DOI: 10.18502/jfrh.v19i3.20055

Original Article

Quality of Antenatal Care and Maternal Mortality in Madagascar: Analysis of Regional Disparities and Non-Linear Modeling

Hery Sylvestre Bemanana; M.D.[1,2], Andriatompoina Felanarivo Razafaindraibe; M.D.[2,3], Sambatra Rafamantanantsoa; M.D.[4]

1 Sylababa Association, Antananarivo, Madagascar
2 University of Toamasina, Toamasina, Madagascar
3 Department of Obstetrics and Gynecology, Analankininina University Hospital Centre, Toamasina, Madagascar
4 Department of Obstetrics-Gynecology, Tanambao University Hospital Centre, University of Toliara, Toliara, Madagascar

Received April 2024; Revised and accepted September 2025

Abstract

Objective: Maternal mortality remains a major public health challenge in Madagascar, with notable regional disparities. Antenatal care (ANC) plays a critical role in preventing maternal deaths, yet its coverage and quality vary significantly across regions. This study aims to assess the association between ANC quality and maternal mortality rate (MMR), focusing on regional disparities and exploring potential non-linear relationships.

Materials and methods: We conducted a retrospective ecological study using publicly available data from Madagascar's 22 regions. ANC indicators included blood pressure monitoring, blood and urine tests, iron supplementation, and antiparasitic treatment. Linear regression and Generalised Additive Models (GAM) were used to examine associations and non-linear patterns. Statistical analyses were performed using R version 4.2.2, with a significance threshold of 5%.

Results: Considerable disparities were observed in ANC coverage across regions. Linear models revealed no significant association between ANC indicators and MMR ($p > 0.05$). However, GAM identified significant non-linear relationships for blood pressure monitoring ($p < 0.0045$) and blood testing ($p < 0.0055$), suggesting potential threshold effects.

Conclusion: Addressing maternal mortality in Madagascar requires enhancing both access to and the quality of ANC. Accounting for regional disparities and non-linear trends is essential in developing effective public health interventions.

Keywords: Antenatal Care; Health Services Accessibility; Maternal Mortality; Madagascar; Public Health; Regression Analysis

Introduction

Maternal mortality is a critical public health issue, particularly in low-income countries (1, 2). According to recent World Health Organisation (WHO) figures, approximately 287,000 women died in 2020 from pregnancy or childbirth-related complications (2). This alarming figure underscores

Correspondence:
Dr. Hery Sylvestre Bemanana
Email: sylvestre.bemanana@outlook.com

the urgent need to improve access to quality antenatal care (ANC), which plays a key role in preventing most maternal deaths (3-5).

Sub-Saharan Africa, where around 95% of global maternal deaths occur, faces considerable challenges in strengthening its health systems (6). The region is marked by some of the highest maternal mortality rates in the world, largely driven by limited access to healthcare infrastructure, inadequate ANC services, and complex socioeconomic factors (7). These barriers often interact to create a cycle of vulnerability for pregnant women.

Madagascar is no exception, with an estimated maternal mortality rate of 408 deaths per 100,000 live births (8). The country struggles with significant disparities in access to healthcare, particularly in rural areas (9). ANC services, though essential, are often insufficient in terms of quality. In this context, quality ANC is defined as a set of recommended interventions delivered during antenatal visits, beyond routine obstetric evaluations. These include regular blood pressure monitoring, blood and urine testing, iron and folic acid supplementation, and the provision of antiparasitic medications.

These essential services contribute to the comprehensive care of pregnant women and are crucial for detecting and managing potential complications. As recent studies suggest, ANC not only provides clinical screening, but also offers key health education opportunities to empower women and support better pregnancy outcomes (3, 4).

This study investigates the relationship between the quality of ANC services and maternal mortality in Madagascar, with an emphasis on several key components of ANC. Each of these variables plays a crucial role in optimal pregnancy management and serves as a proxy indicator of ANC quality and its potential impact on maternal mortality.

Consequently, this research seeks to address the following question: to what extent do proxy indicators of ANC quality influence the maternal mortality ratio in Madagascar? This guiding question underpins our analysis and aims to explore how predictive modelling of maternal deaths based on ANC quality could help reduce risks for pregnant women.

Materials and methods

This study aims to investigate the relationship between the quality of antenatal care (ANC) and the maternal mortality rate (MMR) in Madagascar, using a multivariate approach that allows for a better understanding of the interactions between several variables.

Data Sources: This study draws on data from the Third General Population and Housing Census (RGPH-3, 2018) and the 2021 Demographic and Health Survey (DHS) conducted in Madagascar. To ensure cross-regional comparability, variable harmonisation was carried out, integrating the skilled birth attendance rate from the DHS with maternal mortality estimates from the RGPH-3. The World Health Organisation (WHO) standards were adopted for alignment.

The maternal mortality ratio (MMR) was defined as the number of maternal deaths per 100,000 live births within a specific reference period, following WHO guidelines. Corrections and temporal adjustments were applied to standardise this indicator across sources. Similarly, skilled birth attendance was defined as deliveries attended by qualified health personnel within a health facility.

The analysis was carried out at the level of the 22 administrative regions, which provided a solid basis for assessing the association between skilled birth attendance and MMR.

Population and sampling: The sampling design for 2021 DHS was based on a stratified, two-stage cluster approach. In the first stage, RGPH-3 enumeration areas served as primary sampling units and were selected with a proportional probability proportional to size. Subsequently, households were systematically selected within each group, with an average of 34 households per group. A total of 657 clusters were surveyed, covering 20,510 households in all regions.

All women aged 15 to 49 years living in these households were interviewed using a structured individual questionnaire. Data on antenatal care (ANC) were collected from women who had a live birth within the five years preceding the survey. Sampling weights were applied to ensure representativeness at the regional level, and standard errors were calculated for each indicator using 95% confidence intervals.

The data was then structured to include (i) the proportion of women who received key antenatal interventions and (ii) the regional maternal mortality ratio, expressed per 100,000 live births. This structure ensured appropriate geographic coverage and external validity of the findings. Table 1 presents descriptive characteristics by region.

Variables studied: The main dependent variable is the maternal mortality ratio (MMR), which represents the number of maternal deaths occurring during pregnancy or within 42 days after delivery.

Table 1: Coverage of Prenatal Consultations and Maternal Mortality Rate in Madagascar in 2021(Source: INSTAT (2021). EDS. RGPH-3)

Region	Percentage of women who had a live birth in the last 5 years and took the following during their most recent pregnancy		N*	Percentage of women who received prenatal care for their most recent live birth in the last 5 years and underwent certain examinations			N**	MMR
	Iron in the form of tablets or syrup % (95% CI)	Medication for intestinal parasites % (95% CI)		Blood pressure measurement % (95% CI)	Urine sample collection % (95% CI)	Blood sample collection % (95% CI)		
Analamanga	84.2 (81.8 - 86.4)	70.6 (67.4 - 73.7)	1 190	97.1 (95.9 - 98.0)	59.0 (55.3 - 62.7)	76.2 (73.2 - 78.9)	1 163	215
Alaotra Mangoro	70.5 (64.6 - 75.6)	67.7 (61.7 - 73.2)	397	88.3 (84.1 - 91.6)	27.7 (19.4 - 38.2)	47.2 (39.1 - 54.9)	347	366
Amoron i Mania	72.7 (66.2 - 78.8)	72.2 (65.4 - 78.1)	283	80.2 (73.9 - 85.2)	16.8 (6.8 - 30.7)	43.8 (34.4 - 53.4)	256	439
Analanjirofo	90.4 (87.1 - 92.9)	78.3 (73.9 - 82.5)	479	89.6 (86.1 - 92.3)	56.7 (50.2 - 62.7)	60.6 (54.4 - 66.4)	447	336
Androy	62.1 (55.7 - 68.2)	37.6 (29.6 - 45.6)	400	76.0 (70.4 - 81.2)	29.9 (21.2 - 39.9)	47.9 (40.2 - 56.2)	335	243
Anosy	63.0 (56.0 - 69.6)	53.8 (46.3 - 61.4)	330	81.1 (75.2 - 86.2)	22.4 (12.7 - 35.8)	29.0 (18.5 - 40.1)	255	566
Atsimo Andrefana	70.8 (66.9 - 74.6)	40.9 (35.5 - 46.4)	790	61.2 (56.2 - 66.0)	20.3 (14.0 - 28.6)	41.1 (35.3 - 47.5)	643	642
Atsimo Atsinanana	66.8 (60.2 - 73.0)	66.9 (60.2 - 72.9)	334	83.3 (77.8 - 87.9)	10.5 (2.2 - 27.4)	31.5 (21.8 - 42.1)	272	503
Atsinanana	81.3 (77.1 - 85.0)	71.3 (66.3 - 75.9)	493	78.9 (74.0 - 82.9)	31.8 (24.4 - 40.6)	48.9 (42.1 - 56.0)	430	471
Betsiboka	64.0 (53.3 - 73.5)	53.1 (40.9 - 64.0)	147	80.6 (71.7 - 88.0)	31.7 (17.0 - 47.6)	42.0 (28.7 - 56.8)	123	405
Boeny	81.6 (76.4 - 86.3)	72.9 (66.6 - 78.6)	309	87.5 (82.6 - 91.3)	52.8 (44.3 - 60.9)	62.0 (54.4 - 69.3)	281	290
Bongolava	53.3 (44.9 - 62.0)	52.7 (44.2 - 61.4)	262	83.9 (78.2 - 88.7)	24.1 (13.6 - 36.6)	39.0 (28.8 - 49.0)	246	249
Diana	87.6 (82.9 - 91.4)	74.6 (68.3 - 80.3)	285	96.1 (93.1 - 98.1)	71.4 (64.8 - 77.9)	77.6 (71.5 - 83.2)	272	229
Haute Matsiatra	77.1 (72.7 - 81.3)	82.0 (77.9 - 85.6)	501	86.1 (82.3 - 89.2)	16.8 (9.8 - 27.2)	45.4 (38.7 - 52.3)	481	578
Ihorombe	60.3 (50.3 - 69.5)	45.6 (34.1 - 56.5)	179	71.7 (61.4 - 80.1)	13.8 (3.4 - 39.6)	32.7 (20.0 - 48.9)	137	626
Itasy	75.2 (69.0 - 81.0)	61.7 (54.3 - 69.1)	286	87.2 (82.5 - 91.2)	29.5 (19.5 - 39.9)	54.2 (45.7 - 62.1)	280	159
Melaky	68.5 (55.9 - 79.8)	55.1 (41.3 - 69.5)	94	92.2 (82.7 - 96.9)	38.8 (22.7 - 59.4)	54.7 (39.9 - 70.8)	78	791
Menabe	58.6 (50.9 - 66.0)	46.0 (37.4 - 54.7)	297	69.2 (60.8 - 76.4)	30.1 (19.2 - 43.0)	36.4 (26.1 - 48.7)	209	797
Sava	79.4 (74.8 - 83.4)	68.1 (62.7 - 73.3)	457	88.8 (85.0 - 92.0)	41.1 (33.8 - 49.1)	42.2 (35.0 - 50.0)	419	308
Sofia	76.1 (72.0 - 79.9)	60.3 (55.2 - 65.4)	616	88.4 (85.3 - 91.1)	37.2 (30.4 - 43.9)	46.8 (40.8 - 53.2)	559	339
Vakinankaratra	69.5 (65.1 - 73.8)	64.3 (59.5 - 68.9)	653	82.8 (79.2 - 85.9)	30.7 (24.2 - 37.6)	37.3 (31.2 - 43.9)	630	200
Vatovavy Fitovinany	74.4 (69.4 - 79.0)	80.1 (75.6 - 84.1)	452	71.9 (66.3 - 76.8)	16.9 (9.2 - 28.0)	21.1 (13.5 - 31.6)	415	928

*Number of women who had a live birth in the last 5 years, **Number of women who received prenatal care for the most recent live birth
MMR: Maternal Mortality Ratio

Independent variables relate to key ANC components, namely: (i) Regular blood pressure monitoring (Blood_Pressure) – essential for the detection and managing hypertensive disorders such as pre-eclampsia; (ii) Systematic blood testing (Blood) - allowing the early detection and management of infections or conditions such as anaemia; (iii) Urine testing (Urine) – facilitating the detection and treatment of proteinuria and urinary tract infections; (iv) Iron and folic acid supplementation (Iron) – contributing to the incidence among pregnant women; (v) Administration of antiparasitic medication (Meben) - aimed at minimising maternal health risks associated with parasitic infections.

Statistical analysis: Statistical analyses were performed using R software (version 4.4.2). Several approaches were used to model the relationship between ANC quality and maternal mortality ratio, including multivariate regression techniques to assess the strength and direction of the associations.

Multiple linear regression model: A multiple linear regression model, implemented via the lm package in R, was first used to simultaneously assess the combined impact of the components of antenatal care (ANC) on the maternal mortality rate (MMR), while controlling for potential confounders. The final model is specified as:

$$MMR=\beta0+\beta1(BP)+\beta2(Blood)+\beta3(Urine)+\beta4(Iron)+\beta5(Antiparasitic)+\varepsilon$$

where β0 denotes the intercept, βi are the estimated coefficients for the explanatory variables and ε is the random error term. For each independent variable, a correlation coefficient, a 95% confidence interval (CI) and p-value were calculated. The validity was assessed by verifying standard assumptions of linear regression: normality of the residuals, homoscedasticity, and absence of multicollinearity.

Generalised additive model

To explore potential non-linear relationships, we subsequently fitted a generalised additive model (GAM) using the mgcv package in R. This approach allows for each predictor to be modelled via a smooth, nonparametric function, offering greater flexibility in capturing complex dynamics. The GAM is expressed as

$$MMR=f1(BP)+f2(Blood)+f3(Urine)+f4(Iron)+f5(Antiparasitic)+\varepsilon$$

where fi are smooth functions estimated for each explanatory variable. Graphical outputs were generated to illustrate non-linear effects and to enhance interpretability.

All analyses were performed using R software (version 4.4.2). A statistical significance threshold of $p < 0.05$ was adopted throughout, balancing the risks of Type I and Type II errors and ensuring robust and reproducible inferences.

Ethical Considerations: This study relied exclusively on publicly available secondary data and did not require formal ethical approval. However, rigorous ethical principles were upheld, including scientific integrity, data confidentiality, and anonymity. Data were processed in a manner that excludes the identification of individual respondents. All findings are objectively presented and no data manipulation was carried out. Proper attribution has been ensured for all utilised data sources.

Results

Substantial regional disparities were observed in both iron supplementation and antiparasitic drug administration. Iron coverage ranged from 53.3% (95% CI: 44.9–62.0) in Bongolava to 90.4% (95% CI: 87.1–92.9) in Analanjirofo. For antiparasitic drugs, coverage ranged from 37.6% (95% CI: 29.6–45.6) in Androy to 82.0% (95% CI: 77.9-85.6) in Haute Matsiatra. Maternal mortality also showed substantial variation, from 249 deaths per 100,000 live births in Bongolava to 336 in Analanjirofo, and from 243 in the Androy to 578 in Haute Matsiatra.

Other antenatal care (ANC) indicators showed similar heterogeneity. The coverage of blood pressure measurement ranged from 61.2% (95% CI 56.2–66.0) in Atsimo-Andrefana to 97.1% (95% CI 95.9-98.0) in Analamanga. Urine testing was performed in 10.5% (95% CI 2.2-27.4) of cases in Atsimo-Atsinanana, compared to 71.4% (95% CI 64.8–77.9) in Diana. Blood samples were collected in 21.1% (95% CI: 13.5–31.6) of cases in Vatovavy Fitovinany and 77.6% (95% CI: 71.5–83.2) in Diana. Maternal mortality ratios (MMR) ranged from 642 in Atsimo-Andrefana to 215 in Analamanga and 503, 229, and 928 in Atsimo-Atsinanana, Diana, and Vatovavy Fitovinany, respectively.

Figure 1 highlights the substantial regional disparities in the coverage of quality ANC in Madagascar. Table 2 presents the results of the linear regression models.

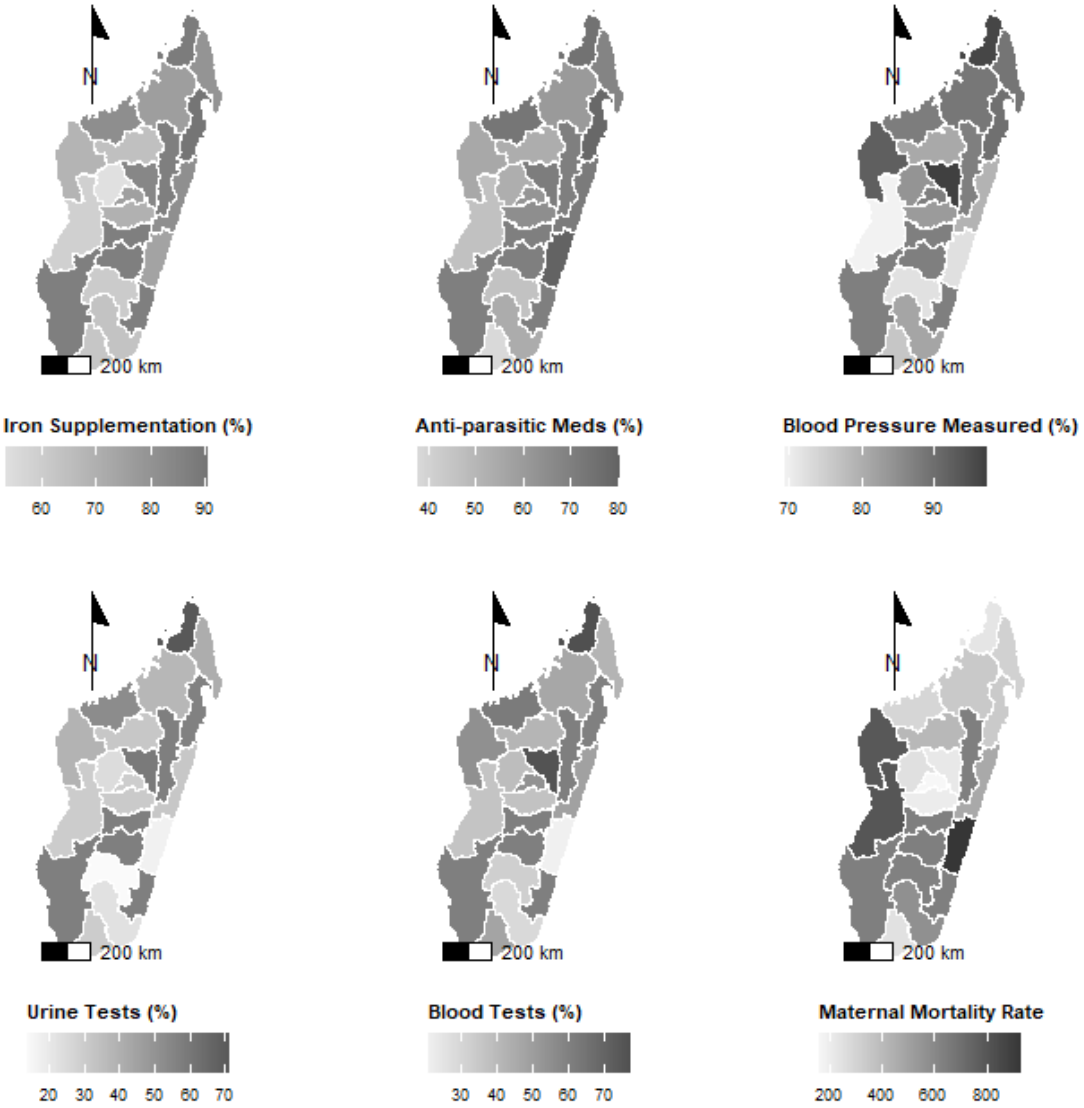

Figure 1: Regional disparity in quality antenatal care in Madagascar

Initial multiple linear regression yielded an R-squared value of 0.41 and an adjusted R-squared of 0.22. None of the explanatory variables demonstrated statistically significant associations with MMR ($p > 0.05$). The analysis of the variance inflation factor (VIF) indicated substantial multicollinearity. The exclusion of the variable *mebendazole* slightly improved the fit of the model ($R^2 = 0.39$; adjusted $R^2 = 0.24$), but no predictor achieved statistical significance. Model comparison did not reveal a significant improvement (residual SS difference = 22,025; $F = 0.6088$; $p = 0.4466$). After excluding *mebendazole*, the VIF decreased, with *iron supplementation* and *blood pressure measurement* showing VIFs < 2, while *urine* and *blood sampling* retained higher VIF (4.30 and 4.59, respectively). The Breusch–Pagan test revealed that there were no heteroskedasticity issues ($p = 0.627$).

The final model, restricted to *blood pressure*, *urine* and *blood sampling*, resulted in an R^2 of 0.37 and an adjusted R^2 of 0.26, with the intercept remaining statistically significant. Both the Breusch–Pagan ($p = 0.83$) and Shapiro–Wilk ($p = 0.12$) tests confirmed homoscedasticity and normality of residuals, respectively. The introduction of interaction terms led to minor improvements, including reduced residual standard error and a higher adjusted R^2. However, the effects of the interaction, such as *blood pressure* × *blood sampling* ($p = 0.069$), approached, but did not reach statistical significance. The comparison confirmed no significant enhancement ($p = 0.1817$).

Table 2: Comparison of mean microbial load reduction (CFU/mL) in plasma-activated water treatments at different exposure times

Variables	Estimator	SE	T-value	P-value
Linear Model 1				
(Intercept)	1572.91	722.11	2.18	0.045
Iron	-3.05	10.87	-0.28	0.783
Mebendazole	5.55	7.11	0.78	0.447
Blood_pressure	-13.37	8.76	-1.53	0.147
Urine_test	1.66	5.72	0.29	0.776
Blood_test	-4.45	7.04	-0.63	0.536
Global Parameters				
Residual Std. Error	190.20			
Multiple R^2	0.41			
Adjusted R^2	0.22			
F-statistic	2.21			
Degrees of freedom	5. 16			
P-value	0.104			
variance inflation factor (VIF)				
Iron	6.47			
Mebendazole	4.86			
Blood pressure	3.47			
Urine_test	4.78			
Blood_test	5.63			
Linear Model 2				
(Intercept)	1190.84	524.60	2.27	0.036*
Iron	4.06	5.86	0.69	0.498
Blood_pressure	-8.90	6.55	-1.36	0.192
Urine_test	0.24	5.36	0.05	0.965
Blood_test	-6.80	6.29	-1.08	0.294
Global Parameters				
Residual std error	188.00			
Multiple R^2	0.39			
Adjusted R^2	0.24			
F-statistic	2.67			
Degrees of freedom	4. 17			
P-value	0.068			
ANOVA: Model 1 vs Model 2				
Sum of squares diff.	22025.00			
F-statistic	0.61			
P-value	0.447			
VIF (Mebendazole removed)				
Iron	1.93			
Blood_pressure	1.99			
Urine_test	4.30			
Blood_test	4.59			
Final Linear Model				
(Intercept)	1379.65	441.56	3.13	0.005
Blood_pressure	-8.45	6.42	-1.32	0.205
Blood_test	-5.95	6.07	-0.98	0.340
Urine_test	1.08	5.14	0.21	0.836
Global Parameters				
Residual std error	185.30			
Multiple R^2	0.37			
Adjusted R^2	0.26			
F-statistic	3.51			
Degrees of freedom	3.18			
P-value	0.037			
VIF				
Blood_pressure	1.97			
Blood_test	4.42			
Urine_test	4.08			
Model with Interactions				
(Intercept)	5490.87	2042.48	2.69	0.017
Blood_pressure	-61.62	28.92	-2.13	0.050
Blood_test	-120.40	58.44	-2.06	0.057
Urine_test	36.71	64.74	0.57	0.579
Blood_pressure: Blood_test	1.47	0.75	1.96	0.069
Blood_pressure: Urine_test	-0.32	0.85	-0.37	0.713
Blood_test: Urine_test	-0.25	0.35	-0.72	0.480
Global Parameters				
Residual std error	173.40			
Multiple R^2	0.54			
Adjusted R^2	0.35			
F-statistic	2.93			
Degrees of freedom	6. 15			
P-value	0.043			
ANOVA: Final vs Interaction Model				
Sum of squares diff.	166765.00			
F-statistic	1.85			
P-value	0.182			
Akaike Information Criterion (AIC)				
Final Model (df=5)	297.77			
Interaction Model (df=8)	296.85			

VIF: Variance Inflation Factor: SE: Standard error

Table 3 summarises the results from the generalised additive model (GAM). This model revealed marked nonlinear associations for *blood pressure* ($p < 0.0045$) and *blood sampling* ($p < 0.0055$), while *urine testing* showed a marginal effect ($p = 0.0976$). Adjusted R^2 for the GAM reached 0.883, indicating markedly superior explanatory power compared to linear models. The estimated degrees of freedom highlighted the complexity of the non-linear relationships.

Table 3: Generalised Additive Model

Term	Estimate	Standard Error	T-value	P-value
(Intercept)	440	15.76	27.92	<0.001
Approximate significance of smooth terms				
Smooth Term	**Degrees of Freedom**	**Degrees of Freedom Reference**	**F-value**	**P-value**
s(Blood_pressure)	9.00	9.00	10.47	0.005
s(Blood test)	1.00	1.00	17.89	0.006
s(Urine_test)	4.86	5.66	3.12	0.098
Global Indicators				
Metric	**Value**			
Adjusted R^2	0.88			
Explained Deviance	0.97			
Generalised Cross-Validation (GCV)	19.584			
Scale Estimate	5.462.8			

The generalised cross-validation (GCV) score was 19,584, and the scale estimate was 5,462.8. Figure 2 shows the crude relationship between MMR and each GAM variable by smoothing of the liss. Figure 3 presents the smoothed GAM curves, illustrating the effect of each predictor on MMR, accounting for simultaneous covariates.

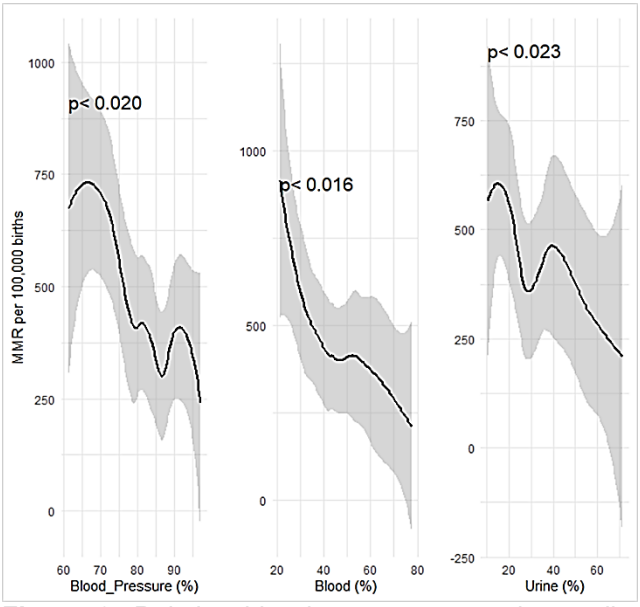

Figure 2: Relationships between maternal mortality rate and antenatal care

Discussion

The results highlight marked regional disparities in the coverage of antenatal care (ANC) and maternal mortality (Table 1 & Figure 1), underscoring the heterogeneity in the quality of the services provided and their impact on maternal health in Madagascar. The primary objective of this study was to examine the relationship between ANC quality and maternal mortality. Linear analyses yielded inconclusive findings (Table 2), revealing substantial multicollinearity and weak associations. In contrast, the generalised additive model (GAM) (Table 3) identified significant nonlinear effects for certain variables, suggesting that a simple linear approach fails to capture underlying dynamics. This finding is consistent with previous research that has demonstrated the need for more flexible modelling approaches when examining the determinants of maternal mortality (10–13).

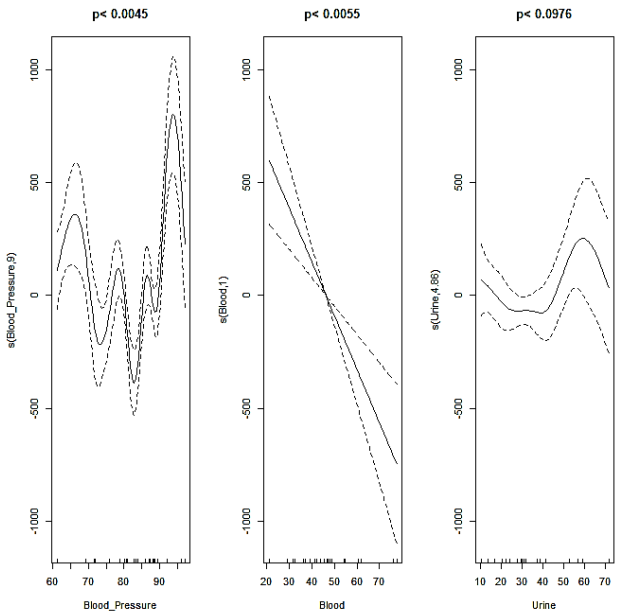

Figure 3: Display of the generalized additive model

Numerous studies from sub-Saharan Africa and other low and middle-income countries have documented the crucial role of adequate ANC

coverage in preventing obstetric complications and reducing maternal deaths (3, 4, 14-16). However, several studies have also indicated that increased coverage does not necessarily result in a proportional decrease in maternal mortality due to contextual factors such as actual quality of care, geographic or financial access, and socioeconomic inequalities (17-19). In the present study, the complexity observed for specific variables, notably blood pressure measurement and biological tests, may reflect regional differences in the organisation of the health system, the availability of human and material resources, or the levels of community awareness (20, 21).

Identification of nonlinear effects in the GAM is consistent with findings from other African settings, where the relationship between maternal health indicators and ANC coverage appears to be modulated by contextual factors (22). Some studies suggest that beyond a certain coverage threshold, the marginal effect on reducing maternal mortality tends to diminish if service quality is not guaranteed (15, 23). On the contrary, in regions where baseline coverage is low, even modest improvements in ANC access can significantly reduce maternal deaths (24, 25).

However, the multiplicity of socio-economic and cultural determinants can lead to non-linear effects, whereby factors such as rural service availability, poverty, or geographic isolation influence the relationship between ANC coverage and maternal mortality (26, 27). In our analysis, blood pressure monitoring and biological tests (blood and urine) showed complex effects on maternal mortality, suggesting that its impact varies according to access and quality and is not strictly linear.

Theoretically, these findings support the perspective that improving coverage must be accompanied by improvements in care quality, better coordination between care components, and the reduction of socioeconomic inequalities (17, 28). The observed regional heterogeneity calls for differentiated public health policies tailored to local contexts, supported by targeted resource allocation, particularly in terms of health workforce training and equipment availability (20, 29).

This study emphasises the importance of modelling approaches capable of capturing the complexity of relationships between ANC quality and maternal mortality. The use of GAMs, which revealed nonlinear patterns, could be extended to other contextual variables, such as distance from health facilities or household poverty indices (13, 22). From an operational point of view, an integrated strategy that combines increased coverage with continuous quality improvement appears essential for sustainable reductions in maternal mortality (14, 23). Furthermore, analysing interactions between various factors (access, availability, quality, socioeconomic determinants) is crucial to understanding the underlying mechanisms and guiding effective public health strategies (11, 24).

In summary, our findings confirm that the relationship between ANC quality and maternal mortality in Madagascar, which reflects trends in many African countries—is not purely linear, but shaped by a complex system of determinants. Recognising this complexity is key to improving the effectiveness of health policies and guiding future research, both in terms of understanding key drivers and evaluating new interventions aimed at improving maternal survival.

Although offering valuable information on the relationship between ANC quality and maternal mortality in Madagascar, this study presents certain limitations. The use of secondary data, although practical, may not fully capture the nuanced contextual elements that influence care quality on the ground. Furthermore, the focus on specific ANC variables can overlook other socio-economic and cultural factors that play a critical role in maternal health outcomes. The complexity of the statistical models, although suited to uncovering nonlinear relationships, may reduce the accessibility of the findings for nonspecialist audiences, potentially limiting their immediate policy relevance. Lastly, the absence of complementary qualitative analysis restricts a deeper understanding of the lived experiences of pregnant women, perspectives that could meaningfully inform the recommendations.

Conclusion

This study revealed notable disparities in the quality of antenatal care and its relationship with maternal mortality in Madagascar. The analyses uncovered complex relationships between care coverage and maternal death rates, suggesting that simply increasing services is not necessarily sufficient to reduce mortality. Linear models did not establish statistically significant relationships, while the generalised additive model (GAM) revealed marked nonlinear associations, particularly regarding blood pressure measurement and blood tests.

These findings underscore the need for a

comprehensive approach that addresses the multiple dimensions that influence the quality and accessibility of care. The existing literature in the African context shows divergent results, with some studies confirming a strong link between the quality of ANC and reduced maternal mortality, while others emphasise the underlying structural and socioeconomic factors.

One of the main implications of this study is the need to improve not only the accessibility of antenatal services but also their effectiveness in terms of early diagnosis and monitoring of complications. Integration of innovative technologies, such as AI-assisted ultrasound, could help bridge gaps in pregnancy monitoring, particularly in rural areas. Additionally, continuous training for healthcare professionals and adaptation of public health strategies to the actual needs of communities remain essential levers to improve maternal health indicators in Madagascar.

In conclusion, while improving coverage of antenatal care is a fundamental goal, it must be accompanied by optimising the quality of services, ensuring context-specific care, and better integrating technological and organisational innovations to guarantee a tangible impact on maternal mortality.

Conflict of Interests

Authors declare no conflict of interests.

Acknowledgments

Sonia Maminirina Fenomanana, Full Professor at the University of Toliara, Madagascar, for her constructive comments.

References

1. Say L, Chou D, Gemmill A, Tunçalp Ö, Moller AB, Daniels J, et al. Global causes of maternal death: a WHO systematic analysis. Lancet Glob Health. 2014;2(6):e323-33.
2. World Health Organization. Trends in maternal mortality 2000 to 2020: estimates by WHO, UNICEF, UNFPA, World bank group and UNDESA/population division. https://www.who.int/publications/i/item/9789240068759 (accessed 2023).
3. Bemanana HS, Rafamantanantsoa S. Maternal mortality in hospital settings in Madagascar: A 43-case study. Médecine d'Afrique Noire. 2023;70(6):349-56. Available at: https://www.santetropicale.com/kiosque/une_uk.asp?id_revue=man&numero=7006&mois_numero=June&libelle_annee=2023&id_article=3655#openModal_3655 .
4. Bemanana HS, Rafamantanantsoa S, Razanabao TE, Razafindraibe AF, Rakotondrafarasata RS, Fenomanana SM. Determinants of maternal mortality in hospital settings in Madagascar. Sante Publique. 2024;36(5):131-8.
5. Lancet Newborn Interventions Review Group; Lancet Every Newborn Study Group. Can available interventions end preventable deaths in mothers, newborn babies, and stillbirths, and at what cost?. Lancet. 2014;384(9940):347-70.
6. Samuel O, Zewotir T, North D. Decomposing the urban-rural inequalities in the utilisation of maternal health care services: evidence from 27 selected countries in Sub-Saharan Africa. Reproductive health. 2021;18(1):216.
7. Apanga PA, Awoonor-Williams JK. Maternal Death in Rural Ghana: A Case Study in the Upper East Region of Ghana. Front Public Health. 2018;6:101.
8. Institut National de la Statistique (INSTAT). RGPH3_Niveaux tendances et caracteristiques de la mortalite à Madagascar. Antananarivo, Madagascar: INSTAT; 2021.
9. Institut National de la Statistique (INSTAT), ICF. Enquête démographique et de santé à Madagascar (EDSMD-V) 2021. Antananarivo, Madagascar; Rockville, Maryland, USA: INSTAT et ICF; 2022.
10. Carroli G, Rooney C, Villar J. How effective is antenatal care in preventing maternal mortality and serious morbidity? An overview of the evidence. Paediatr Perinat Epidemiol. 2001;15 Suppl 1:1-42.
11. Freedman LP, Waldman RJ, de Pinho H, Wirth ME, Chowdhury AM, Rosenfield A. Transforming health systems to improve the lives of women and children. Lancet. 2005;365(9463):997-1000.
12. Hosmer Jr DW, Lemeshow S, Sturdivant RX. Applied logistic regression. 3nd ed. United States of America: Wiley, 2013.
13. Ronsmans C, Graham WJ. Maternal mortality: who, when, where, and why. Lancet. 2006;368(9542): 1189-200.
14. Campbell OM, Graham WJ. Strategies for reducing maternal mortality: getting on with what works. Lancet. 2006;368(9543):1284-99.
15. Lincetto O, Mothebesoane-Anoh S, Gomez P, Munjanja S. Antenatal care. Opportunities for Africa's newborns: Practical data, policy programmatic support for newborn care in Africa. Cape Town: Partnership for Maternal, Newborn and Child Health. 2006:55-62.
16. Tura G, Fantahun M, Worku A. The effect of health facility delivery on neonatal mortality: systematic

review and meta-analysis. BMC Pregnancy Childbirth. 2013;13:18.
17. Aday LA, Andersen R. A framework for the study of access to medical care. Health Serv Res. 1974;9(3):208-20.
18. Gage AJ, Guirlène Calixte M. Effects of the physical accessibility of maternal health services on their use in rural Haiti. Popul Stud (Camb). 2006;60(3):271-88.
19. Say L, Raine R. A systematic review of inequalities in the use of maternal health care in developing countries: examining the scale of the problem and the importance of context. Bull World Health Organ. 2007;85(10):812-9.
20. Benova L, Cumming O, Campbell OM. Systematic review and meta-analysis: association between water and sanitation environment and maternal mortality. Trop Med Int Health. 2014;19(4):368-87.
21. Van Lerberghe W, De Brouwere V. Of blind alleys and things that have worked: history's lessons on reducing maternal mortality. Safe motherhood strategies: a review of the evidence. 2001.
22. Filippi V, Chou D, Ronsmans C, Graham W, Say L. Levels and Causes of Maternal Mortality and Morbidity. 3nd ed. Washington (DC): The International Bank for Reconstruction and Development/The World Bank, 2016.
23. Hounton S, Menten J, Ouédraogo M, Dubourg D, Meda N, Ronsmans C, al. Effects of a Skilled Care Initiative on pregnancy-related mortality in rural Burkina Faso. Trop Med Int Health. 2008;13 Suppl 1:53-60.
24. World Health Organization. Strategies towards ending preventable maternal mortality (EPMM). World Health Organization, 2015.
25. World Health Organization. Trends in maternal mortality 2000 to 2017: estimates by WHO, UNICEF, UNFPA, World Bank Group and the United Nations Population Division: executive summary. https://iris.who.int/handle/10665/327596. (accessed 2019).
26. Lawn JE, Cousens S, Zupan J. 4 million neonatal deaths: when? Where? Why? Lancet. 2005;365(9462):891-900.
27. Rutstein SO, Johnson K. The DHS Wealth Index. DHS Comparative Reports No. 6. United States of America: ORC Macro, 2004.
28. Victora CG, Barros AJD, França GVA, da Silva ICM, Carvajal-Velez L, Amouzou A. The contribution of poor and rural populations to national trends in reproductive, maternal, newborn, and child health coverage: analyses of cross-sectional surveys from 64 countries. Lancet Glob Health. 2017;5(4):e402-e407.
29. Freedman LP, Kruk ME. Disrespect and abuse of women in childbirth: challenging the global quality and accountability agendas. Lancet. 2014;384(9948):e42-4.

Citation: Bemanana HS, Razafaindraibe AF, Rafamantanantsoa S. **Quality of Antenatal Care and Maternal Mortality in Madagascar: Analysis of Regional Disparities and Non-Linear Modeling.** J Family Reprod Health 2025; 19(3): 174-83.