Health Sciences Investigations Journal

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ISSN Online 2704-4890 ISSN Print 2720-7609

Online first publication

Original Research Article

HSI Journal (2026) Volume 8 (Issue 1):1391-1400. https://doi.org/10.46829/hsijournal.2026.3.8.1.1391-1400

Open Access

Predictive modelling of stillbirth risk factors in Ghana: a retrospective study

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Received December 2025; Revised January 2026; Accepted February 2026

Abstract

Background: Stillbirth remains a devastating and unacceptably common occurrence. Quantifying stillbirth risk can support healthcare decision-making. While advancements in prenatal care have led to a global decline in stillbirth rates, millions of babies are stillborn each year. This public health burden is particularly heavy in low- and middle-income countries, where access to quality healthcare may be limited.

Objective: This study investigated the predictors and a predictive model of stillbirth at the Korle-Bu Teaching Hospital.

Methods: Secondary data were extracted from the obstetric department database at Korle-Bu Teaching Hospital and subjected to predictive analysis using R statistical software. The participants in this study were all births in the obstetrics department from 2015 to 2017, excluding terminations. After all exclusions, the final study population consisted of 9253 live births and 293 stillbirths. The logistic model focused on identifying major predictors of stillbirth, with variables including maternal age, hypertension, malaria during pregnancy, placental abruption, and gestation at delivery. The model's overall goodness-of-fit was tested, with statistical significance set at 0.05.

Results: Out of 9,546 births, 293 (3.1%) were stillbirths, including both fresh and macerated types. Predictors of stillbirth included maternal age ≥35 years (OR 1.34, 95% CI 1.02 – 1.77, $p = 0.035$), abruptio placentae (OR 5.83, 95% CI 3.41 – 9.97, $p < 0.001$), malaria in pregnancy (OR 2.59, 95% CI 1.08 – 6.24, $p = 0.034$), and lower gestational age at delivery (OR 0.76 per week, 95% CI 0.73 – 0.79, $p < 0.001$). The model showed moderate discrimination (AUC 0.71, 95% CI 0.67 – 0.75) and excellent calibration (slope 1.00, intercept ~0, Brier score 0.028). At the optimal probability cutoff, sensitivity was 61.4%, specificity 74.6%, and negative predictive value 98.4%.

Conclusion: The predictive model successfully identified key risk factors for stillbirth, offering insights into targeted interventions for high-risk groups. These findings contribute to the standardised approach to stillbirth analysis and reporting, underscoring the importance of improved prenatal care and screening practices in reducing stillbirth incidence. This study fills a crucial research gap by providing a validated predictive model for stillbirth in a resource-limited setting.

Keywords: Stillbirth, eclampsia, gestation, model, maternal, fetal

Cite the publication as Mensah M, Opoku S, Yeboah C, et al. (2026) Predictive modelling of stillbirth risk factors in Ghana: a retrospective study. HSI Journal 8(1):1391-1400. https://doi.org/10.46829/hsijournal.2026.3.8.1.1391-1400

INTRODUCTION

The WHO defines 'stillbirth' as the death of a fetus at or after 28 weeks of pregnancy. Previous studies have however, reported that most upper-middle-income countries use a lower gestational age cutoff point to define stillbirth [1] and therefore count more babies who are not born with signs of life, whilst most low-income countries tend to use a higher gestational age cutoff point as recommended by the World Health Organisation (WHO) [2]. The use of a lower cutoff point by upper-middle-income countries may be attributed to technological advancements and their ability to provide care for babies born at a certain gestational age, thereby increasing their chances of survival [2,3]. Irrespective of the definition, stillbirth is an adverse pregnancy outcome that results in emotional and psychological impacts on families, with financial challenges. In 2015, there were 2.6 million stillbirths globally, with more than 7178 deaths per day.

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Many of these deaths occurred in developing countries, including Ghana [4–6]. In 2021, UNICEF reported an estimated 1.9 million stillbirths at ≥28 weeks of pregnancy, and a global stillbirth rate of 13.9 stillbirths per 1,000 births [4–6]. An earlier study indicated that most stillbirths occur intrapartum, with an estimated proportion of stillbirths varying from 10% in developed countries to 59% in Southeast Asia [7]. The incidence and prevalence of stillbirth are significant health concerns in Ghana. The national stillbirth rates in Ghana were 20 per 1,000 births in 2017 [8]. According to the Ghana Health Service (GHS), the 2020 national stillbirth rate in Ghana was 12.3 per 1,000 total births. Though there is a general downward trend, some regions, including Ashanti and Greater Accra, appear to have a high proportion of stillbirths [8].

In many circumstances, the actual cause of stillbirth remains unidentified, although it can occur owing to several factors, including maternal, fetal and even environmental factors, including excessive heat. Maternal factors that can contribute to stillbirth include diabetes, hypertension, obesity, infections, smoking and poor nutrition [1,7,9]. Additionally, placental abnormalities such as placental abruption, placenta previa, and placental insufficiency are related to stillbirths [3,10]. Fetal-related factors include congenital anomalies and genetic disorders [3,10,11], as well as pregnancy-related factors, including gestational age, multiple pregnancies, and fetal growth restrictions have been reported [9,10,12]. Some of these factors can be modified through appropriate interventions. Hence, using the WHO cutoff point, this study aims to quantify and validate the predictive accuracy of a comprehensive set of identified risk factors in a tertiary hospital in Ghana, as a reasonable quantification of risk factors can equip health care workers to identify pregnancies at high risk and those that can benefit from available interventions.

MATERIALS AND METHODS

Data source

The study employed a Secondary data analysis. Data from January 1, 2015, to December 31, 2017, were obtained from the obstetrics department's records unit at Korle-Bu Teaching Hospital (KBTH), Accra, Ghana – the leading referral centre in Ghana. It is a public teaching hospital with over 2,000 beds, 21 clinical and diagnostic departments, and three Centres of Excellence. A total of 28,080 birth records were sourced from the records unit's electronic database, and multiple imputation techniques were employed to handle missing data. Consequently, the total number of complete data points was 9,546. Inclusion criteria included complete data on key variables of interest, including maternal chronic conditions and pregnancy outcomes. Exclusion criteria included records with incomplete data on these critical variables. Records of terminations of pregnancy were also excluded from the study. Extracted records included information on chronic medical conditions, maternal demographics, obstetric complications, and infants' characteristics.

Risk factors and outcome variable

The outcome variable was stillbirth. It was defined as fetal death from at least 28 weeks of gestation (WHO) [2,4]. Stillbirths were classified based on their clinical appearance at delivery to estimate the timing of fetal death. Fresh stillbirths (lacking signs of skin peeling or degradation) were used as a proxy for intrapartum deaths (occurring during labour). Macerated stillbirths (showing signs of skin desquamation) were used as a proxy for antepartum deaths (occurring before the onset of labour) [4]. Risk factors used included maternal sociodemographic characteristics, obstetric complications and chronic medical diseases. Maternal sociodemographic factors included age (<35 years or> 35 years), marital status (single, cohabiting/married), and educational level (no formal education, primary, secondary, or tertiary). The rest were occupation, ethnicity, and religion. Chronic medical conditions included essential hypertension, sickle cell disease and pre-existing diabetes mellitus. Obstetric complications included eclampsia, placenta previa, abruptio placentae, and premature rupture of membranes. Other characteristics of pregnancy included number parity, previous abortions, malaria in pregnancy, multiple pregnancies and gestational age. To ensure temporal ordering, all maternal complication determinants were extracted from records documented before or at the immediate onset of the birth event. Chronic conditions and malaria episodes were identified from longitudinal Antenatal Care (ANC) records. Complications, such as eclampsia and placental abruption, were recorded by clinicians during the intrapartum period but before the final determination of birth status (live birth vs stillbirth).

Data analysis

Model development. The modelling approach employed a candidate predictor list selected a priori based on clinical relevance, including maternal age, parity, malaria status, and hypertensive disorders. Continuous predictors, such as maternal age and BMI, were assessed for linearity against the log-odds of stillbirth; since no significant non-linearity was detected, they were maintained as linear terms to preserve statistical power. We utilised a backward stepwise selection strategy guided by the Akaike Information Criterion (AIC) to identify the most parsimonious model, ensuring all steps were documented for complete transparency. To safeguard against overfitting, we verified that our Events Per Variable (EPV) ratio exceeded the standard threshold of 10, given our 293 stillbirth events. Furthermore, we conducted internal validation using bootstrapping with 1,000 resamples to confirm the stability of the final coefficients. Multicollinearity was rigorously assessed using Variance Inflation Factors (VIFs), and all retained variables had VIFs below 5. This systematic process ensures that the identified associations between maternal complications and birth outcomes are both statistically robust and clinically meaningful. Logistic regression analysis was complemented by crude and adjusted odds ratios to evaluate the strength of association,

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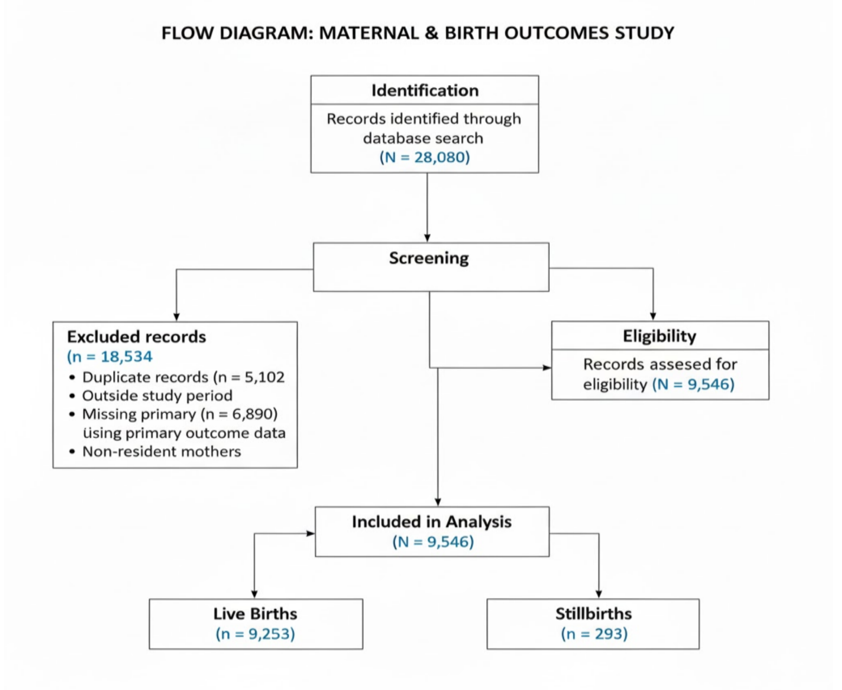

Figure 1. Flowchart of variable selection process.

while accounting for potential confounders. Model selection was iterative, with variables retained based on their statistical significance and contribution to the model's explanatory power. Stata MP version 17 was used for all statistical analyses. Descriptive statistics, including means, standard deviations, and percentages, were calculated to summarise the data. The relationship between predictors and stillbirth was initially explored using chi-square tests for categorical variables and t-tests for continuous variables. The final logistic regression model was selected based on the Akaike Information Criterion (AIC) for the best fit. A Chi-square Goodness-of-Fit test was conducted to evaluate the model's overall fit, and the Receiver Operating Characteristic (ROC) curve was used to assess its predictive accuracy, with an Area Under the Curve (AUC) analysis providing a measure of model performance. Model calibration was assessed using calibration slope and intercept, which measure agreement between predicted probabilities and observed outcomes. Predicted probabilities were divided into deciles, and observed mean outcomes were plotted against predicted probabilities to generate a calibration plot. The Brier score was calculated as the mean squared difference between predicted probabilities and observed outcomes, providing an overall measure of prediction accuracy. Calibration slope values close to 1 and intercepts near 0 indicate good agreement.

RESULTS

The final study population consisted of 9253 live births and 293 stillbirths (Figure 1). Table 1 shows the relationship between mothers' sociodemographic factors and the occurrence of stillbirths. The mean age of mothers with live births was 29.2 ± 5.8 (mean ± SD) with an age range of 15-50 years. The mean age of the women with stillbirths was 30.2 ± 5.8. Regarding maternal age, the proportion of mothers aged < 35 years was 74.1% among stillbirths and 80.1% among live births, and this distribution differed significantly from that of mothers aged ≥ 35 years ($p < 0.01$). Stillbirth was more common among married/ cohabiting compared with single mothers (81.2 % vs. 18.8%). The occurrence of stillbirth was lower in mothers who had attained a tertiary education level compared to those with secondary and primary education, but higher than in mothers with no education, though not statistically significant ($p > 0.05$). The majority (91.1%) of participants were Christians. More than 60% of the respondents were from the urban areas. More than half of the participants were Akans (53.2%), followed by Ga-Adangbes (18.1%). There were no significant associations between stillbirth and marital status, educational level, occupation, religion, or ethnicity ($p < 0.05$) (Table 1).

The cORs of mothers' obstetric factors and medical history associated with stillbirth are presented in Table 2. From the results, mothers who had some obstetric complications had higher odds of stillbirths. For example, participants who had abruptio placenta (cOR: 9.80; 6.00 - 16.00; p < 0.00) had higher odds of stillbirths compared with individuals who did not. Similarly, mothers who had malaria during pregnancy (cOR: 2.82; 1.22 - 6.56; p < 0.02) and those with essential hypertension (cOR: 1.73; CI: 1.26 - 2.37; p < 0.000) had a higher likelihood of stillbirth. No significant association was recorded between stillbirth and sickle cell disease, pre-existing diabetes, PROM, parity group and previous abortions.

Variable selection for the model

All maternal variables, including socio-demographics, obstetric and medical history, that showed a significant association with stillbirth were considered for inclusion in the multivariable analysis, after checking for multicollinearity using VIF and tolerance levels. The Variance Inflation Factor (VIF) measures the impact of collinearity among the variables in the model. From the multicollinearity statistics of the independent variables, the tolerance and VIF values were within acceptable limits for all variables. They included: age group (tolerance = 0.65, VIF = 1.52), eclampsia (tolerance = 0.96, VIF = 1.03), malaria (tolerance = 0.99, VIF = 1.01), abruptio placentae (tolerance = 0.99, VIF = 1.01), and gestational age (tolerance = 0.91, VIF = 1.08). Hence, there was no interaction between these independent variables. The Variance Inflation Factor (VIF) suggested was <10. This means that all explanatory variables help predict stillbirth. Therefore, all the independent variables were used to model stillbirth at the Korle Bu Teaching Hospital (Table 3).

In the multivariable logistic regression analysis, maternal age ≥ 35 years was significantly associated with higher odds of the outcome (adjusted OR 1.34, 95% CI 1.02 – 1.77, p = 0.035). Placental abruption showed a strong independent association (aOR 5.83, 95% CI 3.41 – 9.97, p < 0.001). Malaria during pregnancy was also significantly associated with increased odds (aOR 2.59, 95% CI 1.08 – 6.24, p = 0.034). Increasing gestational age at delivery was protective, with a 24% reduction in odds per unit increase (aOR 0.76, 95% CI 0.73 – 0.79, p < 0.001). Hypertension was not significantly associated with the outcome after adjustment (aOR 1.11, 95% CI 0.79 – 1.55, p = 0.551). The model is a good fit, with a log-likelihood of -1168.8 (Table 4). The fitted model is given as: P (stillbirth = 1) =

Table 1. Relationships between mothers' demographics and the occurrence of stillbirths

Variables	Still births	Live births	cOR (95% C.I)	p-value
Age	30.2 ±5.8	29.3 ±5.8		0.00
Age group				
<35 years	217 (74.1)	7408 (80.1)	1	
≥ 35 years	76 (25.9)	1845 (19.9)	1.41 (1.08-1.84)	0.01
Marital status				
Single	55 (18.8)	1858 (20.1)	1	
Married/cohabiting	238 (81.2)	7395 (79.9)	1.09 (0.81-1.46)	0.58
Educational level				
No formal education	20 (6.8)	707 (7.6)	1	
Primary	35 (11.9)	1002 (10.8)	1.23 (0.71-2.16)	0.45
JHS	140 (47.8)	3858 (41.7)	1.28 (0.80-2.06)	0.30
SHS	75 (25.6)	2382 (25.7)	1.11 (0.68-1.84)	0.67
Tertiary	23 (7.8)	1304 (14.1)	0.62 (0.34-1.14)	0.12
Occupation				
Trader	146 (49.8)	4218 (45.6)	1.62 (0.92-2.89)	0.09
Artisan	90 (30.7)	2595 (28.0)	1.63 (0.91-2.94)	0.10
Salaried worker (professional)	21 (7.2)	770 (8.3)	1.28 (0.64-2.58)	0.48
Salaried worker(non-professional)	15 (5.1)	642 (6.9)	1.10 (0.52-2.23)	0.80
Student	4 (1.4)	283 (3.1)	0.66 (0.22-2.06)	0.48
Housewife	4 (1.4)	134 (1.4)	1.10 (0.52-2.33)	0.56
Unemployed	13 (4.4)	611 (6.6)	1	
Religion				
Christian	267 (91.1)	8196 (88.6)	0.46 (0.06-3.48)	0.45
Muslim	25 (8.5)	1043 (11.3)	0.34 (0.04-2.65)	0.30
Other	1 (0.3)	14 (0.2)	1	
Ethnicity				
Akan	156 (53.2)	4170 (45.1)	1.87 (0.26-13.6)	0.58
Ga/Adangbe	53 (18.1)	2254 (24.4)	1.18 (0.16-8.67)	0.87
Ewe	40 (13.7)	1238 (13.4)	1.62 (0.22-11.9)	0.64
Northerner	19 (6.5)	807 (8.7)	1.18 (0.15-8.97)	0.88
Hausa	12 (4.1)	327 (3.5)	1.84 (0.23-14.4)	0.56
Another Ghanaian tribe	12 (4.1)	407 (4.4)	1.47 (0.19-11.6)	0.71
Non-Ghanaian	1 (0.3)	50 (0.5)	1	

* cOR-crude odds ratio; JHS-Junior High School; SHS- Senior High School; C.I. -confidence Interval

6.73 + 0.29 age + 1.01 hypertension + 0.95 malaria + 1.76 abruption − 0.27 gestation. The multivariable logistic regression model demonstrated moderate discrimination, with an area under the ROC curve of 0.71 (95% CI: 0.67 – 0.75). The sensitivity for predicting stillbirths was 61.4%, while specificity was 74.6%, indicating that the model correctly identified most livebirths but only a moderate proportion of stillbirths. The positive predictive value was low (7.1%) due to the low prevalence of stillbirths, whereas the negative predictive value was high (98.4%), reflecting a strong ability to rule out stillbirths. Model diagnostics showed a mean deviance residual of −0.48 (SD 1.22), standardised Pearson residual of −0.41 (SD 1.49), and leverage values averaging 0.13 (SD 0.05), suggesting no extreme outliers or influential points (Table 5).

In this present study, the AUC of the logistic regression model was 0.71. This means it has a 71% probability of correctly distinguishing between a randomly selected stillbirth case and a live birth case; thus, it can better identify women at higher risk for stillbirth than guessing. It may also be helpful for screening purposes when combined with clinical judgment or other tools, but it may not be sufficient when used alone to make strong clinical decisions.

Table 2. Association between stillbirth and mothers' obstetric and medical history

Variables	Still births	cOR (95% C.I)	p-value
Parity	1 (0-3)		0.00
Parity group			
Nulliparous	77 (26.3)	0.78 (0.60-1.01)	0.06
Multiparous	216 (73.7)	1	
Prev. Abortion			
Yes	123 (42.0)	1.25 (0.99-1.58)	0.07
No	170 (58.0)	1	
BMI at booking	27.1 (23.8-31.1)		0.89
ANC attendance	5 (4.0 – 7.0)		<0.00
Diabetes			
Yes	3 (1.0)	1.32 (0.41-4.21)	0.50
No	290 (99.0)	1	
Essential hypertension			
Yes	48 (16.4)	1.73 (1.26-2.37)	0.00
No	245 (83.6)	1	
Abruptio placenta			
Yes	22 (7.5)	9.80 (6.00-16.00)	<0.00
No	271 (92.5)	1	
Placenta praevia			
Yes	1 (0.3)	0.61 (0.08-4.40)	1.00
No	292 (99.7)	1	
Sickle cell disease			
Yes	8 (2.7)	1.76 (0.86-3.63)	0.14
No	285 (97.3)	1	
PROM			
Yes	9 (3.1)	0.94 (0.48-1.84)	1.00
No	284 (96.9)	1	
Malaria in pregnancy			
Yes	6 (2.0)	2.82 (1.22-6.56)	0.02
No	287 (98.0)	1	
Gestational age at delivery	37 (33-39)		<0.00
Multiple pregnancy (twins, etc.)			
Yes	5 (1.7)	0.46 (0.19-1.13)	0.10
No	288 (98.3)	1	

* cOR-crude odds ratio; BMI, body mass index; ANC, antenatal care

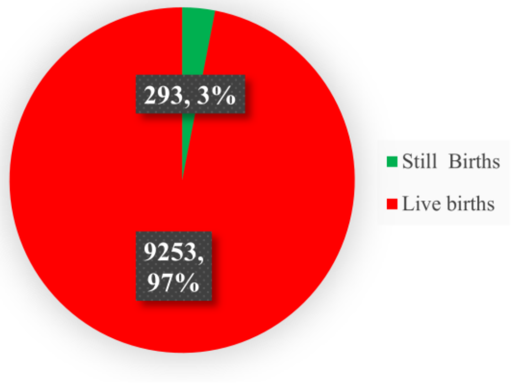

Figure 2: Distribution of stillbirths and live births

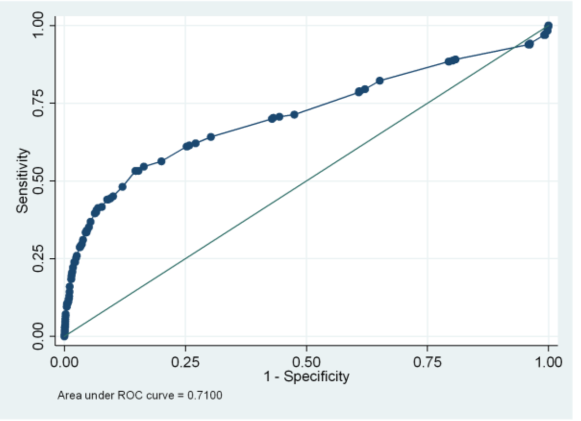

Figure 3. ROC plot of the model

Table 3. Tolerance and VIF

Model	Tolerance	VIF
Age	0.654	1.528
Eclampsia	0.965	1.036
Abruption	0.992	1.009
Malaria	0.999	1.001
Gestational Age	0.918	1.089

Table 4. Multivariate logistic regression analyses between stillbirth and associated factors

Variable	Category	Odds Ratio (OR)	95% CI	p-value
Age group	≥ 35 years	1.34	1.02 – 1.77	0.035
Hypertension	Yes	1.11	0.79 – 1.55	0.551
Abruptio placentae	Yes	5.83	3.41 – 9.97	<0.001
Malaria	Yes	2.59	1.08 – 6.24	0.034
Gestational age at delivery		0.76	0.73 – 0.79	<0.001

Table 5. Logistic Regression Model Performance and Calibration

Domain	Metric	Formula / Description	Value / (95% CI)
Classification performance	Sensitivity	TP / (TP + FN)	61.4%
	Specificity	TN / (TN + FP)	74.6%
	Positive Predictive Value (PPV)	TP / (TP + FP)	7.1%
	Negative Predictive Value (NPV)	TN / (TN + FN)	98.4%
Model diagnostics	Deviance residuals	Mean (SD); Min–Max	−0.48 (1.22); −2.49 to 5.24
	Standardised Pearson residuals	Mean (SD); Min–Max	−0.41 (1.49); −2.54 to 17.89
	Leverage (hat values)	Mean (SD); Min–Max	0.13 (0.05); 0.0002 to 0.18
Calibration	Calibration slope	Regression of observed on predicted logit	1.00
	Calibration intercept	Regression intercept	-2.38×10^{-7}
	Brier score	Mean squared error of probabilities	0.028
Discrimination	Area under ROC curve (AUC)	Asymptotic normal estimate	0.710 (95% CI: 0.673–0.747)

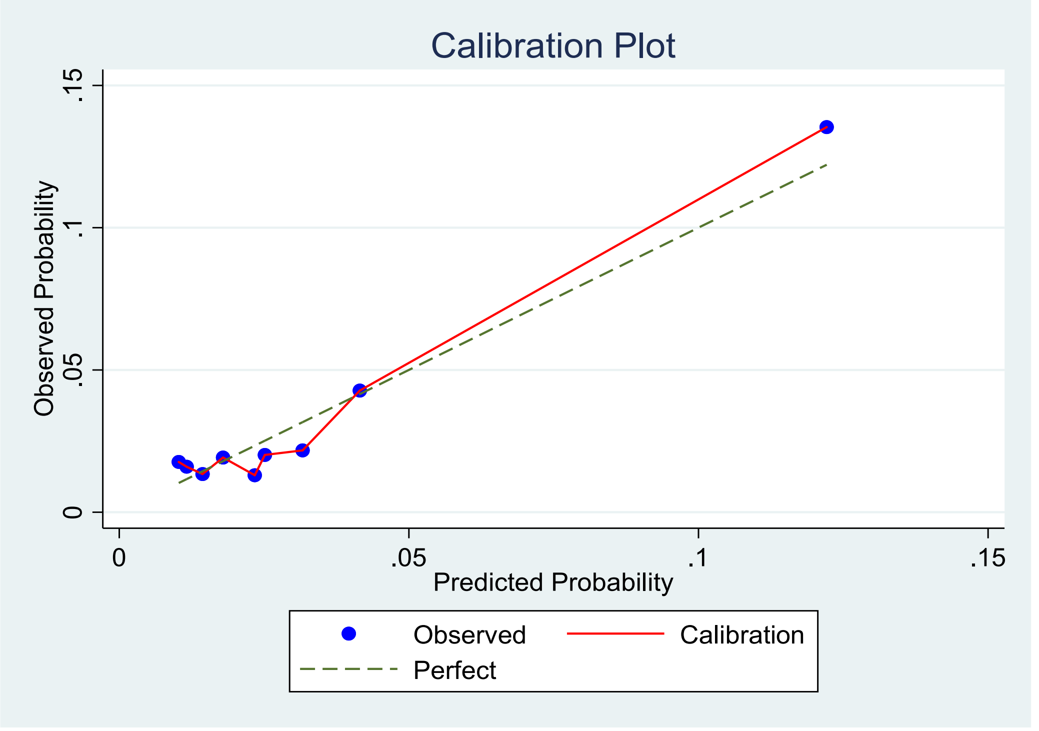

Figure 4. Plot of ROC for determining model performance

DISCUSSION

This study identified risk factors associated with stillbirth among women using a predictive model; the mean age of the women with stillbirths was 30.2. Maternal age, malaria in pregnancy and placental abruption were significant risk factors associated with stillbirth. Pregnant women with eclampsia had no significant association with stillbirth. The stillbirth rate identified in the current study (30.6 per 1000 deliveries) was higher than that reported in a previous Ghanaian survey (14–22 per 1000 births) [13] and that of another study in the Volta region of Ghana [14]. Similarly, it was also greater than those reported in advanced countries, where the rates are generally below 10 per 1000 births [15].

The difference in findings could be that the other study was conducted in a different region and used district-level health facility data. In contrast, the current study uses data from a tertiary referral hospital that receives patients of all kinds. The higher stillbirth rate found in this study could be a result of ineffective implementation of maternal health initiatives in the Greater Accra region. The reason for our higher stillbirth rate compared with advanced countries could be that antenatal care in these countries is much improved compared to that in Ghana [1-3]. It could also be due to differences in reported stillbirth rates. This emphasises the need to standardise the definition of stillbirth globally to facilitate comparability among countries and ensure uniformity. The current study identified a significant association between stillbirth and risk factors such as maternal age. Consistent with the current results, another study conducted among a multiethnic English population found that maternal age is a significant risk factor for stillbirth. In an Ethiopian study, maternal age was identified as a significant risk factor of stillbirth in addition to other factors such as maternal education, maternal occupation, maternal anaemia, and maternal hypertension [4]. We suggest that women's prior childbirth experiences may partly explain the current findings. For example, an earlier study in Mexico found that as mothers gain more experience with childbirth, they tend to rely more on their own experiences than on the instructions of health workers [16]. Our results support the significance of maternal age as a significant risk factor for stillbirth, thus reaffirming the need for targeted prenatal care and intervention strategies.In this study, women who had malaria during pregnancy had significantly higher odds of having stillbirths compared to those who did not, similar to findings from studies conducted in Ghana [17] and Mozambique [18]. Malaria is endemic in Ghana, and it is likely to remain a significant risk factor for stillbirth. Therefore, strategies that protect susceptible populations, such as pregnant women and children under five, including vector control measures, the use of highly effective treatments, and targeted prophylaxis, including Intermittent Preventive Treatments, should be intensified as Ghana seeks to eliminate malaria.

In our findings, placenta abruptio was associated with stillbirth. This is consistent with a report from the United States [19], Israel [20] and another study from Japan, which reported that placental abruption that occurs at an average of 34 weeks of gestation could result in stillbirth [21]. The same study states that the prevention of placenta abruption as a cause of stillbirth is easier compared with other causes. To prevent stillbirth caused by placental abruptio, we propose that prevention and adequate or careful management of risk factors such as hypertensive disease in pregnancy should be re-emphasised. From previous studies, women with pre-eclampsia and eclampsia showed a positive association with stillbirth [22-24]. However, we did not find a significant relationship in our analysis. Nevertheless, intensification of strategies to improve the management of eclampsia may have a positive impact on the number of stillbirths in the healthcare setting. These strategies may include strengthening antenatal and emergency care services for women who develop hypertensive disorders of pregnancy. The predictive model developed in this study, with a moderate predictive accuracy (AUC = 0.71), can serve as a valuable tool for early identification of high-risk pregnancies. This model's utility, however, should be further explored through prospective studies and its integration into clinical practice. The model's relative success in identifying key risk factors for stillbirth suggests that, with further refinement, it could significantly contribute to reducing stillbirth rates through early intervention.

The model for predicting stillbirth had an area under the ROC curve of 71% and a sensitivity of 61%. A previous retrospective cohort study reported a clinical cutoff point based on age, multiparous status, BMI, and pre-gestational diabetes (AUC 0.64, 95% CI 0.58 – 0.70). In this study, stratification by gestational age beyond 32 weeks did not significantly affect model discrimination or individual stillbirth risk prediction. In a previous study, there was no significant difference in the predictive accuracy of the models to predict stillbirth beyond 32, 34 or 36 weeks, respectively [6].

Another study was conducted to develop a model for predicting stillbirth based on a combination of maternal characteristics and medical history, along with first-trimester biochemical and biophysical markers and reported that significant predictors of stillbirth included maternal factors. We suggest that women's prior childbirth experiences may partly explain the current findings (Pregnancy-Associated Plasma Protein A (PAPP-A), Uterine Artery Pulsatility Index (UtA-PI), and Ductus Venosus Pulsatility Index (DV-PIV). Regarding combined screening using maternal factors, PAPP-A, DV-PIV, and UtA-PI detected 50% of all stillbirths due to impaired placentation at a 10% False Positive Rate (FPR) (AUC of 0.81 (95% CI, 0.77 – 0.85)). The addition of serum Placental Growth Factor (PlGF), which resulted in the contribution of serum PAPP-A, improved the Detection Rate (DR) to 61% (AUC of 0.852 (95% CI, 0.816 – 0.888)). These findings suggest that first-trimester biochemical and biophysical markers can potentially predict more than half of subsequent stillbirths that occur due to impaired placentation and unexplained causes [12].

Further, a study conducted in Western Australia used machine learning techniques to predict stillbirth risk in a large cohort of births. In this cohort, 66% of stillbirths were observed in multiparous women. The best performing classifier (XGBoost) predicted 45% (95% CI: 43%, 46%) of stillbirths for all women and 45% (95% CI: 43%, 47%) of stillbirths after the inclusion of previous pregnancy history. The study found that the significant risk factors of stillbirth were maternal age, parity, smoking during pregnancy, pre-existing diabetes, pre-existing hypertension, and previous stillbirth [6]. In another predictive study that aimed to provide a prediction model for stillbirth in a low-resource setting, the following significant risk factors of stillbirth were found: maternal comorbidity, place of residence, maternal occupation, parity, bleeding in pregnancy and fetal presentation. The study's findings suggest that a prediction model based on maternal and fetal factors can be used to identify high-risk pregnancies in low-resource settings. A critical analysis of our findings, compared with global data, reveals that interventions targeting the identified risk factors could significantly impact stillbirth rates. The consistent identification of risk factors across studies underscores their potential as targets for global health initiatives to reduce stillbirths.

Interpretation

The model demonstrates moderate discrimination (AUC = 0.71) and excellent calibration, indicating it can reasonably predict stillbirth risk in this dataset. However, its performance has only been evaluated internally. We do not recommend deployment in clinical care without external validation. Future work should include prospective validation in independent cohorts and evaluation of clinical impact. Given malaria's seasonal variation and its association with stillbirth, we propose including the month or season of delivery as a predictor in future models to account for temporal patterns. This could enhance predictive accuracy and provide insight into season-specific risk interventions. The model treated stillbirth as a single outcome, combining both macerated and fresh stillbirths, with livebirths as the reference. This approach captures the full spectrum of fetal loss, allowing risk factors to be interpreted as increasing the probability of any stillbirth, regardless of type.

Significance of the study and future research

This study's contributions to the existing body of knowledge highlight the importance of localised research in understanding the multifaceted nature of stillbirth. The findings provide a basis for developing context-specific health policies and intervention strategies to reduce stillbirth rates. In addition, the predictive model used in the current study demonstrated moderate efficacy in identifying pregnancies at high risk of stillbirth. This underscores the critical role of targeted screening and monitoring during pregnancy and emphasises the utility of clinical prediction models to identify high-risk pregnancies. Also, by focusing on modifiable risk factors such as malaria and gestational health issues, healthcare providers can implement specific interventions aimed at mitigating the risk of stillbirth. Our findings also advocate for the adoption of evidence-based strategies in prenatal care, aiming to reduce the burden of stillbirths through early identification and management of high-risk pregnancies. Future research should explore integrating predictive models into routine prenatal care, evaluating their real-world applicability and impact on pregnancy outcomes. Validating the predictive model across multiple hospitals and incorporating additional variables, such as biochemical and ultrasound markers, could enhance its predictive accuracy.

This study has several limitations. First, a substantial amount of missing data was excluded, which may have introduced bias and potentially affected the results. Second, the findings relied on facility-based data and therefore excluded stillbirths occurring outside healthcare settings, such as in homes or smaller clinics. As a result, the findings may not fully represent stillbirths in the broader population, limiting their generalizability to the entire Ghanaian population; thus, the conclusions should be interpreted with caution. Additionally, the retrospective nature of the study and the potential presence of unmeasured confounders highlight the need for further research to develop more robust predictive models and to investigate additional risk factors. Seasonal variations in risk factors for stillbirth were not assessed due to the absence of relevant data in the records. Furthermore, stillbirths could not be classified as antepartum or intrapartum because this information was unavailable, preventing the development of a prediction model specifically for antepartum stillbirths. Finally, information on the exact timing of onset for the risk factors used as predictors in the models was limited and therefore not included in the analysis.

Conclusion

Malaria, maternal age, gestation period, and placental abruption are significant risk factors of stillbirth, thereby informing the development of a predictive model that incorporates these variables. This finding is essential for improving health outcomes and better managing patients who present with these characteristics.

DECLARATIONS

Ethical consideration

Ethical approval for this study was obtained from the Ethical and Protocol Review Committee of Korle Bu Teaching Hospital, Accra, Ghana (KBTH-ADM/0004/2023). Institutional approval was also granted by the Kwame Nkrumah University of Science and Technology (KNUST). All study procedures were conducted in accordance with relevant institutional and national ethical guidelines.

Consent to publish

All authors agreed on the content of the final paper.

Funding

None

Competing Interest

The authors declare no conflict of interest

Author contribution

MM conceptualised the study, performed the data analysis, and drafted the manuscript. EO contributed to the study design and data collection. SO assisted with data interpretation and critically reviewed the manuscript. CY contributed to the interpretation of the findings and reviewed the manuscript. All authors read and approved the final manuscript.

Acknowledgement

The authors acknowledge the support of the staff of the Biostatistics Unit and the Department of Obstetrics and Gynaecology, Korle Bu Teaching Hospital, Accra, Ghana. The authors also express their sincere gratitude to Mr Maxwell Okere for his valuable support during the study.

Availability of data

Data is available upon request to the corresponding author

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