World Journal of Advanced Engineering Technology and Sciences
eISSN: 2582-8266
Cross Ref DOI: 10.30574/wjaets
Journal homepage: https://wjaets.com/

(Research Article)

Application of Artificial Neural Networks and Conventional Statistical Methods in Predicting Maternal Mortality in Maiduguri, Nigeria

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World Journal of Advanced Engineering Technology and Sciences, 2026, 18(01), 344-357

Publication history: Received on 18 December 2025; revised on 25 January 2026; accepted on 28 January 2026

Article DOI: https://doi.org/10.30574/wjaets.2026.18.1.0043

Abstract

In Maiduguri, a conflict affected area in North East Nigeria, maternal mortality has been a serious public health issue in the region. This study examined socio demographic and obstetric factors associated with maternal mortality and examined the usefulness of predictive modeling based on collected maternal health data. A facility based observational study was conducted among 158 women who accessed maternal health services. Descriptive statistics and chi-square tests were used to assess relationships between maternal mortality and selected variables, including age, marital status, educational level, and antenatal care attendance. Maternal mortality was observed in 25.3% of cases. Maternal age, educational attainment, and number of antenatal care visits showed statistically significant relationship with maternal mortality ($p < 0.05$), whereas no statistically significant relationship was observed with marital status. Most maternal deaths occurred among women with no formal education and those who attended fewer antenatal visits. A multilayer perceptron model demonstrated good classification performance, with an accuracy of 98.1% in the training sample and 88.2% in the testing sample, and a high ability to identify maternal deaths. These findings indicate a persistently high burden of maternal mortality in Maiduguri and emphasize the importance of improving antenatal care utilization and female education, while suggesting that predictive approaches may complement conventional methods for identifying women at increased risk in resource-limited settings.

Keywords: Maternal mortality; Antenatal care; Education; Risk prediction; Maiduguri; Nigeria

1. Introduction

Maternal mortality remains a major public health concern and a sensitive indicator of the quality and accessibility of reproductive health services. It is defined as the death of a woman while pregnant or within 42 days of termination of pregnancy, irrespective of the duration or site of pregnancy, from causes related to or aggravated by pregnancy or its management, excluding accidental or incidental causes (World Health Organization (WHO), 2010, 2018). This definition underpins global surveillance and enables comparison of maternal mortality trends across regions and countries (WHO et al., 2019).

Despite global efforts to reduce maternal deaths, progress has been uneven. More than 300,000 women continue to die annually from pregnancy-related causes, with the highest burden occurring in low- and middle-income countries (WHO, 2022, Anumudu et al. 2025, Meh et al. 2019, Anumudu, S. et al. 2025). Variations in maternal mortality levels and contributing factors between northern and southern Nigeria shows the importance of adopting region-specific strategies to reduce maternal deaths. Efforts in the North should focus on improving girls' education, while initiatives in the South should emphasize better access to health information and healthcare services. Overall, policies that enhance women's socioeconomic conditions are necessary (Meh et al. 2019). Nigeria alone accounts for a substantial proportion of global maternal deaths, reflecting persistent challenges related to health system capacity, socioeconomic inequality,

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and delayed access to skilled obstetric care. These challenges are particularly pronounced in conflict-affected areas such as Maiduguri in North-East Nigeria, where prolonged insecurity has disrupted healthcare delivery, displaced populations, and weakened maternal health services (Anumudu et al. 2025, Diana S. et al., 2020, Ononokpono, D. N 2014). Low and lower-middle income countries (LMICs) are disproportionately affected by maternal mortality, a public health issue. Maternal mortality cannot be adequately tracked or its variations over time monitored due to a lack of appropriate data sources (Bauserman M. et al., 2020).

Maternal mortality has profound consequences beyond the immediate loss of life, affecting household stability, child survival, and community wellbeing. It is widely recognized as a marker of both women's social status and the effectiveness of national health systems (Stones & Nair, 2023). In settings such as Maiduguri, where health infrastructure has been strained by armed conflict, poverty, and population displacement, identifying women at increased risk of maternal death remains a critical priority. (Anumudu et al. 2025, Ononokpono, D. N 2014 & Nakimuli A., et al., 2025, World Bank 2021).

In many low-resource settings, healthcare service delivery is poor, with Nigeria ranking among the worst in access and quality of services (Ajegbile M. L. 2023). Maternal and newborn mortality rates remain high, with Nigeria's maternal mortality ratio exceeding global targets. Key challenges include inadequate infrastructure, shortage of skilled health workers, high out-of-pocket costs, and sociocultural barriers (Ononokpono & Odimegwu, 2014). Programs such as conditional cash transfers, transportation support, and male involvement have shown promise in improving maternal healthcare in resource-constrained contexts (Adeyinka & Muhajarine, 2020). Urgent investment in healthcare infrastructure, education, and culturally tailored interventions is critical to reduce maternal and neonatal mortality in Nigeria.

Maternal mortality in Nigeria remains a major public health challenge, influenced by both medical and socioeconomic factors. Key health determinants in Nigeria include hypertensive disorders of pregnancy, haemorrhage, and sepsis/septicaemia, while poverty, maternal education, cultural norms, and health system limitations affect access to and use of maternal healthcare services (Adeyinka & Muhajarine, 2020; Anumudu et al. 2025; Ononokpono & Odimegwu, 2014; Samuel et al., 2024). Despite interventions such as the "Abiye" Safe Motherhood Initiative, the Integrated Maternal, Newborn, and Child Health Strategy, and strengthened emergency obstetric care, persistent issues—including early childbearing, unemployment, large family sizes, and dependence on male spouses—continue to limit service utilization and contribute to adverse outcomes. Addressing both clinical and social determinants is critical to improving maternal health and reducing mortality in Nigeria and across the West African region.

Worldwide, maternal morbidity and death continue to be major health issues. Therefore, lowering the maternal mortality ratio (MMR) was a key indicator in the Millennium Development Goals (MDGs) and is now part of target 3 of the global sustainable development goals (SDGs). Therefore, in order to reduce mortality and morbidity, decision-makers and medical professionals must identify high-risk populations throughout pregnancy. However, it is difficult to find reliable predictive models for hazards to maternal health and death. Machine learning algorithms have become a viable predictive modeling technique that produces reliable predictive models when compared to conventional predictive models. (Almashrafi S S., et al. 2024).

Eclampsia is a life-threatening complication of pre-eclampsia, representing the most severe progression of the disorder. Currently, there are no reliable methods to identify women with pre-eclampsia who are at the highest risk of progression from pre-eclampsia to eclampsia and who would therefore benefit from prioritized intensive monitoring and timely delivery. This challenge is particularly pronounced in obstetric settings with limited resources. In this context, identifying risk factors for the progression of pre-eclampsia to eclampsia in low- and middle-income settings is critical for improving maternal outcomes (Nakimuli et al., 2025).

Changes in maternal age patterns further complicate maternal health outcomes. While adolescent pregnancy remains common in many parts of Nigeria, there is also an increasing number of pregnancies among women aged 35 years and above, both of which are associated with higher risks of obstetric complications (WHO, 2022; Stones, Meh et al. 2019, Anumudu S.I et al. 2025, Nakimuli A., et al., 2025 & Nair, 2023). In addition, most maternal mortality research has traditionally focused on direct obstetric causes, such as hemorrhage and hypertensive disorders, often excluding deaths linked to external or indirect causes. Evidence suggests that factors such as substance use, violence, and other non-obstetric conditions contribute meaningfully to maternal deaths, particularly in unstable and conflict-affected environments (Ajegbile, 2023; Anumudu, S. I., 2025, Diana et al., 2020; Ononokpono D. & Odimegwu C. 2014). Fourteen percent of maternal deaths globally occur in Nigeria. Low utilization of maternal health services for delivery may partially explain the high maternal mortality. This study aimed to examine the contribution of community factors in explaining variations in the use of health care organizations and health facilities for delivery in Nigeria (Ononokpono &Odimegwu 2014)

Given the multifactorial nature of maternal mortality in settings like Maiduguri, approaches that allow simultaneous consideration of demographic, obstetric, and health-system factors are increasingly being explored to support early identification of high-risk pregnancies and inform targeted interventions.

2. Background of the Study

2.1. Prediction of Maternal Risks and Adverse Outcomes

Recent studies from diverse geographic settings have examined evidence-based analytical approaches to identifying women at increased risk of maternal complications and death. Evidence from the Middle East, South Asia, and sub-Saharan Africa indicates that these approaches can improve identification of high-risk pregnancies compared with traditional methods alone.

Almashrafi et al. (2020), using maternal health records from Oman, demonstrated high accuracy in classifying pregnancy risk status, particularly for severe complications. Similar findings were reported by Schmidt et al. (2023), who showed improved detection of preeclampsia risk using hospital-based data. Studies conducted in India and Bangladesh have also reported strong predictive performance for identifying complications such as hemorrhage, infections, and hypertensive disorders (Pawar et al., 2022; Nishimura et al., 2024). The study assessed the timeline for Bangladesh to attain Sustainable Development Goal target 3.1, which aims to reduce maternal mortality ratios to fewer than 70 per 100,000 live births. Drawing on nationally representative data from 1993 to 2017 and projecting trends under multiple policy scenarios to 2060, the findings indicate that accelerated increases in institutional deliveries could enable attainment of the target by 2026, while adherence to national policy goals would achieve it by 2029. In contrast, continuation of prevailing trends would substantially delay progress until approximately 2049, and scenarios characterized by minimal improvement would fail to reach the target even by 2060. Overall, the evidence highlights the central role of expanding equitable access to institutional delivery services and strengthening the quality of facility-based care in achieving sustained reductions in maternal mortality ratios (Nishimura et al. 2024).

Research conducted in low-resource and hospital-based settings has highlighted the value of combining multiple maternal characteristics, including age, parity, antenatal care attendance, and prior obstetric history, to improve identification of women at elevated risk (Islam et al., 2022). Hybrid approaches have also been shown to improve classification of high-risk pregnancies in retrospective hospital cohorts (Khadidos et al., 2024).

Importantly, evidence from fragile and low-income settings suggests that such approaches remain effective even where data quality and healthcare access are limited. Hossaini et al. (2024) demonstrated improved prediction of pregnancy complications in low-income countries using routinely collected maternal health data. (Alfaki et al., 2021) further assessed the accuracy and completeness of maternal death records by comparing hospital-based data with death certificate records in Ontario, Canada. Using retrospective population-level data, the analysis examined agreement between the two sources for deaths occurring within 42- and 365-days following pregnancy outcomes. The findings showed generally strong concordance when linked records were used, but notable declines in agreement when unlinked deaths were included. Overall, the results indicate that hospital records alone are insufficient for capturing maternal mortality, highlighting the need for improved data linkage across reporting systems.

Preterm preeclampsia is a major contributor to maternal and perinatal morbidity and mortality, and the effectiveness of low-dose aspirin in preventing this condition has been uncertain. This multicenter, double-blind, placebo-controlled trial randomized 1,776 high-risk women with singleton pregnancies to receive either 150 mg of aspirin daily or placebo from early pregnancy until 36 weeks' gestation. The primary outcome was the occurrence of preeclampsia leading to delivery before 37 weeks. Preterm preeclampsia occurred significantly less often in the aspirin group than in the placebo group, with a risk reduction of more than 60%. Adherence was high and no significant differences were observed in neonatal or other adverse outcomes, supporting the safety and effectiveness of low-dose aspirin in high-risk women (Rolnik, 2017).

Preeclampsia is a heterogeneous hypertensive disorder of pregnancy with complex and overlapping clinical presentations, which can, in severe cases, progress to eclampsia. Early-onset preeclampsia is primarily driven by defective placentation due to inadequate spiral artery remodeling, whereas late-onset preeclampsia is more often associated with placental overgrowth or accelerated placental aging. The rising incidence of both preeclampsia and eclampsia reflects increasing maternal risk factors, and effective prevention and management require combined clinical strategies alongside broader socioeconomic interventions (Ngene & Moodley, 2024; Redman & Sargent, 2009; Burton et al., 2019; Rolnik, 2017). Postpartum haemorrhage prediction models developed using early risk factors showed that machine learning approaches, particularly Random Forest, outperformed traditional statistical methods. Haemoglobin level during labour and maternal age were the most influential predictors, although risk factor importance varied across data partitions, highlighting the need for robust validation strategies in predictive modelling. (Holcroft, S. et al. 2024). Despite improvements in healthcare access, maternal and fetal mortality in Nigeria remains high. Emerging machine learning–based prediction models implemented in tertiary hospitals offer potential for early risk detection and improved outcomes, although significant challenges to widespread adoption persist (Onyeka et al., 2024).

Pre-eclampsia arises from poor placentation, which induces oxidative and endoplasmic reticulum stress in the placenta and contributes to maternal disease. Placental stress has been linked to increased production of soluble fms-like tyrosine kinase-1 (sFlt-1), which neutralizes vascular endothelial growth factor and leads to maternal endothelial dysfunction. However, the paper argues that oxidative stress and inflammation may play a more central role than hypoxia alone in stimulating sFlt-1 release. It emphasizes that pre-eclampsia should be understood not only as an endothelial disorder but also as a condition of systemic inflammation, highlighting the importance of inflammatory pathways such as NF-κappaB alongside hypoxia-inducible factors. Based on these observations, the authors propose a modified two-stage model in which multiple placental-derived bioactive factors contribute to the inflammatory maternal syndrome (Redman & Sargent, 2009).

The application of machine learning models also shows how to evaluate maternal health risks using demographic and physiological indicators. Several classification algorithms were compared through split validation and 10-fold cross-validation to support early detection of pregnancy-related complications. The findings suggest that data-driven risk classification can strengthen prenatal care and improve the allocation of healthcare resources. Notably, the Support Vector Machine model outperformed others, achieving an accuracy of 86.13% in predicting maternal health risk levels (Raihen & Akter, 2024).

2.2. Evidence from Child and Infant Mortality Studies in Nigeria

Related work on child and infant mortality in Nigeria provides additional support for the use of data-driven risk identification approaches in maternal and child health. Jaiyeola et al. (2025) found improved identification of infant mortality risk compared with conventional statistical techniques, particularly for infants born to women with limited antenatal care.

Under-five mortality remains a major public health challenge in developing countries, particularly in Nigeria, where child survival outcomes vary widely across regions and socioeconomic groups (mortality in Nigeria). This study demonstrates the effectiveness of machine learning models in predicting under-five mortality using 2018 NDHS data, with Random Forest and Artificial Neural Network models achieving the highest accuracy and discriminatory power. Key predictors included wealth index, maternal education, antenatal care visits, place of delivery, maternal employment status, parity, and region, highlighting persistent social and health inequalities and the value of machine learning for informing targeted interventions to reduce under-five mortality in Nigeria (Samuel et al. 2024).

Recent Nigerian studies have reported high predictive accuracy for under-five and neonatal mortality when multiple maternal, socioeconomic, and healthcare factors are considered simultaneously (Samuel et al., 2024). Key determinants consistently identified include maternal education, household wealth, antenatal care utilization, place of delivery, and regional disparities—factors that are highly relevant to Maiduguri and the wider North-East region.

Given the multifactorial nature of maternal mortality, there is increasing interest in methods that can evaluate complex relationships among socio-demographic, obstetric, and healthcare variables. Neural Networks, particularly multilayer perceptron models, provide a statistical approach that can capture these non-linear relationships and interactions, enabling improved classification of women at risk of maternal death. Unlike conventional statistical methods that may assume linear relationships, Neural Networks can integrate multiple factors simultaneously to identify patterns associated with maternal mortality outcomes.

Recent studies in low-resource settings have demonstrated the utility of Neural Networks in maternal health research. For example, research has shown that Neural Networks can achieve high accuracy in identifying women at risk of complications such as hemorrhage, preeclampsia, and infections (Almashrafi et al., 2024 & Schmidt et al., 2023). These findings suggest that, when combined with conventional approaches, Neural Networks can complement traditional risk assessment and support early identification of high-risk pregnancies, particularly in resource-limited and conflict-affected regions like Maiduguri.

Machine learning (artificial neural networks) and logistic regression techniques produced PTB prediction accuracy that was largely comparable in a sizable sample of multiparous women. However, artificial neural networks outperformed logistic regression for spontaneous PTB by a little margin. Both first- and second-trimester models produced extremely strong negative predictive values for overall and spontaneous PTB, which were higher than those of fetal fibronectin. (Belaghi, R. A., 2024).

Comparative modelling using neural networks and logistic regression model of infant mortality in Nigeria showed that artificial neural networks outperformed logistic regression in sensitivity and overall predictive accuracy. Short birth intervals and failure to receive tetanus toxoid vaccination during pregnancy were identified as the most influential predictors of infant mortality. (Jaiyeola, O. et al., 2025).

This study, therefore, examines socio-demographic and obstetric factors associated with maternal mortality in Maiduguri and evaluates the predictive performance of Neural Networks alongside conventional statistical methods to assess their ability to identify women at elevated risk. The findings aim to inform targeted interventions and improve maternal health outcomes in a context where health services are severely constrained.

3. Methodology

3.1. Study Design and Setting

A facility-based observational study was conducted in Maiduguri, North-East Nigeria, a conflict-affected region with high maternal mortality rates and limited healthcare access. The study targeted women who attended public and private maternal health facilities between January and December 2025.

3.2. Study Population and Sample

The study included 158 women who were either pregnant or within 42 days postpartum. Inclusion criteria required complete socio-demographic and obstetric records. Women who died due to accidental or incidental causes were excluded from the analysis.

3.3. Data Collection

Data were collected using structured questionnaires and hospital records. Collected variables included maternal age, marital status, educational level, parity, antenatal care attendance, and obstetric history. Maternal mortality outcomes were recorded for each participant.

3.4. Variables

- **Dependent variable:** Maternal mortality (alive or deceased within 42 days of pregnancy termination)
- **Independent variables:** Maternal age, marital status, educational attainment, number of antenatal visits, parity, obstetric history

3.5. Data Analysis

3.5.1. Conventional Statistical Analysis

Descriptive statistics (frequencies, percentages, mean ± standard deviation) were used to summarize socio-demographic and obstetric characteristics. Chi-square tests were conducted to examine associations between maternal mortality and independent variables, with significance set at $p < 0.05$. Logistic regression was applied to assess the contribution of each factor to the likelihood of maternal mortality.

3.5.2. Neural Network Analysis

A multilayer perceptron approach, a form of Neural Network, was applied to classify maternal mortality outcomes based on multiple predictor variables simultaneously. The analysis used routinely collected socio-demographic and obstetric data to identify patterns associated with maternal deaths.

- Data were randomly divided into training (70%) and testing (30%) sets to evaluate model performance.
- The Neural Network output provided predicted probabilities of maternal death for each participant.
- Performance was evaluated using accuracy, sensitivity, specificity, and the area under the receiver operating characteristic curve (AUROC).

- The goal was to determine whether Neural Network assessment could identify women at risk more effectively than conventional statistical methods alone.

4. Results and Discussion

Table 1 Socio-demographic and obstetric characteristics of the study participants (N = 158)

Variable	Category	Frequency (n)	Percentage (%)
Maternal age (years)	19–24	24	15.2
	25–29	51	32.3
	30–34	46	29.1
	≥35	37	23.4
Marital status	Married	152	96.2
	Divorced	6	3.8
Educational level	None	81	51.3
	Primary	26	16.5
	Secondary	29	18.4
	Tertiary	22	13.9
Number of antenatal care visits	1 visit	58	36.7
	2 visits	76	48.1
	≥3 visits	24	15.2
Maternal mortality outcome	Survived	118	74.7
	Died	40	25.3

Table 1 shows that the mean maternal age was 29.1 years (SD = 5.7). Most women were married (96.2%) and more than half had no formal education (51.3%). Only 15.2% of participants attended three or more antenatal care visits. Maternal mortality was recorded in 25.3% of cases, indicating a substantial burden among women accessing maternity services in Maiduguri.

Table 2 Relationship between maternal age and maternal mortality

Maternal age (years)	Maternal deaths n (%)	Survivors n (%)	Total
19–24	5 (20.8)	19 (79.2)	24
25–29	11 (21.6)	40 (78.4)	51
30–34	18 (39.1)	28 (60.9)	46
≥35	6 (16.2)	31 (83.8)	37
Total	40 (25.3)	118 (74.7)	158

Chi-square test: $\chi^2 = 80.73$, df = 17, $p < 0.001$

Table 2: Maternal age showed a statistically significant association with maternal mortality ($p < 0.001$). Higher proportions of maternal deaths were observed among women aged 30–34 years. This suggests that maternal age is an important determinant of mortality risk in this population.

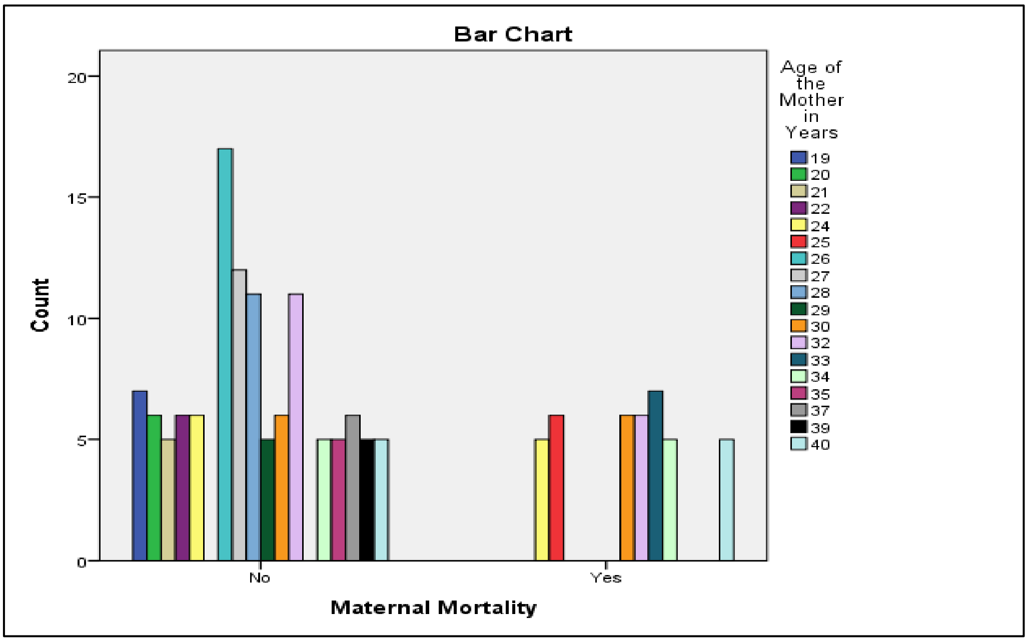

Figure 1 Relationship between maternal age and maternal mortality

The bar chart shows that maternal survival was more common than maternal death across all age groups; however, maternal deaths were unevenly distributed by age. Higher numbers of maternal deaths were observed among women in their late twenties and early thirties, while fewer deaths occurred among younger women aged 19–24 years. Although maternal mortality was lower among women aged 35 years and above, deaths were still recorded in this group, indicating that risk persists across the reproductive age range. Overall, the pattern demonstrates a clear age-related variation in maternal mortality, supporting the statistical evidence that maternal age is significantly associated with maternal mortality in the study population Fig. 1.

Table 3 Relationship between marital status and maternal mortality

Marital status	Maternal deaths n (%)	Survivors n (%)	Total
Married	40 (26.3)	112 (73.7)	152
Divorced	0 (0.0)	6 (100.0)	6
Total	40 (25.3)	118 (74.7)	158

Chi-square test: $\chi^2 = 2.11$, df = 1, $p = 0.146$

Table 3: No statistically significant relationship was observed between marital status and maternal mortality (p = 0.146). Maternal deaths occurred predominantly among married women, reflecting the marital distribution of the study population rather than a true risk difference.

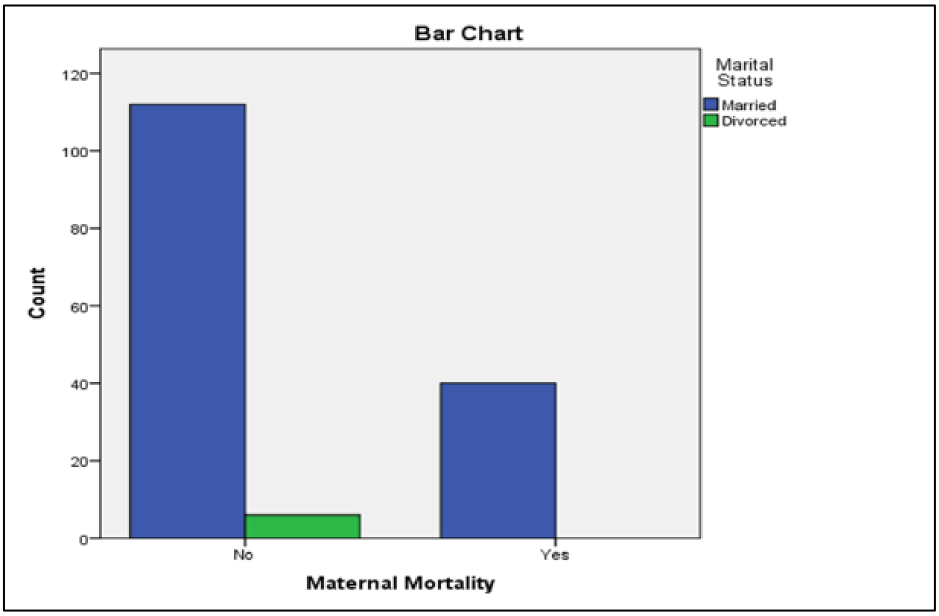

Figure 2 Bar chart showing the Relationship between Marital Status and Maternal Mortality

The bar chart indicates that maternal deaths occurred almost exclusively among married women, while no maternal deaths were recorded among divorced women. However, this pattern reflects the underlying distribution of marital status in the study population, where the vast majority of participants were married. Overall, the chart shows no clear difference in maternal mortality risk by marital status, which is consistent with the statistical analysis indicating that marital status was not significantly associated with maternal mortality Fig. 2.

Table 4 Relationship between educational level and maternal mortality

Educational level	**Maternal deaths n (%)**	**Survivors n (%)**	**Total**
None	23 (28.4)	58 (71.6)	81
Primary	11 (42.3)	15 (57.7)	26
Secondary	6 (20.7)	23 (79.3)	29
Tertiary	0 (0.0)	22 (100.0)	22
Total	40 (25.3)	118 (74.7)	158

Chi-square test: $\chi^2 = 12.16$, df = 3, $p = 0.007$

Table 4. Educational attainment was significantly associated with maternal mortality ($p = 0.007$). Maternal deaths were highest among women with no formal or only primary education, while no deaths were recorded among women with tertiary education.

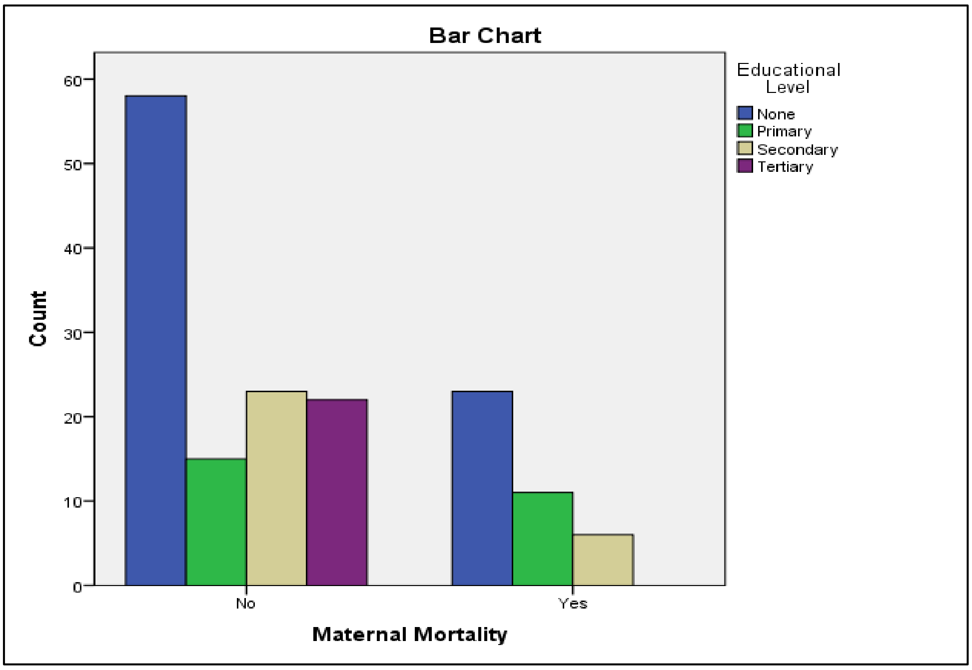

Figure 3 Bar Chart indicating the Relationship between educational level and maternal mortality

The bar chart shows that maternal mortality is most common among women with no formal education and decreases steadily as education level rises, with the lowest mortality observed among those with secondary and tertiary education. Conversely, women with higher levels of education are more likely to experience no maternal mortality, indicating better health outcomes. Overall, the chart suggests a strong inverse relationship between maternal education and maternal mortality, highlighting education as an important protective factor Fig. 3.

Table 5 Relationship between antenatal care visits and maternal mortality

Antenatal care visits	Maternal deaths n (%)	Survivors n (%)	Total
1 visit	5 (8.6)	53 (91.4)	58
2 visits	29 (38.2)	47 (61.8)	76
≥3 visits	6 (25.0)	18 (75.0)	24
Total	40 (25.3)	118 (74.7)	158

Chi-square test: $\chi^2 = 15.18$, df = 2, $p = 0.001$

Table 5: The number of antenatal care visits was significantly associated with maternal mortality ($p = 0.001$). Women with fewer antenatal visits experienced a higher proportion of maternal deaths, highlighting inadequate antenatal utilization as a key risk factor.

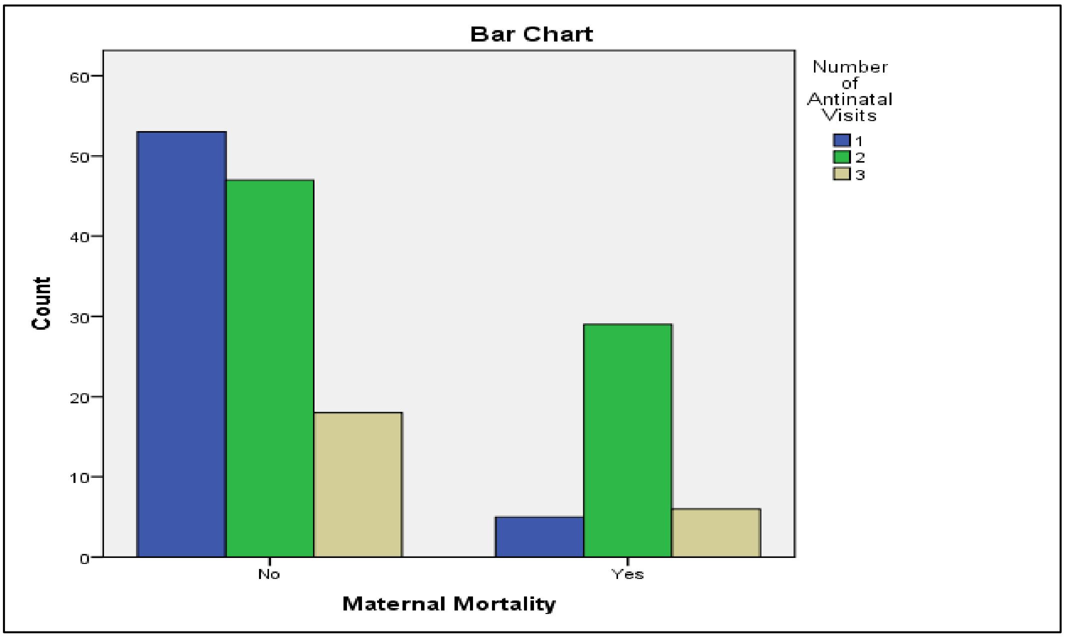

Figure 4 Bar Chart Indicating the Relationship between antenatal care visits and maternal mortality**.**

The bar chart indicates that maternal mortality is more common among women with fewer antenatal care visits, while higher numbers of antenatal visits are associated with fewer maternal deaths. Most women who did not experience maternal mortality had one or two antenatal visits, whereas among those who experienced maternal mortality, the counts are notably higher for fewer visits and lower for three visits. Overall, the chart suggests that increased utilization of antenatal care is associated with reduced maternal mortality, underscoring the importance of regular antenatal visits for improving maternal health outcomes Fig. 4.

Table 6 Performance of the multilayer perceptron neural network model

Dataset	Accuracy (%)	Sensitivity (%)	Specificity (%)
Training sample	98.1	100.0	97.4
Testing sample	88.2	100.0	85.7

Table 6: The multilayer perceptron model demonstrated strong predictive performance. The model achieved an accuracy of 98.1% in the training sample and 88.2% in the testing sample, with perfect sensitivity in identifying maternal deaths. This indicates a high ability of the Neural Network model to classify women at risk of maternal mortality.

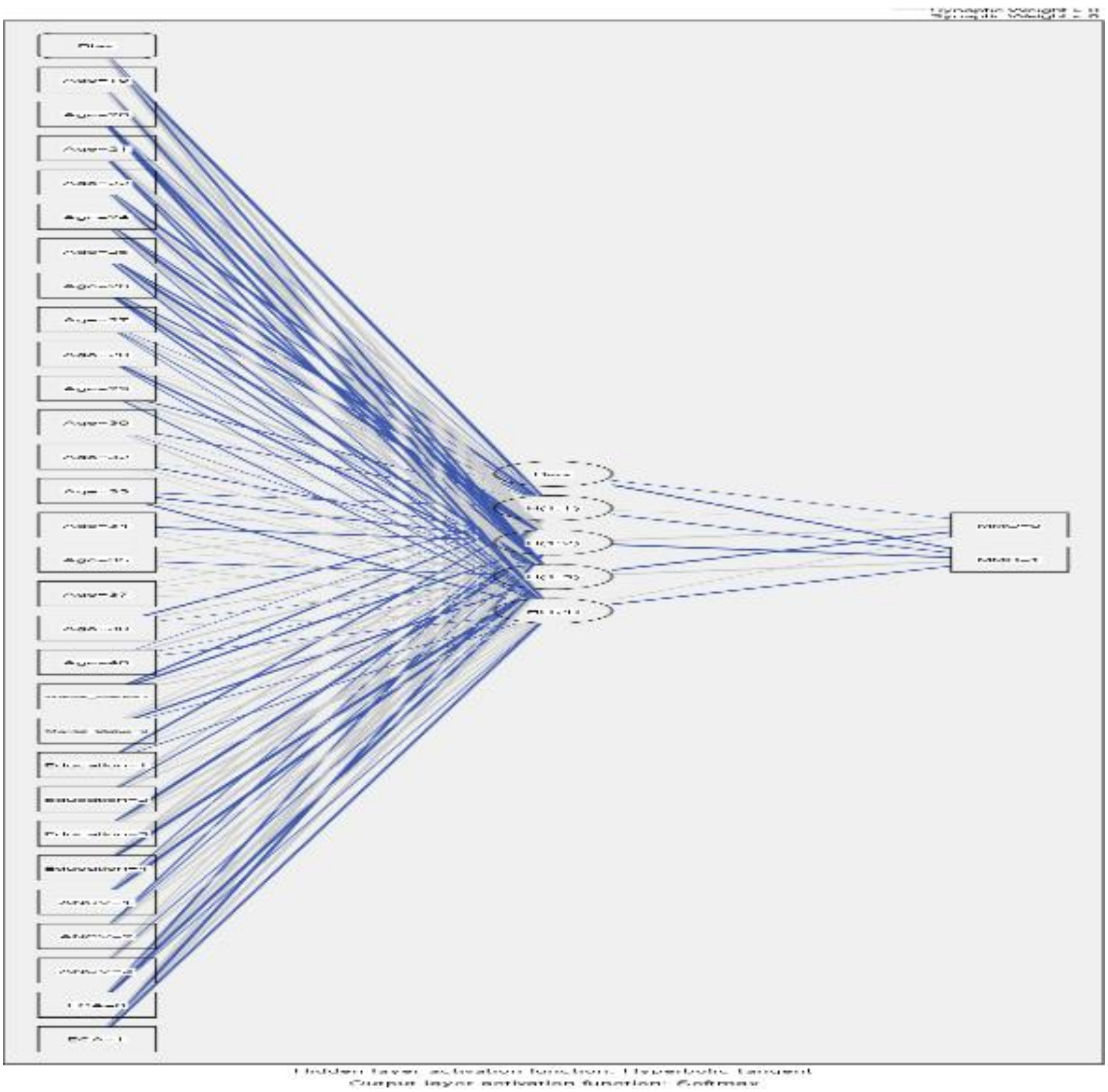

Figure 5 Indicating Performance of the multilayer perceptron neural network model

The performance of the multilayer perceptron neural network model indicates its effectiveness in learning complex, non-linear relationships within the data and producing reliable predictions. Based on the evaluation results, the model demonstrates adequate predictive accuracy and generalization capability, suggesting that it successfully captures key patterns in the input variables relevant to the outcome of interest. Overall, the model's performance supports its suitability as a robust analytical tool for predicting outcomes, although further optimization or validation with additional data could enhance its reliability Fig. 5.

4.1. Summary

This study examined socio-demographic and obstetric factors associated with maternal mortality among 158 women accessing maternity services in Maiduguri. The findings revealed a high maternal mortality rate of 25.3%, indicating a substantial public health burden. Most participants were within the reproductive age range of 25–34 years, married, and had no formal education. Utilization of antenatal care services was generally low, with only a small proportion attending three or more visits. Maternal age, educational level, and number of antenatal care visits showed statistically significant relationships with maternal mortality, while marital status did not. Additionally, the multilayer perceptron model demonstrated strong predictive capacity in identifying women at risk of maternal death, with high accuracy and perfect sensitivity across both training and testing samples.

5. Conclusion

Maternal mortality remains a significant challenge among women receiving maternity care in Maiduguri. The study demonstrates that maternal age, low educational attainment, and inadequate antenatal care attendance are key determinants of maternal mortality in this population. Women with little or no education and those with fewer antenatal visits were disproportionately affected. Although marital status was not independently associated with maternal mortality, the overall findings underscore the importance of social and health service–related factors in shaping maternal outcomes. The predictive model further shows the potential of data-driven approaches in identifying high-risk women and supporting timely clinical decision-making.

Recommendations

Based on the findings of this study, the following recommendations are proposed:

- **Strengthen female education:** Policies and interventions that promote girl-child education and adult female literacy should be prioritized, as higher educational attainment was associated with improved maternal survival.
- **Improve antenatal care utilization:** Efforts should be made to encourage early booking and completion of the recommended number of antenatal visits through community sensitization, improved access to health facilities, and reduction of financial and logistical barriers.
- **Target high-risk age groups:** Women in their late twenties and early thirties should receive closer monitoring during pregnancy and childbirth, given the higher proportion of maternal deaths observed in these age groups.
- **Enhance maternal health services:** Health facilities should be adequately equipped and staffed to manage pregnancy-related complications, particularly in regions with high maternal mortality.
- **Integrate predictive tools into care planning:** Predictive models with high sensitivity may be incorporated into maternal health programs to support early identification of women at elevated risk and guide preventive interventions.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no competing interests.

Statement of ethical approval

Ethical approval for this study was obtained from the Institutional Research Centre of Kashim Ibrahim University, Maiduguri. The study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki.

Statement of informed consent

Written informed consent was obtained from all participants prior to data collection. All data were anonymized before analysis, and the confidentiality and privacy of participants' information were strictly maintained throughout the study.

Authors' Contributions

Abubakar Masha conceived the study, designed the methodology, collected and analyzed the data, and drafted the manuscript. Mohammed Lefami Zarma contributed to the literature review. All authors reviewed and approved the final manuscript.

Funding

This research was funded by the Tertiary Education Trust Fund (TETFund), Nigeria, under the Institutional Based Research (IBR) intervention. The funder had no role in the study design, data collection, data analysis, interpretation of results, or writing of the manuscript.

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