

Modeling Teenage Births in the Central Gonja District of the Savannah Region of Ghana

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Abstract

Teenage birth is a pertinent public health and socio-economic subject in many developing countries, including Ghana. This paper offers a comprehensive statistical modeling of teenage births within the Central Gonja District of the Savannah Region. Using the mixed-methods design, the research integrates Geographic Information Systems, multilevel logistic regression, and time series analysis to identify spatial hotspots, sociodemographic determinants, and temporal trends in births among teenagers. Primary data were collected from 331 teenage girls aged between 10 and 19 years through a statistical consideration of representativeness and logical feasibility, reinforced by secondary data collected from health facilities from 2014-2024. Results showed that hotspots for teenage births were highly concentrated in the southwest and north-central parts of the district. Sociocultural determinants such as low educational attainment, rural residence, and early marriage were strongly associated with high teenage birth rates. Multilevel analysis showed that individual-level determinants of teenage birth results such as education level and marital status, and community-level determinants like mean level of education, prevalence of contraceptives, unemployment were significant, accounting for 21.5% variation at the community level. Seasonal patterns of adolescent births were revealed by time series analysis of births among adolescents characterized by a decline at the beginning and end of the year. The predictive model founded on socio-demographic variables, predicted a relatively stable birth rate over time. These findings propose the need for combined interventions that takes

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into account both individual behavior and broader structural factors. The study provided policy-relevant information to policymakers, healthcare providers, and Non-Governmental Organizations (NGOs) with an objective in reducing adolescent births and enhancement in reproductive health outcomes in rural Ghana.

Keywords: Adolescent Birth, Multilevel Modeling, GIS, SARIMA, Ghana, Public Health

MSC 2020 Classification: 62P25, 62J12, 62M10, 62M30, 91D20

1. Introduction

Teenage pregnancy is described by the World Health Organization (WHO) as pregnancy that arises in girls aged 10 – 19 years. Addressing this matter is very critical, as childbirth fundamentally depends on pregnancy. It is still a global public health issue with severe consequences for adolescents and their families as well as countries in general. Globally, about 16 million teenage girls give birth annually, and 95% of these occur in low- and middle-income nations (Ayele et al., 2018; Neal et al., 2012). Poverty remains a major influence, as economically disadvantaged girls are pushed into early marriages or sexual activities to support themselves or their families (Nyarko, 2019). Teen pregnancy is a continued thorn-in-the-flesh of national efforts to alleviate adolescent reproductive health in Ghana. It is associated with high maternal and neonatal complications, including obstetric fistula, increased preterm birth, and increased perinatal death rates. The Savannah Region and Central Gonja District are the areas most affected by socio-cultural perceptions, a lack of access to education and healthcare, and poverty. According to the 2022 Ghana Demographic and Health Survey conducted by the Ghana Statistical Service, 26% of adolescent girls from 15 to 19 years in the Savannah Region became pregnant in 2022 compared to just 6% in the Greater Accra Region.

Regardless of national intervention and policy, such as the Adolescent Health and Development Program and child marriage campaigns, teen pregnancy has remained exceedingly high in rural Ghana (Mohammed, 2023). While studies in the past have tried to investigate the determinants of adolescent childbirth at individual levels, little attention has been given to spatial disparities, community-level influences, and temporal patterns at the district levels. This study tries to fill these knowledge gaps through the application of advanced statistical techniques in estimating teen births in the Central Gonja District. The study explicitly looks into the spatial clustering of cases, examines individual and community-level socio-demographic factors, and uses time series analysis to examine trends and forecast future births.

2. Literature Review

Previous studies show that adolescent birth remains a major global and national public health issue, shaped by biological, social, cultural, and economic factors. Evidence across the globe from WHO (2023) reveals wide regional variations, with Sub-Saharan Africa always recording high adolescent birth rates while the Western Europe record much lower rates due to strong sexual education systems and high access to contraception (Langille, 2007). Also, in a comparative analysis from over 90 countries, highlighted that countries with comprehensive reproductive health programs show lower teen birth rates (Neal et al., 2012). While socioeconomic improvements and reduced income inequality have been shown to correlate with falling adolescent birth rates globally (Santelli et al., 2017), teenage births are also linked with negative maternal and neonatal outcomes, including preterm birth and low birth weight (Chen et al., 2007)

In Ghana, it is revealed that teenage pregnancy is disproportionately high in marginalized and rural communities due to barriers such as poverty, cultural norms, financial motivations, weak

sexual education, and limited access to education and reproductive health information (Krugue et al., 2017; Guéye et al., 2020; Ojukwu et al., 2024), while national survey analyses report the prevalence rate of about 15% with significantly higher rates in rural areas and northern regions (Mohammed, 2023).

Methodologically, past studies use a range of statistical approaches such as multilevel logistic regression to account for the hierarchical nature of adolescent reproductive behavior within communities (Senkyire, 2017; Kefale et al., 2020; Tebeje et al., 2024). Spatial regression models have also exposed significant clustering of teenage pregnancy in specific areas with extreme poverty and cultural norms (Bolarinwa et al., 2022; Tebeje et al., 2024; Assimamaw et al., 2024). Trend analysis incorporating decomposition techniques further demonstrate that changes in adolescent pregnancy over time are largely driven by shifts in sociodemographic structure such as education and marital status (Gebeyehu et al., 2023). Time series analysis, specifically Auto Regressive Integrated Moving Average (ARIMA) and Seasonal Autoregressive Integrated Moving Average (SARIMA) models, have proven useful in forecasting teenage birth trends and observing seasonal patterns (Fagbamigbe et al., 2019; Asmamaw et al., 2023).

In general, literature has demonstrated that teenage pregnancy is a complicated issue shaped by socioeconomic, demographic, cultural, and structural factors. The combination of models has been widely recommended for analyzing such complex phenomena, especially in rural areas like Central Gonja, where both community-level and temporal dynamics strongly influence teenage birth patterns.

3. Methods

The study used a mixed-method study incorporating descriptive, analytical, and longitudinal approaches. Primary and secondary data sources were collected. Primary data were obtained

from 331 adolescent girls aged between 10 – 19 years through structured questionnaires conducted in six selected communities in the Central Gonja District.

The sample size was calculated using the formula for estimating proportions (Cochran, 1977), ensuring statistical consistency and representativeness:

$$n = \frac{Z^2 p(1 - p)}{e^2}$$

where

Z: Z-value matching with the chosen confidence level (1.96 for 95%).

p: probability of teenage births in the district (26%) – Ghana Statistical Service (GSS), 2022.

e: margin of error (5%).

n: required sample size.

Therefore

$$n = \frac{1.96^2 \times 0.26(1 - 0.26)}{0.05^2} = 296$$

For convenience and to ensure adequate representation across all selected communities, the sample size was rounded up to 331 respondents using a 10% rate for the adjustment.

$$n_{adj} = \frac{296}{1 - 0.10} \approx 331$$

Sample size = 331 participants.

The communities were selected to represent both rural and urban settings using purposive sampling technique. Secondary data were gathered from the District Health Directorate on the accumulated monthly counts of teenage births from 2014 to 2024 and used for the trend analysis.

It is important to note that the secondary data covered COVID 19 years (2020-2021), which had a lot of pressure on the health facilities and their operations but the disruption was insignificant.

The region did not experience lockdown during this period and hence birth records were not significantly affected.

Spatial patterns of births among adolescents were analyzed using Geographic Information Systems (GIS) to identify hotspots in communities with health facilities.

3.1. Multilevel Logistic Regression

A two-level multilevel logistic regression model was adopted to measure the likelihood of a teenage girl i in community j who has experienced childbirth. The model is specified as follows:

$$\text{logit}(P_{ij}) = \beta_0 + \beta_1 X_{ij} + \beta_2 Z_j + u_j + \varepsilon_j$$

Where P_{ij} is probability of a teenage birth for individual i in community j . β_0 is the intercept (i.e. the effect on the likelihood of being pregnant as a teen under no control of predictors), β 's are the fixed coefficients, X_{ij} is the individual-level predictors, Z_j is the community-level predictors, u_j is the random effect (impact of the community on an adolescent to get pregnant) for community j and ε_{ij} is the random errors at the individual levels. u_j captures unobserved community influences. It does not receive a regression coefficient because it is modeled as a random deviation and not a fixed predictor.

The two-level modeling incorporating individual determinants (e.g., education, age, marital status) and community-level determinants (e.g., unemployment, mean education, contraceptive use) were used in the model because the data were clustered by community and more importantly accounts for within-cluster correlation.

3.2. Trend Analysis

Time series analysis using Seasonal Autoregressive Integrated Moving Average (SARIMA) models was conducted on teen birth monthly data from 2014 to 2024 to determine trends and seasonality.

Seasonal Autoregressive Integrated Moving Average (SARIMA) model is an extension of the Autoregressive Integrated Moving Average (ARIMA) model that incorporates both non-seasonal and seasonal components to analyze and forecast time-series data exhibiting repeated seasonal patterns (Box et al., 2008).

Time series analysis using SARIMA models was employed to identify trends and seasonal patterns in teenage birth rates on monthly data from 2014 to 2024 and forecast future rates.

Seasonal Autoregressive Integrated Moving Average (SARIMA):

$$Y_t = \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \dots + \theta_1 \epsilon_{t-1} + \theta_2 \epsilon_{t-2} + \dots + \phi_1 Y_{t-s} + \phi_2 Y_{t-2s} + \dots + \theta_1 \epsilon_{t-s} + \theta_2 \epsilon_{t-2s} + \dots + \epsilon_t$$

Where Y_t is the value at time t , ϕ_i is autoregressive (AR) parameters, θ_j is moving average (MA) parameters, ϕ_k is seasonal autoregressive (SAR) parameters at lag $k s$, θ_l is the seasonal moving average (SMA) terms at lag $l s$, s is the seasonal period (12-month intervals), ϵ_t is the error term

All participants or guardians gave informed consent before inclusion.

4. Results

Teenage birth spatial clustering was revealed, which was non-random, with the greatest densities in the north-central and southwest parts of the district. The spatial hotspots were established using the top 25th percentile of the reported teenage births over ten years. The clustering that was observed indicates that teenage reproductive behavior may be influenced by local socio-cultural norms, access to education, and availability of contraceptive services as revealed in Figure 1.

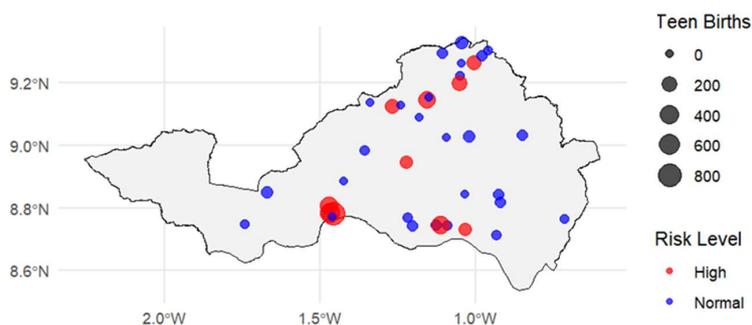


Figure 1: Spatial Distribution of Teenage Births in the Central Gonja District of Ghana

Descriptive statistics showed that a high proportion of teen mothers were from rural residences, had low educational levels, and were married at birth. Over 70% of the participants remained in rural locations, 78% had Junior High School education (Basic 7 to 9) or lower, 40% were married and 46% are unemployed as given in Table 1.

Table 1: Demographic Characteristics of Respondents

Variable	Category	N =331
Educational Level	No Formal Education	82 (25%)
	Primary	69 (21%)
	Junior High School	107 (32%)
	Senior High School	73 (22%)
Marital Status	Married	132 (40%)
	Unmarried	199 (60%)
Employment Status	Unemployed	153 (46%)
	Self-employed	79 (24%)
	Student	99 (30%)
Monthly Income	Above GHS1000	6 (1.8%)
	GHS500 – GHS1000	100 (30%)
	GHS200 – GHS500	145 (44%)
	Less than GHS200	80 (24%)
Religion		

	Christianity	56 (17%)
	Islam	275 (83%)
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Residential Type		
	Urban	99 (30%)
	Rural	232 (70%)
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R version 4.5.0 was used to generate the Multilevel logistic regression analysis results in Table 2. While the Crude Odd Ratio (COR) showed the influence each variable had on teenage births without controlling other factors, the Adjusted Odd Ratio (AOR) showed the independent influence of each variable on teen births. It is confirmed that lower education (AOR = 0.12, $p < 0.001$), marital status (AOR = 0.10; $p = 0.042$), and religion (Muslim; AOR = 3.89; $p = 0.008$) were significant and strongly predictive of teen birth. That is to say, teenage girls with senior high education are 88% less likely to experience teenage birth compared with their counterparts with no education. Also, married adolescents are far more likely to give birth and Muslim girls are approximately four times more likely to give birth as teenagers compared to their Christian counterparts. Lower community average education, higher unemployment, and lower use of contraceptives at the community level were also significantly associated with teen births (Table 2), with an intraclass correlation coefficient (ICC) of 21.5%, demonstrating the importance of the community context as shown in Table 3.

Variable	COR (95% CI)	<i>P</i> -value	AOR (95% CI)	<i>P</i> -value
Educational level				
No formal education	0.75(0.26, 2.12)	0.6	0.11 (0.02, 0.47)	0.012
Primary	0.72(0.24, 2.13)	0.5	1.06 (0.30, 3.83)	0.257
Senior High School	0.12(0.05, 0.26)	<0.001	0.12 (0.04, 0.35)	0.001

Age	1.18(0.96, 1.45)	0.11	1.12 (0.83, 1.48)	0.398
Marital Status				
Unmarried	0.10(0.03, 0.24)	<0.001	0.10 (0.02, 0.30)	0.042
Occupation				
Student	0.08(0.02, 0.20)	<0.001	0.05 (0.01, 0.19)	0.628
Unemployed	0.97(0.25, 3.17)	>0.9	0.89 (0.20, 3.32)	0.047
Religion				
Islam	3.25(1.65, 6.27)	<0.001	3.89(1.55, 10.03)	0.008
Contraceptive Use				
Yes	1.68(0.83, 3.68)	0.2	1.93 (0.75, 5.32)	0.064
Average Education	1.51×10^{13}		1.51×10^{13}	
Proportion of contraceptive use	1.29×10^{12}		1.29×10^{12}	
Proportion of Occupation	1.28×10^{12}		1.28×10^{12}	

Table 2: Individual-level and Community-level Determinants Related to Teenage Birth

COR – Crude Odd Ratio and AOR-Adjusted Odd Ratio

Table 3: Measure of Variation of Teenage Births by Multilevel Regression Analysis

Component	Estimate
Random Intercept Variance (Resident Type = rural/urban)	0.901
ICC	0.215

Time series using Autoregressive Integrated Moving Average, ARIMA (1,0,0) (0,0,1) [12] in its decomposed form exhibits clear seasonal cycles characterized by regular rises and falls over most years. These show that teenage births follow a seasonal pattern. The troughs often occur in the middle of the year or at the end of the year, while spikes appear around the early and late

months in every year for the time period under observation, emphasizing the seasonal effect possibly caused by the school cycles (dropouts during farming season) and cultural period such as Damba and fire festivals, influencing marriages. The residual (remainder) displays inexplicable fluctuations after removing trend and seasonality, which is mostly centered around 1 (or 0 after logarithmic transformation), with occasional spikes shown in Figure 2.

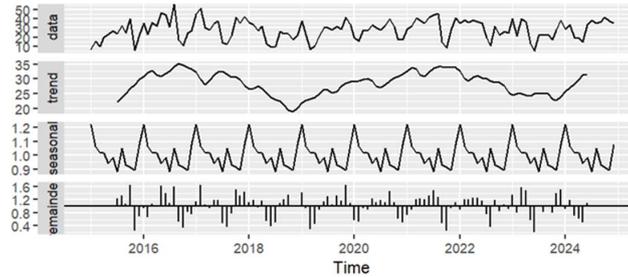


Figure 2: Decomposition of Times Series Plot of Teenage Births in the Central Gonja District.

The model run with R version 4.5.0, produced an AIC of 893.08, showing a fairly good balance between model complexity and goodness-of-fit. The log-likelihood value of -442.54 takes care of the overall adequacy of the model. The BIC of 904.23 also falls within an acceptable range (Table 4).

Table 4: Model Fit Statistics

Statistics	Value
σ^2 (Residual Variance)	95.27
Log Likelihood	-442.54
AIC	893.08
BIC	904.23

AIC-Akaike Information Criteria, BIC-Bayesian Information Criteria

The Root Mean Squared Error (RMSE) and the Mean Absolute Error (MAE) values are 9.64 and 7.57 respectively implies a good predictive accuracy (Table 5) as produce in R version 4.5.0.

Table 5: Residual Measures

Metric	Value
ME (Mean Error)	-0.0204
RMSE (Root Mean Square Error)	9.6376
MAE (Mean Absolute Error)	7.5732
MPE (Mean Percentage Error)	-22.05%
MAPE (Mean Absolute Percentage Error)	41.46%
MASE (Mean Absolute Scaled Error)	0.5602
ACF1 (Autocorrelation of Residuals at Lag 1)	0.0194

The teenage birth plot of Central Gonja District shows a stable trend with clear seasonal fluctuations over the years. The ARIMA (1,0,0) (0,0,1) [12] model captures repeating peaks and dips to suggest persistent seasonal patterns. A short-term projection suggests that teenage birth rates will be fairly level until 2026, without any sudden upward or downward curves. Such evidence is important in on-time and targeted adolescent reproductive health intervention planning as given in Figure 3

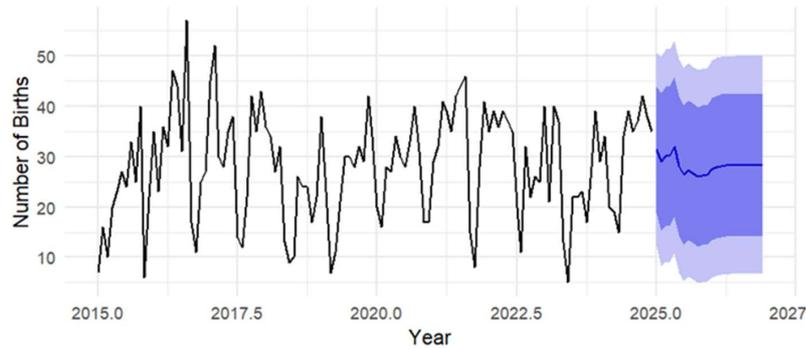


Figure 3: Forecast of Teenage Birth in the Savannah Region of Ghana

5. Discussion

This study confirms past studies on how education, marital status, and rural residence affect teen birth. Marital status and religion are found to have a strong effect consistent with findings from other sub-Saharan countries where cultural values support early marriage and childbearing (Dubik et al., 2022; Ayele et al., 2018). Defining community-level factors such as education level and unemployment in addition to others is consistent with the ecological perspective that adolescent reproductive activity is not only influenced by individual choice but also by structural contexts (Kefale et al., 2020; Tebeje et al., 2024; Birhanu et al., 2019; Wado et al., 2019).

The spatial heterogeneity depicted in GIS mapping highlights the value of geographically targeted interventions (Assimamaw et al., 2024). The geospatial insights established in this study provide a new evidence base for the district health management team to prioritize high-risk communities for targeted intervention. Hotspots can be identified as the target for reproductive health education, family planning, and youth program interventions. The identification of seasonality has practical implications because it underscores the need for time-sensitive programming where reproductive health interventions are scaled up in periods preceding

predicted peak times. This analysis supports the necessity of year-round, sustained efforts rather than one-time campaigns (Bolarinwa et al., 2022).

6. Conclusion

Teenage births in the Central Gonja District are shaped by both individual and community factors as well as temporal factors. Policymakers should consider integrated methods that address personal behavior and structural inequality requirements because the approach adopted in this research informs deeper insights into where teenage births are concentrated, why they happen and when they peak in the district. District-specific programs, aimed at mitigating this matter, with integration of spatial and temporal data should be a priority for policymakers. Some of which are recommended below:

1. Deployment of programs targeted at adolescent reproductive health to hotspot areas like Yapei, Buipe, Mpaha and Kusawgu.
2. The trend analyses should be used to guide the timing of interventions like community education, and contraceptive distribution in that precede peak months.
3. Community programs that promote girl-child education should be implemented or intensified. Also, scholarship for the vulnerable and livelihood programs should be introduced in hotspot areas
4. Strengthen the school re-entry policy for girl who get pregnant to return to school after delivery.
5. Traditional and religious leaders should be engaged in advocacy program to discourage early marriages.

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