (0.13 -0.17)	562 (483 – 653)
	Bauchi	0.14 (0.12-0.17)	533 (452 – 628)
	Taraba	0.14 (0.12 -0.16)	687 (599 – 788)
North West	Katsina	0.14 (0.12 -0.17)	551 (467 – 649)
	Jigawa	0.18 (0.15 – 0.22)	728 (595 – 892)
	Kano	0.16 (0.12 -0.21)	604 (459 – 794)
	Kaduna	0.12 (0.10 -0.14)	541 (453 – 646)
	Kebbi	0.17 (0.14 -021)	780 (633 – 962)
	Sokoto	0.19 (0.16 – 0.22)	662 (553 – 793)
	Zamfara	0.17 (0.14 – 0.20)	646 (540 – 773)
South East	Anambra	0.06 (0.04 -0.07)	331 (255 – 430)
	Enugu	0.10 (0.09 -0.12)	768 (683 – 865)
	Ebonyi	0.10 (0.08 – 0.13)	574 (467 – 705)
	Abia	0.08 (0.07 – 0.10)	602 (504 – 718)
	Imo	0.08 (0.07 -0.10)	564 (480 – 663)
South South	Edo	0.06 (0.05 -0.08)	374 (287 – 487)
	Cross River	0.09 (0.08 -0.11)	539 (452 – 643)
	Akwa Ibom	0.11 (0.10 -0.13)	762 (666 – 872)
	Rivers	0.10 (0.08 -0.12)	695 (568 – 850)
	Bayelsa	0.15 (0.12 – 0.19)	832 (671 – 1033)
	Delta	0.08 (0.07 – 0.10)	582 (503 – 674)
South West	Oyo	0.07 (0.05 – 0.08)	367 (288 – 468)
	Osun	0.06 (0.05 – 0.08)	502 (390 – 646)
	Ekiti	0.09 (0.07 – 0.11)	568 (434 – 742)
	Ondo	0.09 (0.07 0 11)	566 (460 – 697)
	Lagos	0.04 (0.02 – 0.06)	280 (172 – 457)
	Ogun	0.08 (0.06 – 0.09)	421 (336 – 528)

Table 2: Model-based Estimate of maternal mortality rates (MMRates) and maternal mortality ratio (MMRatio) in All States in Nigeria, 2013

Region	States	MMRate	MMRatio
North Central	Kogi	0.14 (0.12 – 0.17)	572 (485 – 674)
	Niger	0.17 (0.13 – 021)	660 (525 -829)
	Abuja	0.13 (0.11 – 0.15)	439 (368 -525)
	Nasarawa	0.11 (0.10 – 0.13)	422 (358 – 497)
	Benue	0.21 (0.17 -0.28)	1257 (973 – 1625)
	Kwara	0.14 (0.12 – 0.17)	809 (667 – 982)
	Plateau	0.14 (0.12 – 0.16)	514 (466 -592)
North East	Yobe	0.12 (0.10 – 0.14)	591 (505 – 692)
	Borno	0.14 (0.11 – 0.17)	856 (689 – 1062)
	Adamawa	0.12 (0.10 – 0.14)	494 (415 – 587)

	Gombe	0.13 (0.11 – 0.15)	691 (607 – 788)
	Bauchi	0.20 (0.17 -0.24)	998 (845 – 1179)
	Taraba	0.08 (0.08 – 0.09)	371 (332 – 414)
North West	Katsina	0.23 (0.19 – 0.29)	1621 (1295 – 2029)
	Jigawa	0.18 (0.14 – 0.22)	960 (766 – 1204)
	Kano	0.08 (0.08 – 0.14)	325 (193 – 545)
	Kaduna	0.08 (0.06 – 0.10)	267 (213 -334)
	Kebbi	0.12 (0.10 – 0.15)	584 (490 -696)
	Sokoto	0.14 (0.11 – 0.16)	963 (810 – 1146)
	Zamfara	0.11 (0.09 – 0.13)	480 (385 – 599)
South East	Anambra	0.09 (0.07 – 0.11)	632 (517 774)
	Enugu	0.09 (0.07 - 0.10)	503 (430 -588)
	Ebonyi	0.08 (0.07 -0.09)	641 (541 -760)
	Abia	0.13 (0.11 – 0.15)	915 (784 – 1068)
	Imo	0.07 (0.06 – 0.08)	433 (375 -499)
South South	Edo	0.11 (0.08 – 0.13)	691 (554 – 862)
	Cross River	0.08 (0.07 – 0.09)	620 (542 – 710)
	Akwa Ibom	0.15 (0.14 – 0.17)	939 (826 – 1066)
	Rivers	0.07 (0.05 – 0.08)	483 (387 -603)
	Bayelsa	0.16 (0.13 – 0.20)	1169 (937 -1458)
	Delta	0.07 (0.06 – 0.09)	454 (388 – 532)
South West	Oyo	0.04 (0.03 -0.05)	262 (186 – 386)
	Osun	0.08 (0.07 -0.10)	620 (508 – 759)
	Ekiti	0.11 (0.09 – 0.14)	681 (552 – 842)
	Ondo	0.09 (0.07 – 0.10)	624 (523 – 743)
	Lagos	0.01 (0.01 – 0.02)	95 (57 – 158)
	Ogun	0.08 (0.07 – 0.10)	453 (378 -543)

Table 3: Model-based Estimate of maternal mortality rates (MMRates) and maternal mortality ratio (MMRatio) in All States in Nigeria, 2018

Region	States	MMRate	MMRatio
North Central	Kogi	0.14	2308 (2247 – 2314)
	Niger	0.09	2464 (2456 -2654)
	Abuja	0.21	1206 (1072 -1442)
	Nasarawa	0.14	949 (929 – 954)
	Benue	0.09	626 (617 – 628)
	Kwara	0.14	591 (540 – 614)
	Plateau	0.12	862 (844 -992)
North East	Yobe	0.10	480 (445 – 494)
	Borno	0.10	357 (291 -394)
	Adamawa	0.12	659 (614 – 687)
	Gombe	0.13	811 (743– 862)
	Bauchi	0.10	651 (601 – 788)
	Taraba	0.11	420 (377 – 536)
North West	Katsina	0.07	188 (150 – 199)
	Jigawa	0.10	173 (70 – 227)
	Kano	0.06	233 (149 – 281)
	Kaduna	0.07	326 (273 – 346)
	Kebbi	0.10	665 (617 -689)
	Sokoto	0.12	320 (294 -328)
	Zamfara	0.09	809 (761 – 830)
South East	Anambra	0.09	667 (645 – 799)
	Enugu	0.12	681 (649- 685)
	Ebonyi	0.11	831 (803 -937)
	Abia	0.14	886 (837 -971)
	Imo	0.10	969 (928 – 1068)
South South	Edo	0.15	3719 (3683 -3725)

	Cross River	0.16	1872 (1862 – 1974)
	Akwa Ibom	0.13	890 (859 – 1094)
	Rivers	0.09	1083 (1064 – 1188)
	Bayelsa	0.26	444 (414 -647)
	Delta	0.12	1735 (1658 -1857)
South West	Oyo	0.10	323 (309 – 423)
	Osun	0.13	895 (797 – 1025)
	Ekiti	0.18	943 (508 – 759)
	Ondo	0.15	1059 (1046 – 1163)
	Lagos	0.07	546 (503 – 644)
	Ogun	0.13	13 (12 – 15)

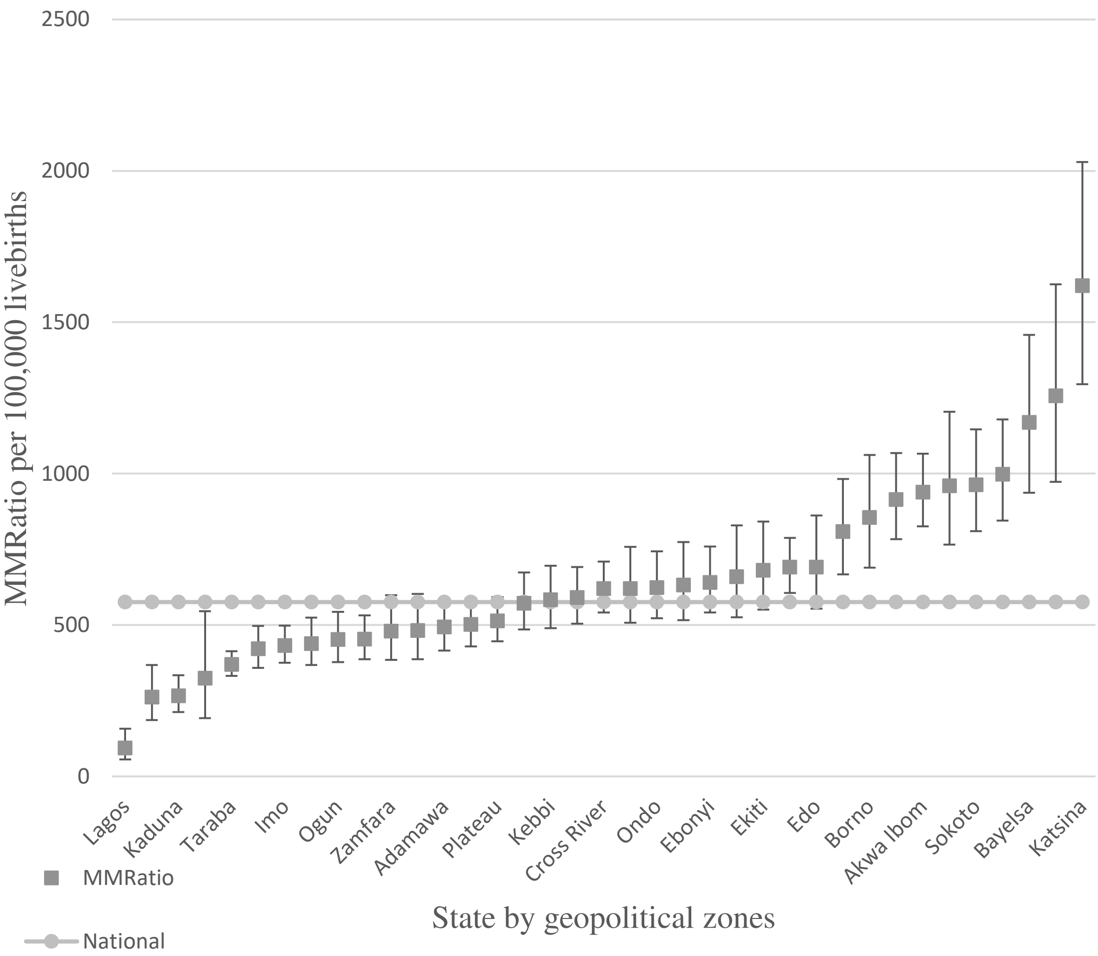

Figure 3: Model-based maternal mortality ratio estimates for all 36 States of Nigeria, 2013

states have MMR estimates higher than the published national average. However, in 2013, half of the states have MMR below the published estimates by the Nigeria DHS and the other half have MMR higher than the national estimates by the Nigerian DHS. In figures 2 and 4 spatial geographical variations in the MMR from the model-based method for both 2008 and 2013 are presented respectively. Identical patterns, denoted by color-codes (see figure legend) are seen in the various geo-political zones. The MMRatio levels are similar in clusters in the North and this mirrors what is also observed towards the West and the East.

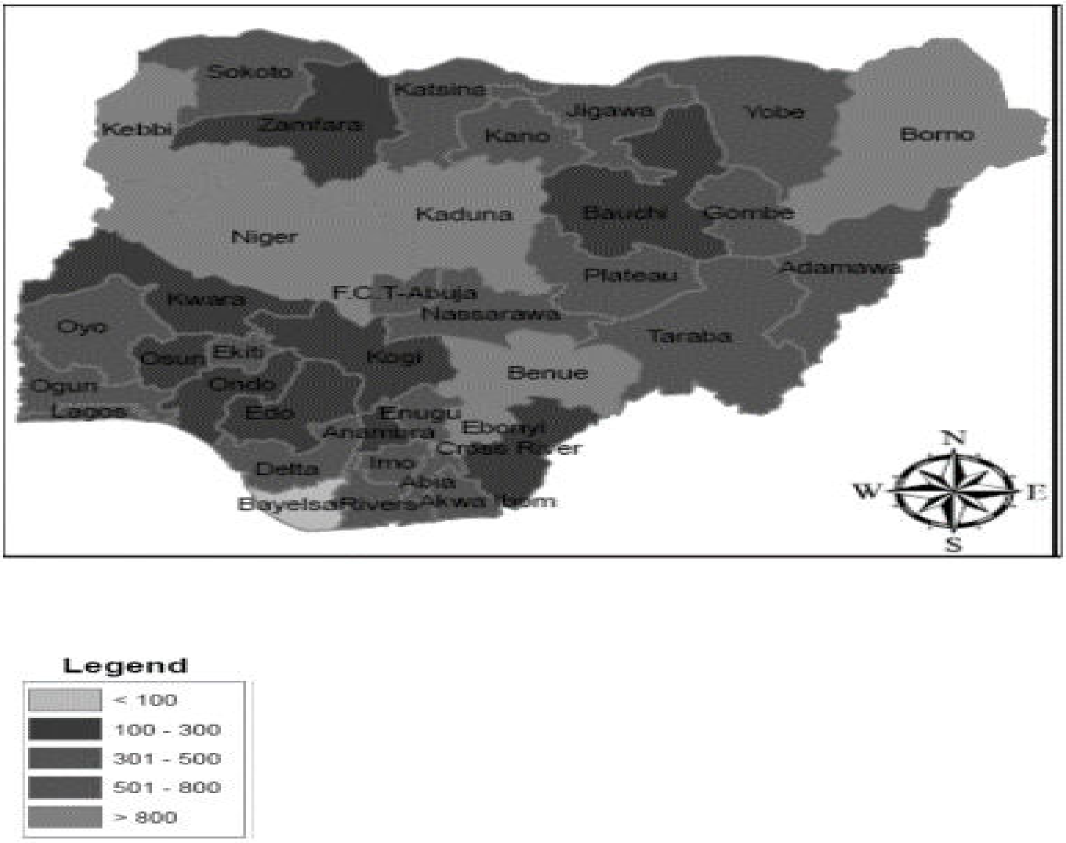

Figure 4: Map showing Model-based sub-national maternal mortality ratio (MMRatio) estimates, for 36 states and FCT, Nigerian DHS 2013

Discussion

The study has successfully provided plausible estimates of MM, highlighting the critical areas where maternal mortality rates and ratios are highest in the major sub-populations in Nigeria. Prior to this research, attempts have not been made at using the widely accepted Nigerian Demographic Health Survey datasets to generate disaggregated rates for MM in Nigeria. There were arguments also on the magnitude of mortality among women of reproductive age in Nigeria. This study has ascertained the number of maternal deaths observed in each state in Nigeria. The findings show that MMR in Nigeria has not decreased significantly. It was in fact noticed that there was a slight spike in the estimates of MMR from the 2013 datasets as compared to the 2008 datasets and the percentage of maternal deaths increased across the three surveys. MM was relatively lower in the Southern part of Nigeria compared to the Northern regions. The South West experienced a slight increase in MMRatio of about 4.8% from 2008 to 2018. However, the Mortality trends declined about 18% in the North West and 54.2% in the South east from 2008 to 2018.

Also, although the Northern region had a higher burden of MM, a few states contributed to the burden of MM reported in the various geo-political regions. For instance, in 2008, Taraba state in the North East and Kaduna and Zamfara states in the North West, contributed largely to the MMRatio of the Northern region compared to other states in the same region. Ebonyi state in the South East and Akwa Ibom State in the South South also had MMRatio that were as high as those observed in the Northern parts of the country. Similarly in 2013, Niger state in the North Central, Borno state in the North East and Kaduna and Kebbi states in the North West contributes largely to the high magnitude of MMR for the Northern states. Although the Southern states had lower level of MM compared to the states in the North, Ebonyi state in the South East and Akwa Ibom in the South South had relatively high MMRatio as well. This is one of the advantages of this study; further investigation has been made to ensure that each state in the geo-political region is accounted for, to reveal the magnitude of burden they contribute to each region. The observed differences in MM between the various states mirrors inequalities that has been observed in other developed countries[15]. These states' estimates also differ greatly from hospital-based studies in the various states in the country, which are relatively high *(additional table 1*). This resonates with a previous study in Malawi[16]. This highlights possible political will issue and administrative lag in commitment to the health services of individual states. This trickles to the allocation of resources from the central pool to address the healthcare needs of each state. If there are no small area sub-national estimates of mortality indices, in this case MM, and resources are being allocated to each state equally or based on other indicators other than the burden of mortality and monitored and evaluated healthcare needs, then, the real high risk areas will be neglected. This might in turn cause the heavy inequality in the MM experience of women in neighbouring states within the same geographical locations. In addition, the Northern region has states with high fertility in the country. This means that women of reproductive years are more exposed to the risk of child-bearing in these regions. It is also known that these regions are socially conservative and have practices of early girl- marriages most especially in their rural regions, which can be found largely in northern areas compared to the south[17].

In comparison with sub-national MM estimates, findings from this study suggests that facility-based estimation of MMR, are not substantive representative of these states in which they were carried out. These studies might have over reported the phenomenon, in that it is concentrated for women that were able to access health care at the clinics where the study was carried out. This leaves out other deaths that occur at home, that could not reach the health care centres or hospitals, and in fact the deaths that were measured might just be emergencies that were rushed into the clinics. Hospital based MMR is rather influenced by a delay in the health seeking behaviour of the women. It can be concluded that facility-based estimates are unacceptably high. Also, worthy to be observed is that these model-based estimates slightly differ from the set of estimates presented by the Institute for Health Metrics and Evaluation (IHME) of the University of Washington in Seattle. Their regression model differed from the UN Interagency with the use of more AIDS or AIDS-related deaths in to the regression model used in obtaining the MMRatio. The IHME estimated maternal deaths to be 342,900 compared to the UN estimates of 358,000 maternal deaths. This was used to obtain IHME estimates of 251 per 100,000 live-birth (range 221-289) and UN estimates was 260 (range 200-370). According to Abouzahr[11], these estimates differ in the statistical methods used in deriving the parameters and does not necessarily mean one is superior to the other. While the UN estimates used Gross National Income (GNI) as a covariate in their analysis, as well as general fertility rate and proportion of deliveries attended to by skilled birth attendants, in addition the IHME covariates included total fertility rate, HIV zero-prevalence, neonatal mortality, age-specific female education as well as age. Although still birth attendant was included in the IHME analysis, it was not an addition of the predictive validity of the estimates of MM. It is difficult to judge one method as superior to another as the statistical models are rather descriptive than explanatory in nature. Hence, it will suffice to say experts in various countries study county specific situation and data availability to solve issues of estimates for policy decision making. For this study, the Empirical Bayesian Method for small area estimates works perfectly in Nigerian. This approach centres the estimates around an average by borrowing information within the population to generate a refined estimate with assumptions suitable for small area estimations. This is a major strength for the small area estimation technique utilizing the empirical Bayesian method. Furthermore, the estimates from this method yielded a narrower 95% confidence intervals for generated estimates.

In order to tackle high MM in Nigeria, sub-national disparities need to be addressed. This can be urban-rural, geo-political region and even the various states' context. This is beside the concentrated effort made at the central government level. Socio-economic and health development imbalances impede the progress of a country's global or public health improvement. If there are left behind groups in a population, achieving any of the sustainable goals will be sabotaged by huge spatial inequalities. The disaggregation of the data into the sub-population as adopted in this study has provided plausible estimates with which MM in Nigeria's sub-population can be described, monitored and curbed. At this stage, in Nigeria, level of MM produced in this study for each sub-population might not be precise estimates, but it is sufficient to raise the consciousness of the government and policy makers to the magnitude in various types of places of residence, geo-political zones and states. For instance, estimates bordering between 300-700 per 100,000 might be given same policy responses, however, sub-population with estimates higher than that are definitely red flagged areas. Evidence-based decisions clearly require reliable estimates, in the absence of which resources will be wasted undetected. This has provided researched evidence for a need to target intervention programmes to the high risks areas like the North Central, North West and some part of the South-South, where MM is highest and most likely to occur.

With increasing demographic transition and change in population dynamics, there is a need to delineate population data to accommodate the heterogeneity of various socio-demographic groups. In Africa, women of reproductive age differ by risks process, urbanization, and geopolitical regions, which provides a challenge for policy implementation. This study has provided estimates that allow for spatial mapping of small area MM experience in Nigeria. This helps for understanding geographical variation and allocating decentralized resources, and policies to curb MM in sub-national areas with high level of MM. This can also assist social demographers in assessing etiological hypotheses in researching the high-risk areas of MM in Nigeria per state. In many instances, maternal health policies are rather generic; they are extended to all women of reproductive ages and do not account for disparities among most vulnerable and underserved women. Consequently, since challenges and choices differ for women in various environments and socio-economic groups, pooling programs and intervention without adaptive solutions is not as effective. Despite several interventions, Maternal Mortality (MM) remains high in Nigeria. The focus ought then to shift from pushing out programmes and intervention arbitrarily to ensuring maternal health care are evidence-based, tailor-made and available for underserved population that contribute largely to maternal health inequities. It is widely accepted that actions that improve the maternal health of women of reproductive ages not only vary across the age groups but also from countries, communities, and other subpopulations as applies. This makes this study fulfil one of the basic tenants of public health in understanding spatial patterns of health-related problems[18], since public health interventions, even though will be a common thread, actions, programmes for each subpopulation should be guided by evidence drawn from sound scientific-research[19]. This has also in essence crossed the hurdles of unreliable national estimates due to unavailability of CVRS and the rareness of maternal deaths in a statistical sense[20].

Reliable sub-population data and estimates on mortality are essential for policy and for planning to monitor the progress and development of a country against set goals. In Nigeria, since Vital Statistics Registration System (CVRS) is unavailable, small area demographic estimation methods can be explored in the interim. This can be by disaggregating population-based data and exploring direct estimation or using model-based approaches[10.21]. Within country comparison of demographic estimates, mortality will reveal the dimensions of inequalities in the population. While the availability of the NDHS has brought a rich dataset for demographers to understand the dynamics of population and estimates indices in Nigeria, strengthening the complete CVRS should be a key priority in the country. The registering of births and deaths should be an integral part of the nation's health surveillance culture. In the meantime, more investments should be put in place into the NDHS in enhancing the data quality. Small area datasets need to be collected in national surveys. It might be expensive to have a single survey capture all the information needed, however, data on both health and inequity might be gotten from different sources. For instance, if the data source captures studies for different purposes, it might decide to collect data not only at household level but also put into consideration disaggregation that allows for regional analysis and sub-national estimates which might include, race, ethnicity, economic status etc. Therefore, it means sampling must always align with administrative stratification for uniformity. Also, since health intervention programmes are aimed to curb health menaces and also to reduce disparities, regional or state level monitoring of demographic indices will be a useful tool to provide benchmarking terms. This will ensure that there is appropriate resource allocation according to the magnitude of burden in each sub-national population. This is particularly more effective when the country's health system is decentralized and allows to capture the substantial differences that may occur in the various geographical areas.

It is no news that a population-wide intervention would cost more money and resources to implement, hence, focused sub-population-based interventions have been proven to bring about more reduction in MM[22]. Building a sustainable evaluation capacity at the country and state levels will help in the allocation of scarce resources. Evidence-based intervention, programmes, and policies can be made to various states and geo-political zones. This enhances the cases of inclusiveness for rural residents and vulnerable people across the country. There is a need to improve and scale-up demographic estimates for mortality and fertility in different sub-populations in Nigeria exploring the robustness of the Bayesian method and more importantly to strengthen small area demographic estimates in Nigeria and Sub-Saharan Africa at large. The Bayesian method is a rich method that can utilize data from ranges of sources and measure uncertainty in resultant rates. It also has the capability of smoothing data across age, time and space as well as correct mortality data for its incompleteness. More investigation will be required, largely through qualitative researches and probably maternal surveillance audits and autopsies, to determine the factors contributing to a high level of maternity mortality (MM) in the high-risk zones in Nigeria.

Conclusion

In conclusion, our model-based estimates have provided opportunity for disaggregation of population data in generating demographic estimates has also been introduced as a plausible means of handling the issues of health disparities across varying sociodemographic groups in the Nigerian population. This is a novel area in demographic research as attention becomes drawn to precision public health to enhance health outcomes through equitable, data-driven policies in population health. This same method can be applied to the under-five mortality and fertility patterns of the various states and geo-political zones in Nigeria. Small area estimation has shown promising possibilities of handling the data inadequacies in some demographic or geopolitical groups that might have insufficient sample sizes for direct estimations of demographic indicators.

Consent to participate

Consent was obtained to use the Demographic and Health Survey Data.

Competing interests

The authors declare that they have no competing interests

Authors' contributions

OOB designed the study, performed the analysis, and drafted the manuscript for publication. JOA and OA provided scientific advice on the design of the study, data analysis and throughout the preparation of the manuscript. All authors read and approved the manuscript.

Additional Table 1: Previous estimates of maternal mortality in Nigeria

Sources	Reference Period	Method	Maternal deaths	MMRatio
Medical institution in Western States[23]	1972	Retrospective Hospital-based Study	Not available	380
Medical institution in western states[24]	1973	Retrospective Hospital-based Study	Not available	470
Maternal Death Review, University of Ilorin Teaching Hospital[24]	1972-1983	Retrospective Hospital-based Study	624	450
University of Nigeria Teaching Hospital, Nssukka, Enugu State[25]	1991-2000	Retrospective Hospital based study	182	1406
Ogun State University Teaching Hospital[26]	1988-1997	Retrospective Hospital based study	92	1700
University of Nigeria Teaching Hospital, Nssukka, Enugu State[25]	1976-1985	Retrospective Hospital based study	127	270
Research and Statistics Department of the Ministry of Health; Retrospective study of information contained in the vital statistics register in Kano State[27]	2003	A non-linear regression model was fitted to obtain the best temporal trajectory for the Maternal Mortality Ratio	4154	2420
University of Port-Harcourt Teaching Hospital; Retrospective maternity histories[28]	1999	Direct (Maternal deaths per total deliveries)	45	2735.6
Maternal Death Review, Federal Medical Centre Yola, Adamawa State[29]	2007-2011	Retrospective Hospital-based Study	54	636
Lagos University Teaching Hospital[30]	1989- 1998	Retrospective Hospital based study	Not available	2920
University Teaching Hospital, Jos[31]	1985-2001	Retrospective Hospital-based Study	267	740
Olabisi Onobanjo University Teaching hospital, Ogun State[32]	2000-2005	Retrospective Hospital based study-with autopsy record	75	2989.2
University of Ilorin Teaching Hospital[33]	1997-2002	Retrospective Hospital Survey	108	825
Maternal Death Review, Saint Philomena Catholic Hospital[34]	1996- 2000	Retrospective Hospital-based Study	32	454
Maternal Death Review, Central Hospital, Benin City, Edo State[35]	1994-2003	Retrospective Hospital based study	146	518
Adeoyo Maternity Hospital, Ibadan[36]	2003-2004	Retrospective Hospital Survey	84	963
University of Uyo Teaching Hospital[37]	2000-2005	Retrospective Hospital Survey	91	2577
University of Nigeria Teaching Hospital[38]	2004-2008	Retrospective Hospital based study	60	840
State Specialists Hospital, Bauchi[39]	2001-2008	Retrospective Hospital based study	Not available	1732
Maternal Death Review, University of Maiduguri Teaching Hospital[40]	2001-2005	Retrospective Hospital-based Study	Not available	430
Retrospective Cross Sectional study, Bidia and Riverine Urban Slums in Lagos[41]	2010 (but referring to years back)	Indirect Sisterhood method	Not available	1050
Retrospective Cross sectional study , 3 Rural Community in Zaria, Kaduna State[42]	2010 (but referring to years back)	Indirect Sisterhood method	328	1400
Jos University Teaching Hospital[43]	2006-2008	Prospective Hospital Survey	56	1260
Maternal Death Review, Federal Medical Centre Lokoja[44]	2005-2009	Retrospective Hospital-based Study	44	463
Community; Jigawa, Kastina, Yobe and Zamfara[45]	2011	Direct Sisterhood method	298	1271
Maternal Death Review, Federal Medical Centre Yola, Adamawa State[29]	2007-2011	Retrospective Hospital-based Study	54	636
Maternal Death Review, Federal Medical Centre, Makurdi[46]	2012	Retrospective Hospital-based Study	29	1381
All Nigeria[47]	2013	Multi-level Regression model	Not available	560
Retrospective Cohort Study , 24 Local Governments in Jigawa State[48]	2001	Indirect Sisterhood method	300	1012
Retrospective Cohort Study, 6 Local Governments in Kebbi State (17)	2001	Indirect Sisterhood method	204	890

References

1. World Health Organization. World Health Day 1998 - Safe Motherhood. Vol. 72, Division of Reproductive Health. Geneva, Switzerland; 1998.
2. World Health Organization. Trends in Maternal Mortality 2000 to 2017: Estimates by WHO, UNICEF, UNFPA, World Bank Group and the United Nations Population Division. Geneva; 2019.
3. World Health Organization. Trends in Maternal Mortality : 2000 to 2017. Estimates by WHO, UNCEF, UNFPA, The World Bank and the United Nations Population Division. 2017. 1–119 p.
4. Merdad L, Hill K and Graham W. Improving the Measurement of Maternal Mortality : The Sisterhood Method Revisited. PLoS One. 2013;8(4):1–12.
5. Abouzahr C. Making sense of maternal mortality estimates. Working Paper Series No. 11. Australia; 2010. Report No.: 11.
6. Hill K, Arifeen E, Koenig M, Al-sabir A, Jamil K and Raggers H. How should we measure maternal mortality in the developing world ? A comparison of household deaths and sibling history approaches. Bull World Health Organ. 2006;84(3):173–80.
7. Graham WJ. Now or never : the case for measuring maternal mortality. The Lancet. 2002;359:701–4.
8. Harrison KA. The Struggle to Reduce High Maternal Mortality in Nigeria. Afr J Reprod Health. 2009;13(3):9–20.
9. WHO UNICEF UNFPA and The World Bank. Trends in Maternal Mortality 1990 to 2010. World Health Organization. Geneva; 2012.
10. Reza A and Bergen N. Area-based units of analysis for strengthening health inequality monitoring. Bullentin of World Health Organization. 2016;94(August):856–8.
11. Abouzahr C. New estimates of maternal mortality and how to interpret them: choice or confusion? Reproductive Health Matters (RHM). 2011;19(37):117–28.
12. World Health Organization. Trends in Maternal Mortality : 1990 to 2013. Estimates by WHO, UNCEF, UNFPA, The World Bank and the United Nations Population Division. 2014.
13. Ahmed S and Hill K. Maternal mortality estimation at the subnational level : a model- based method with an application to Bangladesh. Bull World Health Organ. 2011;89:12–21.
14. McCarthy J and Maine D. A Framework for Analyzing the Determinants of Maternal Mortality. Stud Fam Plann. 1992;23(1):23–33.
15. Ronsmans C and Graham WJ. Maternal mortality : who , when , where , and why. Lancet. 2006;368:1189–200.
16. Beltman JJ, Akker T Van Den, Lam E, Moens M, Kazima J, Massaquoi M and Jos van Roosmalen . Repetition of a sisterhood survey at district level in Malawi : the challenge to achieve MDG 5. 2011;1–5.
17. Gulumbe U, Alabi O, Omisakin OA and Omoleke S. Maternal mortality ratio in selected rural communities in Kebbi State , Northwest Nigeria. BMC Pregnancy Childbirth. 2018;2(18:503):1–6.
18. Elliott P and Wartenberg D. Spatial epidemiology: Current approaches and future challenges. Environ Health Perspect. 2004;112(9):998–1006.
19. Department of Health and Human Services. Evidence-Based Clinical and Public Health : Generating and Applying the Evidence. Secretary's Advisory Committee on National Health Promotion & Disease Prevention Objectives for 2020. 2010.
20. Atkinson EJ, Crowson CS, Pedersen RA and Therneau TM. Poisson Models for person-years and expected rates. 2008.
21. Hosseinpoor AR, Bergen N and Magar V. Monitoring inequality: An emerging priority for health post-2015. Bulletin of the World Health Organization. 2015;93(9).
22. Kidney E, Winter HR, Khan KS, Gülmezoglu AM, Meads CA, Deeks JJ and MacArthur, C. Systematic review of effect of community-level interventions to reduce maternal mortality. BMC Pregnancy Childbirth. 2009;9(2):1–9.
23. Oduntan OS and Odunlami VB. Maternal mortality in Western Nigeria . Tropical Geographical Medicine. 1975;27(3):313–216.
24. Adetoro OO. Maternal mortality - a twelve-year survey at the University of Ilorin Teaching Hospital (U.I.T.H.) Ilorin, Nigeria. International Journal of Gynecology and Obstetrics. 1987;25(2):93–8.
25. Okaro JM, Umesulike AC, Onah HE, Chukwuali OF, Ezugwu FO and Nweke PC. Maternal Mortality at the University of Nigeria Teaching Hospital , Enugu , Before and After Kenya. Afr J Reprod Health. 2001;5(2):90–7.
26. Olatunji AO and Sule-odu AO. Maternal mortality at Sagamu , Nigeria--a ten year review (1988 - 1997). Nigerian Postgraduate Medical Journal. 2001;8(1):12–5.
27. Adamu YM, Salihu HM, Sathiakumar N and Alexander GR. Maternal mortality in Northern Nigeria : a population-based study. European Journal of Obstertrics and Gynecology and Reproductive Biology. 2003;109:153–9.
28. Uzoigwe SA and John CT. Maternal mortality in the University of Port Harcourt Teaching Hospital , Port Harcourt in the last year before the new millennium . Nigerian Medical Journal. 2004;13(1):32–5.
29. Bukar M, Kunmanda V, Moruppa JY, Ehalaiye B, Takai UI and Ndonya DN. Maternal Mortality at Federal Medical Centre Yola , Adamawa State : A Five-Year Review. Annal s of Medical &Health Science Research. 2013;3(4):568–71.
30. Daramola AO, Banjo AA and Elesha SO. Maternal deaths in the Lagos University Teaching Hospital : a ten-year review (1989 - 1998). Nigerian Postgraduate Medical Journal. 2004;11(4):274–8.
31. Ujah IA, Aisien JT, Mutihir JT, Vanderjagt DJ, Glew RH and Uguru VE. Factors Contributing to Maternal Mortality in North-Central Nigeria : A Seventeen-year Review. Afr J Reprod Health. 2005;9(3):27–40.
32. Oladapo OT, Lamina MA and Fakoya TA. Maternal deaths in Sagamu in the new millennium : a facility-based retrospective analysis. BMC Pregnancy Childbirth. 2006;6(6):1–7.

33. Aboyeji AP, Ijaiya MA and Fawole AA. Maternal Mortality in a Nigerian Teaching Hospital.pdf. Tropical Doctor; 2007. p. 83–5.
34. Onakewhor JU and Gharoro EP. Changing trends in maternal mortality in a developing country. Nigerian Journal of Clinical Practices. 2008;11(2):111–20.
35. Abe E and Omo-aghoja LO. Maternal Mortality at the Central Hospital , Benin City Nigeria : A Ten Year Review. 2008;12(3):17–26.
36. Olapade E and Lawoyin TO. Maternal Mortality in a Nigerian Maternity Hospital. African Journal of Biomedical research. 2008;11:267–73.
37. Abasiattai A and Umoiyoho A. A 6-Year Review Of Maternal Deaths In A Teaching Hospital In South-South, Nigeria. The Internet Journal of Gynecology and Obstertrics. 2008;11(1):1–9.
38. Ezugwu EC, Onah HE, Ezugwu FO and Okafor II. Maternal Mortality in a Transitional Hospital. Afr J Reprod Health. 2009;13(4):67–72.
39. Mairiga AG and Saleh W. Maternal mortality at the State Specialist Hospital Bauchi , Northern Nigeria. PubMed Commons. East Africa Medical Journal. 2009;86(1):25–30.
40. Bukar M, Audu BM and Takai UI. Trends in maternal mortality at University of Maiduguri teaching hospital, Maiduguri, Nigeria - A five year review. Nigerian Medical Journal. 2010;51(4):147–51.
41. Anastasi E, Bernasconi A, Hill O, Adebayo O and Ekanem EE. Estimation of maternal and perinatal mortality in the urban slums of Badia and Riverine in Lagos, Nigeria through the sisterhood method and preceding births technique. Medicos Sin Fronteras. 2010;545.
42. Idris H, Tyoden C, Ejembi C and Taylor K. Estimation of Maternal Mortality using the Indirect Sisterhood Method in Three Communities in Kaduna State , Northern Nigeria. Afr J Reprod Health. 2010;14(3):77–82.
43. Ngwan SD and Swende TZ. Maternal mortality in JOS Nigeria : A facility based prospective Review. Int J Biol Med Res. 2011;2(2):565–8.
44. Alabi OO, Olarunfemi G and Onile TG. The trend in maternal mortality in an upgraded tertiary facility in North. Nigerian Journal of Medicine. 2012;21(3):282–9.
45. Doctor HV, Olatunji A, Findley SE, Afenyadu GY, Abdulwahab A and Jumare A. Maternal mortality in northern Nigeria: Findings of a health and demographic surveillance system in Zamfara State, Nigeria. Trop Doct. 2012;42(3):140–3.
46. Gi A, Ochejele S and Sd N. A Review of Underlying Causes of Maternal Deaths in Benue North Central Nigeria. 2013;1(2):42–7.
47. World Health Organization. Trends in Maternal Mortality : 1990 to 2015. Estimates by WHO, UNCEF, UNFPA, The World Bank and the United Nations Population Division. 2015.
48. Sharma V, Brown W, Kainuwa MA, Leight J and Nyqvist MB. High maternal mortality in Jigawa State, Northern Nigeria estimated using the sisterhood method. BMC Pregnancy Childbirth. 2017;17(163):1–6..