

Eurasian Scientific Herald 	Forecasting Annual Maternal Mortality Rate For Kazakhstan Using The Multilayer Perceptron
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ABSTRACT	Maternal mortality remains a pressing global public health challenge, with nearly 800 women dying daily from preventable pregnancy-related causes, predominantly in low- and lower-middle-income countries. While global maternal mortality ratios (MMR) declined by 34.3% between 2000 and 2020, significant disparities persist, with low-income nations experiencing MMRs over 40 times higher than those in Europe. Kazakhstan, despite notable socioeconomic progress and targeted health interventions, continues to underperform relative to OECD counterparts in maternal health outcomes, prompting the need for evidence-based forecasting to guide policy responses. This study employs annual time series data on Kazakhstan’s MMR from 1985 to 2023 to model and predict future trends for the period 2024 to 2035. Using a Multilayer Perceptron artificial neural network (ANN) approach, specifically the ANN (12, 12, 1) architecture with hyperbolic tangent activation function; the research capitalizes on the model’s flexibility and capacity for nonlinear pattern recognition. Data were sourced from the World Bank online database, and model stability was rigorously evaluated using residual analysis and forecast evaluation criteria, including Mean Squared Error (MSE) and Mean Absolute Error (MAE). The findings show that the applied neural network model exhibits strong stability, with an MSE of 2.643 and MAE of 1.029, supported by favourable residual diagnostics. Out-of-sample projections indicate that Kazakhstan’s annual MMR will remain consistently low throughout the forecast horizon, with predicted values ranging from 10.38 to 14.04 per 100,000 live births between 2024 and 2035. These projections suggest a sustained decline from historical peaks, including the spike observed in 2020 (36.5 per 100,000 live births). The study points to the importance of continued investment in maternal health interventions, targeted efforts to address socioeconomic determinants such as secondary education enrollment and domestic violence, and strengthening healthcare systems to maintain this positive trajectory. Policymakers and health authorities in Kazakhstan are encouraged to persistently address local drivers of maternal mortality while leveraging predictive analytics for proactive resource allocation and strategic planning.
Keywords:	Artificial Neural Network, Kazakhstan, Maternal Health Policy, Maternal Mortality Ratio, Multilayer Perceptron, Time Series Forecasting.

INTRODUCTION & OVERVIEW

Maternal mortality constitutes a formidable global public health challenge, with

approximately 800 women succumbing daily to preventable pregnancy or childbirth-related complications (WHO, 2023). This burden disproportionately afflicts low- and middle-income nations relative to their developed counterparts. Globally, the maternal mortality ratio (MMR) stood at 233 per 100,000 live births in 2020 (WHO, 2020). Encouragingly, the intervening two decades witnessed a substantial 34.3% reduction in global MMR between 2000 and 2020, corresponding to an average annual decline of 2.9% (WHO, 2023; WBG, 2023; WHO, 2020). Notwithstanding this progress, the epidemiological landscape remains starkly inequitable; nearly 95% of all maternal deaths recorded in 2020 occurred within low- and lower-middle-income countries (WHO, 2024). The disparity is further underscored by comparative estimates from 2017, wherein low-income nations recorded an MMR of 462 per 100,000 live births, contrasted sharply with 11 per 100,000 in high-income settings (WHO, 2023). The least developed regions continue to bear the heaviest burden, with maternal mortality rates reaching 415 per 100,000 live deliveries; a figure exceeding European rates by more than fortyfold (UNFPA, 2017). Numerous sociodemographic and systemic determinants shape maternal mortality trajectories, including maternal age, marital status, antenatal care attendance, educational attainment, divorce prevalence, and health workforce deficits, among others (Lima Figueiredo et al., 2024; Sageer *et al.*, 2019). Despite notable socioeconomic advancement and the deployment of numerous primary healthcare initiatives; particularly those targeting maternal well-being; over the past two decades, Kazakhstan remains the weakest performer among Organisation for Economic Co-operation and Development (OECD) member states with respect to core health indicators (Gulis *et al.*, 2021). Against this backdrop, the present investigation seeks to model and forecast Kazakhstan's MMR utilizing the multilayer perceptron approach. The resultant projections are anticipated to illuminate prospective MMR trajectories, thereby catalyzing informed national policy

responses aimed at further curtailing avoidable maternal deaths.

LITERATURE REVIEW

The global body of evidence on maternal mortality has expanded considerably over recent decades, yet significant gaps persist in understanding country-specific trajectories and predictive dynamics. Several studies have examined the Iranian context, where Babaey et al. (2025) employed a qualitative policy analysis to demonstrate that targeted health system interventions have substantially reduced maternal mortality, underscoring the effectiveness of structured policy frameworks. Similarly, Pouyanfar et al. (2022) conducted a systematic review identifying hemorrhage (43.7%), preeclampsia/eclampsia (24.5%), and other hypertensive disorders (24%) as predominant causes of maternal death in Iran, while Zalvand et al. (2019) reinforced these findings, adding circulatory system diseases (8.1%) and identifying gravidity, delivery type, socioeconomic status, and geographic location as critical determinants. These Iranian studies collectively emphasize the multifactorial etiology of maternal mortality and the importance of context-specific interventions. However, they remain largely descriptive and retrospective, lacking predictive modeling capabilities. In contrast, the current study advances the field by employing a multilayer perceptron neural network to forecast MMR trajectories, offering prospective insights that enable proactive policy formulation rather than reactive analysis of past mortality events.

The Central Asian regional context, particularly Kazakhstan, has received increasing scholarly attention, revealing concerning trends that diverge from global improvements. Nukeshtayeva et al. (2024) conducted a comprehensive stepwise linear regression analysis examining MMR determinants across 17 Kazakh regions from 2000 to 2020, documenting a dramatic tripling of the national MMR from 13.7 in 2019 to 36.5 per 100,000 live births in 2020, with secondary education enrollment and domestic violence incidence emerging as significant predictors.

Zhamantayev et al. (2023) extended this regional perspective, comparing Central Asian countries and demonstrating that while the regional MMR declined by 38% between 2000 and 2020, Kazakhstan experienced a sharp increase in 2020 with indirect causes of maternal deaths reaching 76.3%, highlighting the shifting epidemiological profile. Their correlation analysis further revealed a strong association between MMR and total health expenditure ($r_{\max} = 0.89, p < 0.01$), implicating health financing as a critical determinant. Turekulova et al. (2025) provided complementary evidence through a retrospective DALY analysis in Almaty, showing marked increases in disability-adjusted life years for severe pre-eclampsia (from 109.3 to 187.2 per 100,000) and eclampsia (from 3.1 to 159.3 per 100,000) between 2018 and 2020, with women aged 25–29 years exhibiting the largest burden increase. These studies collectively portray a concerning deterioration in maternal health outcomes in Kazakhstan, yet they are constrained by their retrospective, observational designs and do not extend beyond historical description. The present investigation addresses this critical gap by applying advanced artificial neural network methodology to generate empirically grounded forecasts, thereby equipping policymakers with anticipatory evidence to preempt further deterioration.

Beyond Iran and Central Asia, investigations from Iraq and Albania offer additional comparative insights into maternal mortality patterns. Huda et al. (2024) conducted a cross-sectional review of 942 maternal deaths in Iraq, reporting an MMR of 28 per 100,000 live births with postpartum hemorrhage (35.1%), pulmonary embolism (26.1%), and hypertension (15.5%) as leading causes, while highlighting systemic deficiencies in death registration (20.8% without forms) and review mechanisms (only 27.4% underwent committee review). Shaban et al. (2024) subsequently identified COVID-19 as the predominant causative agent (40%) in Iraqi maternal deaths, with most deceased women being housewives, urban residents, aged 20–39 years, with

incomplete primary education, delivering at governmental hospitals. Thamir et al. (2021) similarly confirmed the devastating impact of COVID-19 pneumonia on maternal and fetal outcomes, emphasizing the vulnerability of pregnant women during infectious disease outbreaks. Obeid et al. (2020) further documented high MMR in a major Baghdad hospital over eight years, attributing the majority of deaths occurring within the first 12 hours of admission to delays in hospital access and inadequate emergency obstetric facilities during the ISIS threat period. Gabrani et al. (2020) examined primary healthcare utilization in Albania, identifying geographical and financial access as key determinants for public facility users, while equipment availability drove private sector utilization, reinforcing the importance of health system strengthening. Tappis et al. (2023) conducted a rapid cross-sectional assessment in Iraq, revealing gaps in knowledge and practice of high-impact interventions, including skin-to-skin thermal care and early breastfeeding initiation, despite available resources for basic and advanced care. These diverse studies, while geographically and methodologically varied, consistently underscore the critical roles of health system readiness, emergency obstetric access, and sociodemographic determinants in shaping maternal outcomes. However, they are uniformly retrospective and context-bound, offering limited generalizability and no predictive capacity. The current study transcends these limitations by employing a robust multilayer perceptron model on Kazakhstan's longitudinal MMR data, providing not only descriptive insights but also scientifically rigorous forecasts that can inform targeted, evidence-based maternal health interventions and resource allocation strategies.

METHODOLOGY

This study employs the Artificial Neural Network (ANN) approach, a flexible and robust computational paradigm renowned for its capacity to model complex nonlinear relationships without requiring explicit assumptions about underlying data-generating processes. The ANN constitutes a data-

processing architecture comprising numerous highly interconnected processing elements, or neurons, organized in layered structures that conceptually mimic the organizational and functional principles of biological nervous systems. Through iterative learning algorithms, these networks adaptively adjust interconnection weights to minimize prediction errors, enabling the capture of intricate patterns and dependencies inherent in time series data. Given the absence of universally established guidelines for determining optimal ANN architecture, the present investigation adopts the empirically validated ANN (12, 12, 1) topology, comprising twelve input neurons, twelve hidden neurons, and a single output neuron. The hyperbolic tangent activation function is applied to introduce nonlinearity into the network's transformations, facilitating the approximation of complex functional mappings between historical MMR observations and future values. This methodological framework is systematically implemented to generate annual maternal mortality ratio predictions for Kazakhstan, harnessing the ANN's superior pattern recognition and generalization capabilities to produce scientifically robust forecasts that can meaningfully inform maternal health policy and strategic planning.

Data Issues

The empirical investigation presented herein is predicated upon annual maternal mortality ratio (MMR) data for Kazakhstan, spanning the period from 1985 to 2023. This temporal scope, encompassing thirty-nine observations, provides a sufficiently extensive historical baseline to capture underlying trends, cyclical fluctuations, and structural shifts in maternal mortality dynamics over nearly four decades. The out-of-sample forecasting horizon extends from 2024 to 2035, thereby generating prospective estimates that cover a twelve-year forward-looking period. All time series data utilized in this research were systematically extracted from the World Bank's online open-access database, a globally recognized and authoritative repository that ensures data consistency, reliability, and cross-country comparability. The utilization of this standardized source enhances the reproducibility of the study and facilitates potential future comparative analyses with other nations or regional aggregates.

FINDINGS OF THE STUDY

ANN Model Summary

Table 1: ANN model summary

Variable	K
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	0.036049
MSE	2.642843
MAE	1.029153

Residual Analysis for the Applied Model

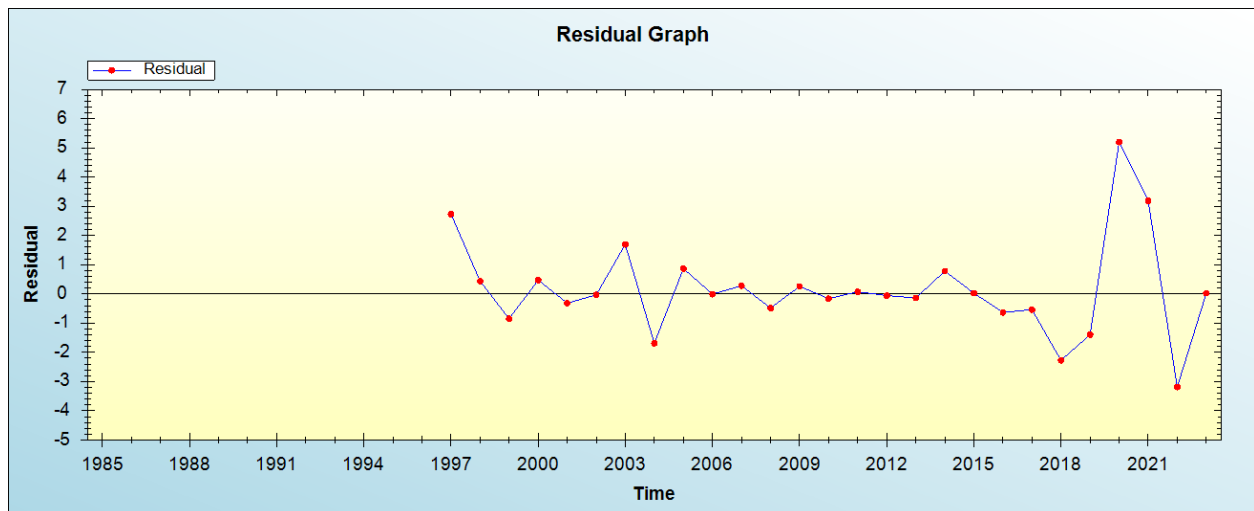


Figure 1: Residual analysis

In-sample Forecast for K

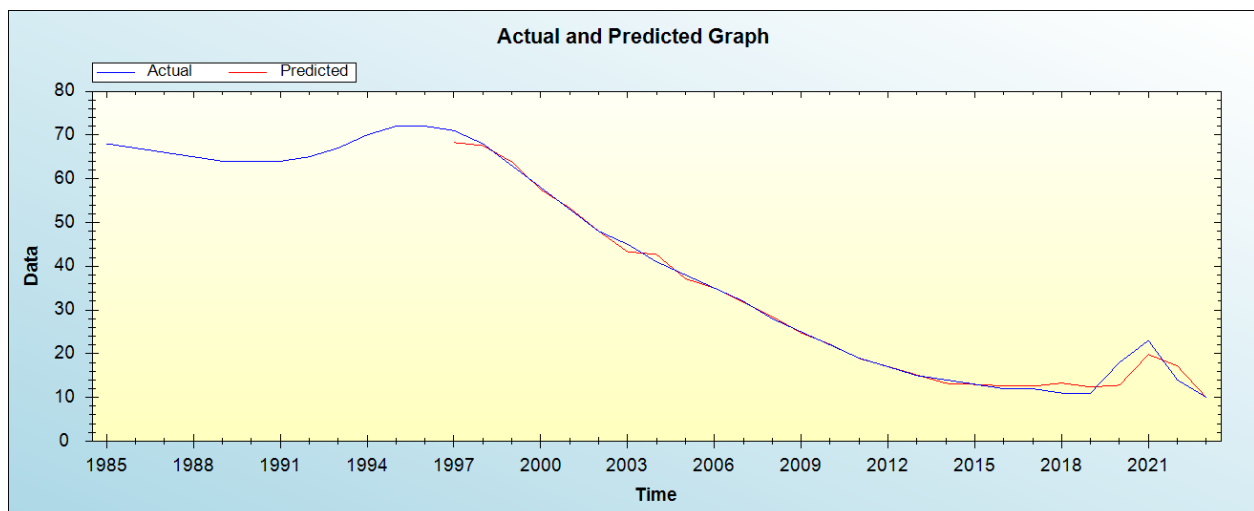


Figure 2: In-sample forecast for the K series

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

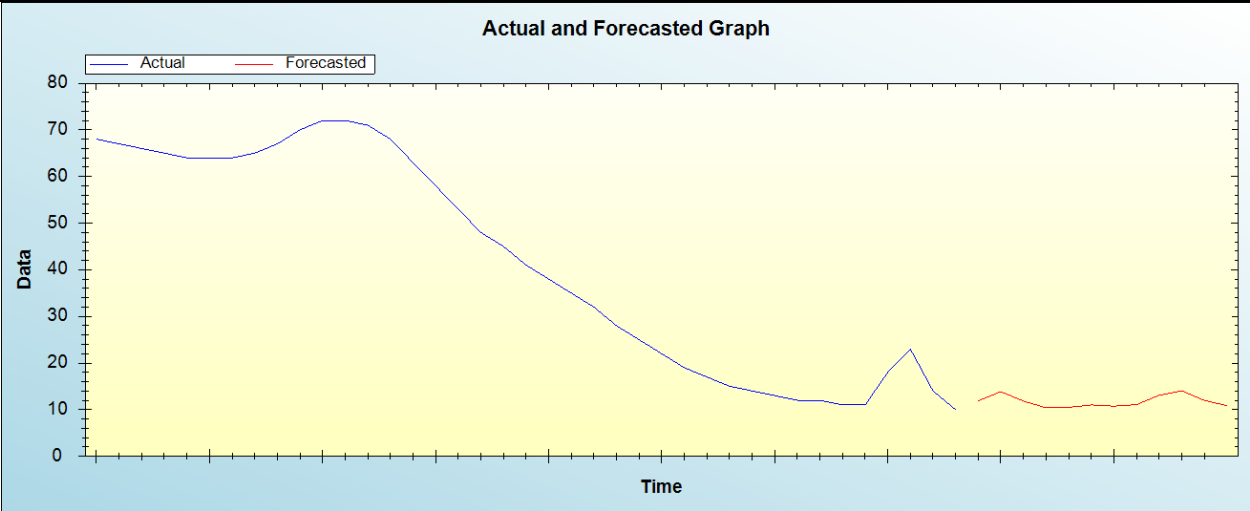


Figure 3: Out-of-sample forecast for K: actual and forecasted graph

Out-of-Sample Forecast for K: Forecasts only

Table 2: Tabulated out-of-sample forecasts

Year	Forecasted MMR
2024	11.9143
2025	13.8670
2026	11.8211
2027	10.3768
2028	10.4983
2029	11.0111
2030	10.7377
2031	11.0587
2032	13.0830
2033	14.0361
2034	11.9727
2035	10.8568

The principal empirical findings of this investigation are presented in Table 1, which summarizes the key performance metrics and architectural specifications of the applied neural network model. The stability and predictive reliability of the ANN (12, 12, 1)

model is rigorously corroborated through multiple evaluative criteria, including the attained Mean Squared Error (MSE) of 2.643 and Mean Absolute Error (MAE) of 1.029, which attest to the model’s superior forecasting accuracy. Further validation is derived from the

residual diagnostic plot depicted in Figure 1, wherein the residuals show random dispersion around the zero mean without discernible systematic patterns, thereby confirming the absence of autocorrelation, heteroscedasticity, or other specification errors that might compromise the integrity of the projections. Based upon the robust out-of-sample forecasts generated from this well-specified and empirically validated model, it is projected that Kazakhstan's annual maternal mortality ratio will sustain a persistently low trajectory throughout the entire forecast horizon spanning 2024 to 2035. This encouraging prognostic indication suggests that the declining momentum in maternal mortality, notwithstanding the anomalous spike observed in 2020, is poised to resume and stabilize at commendably low levels in the forthcoming years.

Projected Trajectory & Policy Implications

The out-of-sample forecasts, detailed in Table 2 and visualized in Figure 3, project that Kazakhstan's maternal mortality ratio (MMR) will remain persistently low throughout the 2024–2035 period, with predicted values fluctuating between 10.38 and 14.04 per 100,000 live births, averaging approximately 11.86 over the forecast horizon. This trajectory represents a remarkable and sustained improvement over historical peaks, notably the alarming spike to 36.5 per 100,000 live births recorded in 2020 (Nukeshtayeva et al., 2024) and significantly surpasses the global average of 233 per 100,000 live births (WHO, 2020). The projected MMR for 2030, estimated at 10.74 per 100,000 live births, substantially undercuts the Sustainable Development Goal (SDG) 3.1 target of 70 per 100,000 live births by 2030 (WHO, 2015), positioning Kazakhstan among the world's top-performing nations in maternal health outcomes. This encouraging forecast aligns with Zhamantayev *et al.*'s (2023) regional analysis showing a 38% decline in Central Asian MMR between 2000 and 2020, yet diverges sharply from their concerning finding that indirect causes of maternal deaths in Kazakhstan reached 76.3% in 2020, suggesting a shifting epidemiological profile that warrants

continued vigilance. The projected sustained low trajectory corroborates Gulis *et al.*'s (2021) observation that despite Kazakhstan being the weakest performer among OECD countries in health indicators, significant socioeconomic development and targeted health programming have yielded measurable dividends. However, the forecasted plateau at approximately 11–12 deaths per 100,000 live births also signals the potential exhaustion of gains achievable through current policy frameworks, implying that further reductions may require novel, more nuanced interventions addressing the residual determinants identified by Lima Figueiredo *et al.* (2024) and Sageer *et al.* (2019), including maternal age, educational attainment, antenatal care utilization, and health workforce density. The persistence of MMR at this level, while commendable in absolute terms, suggests that Kazakhstan could be approaching an epidemiological floor where traditional health system strengthening yields diminishing returns, necessitating a paradigm shift toward addressing deeper structural and social determinants that perpetuate the remaining mortality burden.

Comparative Context & Theoretical Integration

Situating these findings within the broader evidence base, Kazakhstan's projected MMR trajectory reveals both convergence with and divergence from regional and global patterns. The forecasted annual MMR of approximately 11 per 100,000 live births positions Kazakhstan considerably below the Central Asian regional average of 29.5 per 100,000 live births documented by Zhamantayev *et al.* (2023) and dramatically lower than the low-income country average of 462 per 100,000 live births (WHO, 2023), yet remains marginally above the European average of 11 per 100,000 live births (WHO, 2023). This intermediate positioning suggests that while Kazakhstan has successfully navigated the epidemiological transition from high to low maternal mortality, achieving parity with high-income nations remains an elusive objective requiring continued policy commitment. Our projections align with Nukeshtayeva *et al.*'s (2024) finding that

secondary education enrollment and domestic violence incidence emerged as significant predictors of MMR, pointing to the importance of multisectoral approaches that extend beyond the health sector. However, the projected stabilization of MMR at approximately 11 per 100,000 live births challenges the earlier conclusions of Turekulova *et al.* (2025), who documented substantial increases in DALYs for hypertensive disorders of pregnancy in Almaty between 2018 and 2020, suggesting that localized deteriorations may not necessarily translate into national-level reversals. The forecasted plateau also reflects the complex interplay of macro-structural determinants identified in the broader literature, including total health expenditure (Zhamantayev *et al.*, 2023), health workforce availability, and socioeconomic development indicators, implying that isolated health sector interventions cannot overcome broader systemic constraints without integrated multisectoral approaches. Moreover, the persistent albeit low mortality trajectory resonates with Pouyanfar *et al.*'s (2022) and Zalvand *et al.*'s (2019) identification of hemorrhage, hypertensive disorders, and embolism as predominant direct causes of maternal death, suggesting that even in low-mortality settings, obstetric emergencies remain a critical clinical priority requiring sustained investment in emergency obstetric care infrastructure, skilled birth attendance, and timely referral mechanisms. The projected trajectory, while encouraging, also raises important theoretical questions regarding the limits of health system interventions in achieving near-zero maternal mortality and the necessity of addressing upstream determinants including gender inequality, poverty and educational disparities that operate beyond the clinical domain.

RECOMMENDATIONS & CONCLUSION

The following practical policy measures are recommended to sustain this favourable trajectory and address residual mortality burden:

- i. **Strengthen Surveillance and Response Systems:** Enhance Maternal Death Surveillance and Response (MDSR) mechanisms to ensure complete ascertainment and timely review of all maternal deaths, addressing the substantial proportion of indirect causes. Establish standardized protocols for death notification, confidential enquiry, and committee review at all administrative levels, with clear accountability frameworks and feedback loops to translate findings into clinical practice improvements.
- ii. **Address Socioeconomic Determinants Through Multisectoral Collaboration:** Intensify investments in secondary education enrollment for girls, through targeted scholarships, retention programs, and community awareness campaigns. Concurrently, implement comprehensive strategies to address domestic violence incidence, another identified determinant, through strengthened legal frameworks, survivor support services, and primary prevention programs integrated into reproductive health services.
- iii. **Optimize Health Financing for Maternal Health:** Sustain and potentially increase total health expenditure. Allocate dedicated budget lines for maternal health services, including emergency obstetric care infrastructure, skilled birth attendance, referral systems, and community-based interventions targeting hard-to-reach populations.
- iv. **Enhance Emergency Obstetric and Newborn Care (EmONC):** Strengthen EmONC signal function capacity across all levels of the health system, ensuring 24/7 availability of comprehensive emergency obstetric services including caesarean section, blood

transfusion, and management of hypertensive disorders and hemorrhage. Prioritize the decentralization of specialist obstetric services to high-volume district hospitals, creating dedicated obstetrician posts or attaching Obstetrics and Gynaecology registrars under provincial consultant supervision to expand specialist coverage and strengthen workforce development.

- v. **Invest in Health Workforce Development:** Address health workforce shortages through expanded training, recruitment and retention incentives for midwives, nurses, and physicians, with particular emphasis on rural and underserved regions. Implement competency-based continuing education programs focused on evidence-based management of obstetric emergencies, including the leading direct causes of maternal death; hemorrhage, hypertensive disorders, and embolism.
- vi. **Strengthen Primary Healthcare and Antenatal Care:** Expand geographic and financial access to primary healthcare services, particularly antenatal care, through infrastructure development, community-based demand-generation strategies and elimination of financial barriers to maternity services. Integrate comprehensive sexual and reproductive health education into national curricula to address early pregnancy and promote reproductive health-seeking behaviours.
- vii. **Establish Continuous Quality Improvement Systems:** Institutionalize regular clinical audits, emergency obstetric drills, and competency-based training programs across all maternity facilities to ensure consistent adherence to evidence-

based guidelines and protocols. Foster a culture of safety, transparency, and continuous learning within the health system to optimize clinical outcomes and prevent avoidable maternal deaths.

The empirical evidence generated through this study projects Kazakhstan's maternal mortality ratio at approximately 11 deaths per 100,000 live births through 2035, confirming that the nation is well-positioned to achieve and substantially surpass the SDG 3.1 target of 70 per 100,000 live births under current policy trajectories. This encouraging projection reflects the cumulative impact of sustained socioeconomic development, targeted health programming and policy commitment over recent decades. However, the forecasted plateau at approximately 11–12 deaths per 100,000 live births signals that further reductions may require transformative, multisectoral interventions addressing both clinical and social determinants of maternal mortality. The persistent albeit low mortality burden, particularly from indirect causes, implies that traditional health system strengthening may yield diminishing returns, necessitating a paradigm shift toward upstream determinants including gender inequality, educational disparities, poverty, and systemic health system constraints. Without sustained policy commitment, continued investment in evidence-based strategies, and intensified focus on the residual determinants of maternal mortality, Kazakhstan risks perpetuating a plateau in maternal health outcomes that, while commendable by global standards, falls short of the near-zero mortality achievable through comprehensive, equitable, and resilient health systems. Urgent policy recalibration and sustained implementation of the recommended measures are imperative to consolidate gains, address emerging challenges and position Kazakhstan as a regional leader in maternal health excellence.

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