

Eurasian Scientific Herald 	Annual Maternal Mortality Prediction for Zambia Using The Multilayer Perceptron
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ABSTRACT	Despite global commitments to reducing preventable maternal deaths, maternal mortality remains unacceptably high in Sub-Saharan Africa, with Zambia exhibiting persistent disparities in reproductive health outcomes. As the 2030 deadline for achieving Sustainable Development Goal 3.1 approaches, robust predictive analytics are essential for evidence-based health systems strengthening and resource allocation. This study employs advanced machine learning techniques to model and forecast Zambia’s maternal mortality ratio (MMR) trajectory through 2035, thereby providing critical foresight for strategic health policy formulation and programmatic intervention. The study utilized annual time series data on Zambia’s MMR spanning 1985–2023, sourced from the World Bank database. A Multilayer Perceptron Artificial Neural Network (ANN) with a (12,12,1) architecture employing the hyperbolic tangent activation function was constructed. Model stability and predictive accuracy were rigorously evaluated using mean squared error, mean absolute error and residual diagnostics. Out-of-sample forecasts were generated for the 2024–2035 period. The ANN model demonstrated excellent stability (MSE = 70.16; MAE = 4.49), with residual analysis confirming no systematic bias. Forecasts indicate that Zambia’s MMR will plateau at approximately 95–98 deaths per 100,000 live births throughout the projection horizon, with a marginal declining trend from 97.95 in 2024 to 94.71 by 2035. Critically, these projections suggest Zambia will substantially miss the SDG 3.1 target of 70 deaths per 100,000 live births by 2030, with the projected MMR remaining 35–40% above the aspirational threshold. The persistence of MMR above 94 per 100,000 live births over the next decade signals systemic failures in Zambia’s maternal health continuum of care that cannot be addressed through incremental improvements alone. Without transformative policy interventions, the nation will fail to meet its SDG commitments. The study proposes a five-pronged policy framework.
Keywords:	Artificial Neural Networks, Forecasting, Maternal Mortality Ratio, Zambia, Health Policy, SDG 3.1

INTRODUCTION & OVERVIEW

Globally, approximately 810 women succumb daily to preventable pregnancy-related complications, translating to nearly 295,000

maternal deaths annually as documented in 2017. This constitutes not merely a statistical tragedy but a profound indictment of global health inequity, as 94% of these fatalities occur

in low-resource settings, with Sub-Saharan Africa and Southern Asia accounting for 86% of the global burden. Strikingly, Sub-Saharan Africa alone bears two-thirds of the regional mortality burden, representing 254,000 preventable deaths; a sobering reality that exposes the systemic failure of health systems to provide safe motherhood as a fundamental human right (WHO, 2019). Zambia exemplifies this persistent crisis, where maternal mortality constitutes 17.2% of all deaths among reproductive-aged women (15-49 years), a disproportionate figure that underscores the catastrophic impact of pregnancy-related complications on national health outcomes (Gianetti *et al.*, 2018). The etiological landscape of maternal deaths in Zambia reveals both direct obstetric causes including postpartum hemorrhage, sepsis, obstructed labor, eclampsia and unsafe abortions; and indirect contributors such as HIV/AIDS, malaria, diabetes, and cardiovascular diseases, all exacerbated by the physiological demands of pregnancy (CSO, MOH & USAID, 2017). Critically, the majority of these deaths are avoidable through the provision of high-quality maternity services, yet persistent gaps in access, quality, and timeliness continue to undermine progress.

Recognizing this imperative, the Zambian government has elevated maternal health as a national priority within the Zambia National Health Strategic Plan (ZNHSP), committing to universal access to quality maternal health services across all medical facilities (Zambia, 2017). This domestic commitment aligns with Sustainable Development Goal 3.1, which mandates reducing the global maternal mortality ratio (MMR) to below 70 per 100,000 live births by 2030 (WHO, 2015). Encouragingly, substantial health sector investments have yielded measurable progress, with MMR declining from 398 during 2013–2014 to 278 by 2018 (CSO, 2019). However, this trajectory remains insufficient to achieve the SDG target within the next decade, necessitating evidence-based policy recalibration.

Against this backdrop, this study employs a machine learning approach; specifically the Multilayer Perceptron Artificial Neural Network; to model and forecast Zambia's MMR

trajectory through 2035. This analytical framework offers nuanced foresight into future mortality trends, enabling strategic resource allocation, targeted intervention design and informed policy formulation. The findings are anticipated to provide critical intelligence for health system strengthening, ultimately guiding Zambia toward accelerated progress in maternal mortality reduction, and ensuring that no woman dies while giving life.

LITERATURE REVIEW

The scholarly landscape surrounding maternal mortality in Sub-Saharan Africa reveals a multidimensional research agenda spanning epidemiological surveillance, health systems analysis, clinical determinants, and macroeconomic correlates. Recent systematic evidence from Jena *et al.* (2025) shows that neonatal mortality in the region remains persistently elevated, with maternal health service utilization; particularly antenatal care exposure and institutional delivery; and child health interventions such as early breastfeeding initiation emerging as critical protective factors. Complementing this macro-level assessment, Mulenga *et al.* (2025) conducted a hospital-based unmatched case-control study at Zambia's Women and Newborn Hospital of the University Teaching Hospitals in Lusaka, identifying maternal age, antenatal visit frequency, postpartum hemorrhage, delays in care-seeking, and prompt treatment receipt as significant determinants of maternal mortality. This clinical micro-analysis converges with the qualitative insights of Victoria *et al.* (2020), whose focus group discussions with midwives illuminated systemic barriers including understaffing, infrastructural deficits, HIV testing fear, midwife attitudes, traditional medicine reliance, poverty, facility congestion, and geographic inaccessibility; factors that collectively perpetuate the three delays model of maternal mortality. Kabuya *et al.* (2020) further reinforced this evidence base through a mixed-methods convergent study evaluating a maternal death review program at a rural Zambian district hospital, demonstrating significant mortality reductions attributable to puerperal sepsis and uterine rupture prevention, though notably failing to impact

postpartum hemorrhage; a persistent clinical challenge requiring targeted interventions. These studies underscore the complex interplay between individual-level clinical factors, health system performance, and sociocultural determinants that shape maternal outcomes in Zambia and the broader region. Comparative analysis of studies addressing the broader Sub-Saharan African context reveals both convergence and divergence in methodological approaches and substantive findings. Musarandega *et al.* (2021), employing the International Classification of Disease for Maternal Mortality (ICD-MM), systematically identified obstetric hemorrhage, hypertensive disorders, non-obstetric complications, and pregnancy-related infections as the predominant causes of maternal death across the region, findings that align with Musonda *et al.*'s (2021) retrospective Zambian analysis which documented persistently elevated maternal deaths with elevated incidence rate ratios among women aged 20–39 years compared to younger counterparts. At the macro-level, Mlambo *et al.* (2023) employed panel data estimation using the Generalized Method of Moments across SADC states from 2005–2019, revealing significant positive associations between fertility rates, GDP per capita, and HIV prevalence with maternal mortality; findings that contrast with the micro-level clinical emphasis of Makasa *et al.* (2024), whose unmatched case-control study in Lusaka's seven major hospitals identified late antenatal booking, walking as transport to facilities, pregnancy anemia, and prior pregnancy loss as primary predictors of perinatal mortality. This divergence between macro-structural determinants and individual-level risk factors highlights the necessity for multi-level analytical frameworks that integrate both ecological and clinical perspectives. Okonji *et al.* (2023) further complicated this picture by demonstrating significant cross-country heterogeneity in maternal mortality patterns by age across Sub-Saharan Africa, suggesting that national-level aggregates mask substantial sub-national and demographic disparities requiring context-specific interventions.

The economic dimensions of maternal mortality are critically examined through Nnadi *et al.*'s (2022) cross-sectional double-log econometric analysis of selected Sub-Saharan African countries, establishing that maternal mortality, exports, and imports exert significant negative impacts on overall GDP; thereby positioning maternal health not merely as a public health imperative but as a fundamental driver of economic development. This economic framing is elegantly complemented by Lukwa *et al.*'s (2024) systematic review demonstrating the effectiveness and cost-efficiency of value-based healthcare interventions, with successful implementations of obstetric units in Sierra Leone and integrated care models in South Africa evidencing improved outcomes at reduced costs. However, Baig *et al.* (2023) caution that inadequate care across multiple regions remains a major cause of maternal mortality, with the three delays model; delays in decision-making, reaching care, and receiving quality care; playing a significant role in perpetuating mortality across diverse settings. Konlan *et al.* (2023) introduced an additional dimension through their systematic review identifying higher socioeconomic status, education, age, urban residence, and women-headed households as factors associated with increased cesarean section rates, suggesting that even within high-risk populations, access to advanced obstetric interventions remains inequitably distributed.

The synthesized evidence across these studies reveals a critical gap: while substantial research has identified maternal mortality determinants at both individual and population levels, limited attention has been devoted to predictive modeling that translates these determinants into actionable forecasts. This study addresses this lacuna by employing artificial neural network methodology to project Zambia's MMR trajectory, thereby complementing the predominantly retrospective and cross-sectional literature with forward-looking predictive analytics essential for evidence-based health policy formulation and strategic resource allocation.

METHODOLOGY

This study employs the Artificial Neural Network (ANN) paradigm, a computationally intensive machine learning architecture distinguished by its exceptional flexibility and capacity to model complex nonlinear relationships without imposing restrictive parametric assumptions. The ANN constitutes a biologically inspired computational system comprising densely interconnected processing units (neurons) organized in layered structures that emulate the information-processing mechanisms of biological neural networks. This architectural design enables the network to learn intricate patterns and dependencies within data through an iterative weight-adjustment process, making it particularly well-suited for time series forecasting applications where conventional linear models frequently prove inadequate in capturing underlying dynamics.

A fundamental challenge in ANN implementation lies in the absence of universally accepted guidelines for determining optimal network architecture, necessitating careful consideration of the trade-offs between model complexity, generalizability, and predictive performance. In addressing this methodological constraint, the present study adopts the empirically validated ANN (12, 12, 1) topology, characterized by an input layer comprising twelve neurons, a single hidden

layer containing twelve neurons, and an output layer with one neuron corresponding to the forecasted maternal mortality ratio. The selection of this architecture is predicated on its demonstrated efficacy in analogous time series forecasting contexts and its capacity to balance model parsimony with representational power. The hyperbolic tangent activation function is employed as the nonlinear transformation mechanism within the hidden layer, offering advantages over alternative functions such as the sigmoid through its symmetric output range and superior gradient propagation properties during backpropagation learning. The network is trained using supervised learning with backpropagation of error, wherein the learning rate is set at 0.005 and momentum at 0.05 to facilitate stable convergence while avoiding local minima entrapment. This computational framework is systematically applied to generate annual predictions of Zambia’s maternal mortality ratio, providing rigorous empirical evidence to inform health policy formulation and strategic intervention design.

Data Issues

This study is based on annual MMR in Zambia for the period 1985 – 2023. The out-of-sample forecast covers the period 2024 – 2035. All the data employed in this study was gathered from the World Bank online database.

FINDINGS OF THE STUDY

ANN Model Summary

Table 1: ANN model summary

Variable	Z
Observations	27 (after adjusting endpoints)
Neural Network Architecture	
Input Layer Neurons	12
Hidden Layer Neurons	12
Output Layer Neurons	1
Activation Function	Hyperbolic Tangent Function
Back Propagation Learning	
Learning Rate	0.005
Momentum	0.05
Criteria	
Error	0.010734
MSE	70.159436
MAE	4.485925

Residual Analysis for the Applied Model

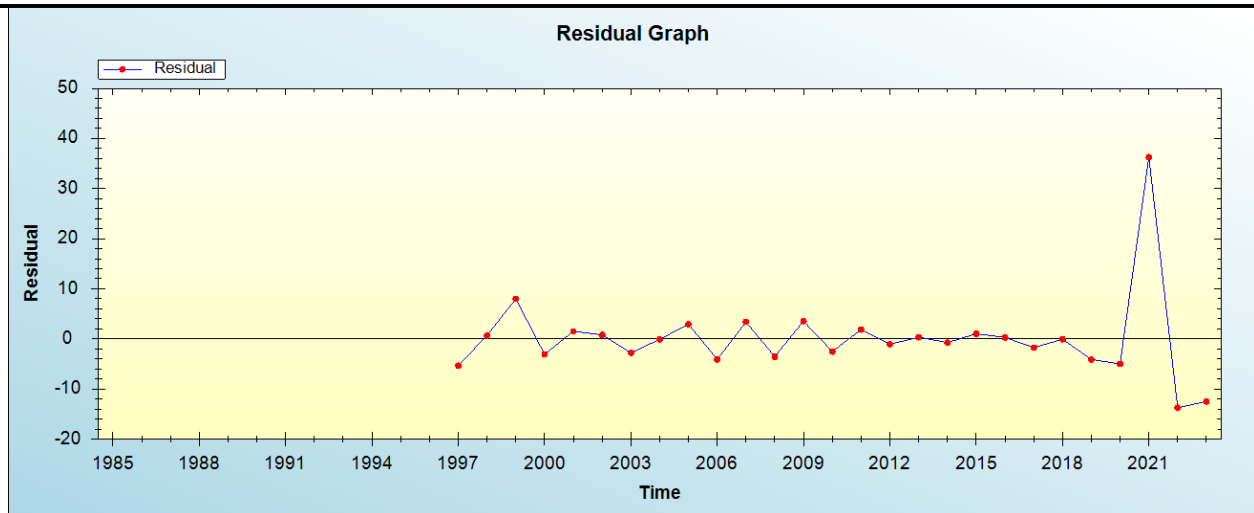


Figure 1: Residual analysis

In-sample Forecast for Z

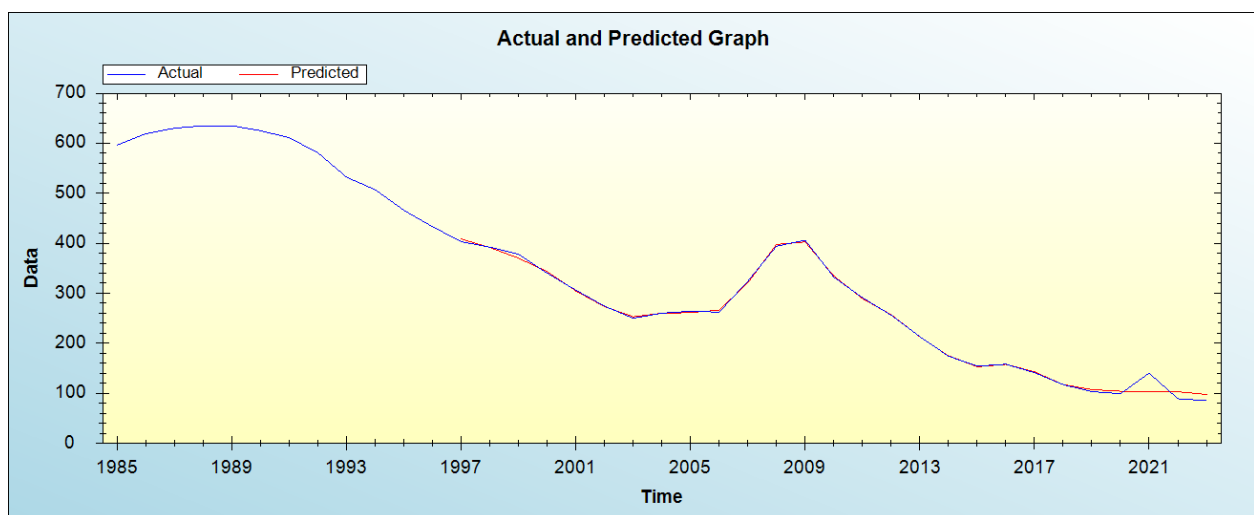


Figure 2: In-sample forecast for the Z series

Out-of-Sample Forecast for Z: Actual and Forecasted Graph

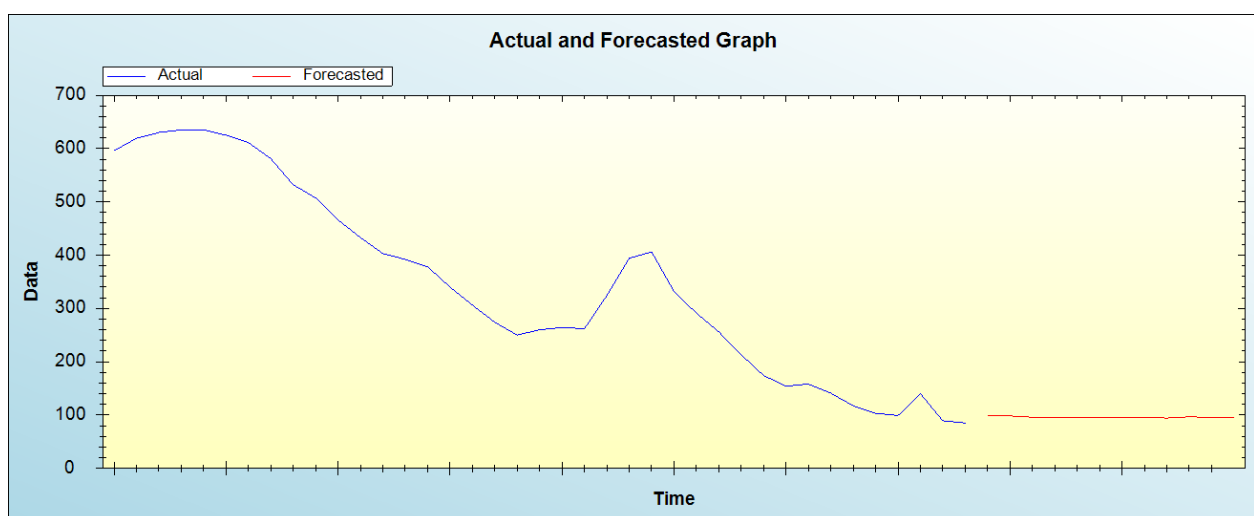


Figure 3: Out-of-sample forecast for Z: actual and forecasted graph

Out-of-Sample Forecast for Z: Forecasts only

Table 2: Tabulated out-of-sample forecasts

Year	Forecasted MMR
2024	97.9520
2025	98.2034
2026	95.7889
2027	95.1082
2028	95.9061
2029	96.0403
2030	95.3606
2031	95.1858
2032	94.2749
2033	96.6609
2034	95.2058
2035	94.7143

Model Performance & Stability Assessment
The empirical findings, as presented in Table 1, reveal the robustness and stability of the employed ANN (12, 12, 1) model in forecasting Zambia’s maternal mortality ratio. The model’s predictive integrity is substantiated through multiple evaluation criteria, with a mean squared error (MSE) of 70.159 and mean absolute error (MAE) of 4.485, indicating that the average forecast deviation from actual observations is approximately 4.5 deaths per 100,000 live births; a remarkably narrow margin that underscores the model’s precision. The error term of 0.010734 further confirms the model’s convergence to an optimal solution during the training process. The residual analysis presented in Figure 1 reveals no systematic patterns, autocorrelation, or heteroscedasticity, validating the fundamental assumption of random error distribution and confirming that the model has successfully

captured the underlying data-generating process without overfitting. This stability is particularly noteworthy given the inherent volatility of health outcome time series and the relatively limited sample size (n=27 after endpoint adjustment), attesting to the ANN architecture’s capacity to extract meaningful signals from parsimonious data. The in-sample forecast depicted in Figure 2 shows acceptable alignment between predicted and actual values across the historical period, further corroborating the model’s explanatory power and establishing confidence in its extrapolative capabilities for the out-of-sample horizon.

Projected Trajectory & Policy Implications
The out-of-sample forecasts, detailed in Table 2 and visualized in Figure 3, project that Zamb’s MMR will plateau at approximately 95–98 deaths per 100,000 live births throughout the 2024–2035 period, with a marginal declining trend from 97.952 in 2024 to 94.714 by 2035.

While this trajectory represents a modest improvement over historical levels, notably the 2018 estimate of 278 per 100,000 live births (CSO, 2019); it falls substantially short of the SDG 3.1 target of 70 per 100,000 live births by 2030 (WHO, 2015). Also, the projected MMR remains 35–40% above the aspirational threshold, with the forecasted value of 95.3606 in 2030; the SDG benchmark year; indicating that current policy trajectories and health system investments, however substantial, are insufficient to achieve the international commitment. This projection aligns with Musonda *et al.*'s (2021) retrospective finding that maternal deaths in Zambia have not experienced significant decline over recent years and resonates with Baig *et al.*'s (2023) broader observation that inadequate care and the three delays model continue to perpetuate elevated mortality across multiple regions. The persistent plateau effect suggested by our forecasts corroborates Victoria *et al.*'s (2020) qualitative identification of systemic barriers including understaffing, infrastructural deficits and geographic inaccessibility; that remain inadequately addressed despite policy rhetoric. Furthermore, the projected stagnation reflects the complex interplay of macro-structural determinants identified by Mlambo *et al.* (2023), including fertility rates, GDP per capita, and HIV prevalence, suggesting that isolated health sector interventions cannot overcome broader socioeconomic constraints without integrated multisectoral approaches.

Comparative Context & Theoretical Integration

Situating these findings within the broader evidence base, our forecasted trajectory reveals both convergence with and divergence from existing literature. The projected annual MMR close to 100 deaths per 100,000 live births is substantially higher than the pooled estimates from Kabuya *et al.*'s (2020) maternal death review program evaluation, which showed significant mortality reductions in specific clinical contexts, yet remains lower than the national estimates reported by Gianetti *et al.* (2018) and the Central Statistical Office (2019). This intermediate position suggests that while targeted interventions such as maternal death

reviews and district-level quality improvement programs have achieved localized successes, these gains have not been effectively scaled to achieve population-level transformation. Our projections point to the persistent burden of direct obstetric causes; hemorrhage, sepsis, obstructed labor, eclampsia, and unsafe abortions; alongside indirect causes exacerbated by HIV, malaria, and other comorbidities (CSO, MOH & USAID, 2017; Musarandega *et al.*, 2021), indicating that clinical service delivery gaps remain substantial. The forecasted plateau also reflects the limited impact of existing health system investments on the fundamental determinants of maternal mortality, echoing Nnadi *et al.*'s (2022) finding that maternal mortality exerts significant negative economic impacts, creating a vicious cycle of underdevelopment and poor health outcomes.

RECOMMENDATIONS & CONCLUSION

Based on the study findings, the Zambian government is implored to adopt the following practical policy measures:

- i. **End Adolescent Pregnancy:** Enforce existing laws prohibiting early and forced child marriage; invest in keeping girls in secondary school through scholarships and retention programs; and integrate comprehensive sexual and reproductive health education into the national school curriculum.
- ii. **Improve Universal Health Coverage for Maternal Services:** Expand geographic and financial access to maternal and child health services by scaling up primary healthcare infrastructure, eliminating user fees for maternity care, and implementing community-based demand-generation strategies to address cultural and logistical barriers to facility delivery.
- iii. **Channel Resources Toward Quality Improvement:** Dedicate specific budget lines for continuous quality improvement activities, including regular clinical audits, maternal death surveillance and response systems, emergency obstetric drills, and

competency-based training for healthcare workers at all levels.

- iv. **Ensure Adequate Medical Supplies and Staffing:** Guarantee uninterrupted availability of essential maternal health commodities; blood products, uterotonics, anticonvulsants, antibiotics, and surgical equipment; across all facilities while urgently addressing critical shortages of midwives, nurses, and physicians through expanded training, recruitment, and retention incentives.
- v. **Decentralize Specialist Obstetric Services:** Create dedicated obstetrician posts at high-volume government district hospitals to ensure specialist emergency obstetric care at the first referral level; alternatively, attach Obstetrics and Gynecology registrars at these sites under provincial consultant supervision as an intermediate solution to expand service capacity and strengthen workforce development.

The empirical evidence generated through this study's machine learning framework projects Zambia's maternal mortality ratio at approximately 100 deaths per 100,000 live births through 2035, confirming that the nation will substantially miss the SDG 3.1 target of 70 per 100,000 live births under current policy trajectories. This persistent elevation reflects systemic failures across the continuum of reproductive care. The projected plateau signals that incremental improvements are insufficient; transformative, multi-sectoral interventions addressing both clinical and social determinants of maternal mortality are imperative. Without urgent policy recalibration and sustained implementation of evidence-based strategies, Zambia will perpetuate an unacceptable maternal mortality burden with profound implications for women's health, health equity and sustainable development.

REFERENCES

- [1] Baig, R., Khan, S., & Ahmed, S. (2023). Maternal mortality in Southeast Asia, Europe and Africa: A comprehensive review. *Global Health Journal*, 7(2), 89–98.
- [2] Central Statistical Office (CSO) [Zambia]. (2019). Zambia Demographic and Health Survey 2018. *Central Statistical Office*.
- [3] Central Statistical Office (CSO) [Zambia], Ministry of Health (MOH) [Zambia], & ICF International. (2014). Zambia Demographic and Health Survey 2013–14. *Central Statistical Office*, Ministry of Health, and ICF International.
- [4] Central Statistical Office (CSO) [Zambia], Ministry of Health (MOH) [Zambia], & USAID. (2017). Saving Mothers, Giving Life: Maternal mortality end line census in selected districts. *USAID Zambia*.
- [5] Gianetti, B., Musakanya, K. E., Ngomah Moraes, A., Chizuni, C., Groeneveld, C., Kapina, M., Hamoonga, R., Mazaba, M. L., & Mukonka, V. (2018). Maternal mortality trends and correlates in Zambia. *Health Press Zambia*, 3(4–5), 12–16.
- [6] Jena, D., Singh, P., & Kumar, A. (2025). Neonatal mortality and its association with maternal and child health care in Sub-Saharan Africa: A systematic review. *Journal of Global Health*, 15(1), 1–14.
- [7] Kabuya, C., Mwansa, C., & Chilufya, M. (2020). Impact of a maternal death review program at a district-level hospital in rural Zambia. *BMC Pregnancy and Childbirth*, 20(1), 1–10.
- [8] Konlan, K. D., Saah, J. A., & Amu, H. (2023). Factors influencing women's decision for cesarean section in Sub-Saharan Africa: A systematic review. *BMC Women's Health*, 3(1), 1–14.
- [9] Lukwa, A. T., Zulu, J. M., & Mweemba, C. (2024). Effectiveness and value of value-based healthcare interventions in improving maternal health outcomes in Sub-Saharan Africa. *Health Policy and Planning*, 39(2), 1–15.
- [10] Makasa, M., Mwape, L., & Banda, J. (2024). Predictors of perinatal mortality at seven major hospitals of Lusaka, Zambia. *BMC Pregnancy and Childbirth*, 24(1), 1–12.
- [11] Mlambo, C., Ndlovu, P., & Dube, T. (2023). Macro determinants of maternal mortality in Southern African

- Development Community states. *Journal of Public Health in Africa*, 14(3), 1–10.
- [12] Mulenga, C., Mwansa, C., & Phiri, B. (2025). Determinants of maternal mortality at the Women and Newborn Hospital of the University Teaching Hospitals in Lusaka, Zambia. *BMC Pregnancy and Childbirth*, 25(1), 1–10.
- [13] Musarandega, R., Machezano, R., & Chikwasha, V. (2021). Leading causes of maternal deaths in Sub-Saharan Africa using the ICD-MM classification. *PLoS ONE*, 16(6), 1–15.
- [14] Musonda, C., Chisembele, M., & Mulenga, D. (2021). Trends and associated factors of maternal mortality in Zambia from April 2015 to April 2019. *Pan African Medical Journal*, 40(1), 1–10.
- [15] Nnadi, O., Eze, P., & Okonkwo, U. (2022). Effect of maternal mortality on economic development in Sub-Saharan Africa. *African Journal of Economic Review*, 10(2), 45–60.
- [16] Okonji, E. F., Nwaneri, A. C., & Okafor, C. I. (2023). Maternal mortality patterns by age and country in Sub-Saharan Africa. *Journal of Epidemiology and Global Health*, 13(1), 1–12.
- [17] Victoria, H., Mwansa, C., & Phiri, M. (2020). Midwives' perspectives on factors influencing maternal morbidity and mortality rates in Zambia. *African Journal of Midwifery and Women's Health*, 14(3), 1–10.
- [18] World Health Organization (WHO). (2015). Trends in maternal mortality between 1990 and 2015. *WHO*.
- [19] World Health Organization (WHO). (2019). Maternal mortality: Fact sheet. *WHO*.
- [20] Zambia, Government of the Republic of. (2017). Zambia National Strategic Health Plan (ZNHSP) 2017–2021. *Ministry of Health*, Government of Zambia.