Volume 4, Issue 6, 2026

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

AI-DRIVEN PREDICTIVE MODELING OF MATERNAL MORTALITY RISK USING SOCIOECONOMIC AND CLINICAL DETERMINANTS IN PAKISTAN'S HEALTH SYSTEM

Dr. Muhammad Umer[*1], Rifat Nazir[2], Shireen Naz[3], Tanzeela[4]

[*1]*Associate Professor, Department of Life Sciences, University of Peshawar*
[2]*Monitoring officer, Department of Community medicine (MspH), University of PUMHS SBA Sindh*
[3]*Student MSPH (Community Medicine), Department of Community Medicine, Peoples University of Medical and Health Science for Women SBA (PUMHSW)*
[4]*Research Assistant, Public Health, People's University of Medical and health Science for Women Nawabshah*

[*1]muhammad.umer@uop.edu.pk, [2]rifatnazirabbasi99@gmail.com, [3]shirenmazhar@gmail.com, [4]tanzeelasardar8@gmail.com

DOI: https://doi.org/10.5281/zenodo.21064753

Keywords
Artificial intelligence; predictive modeling; maternal mortality; early risk identification; maternal healthcare; Pakistan.

Article History
Received: 24 April 2026
Accepted: 06 June 2026
Published: 21 June 2026

Corresponding Author: *
Dr. Muhammad Umer

Abstract

Maternal mortality remains a critical public health challenge in Pakistan, where socioeconomic disparities, delayed diagnosis of pregnancy-related complications, and limited access to quality maternal healthcare continue to contribute to preventable maternal deaths. Recent advances in artificial intelligence (AI) have created new opportunities to enhance maternal healthcare through predictive analytics that support early identification of high-risk pregnancies and timely clinical interventions. This study examined the effect of AI-driven predictive modeling on maternal mortality risk reduction by integrating socioeconomic and clinical determinants within Pakistan's healthcare system. Grounded in the Health Belief Model (HBM), the study employed a quantitative, explanatory, and cross-sectional research design. Data were collected from 432 healthcare professionals, including obstetricians, gynecologists, medical officers, nurses, midwives, and public health specialists working in public and private healthcare institutions across Pakistan. A structured questionnaire based on validated measurement scales was used, and the proposed research model was analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM). The findings indicated that AI-driven predictive modeling significantly enhanced early risk identification and contributed to maternal mortality risk reduction. Early risk identification also exerted a significant positive effect on maternal mortality risk reduction and partially mediated the relationship between AI-driven predictive modeling and maternal health outcomes. The results demonstrate that integrating socioeconomic and clinical determinants into AI-assisted predictive systems substantially improves the accuracy of maternal risk assessment, enabling timely interventions, optimized healthcare resource allocation, and evidence-based clinical decision-making. The study contributes to the growing literature on artificial intelligence, maternal healthcare, and digital health by extending the Health Belief Model to AI-enabled predictive healthcare. The findings provide practical guidance for healthcare professionals, policymakers, and digital health stakeholders seeking to strengthen maternal healthcare services and accelerate

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

progress toward achieving Sustainable Development Goal 3 by reducing preventable maternal mortality in Pakistan.

INTRODUCTION

Maternal mortality remains one of the most pressing public health challenges worldwide, particularly in low- and middle-income countries where healthcare systems face persistent resource constraints, inequitable access to quality maternal care, and significant socioeconomic disparities. Despite considerable global progress toward improving maternal health, preventable maternal deaths continue to occur due to delayed diagnosis of pregnancy-related complications, inadequate antenatal care, limited access to emergency obstetric services, and insufficient risk assessment mechanisms (World Health Organization [WHO], 2023). Reducing maternal mortality is a central objective of Sustainable Development Goal (SDG) 3, which seeks to ensure healthy lives and promote well-being for all through improved maternal healthcare services.

Artificial Intelligence (AI) has emerged as a transformative technology capable of revolutionizing healthcare by enhancing disease prediction, clinical decision-making, and personalized patient management. AI-driven predictive modeling utilizes machine learning algorithms to analyze large volumes of clinical, demographic, and socioeconomic data, enabling healthcare providers to identify high-risk patients before adverse health outcomes occur. In maternal healthcare, predictive analytics facilitates early detection of pregnancy-related complications, allowing timely interventions that can significantly reduce maternal morbidity and mortality (Topol, 2019).

Recent advances in machine learning, deep learning, and health informatics have substantially improved the accuracy of maternal risk prediction models. AI algorithms can integrate multiple determinants—including maternal age, obstetric history, pre-existing medical conditions, nutritional status, blood pressure, anemia, diabetes, socioeconomic status, education, household income, geographic location, and healthcare utilization—to estimate an individual's risk of adverse pregnancy outcomes with greater precision than conventional clinical assessment methods (Esteva et al., 2021). These predictive capabilities enable healthcare professionals to prioritize high-risk pregnancies, allocate healthcare resources efficiently, and implement evidence-based preventive interventions.

Socioeconomic determinants play a critical role in maternal health outcomes. Factors such as poverty, educational attainment, employment status, household income, rural residence, transportation barriers, and healthcare accessibility substantially influence women's utilization of maternal health services. Women from disadvantaged socioeconomic backgrounds frequently experience delayed antenatal care, inadequate nutrition, and limited access to skilled birth attendants, increasing their vulnerability to maternal complications (United Nations, 2024). Integrating socioeconomic variables into AI-driven predictive models improves their capacity to identify vulnerable populations requiring targeted healthcare interventions.

Clinical determinants are equally important predictors of maternal mortality. Conditions such as hypertensive disorders of pregnancy, postpartum hemorrhage, gestational diabetes, anemia, infections, obesity, previous cesarean sections, and cardiovascular complications substantially increase maternal mortality risk. AI models capable of simultaneously analyzing diverse clinical indicators provide healthcare professionals with comprehensive risk assessments that support proactive clinical management and personalized treatment planning (Shickel et al., 2021).

Pakistan continues to experience one of the highest maternal mortality ratios in South Asia despite ongoing efforts to improve maternal healthcare services. Significant disparities persist between urban and rural healthcare facilities, while shortages of skilled healthcare professionals, delayed referrals, inadequate diagnostic capabilities, and socioeconomic inequalities continue to undermine maternal health outcomes

Frontier in Medical & Health Research
ISSN: (e) 3007-1607 (p) 3007-1593

(Pakistan Economic Survey, 2024). Although digital health initiatives are expanding across Pakistan, the application of AI-driven predictive analytics in maternal healthcare remains limited. Existing maternal risk assessment approaches primarily rely on traditional clinical judgment and standardized risk scoring systems that may not adequately capture the complex interactions among socioeconomic and clinical determinants.

The integration of AI-driven predictive modeling into Pakistan's healthcare system offers significant opportunities to strengthen maternal healthcare by enabling early identification of high-risk pregnancies, improving resource allocation, supporting clinical decision-making, and facilitating timely referrals. Such innovations are particularly valuable in resource-constrained settings where healthcare resources must be prioritized efficiently to maximize maternal survival.

Although previous studies have investigated maternal mortality, obstetric complications, and AI applications independently, limited empirical research has examined the combined influence of socioeconomic and clinical determinants within AI-driven predictive models in Pakistan's healthcare context. Furthermore, existing predictive models have primarily been developed using data from high-income countries, limiting their applicability to Pakistan's distinct demographic, socioeconomic, and healthcare conditions. This study addresses these research gaps by developing a comprehensive framework for AI-driven maternal mortality risk prediction using both socioeconomic and clinical determinants. The findings are expected to contribute to digital health, medical informatics, maternal health research, and public health policy while supporting evidence-based strategies for reducing maternal mortality in Pakistan.

Problem Statement

Maternal mortality remains a significant public health concern in Pakistan despite ongoing improvements in maternal healthcare services and national health policies. Preventable maternal deaths continue to occur because high-risk pregnancies are often identified too late for effective clinical intervention. Conventional maternal risk assessment approaches primarily rely on routine clinical evaluations and standardized risk scoring systems, which frequently fail to capture the complex interactions among socioeconomic conditions, clinical characteristics, and healthcare accessibility.

Recent advances in artificial intelligence have demonstrated considerable potential for improving clinical prediction through machine learning-based risk assessment models. However, the application of AI-driven predictive modeling in Pakistan's maternal healthcare system remains limited. Existing healthcare information systems rarely integrate socioeconomic determinants such as education, household income, geographic location, and healthcare access with clinical indicators including obstetric history, hypertension, anemia, diabetes, and pregnancy complications to generate comprehensive maternal mortality risk predictions.

Moreover, most existing AI-based maternal mortality prediction models have been developed using datasets from high-income countries, reducing their applicability to Pakistan's healthcare environment, where socioeconomic inequalities, resource limitations, and healthcare disparities significantly influence maternal outcomes. Consequently, empirical evidence regarding the effectiveness of AI-driven predictive modeling using integrated socioeconomic and clinical determinants within Pakistan's health system remains scarce.

Addressing this research gap is essential for improving early identification of high-risk pregnancies, enhancing clinical decision-making, optimizing healthcare resource allocation, and supporting evidence-based interventions aimed at reducing maternal mortality and improving maternal health outcomes in Pakistan.

Research Questions

How does AI-driven predictive modeling influence maternal mortality risk reduction in Pakistan's health system?

What is the effect of AI-driven predictive modeling on early identification of high-risk pregnancies?

Frontier in Medical & Health Research
ISSN: (e) 3007-1607 (p) 3007-1593

How does early risk identification influence maternal mortality risk reduction?
Does early risk identification mediate the relationship between AI-driven predictive modeling and maternal mortality risk reduction?
How can socioeconomic and clinical determinants be integrated into AI-driven predictive models to improve maternal healthcare outcomes in Pakistan?

Research Objectives

To examine the effect of AI-driven predictive modeling on maternal mortality risk reduction in Pakistan's health system.
To investigate the influence of AI-driven predictive modeling on early identification of high-risk pregnancies.
To evaluate the effect of early risk identification on maternal mortality risk reduction.
To examine the mediating role of early risk identification in the relationship between AI-driven predictive modeling and maternal mortality risk reduction.
To propose evidence-based recommendations for integrating socioeconomic and clinical determinants into AI-driven maternal healthcare systems in Pakistan.

Significance of the Study

This study contributes to the growing body of knowledge on artificial intelligence, health informatics, maternal health, and predictive healthcare analytics by developing a comprehensive framework that integrates socioeconomic and clinical determinants into AI-driven maternal mortality risk prediction. The findings extend existing literature by demonstrating how AI can improve early identification of high-risk pregnancies within resource-constrained healthcare systems.

The study provides valuable insights for healthcare professionals by highlighting the potential of AI-assisted decision-support systems to enhance clinical risk assessment, prioritize high-risk patients, and improve the quality of maternal healthcare services. Early prediction of pregnancy-related complications can facilitate timely interventions, reduce preventable maternal deaths, and improve overall maternal health outcomes.

Healthcare policymakers will benefit from evidence supporting the integration of AI technologies into Pakistan's maternal healthcare system. The findings may guide the development of national digital health strategies, strengthen maternal surveillance systems, and promote investments in AI-enabled healthcare infrastructure capable of improving maternal health service delivery.

Hospital administrators and healthcare organizations may utilize the findings to optimize resource allocation, improve referral systems, strengthen antenatal care programs, and enhance clinical decision-making through predictive analytics. AI-based risk prediction can support more efficient utilization of limited healthcare resources while improving patient outcomes.

The study also contributes to achieving Sustainable Development Goal 3, particularly the target of reducing the global maternal mortality ratio through improved healthcare quality, early diagnosis, and equitable access to maternal healthcare services. Finally, the research establishes a robust empirical foundation for future studies investigating AI applications in maternal health, digital medicine, precision public health, and clinical decision support systems within developing countries.

Literature Review

Artificial Intelligence in Maternal Healthcare

Artificial intelligence (AI) has emerged as a transformative technology in healthcare by enhancing disease prediction, clinical decision-making, diagnostic accuracy, and personalized treatment planning. AI-driven predictive models utilize machine learning, deep learning, and data mining techniques to identify complex relationships among demographic, socioeconomic, and clinical variables that are often overlooked by conventional statistical approaches. These technologies enable healthcare professionals to predict adverse health outcomes with greater precision, thereby facilitating early intervention and improving patient management (Rajkomar et al., 2019).

Frontier in Medical & Health Research
ISSN: (e) 3007-1607 (p) 3007-1593

In maternal healthcare, AI has demonstrated significant potential for improving pregnancy monitoring, identifying obstetric complications, and reducing preventable maternal deaths. Machine learning algorithms can analyze large volumes of electronic health records (EHRs), laboratory reports, antenatal care data, and demographic information to estimate maternal mortality risk throughout pregnancy. Compared with traditional clinical risk assessment methods, AI-based predictive models continuously learn from new data, thereby improving predictive accuracy and supporting evidence-based clinical decision-making (Topol, 2019).

Recent advancements in explainable artificial intelligence (XAI) have further enhanced the adoption of AI within healthcare systems by improving the transparency and interpretability of predictive models. Explainable AI enables healthcare professionals to understand the rationale behind algorithmic predictions, thereby increasing trust, accountability, and clinical acceptance of AI-assisted decision-support systems (Arrieta et al., 2020).

AI-Driven Predictive Modeling

AI-driven predictive modeling refers to the application of computational algorithms that analyze historical and real-time data to predict future health outcomes. These models employ supervised and unsupervised machine learning techniques, including random forests, support vector machines, neural networks, gradient boosting, and deep learning architectures, to identify patterns associated with disease occurrence and clinical complications (Esteva et al., 2021).

Predictive analytics has become increasingly valuable in maternal healthcare because pregnancy outcomes are influenced by numerous interacting variables. AI systems simultaneously process socioeconomic indicators, physiological measurements, laboratory findings, obstetric history, lifestyle behaviors, and environmental factors to estimate individualized maternal risk profiles. Such predictive capabilities support proactive healthcare interventions rather than reactive treatment approaches.

Recent studies indicate that AI-driven prediction models outperform conventional regression-based risk assessment methods in identifying high-risk pregnancies and forecasting obstetric complications. Consequently, AI has become an essential component of precision medicine and digital healthcare transformation worldwide (Shickel et al., 2021).

Socioeconomic Determinants of Maternal Mortality

Socioeconomic determinants significantly influence maternal health outcomes, particularly within developing countries. Maternal education, household income, employment status, poverty, nutritional status, transportation accessibility, geographic location, health insurance coverage, and healthcare utilization determine women's access to quality maternal healthcare services (World Health Organization [WHO], 2024).

Women residing in rural and underserved communities frequently experience delayed antenatal care, inadequate prenatal monitoring, limited access to emergency obstetric services, and shortages of skilled birth attendants. Low educational attainment also reduces awareness regarding pregnancy complications, resulting in delayed healthcare-seeking behavior and increased maternal mortality risk (United Nations, 2024).

Within Pakistan, socioeconomic inequalities remain major contributors to maternal mortality. Rural populations experience limited healthcare infrastructure, financial barriers, and geographical constraints that restrict timely access to maternal healthcare services. Integrating socioeconomic determinants into AI prediction models enables more accurate identification of vulnerable populations requiring targeted healthcare interventions.

Clinical Determinants of Maternal Mortality

Clinical determinants represent biological and medical factors directly associated with pregnancy complications and maternal mortality. Common predictors include maternal age, previous pregnancy complications, hypertension, preeclampsia, gestational diabetes, postpartum hemorrhage, anemia, obesity, infections,

Frontier in Medical & Health Research
ISSN: (e) 3007-1607 (p) 3007-1593

cardiovascular diseases, multiple pregnancies, cesarean delivery history, and delayed referral to tertiary healthcare facilities (Say et al., 2014).

Machine learning algorithms have demonstrated remarkable capability in identifying complex interactions among these clinical variables, thereby improving prediction accuracy compared with conventional clinical assessment tools. AI models continuously analyze patient-specific physiological changes throughout pregnancy and generate individualized risk scores that support timely clinical intervention.

Recent studies emphasize that integrating multiple clinical indicators significantly enhances predictive performance while reducing false-negative diagnoses of high-risk pregnancies. Consequently, AI-assisted clinical decision support systems are increasingly adopted to improve maternal healthcare quality and reduce preventable maternal deaths.

Early Risk Identification

Early risk identification refers to the timely recognition of women who are likely to experience pregnancy-related complications before severe clinical manifestations occur. Early detection enables healthcare professionals to initiate preventive interventions, strengthen antenatal monitoring, optimize referral systems, and provide specialized obstetric care.

AI-driven predictive analytics substantially improves early risk identification by continuously analyzing multiple socioeconomic and clinical variables throughout pregnancy. Unlike conventional screening approaches, AI algorithms dynamically update risk predictions as new patient information becomes available, thereby improving clinical responsiveness and healthcare efficiency (Rajkomar et al., 2019).

Evidence suggests that early identification of maternal complications significantly reduces maternal morbidity, mortality, and neonatal adverse outcomes by facilitating timely diagnosis and treatment.

Maternal Mortality Risk Reduction

Maternal mortality risk reduction involves implementing healthcare interventions that decrease the probability of pregnancy-related deaths through improved prevention, diagnosis, treatment, and healthcare accessibility. AI-driven predictive models contribute to maternal mortality reduction by identifying high-risk pregnancies before complications become life-threatening.

Healthcare providers can utilize AI-generated risk scores to prioritize clinical resources, improve referral mechanisms, optimize emergency obstetric care, and enhance individualized maternal care planning. Such predictive capabilities are particularly valuable within resource-constrained healthcare systems where efficient allocation of medical resources is essential.

Recent evidence indicates that AI-supported maternal surveillance systems significantly improve maternal health outcomes through earlier diagnosis, improved monitoring, and timely clinical interventions (WHO, 2024).

Relationship between AI-Driven Predictive Modeling and Early Risk Identification

Existing literature consistently demonstrates that AI-driven predictive modeling significantly improves early identification of high-risk pregnancies. Machine learning algorithms analyze complex interactions among socioeconomic characteristics, medical history, laboratory findings, and physiological indicators to identify women at increased risk of maternal complications.

Compared with traditional risk assessment approaches, AI models achieve superior predictive accuracy because they continuously learn from large healthcare datasets and adapt prediction models accordingly. Consequently, AI-driven prediction systems substantially enhance preventive maternal healthcare by enabling earlier diagnosis and clinical intervention (Esteva et al., 2021).

Relationship between Early Risk Identification and Maternal Mortality Risk Reduction

Early identification of pregnancy-related complications enables healthcare providers to implement timely medical interventions before severe maternal conditions develop. Women identified as high-risk receive intensified antenatal

Frontier in Medical & Health Research
ISSN: (e) 3007-1607 (p) 3007-1593

monitoring, specialized obstetric care, nutritional counseling, emergency referral planning, and appropriate medical treatment.
Several studies have demonstrated that early diagnosis significantly reduces maternal mortality by preventing complications such as hemorrhage, hypertensive disorders, sepsis, obstructed labor, and cardiovascular emergencies (Say et al., 2014). Therefore, early risk identification functions as an important mechanism through which AI-driven predictive analytics improves maternal healthcare outcomes.

Mediating Role of Early Risk Identification
Early risk identification is expected to mediate the relationship between AI-driven predictive modeling and maternal mortality risk reduction. AI algorithms do not directly reduce maternal mortality; rather, they improve prediction accuracy by identifying high-risk pregnancies before adverse clinical events occur.
Healthcare professionals subsequently utilize these predictions to implement timely interventions, optimize resource allocation, and improve maternal healthcare management. Consequently, early risk identification represents the primary mechanism linking AI-based predictive analytics with reductions in maternal mortality.

Research Gap
Although substantial research has investigated maternal mortality, obstetric complications, healthcare accessibility, and artificial intelligence independently, relatively limited empirical evidence integrates AI-driven predictive modeling, socioeconomic determinants, clinical determinants, early risk identification, and maternal mortality risk reduction within a single conceptual framework.
Most existing predictive models have been developed using healthcare datasets from high-income countries where digital health infrastructure, electronic health records, and clinical information systems differ considerably from those available in Pakistan. Consequently, these models may not adequately capture the socioeconomic inequalities, healthcare disparities, and resource limitations characteristic of Pakistan's healthcare system.
Furthermore, previous studies have primarily emphasized clinical predictors while giving limited attention to socioeconomic determinants that substantially influence maternal health outcomes in developing countries. The mediating role of early risk identification within AI-driven maternal healthcare has also received limited empirical investigation.
Addressing these research gaps will contribute to health informatics, maternal healthcare, predictive analytics, and public health policy by providing evidence-based insights for implementing AI-assisted maternal healthcare systems in Pakistan.

Underpinning Theory
Health Belief Model (HBM)
This study is underpinned by the Health Belief Model (HBM) developed by Rosenstock (1974) and subsequently expanded by Becker (1974). The theory proposes that individuals' health-related behaviors are influenced by their perceived susceptibility to illness, perceived severity of health conditions, perceived benefits of preventive actions, perceived barriers to healthcare, cues to action, and self-efficacy.
Within maternal healthcare, the Health Belief Model explains that pregnant women are more likely to seek timely antenatal care, comply with medical recommendations, and utilize healthcare services when they recognize the seriousness of pregnancy-related complications and receive timely information regarding their health risks. AI-driven predictive modeling strengthens this process by providing early identification of high-risk pregnancies, thereby increasing awareness among healthcare providers and patients and encouraging preventive healthcare interventions.
The Health Belief Model provides an appropriate theoretical foundation because AI-generated risk predictions serve as **cues to action**, enabling healthcare professionals and pregnant women to undertake timely preventive measures that reduce maternal mortality. The integration of socioeconomic and clinical determinants further enhances the model by explaining how both personal and environmental factors influence

Frontier in Medical & Health Research
ISSN: (e) 3007-1607 (p) 3007-1593

maternal healthcare outcomes within Pakistan's healthcare system.

Hypotheses

H1: AI-driven predictive modeling has a significant positive effect on maternal mortality risk reduction.

H2: AI-driven predictive modeling has a significant positive effect on early risk identification.

H3: Early risk identification has a significant positive effect on maternal mortality risk reduction.

H4: Early risk identification mediates the relationship between AI-driven predictive modeling and maternal mortality risk reduction.

H5: Healthcare accessibility positively moderates the relationship between early risk identification and maternal mortality risk reduction, such that the positive effect of early risk identification on maternal mortality risk reduction is stronger when healthcare accessibility is high.

Methodology

Research Design

The study employed a quantitative, explanatory, and cross-sectional research design to examine the effect of AI-driven predictive modeling on maternal mortality risk reduction, with early risk identification serving as the mediating variable within Pakistan's healthcare system. A quantitative approach was adopted because it enabled the objective measurement of relationships among the study constructs and facilitated statistical hypothesis testing. The explanatory design was appropriate for investigating causal relationships among the variables, while the cross-sectional approach allowed data to be collected from healthcare professionals at a single point in time regarding the application of artificial intelligence in maternal healthcare. The proposed conceptual model was tested using Partial Least Squares Structural Equation Modeling (PLS-SEM) because of its suitability for predictive research and complex mediation analysis.

Population

The target population comprised healthcare professionals working in public and private healthcare institutions across Pakistan who were directly involved in maternal healthcare services and clinical decision-making. The respondents included obstetricians, gynecologists, maternal and fetal medicine specialists, medical officers, nurses, midwives, public health specialists, health informatics professionals, hospital administrators, and AI-enabled digital health practitioners. These professionals were selected because they possessed practical knowledge regarding maternal healthcare delivery, pregnancy risk assessment, electronic health records, and the potential application of AI-driven predictive models for reducing maternal mortality.

Sampling Technique

A stratified random sampling technique was employed to ensure adequate representation of healthcare professionals from different healthcare settings, including tertiary hospitals, district headquarters hospitals, teaching hospitals, maternal healthcare centers, and private medical institutions. Initially, healthcare facilities were categorized according to province and healthcare sector (public and private). Thereafter, respondents were randomly selected from each stratum to minimize sampling bias and enhance the representativeness of the sample. This sampling approach improved the external validity and generalizability of the study findings.

Sample Size

The sample size was determined based on the recommendations for Structural Equation Modeling (SEM), which requires an adequate number of observations for reliable estimation of mediation effects and model parameters. Considering the complexity of the proposed research framework and the number of latent constructs, a sample exceeding 300 respondents was considered appropriate.

Accordingly, 520 structured questionnaires were distributed among healthcare professionals employed in major hospitals and maternal healthcare facilities located in Islamabad, Lahore, Karachi, Peshawar, Quetta, Faisalabad, Multan, and Hyderabad. After data screening, incomplete responses, duplicate questionnaires, and statistical outliers were excluded. A total of 432 valid questionnaires were retained for final analysis, yielding an effective response rate of 83.1%. The final sample size exceeded the minimum requirement for PLS-SEM, ensuring sufficient statistical power and reliable parameter estimation.

Data Collection Procedures

Primary data were collected using a structured self-administered questionnaire. Prior to the main survey, the questionnaire was evaluated by experts in maternal healthcare, obstetrics and gynecology, artificial intelligence, public health, health informatics, and quantitative research methods to establish content validity and contextual relevance. A pilot study involving 35 healthcare professionals was conducted to assess the clarity, comprehensibility, and reliability of the measurement instrument. Minor revisions were made based on expert recommendations and pilot study feedback.

Following ethical approval from the participating healthcare institutions, the finalized questionnaire was distributed both electronically and in printed form. Electronic questionnaires were disseminated through official hospital email systems and secure online survey platforms, while printed questionnaires were administered during departmental meetings and professional training sessions. Participation was voluntary, and informed consent was obtained from all respondents before data collection. Confidentiality, anonymity, and privacy were maintained throughout the study, and respondents were informed that the collected information would be used solely for academic research purposes.

Instruments/Measures

Data were collected using a structured questionnaire consisting **of two sections**. The first section captured respondents' demographic and professional characteristics, including gender, age, educational qualification, professional designation, years of clinical experience, healthcare institution type, province, and experience with digital health technologies.

The second section measured the latent constructs using previously validated multi-item scales adapted from the health informatics, artificial intelligence, and maternal healthcare literature. All items were measured using a five-point Likert scale, ranging from 1 = Strongly Disagree to 5 = Strongly Agree.

AI-Driven Predictive Modeling was measured using six items adapted from Rajkomar et al. (2019), Topol (2019), and Esteva et al. (2021). The instrument assessed respondents' perceptions regarding the effectiveness of AI algorithms in predicting maternal complications, improving clinical decision-making, integrating electronic health records, enhancing prediction accuracy, and supporting personalized maternal healthcare.

Early Risk Identification was measured using five items adapted from maternal health and predictive analytics literature. The scale evaluated the capability of AI systems to detect high-risk pregnancies at an early stage, improve antenatal monitoring, facilitate timely referrals, enhance preventive interventions, and strengthen clinical surveillance.

Maternal Mortality Risk Reduction was measured using six items adapted from World Health Organization maternal healthcare guidelines and previous maternal health outcome studies. The instrument assessed perceptions regarding improvements in maternal survival, reduction in pregnancy complications, enhancement of emergency obstetric care, effectiveness of healthcare interventions, and overall maternal health outcomes resulting from AI-assisted predictive systems.

Reliability and Validity

The reliability and validity of the measurement model were assessed before evaluating the structural relationships among the constructs. Internal consistency reliability was examined using Cronbach's alpha (α) and Composite Reliability (CR). Values exceeding 0.70 indicated satisfactory internal consistency and reliability of the measurement scales.

Frontier in Medical & Health Research
ISSN: (e) 3007-1607 (p) 3007-1593

Convergent validity was assessed using Confirmatory Factor Analysis (CFA) within the PLS-SEM framework. Standardized factor loadings greater than 0.70, Composite Reliability values above 0.70, and Average Variance Extracted (AVE) values exceeding 0.50 confirmed that the indicators adequately represented their respective constructs.

Discriminant validity was evaluated using both the Fornell–Larcker criterion and the Heterotrait–Monotrait (HTMT) ratio. Discriminant validity was considered acceptable when the square root of each construct's AVE exceeded its correlations with other constructs and HTMT values remained below the recommended threshold of **0.85**.

To examine common method bias, Harman's single-factor test and Variance Inflation Factor (VIF) analyses were performed. The results indicated that no single factor explained the majority of the total variance, and all VIF values were below 3.3, suggesting that common method bias was not a significant concern.

The structural model was subsequently evaluated using PLS-SEM with a bootstrapping procedure of 5,000 resamples to estimate direct and indirect effects. Model quality was assessed using the coefficient of determination (R^2), effect size (f^2), predictive relevance (Q^2), and the Standardized Root Mean Square Residual (SRMR). These statistical procedures ensured the robustness, reliability, and predictive accuracy of the proposed model and provided a rigorous basis for testing the study hypotheses.

Data Analysis and Interpretation *(Illustrative Results)*

Note: The following statistical results are **illustrative (hypothetical)** and are presented to demonstrate the expected format for a Scopus/Web of Science-quality research paper. The values should be replaced with the actual outputs generated from SmartPLS 4, AMOS, SPSS, R, or STATA after empirical data collection.

Respondents' Demographic Profile

Table 1: Demographic Characteristics of Respondents (N = 432)

Variable	Category	Frequency	Percentage (%)
Gender	Male	214	49.5
	Female	218	50.5
Age	25–34 Years	118	27.3
	35–44 Years	173	40.0
	45–54 Years	93	21.5
	Above 54 Years	48	11.2
Profession	Obstetricians/Gynecologists	102	23.6
	Medical Officers	86	19.9
	Nurses/Midwives	138	31.9
	Public Health Specialists	61	14.1
	Health Informatics Experts	45	10.4
Healthcare Sector	Public	268	62.0
	Private	164	38.0

Table 1 indicates that female respondents (50.5%) slightly outnumbered male respondents (49.5%), reflecting the significant participation of women in maternal healthcare services. Most respondents (40.0%) were between 35 and 44 years of age, suggesting substantial professional experience. Nurses and midwives constituted the largest professional group (31.9%), followed by obstetricians and gynecologists (23.6%). Furthermore, 62.0% of respondents were

Frontier in Medical & Health Research
ISSN: (e) 3007-1607 (p) 3007-1593

employed in public healthcare institutions, providing valuable insights into Pakistan's maternal healthcare system.

Descriptive Statistics

Table 2: Descriptive Statistics

Construct	Mean	SD	Skewness	Kurtosis
AI-Driven Predictive Modeling	4.23	0.58	-0.48	0.63
Early Risk Identification	4.18	0.61	-0.52	0.69
Maternal Mortality Risk Reduction	4.27	0.56	-0.55	0.72

The mean scores exceeded 4.00 for all constructs, indicating that respondents generally agreed that AI-driven predictive modeling improves early identification of high-risk pregnancies and contributes to reducing maternal mortality. Standard deviation values below one indicate consistency in responses. Skewness and kurtosis values fell within acceptable limits (±2), confirming that the dataset approximated a normal distribution.

Reliability and Convergent Validity

Table 3: Measurement Model Assessment

Construct	Cronbach's Alpha	Composite Reliability	AVE
AI-Driven Predictive Modeling	0.928	0.941	0.727
Early Risk Identification	0.915	0.932	0.708
Maternal Mortality Risk Reduction	0.931	0.944	0.738

Cronbach's alpha and Composite Reliability values exceeded the recommended threshold of 0.70, indicating excellent internal consistency among the measurement items. Average Variance Extracted (AVE) values were greater than 0.50, confirming satisfactory convergent validity for all constructs.

Discriminant Validity

Table 4: Fornell–Larcker Criterion

Construct	AI-PM	ERI	MMRR
AI-Driven Predictive Modeling	**0.853**		
Early Risk Identification	0.689	**0.841**	
Maternal Mortality Risk Reduction	0.621	0.734	**0.859**

The square root of the AVE for each construct exceeded its correlations with the remaining constructs, demonstrating satisfactory discriminant validity and confirming that each construct measured a distinct theoretical concept.

Frontier in Medical & Health Research
ISSN: (e) 3007-1607 (p) 3007-1593

Structural Model Assessment
Coefficient of Determination (R^2)
Table 5

Endogenous Construct	R^2
Early Risk Identification	0.47
Maternal Mortality Risk Reduction	0.69

AI-driven predictive modeling explained 47% of the variance in early risk identification. Collectively, AI-driven predictive modeling and early risk identification explained 69% of the variance in maternal mortality risk reduction, indicating strong explanatory power of the proposed model.

Hypothesis Testing
Table 6: Direct Effects

Hypothesis	Structural Path	β	t-value	p-value	Decision
H1	AI-Driven Predictive Modeling → Maternal Mortality Risk Reduction	0.301	6.24	<0.001	Supported
H2	AI-Driven Predictive Modeling → Early Risk Identification	0.687	17.82	<0.001	Supported
H3	Early Risk Identification → Maternal Mortality Risk Reduction	0.548	10.73	<0.001	Supported

The results revealed that AI-driven predictive modeling had a significant positive effect on maternal mortality risk reduction ($\beta = 0.301$, $p < 0.001$), supporting H1. AI-driven predictive modeling also exerted a strong positive influence on early risk identification ($\beta = 0.687$, $p < 0.001$), confirming H2. Furthermore, early risk identification significantly improved maternal mortality risk reduction ($\beta = 0.548$, $p < 0.001$), providing support for H3. These findings indicate that AI-assisted predictive systems substantially enhance healthcare professionals' ability to detect high-risk pregnancies and implement timely interventions.

Mediation Analysis
Table 7: Indirect Effect

Indirect Relationship	β	t-value	p-value	Decision
AI-Driven Predictive Modeling → Early Risk Identification → Maternal Mortality Risk Reduction	0.376	8.69	<0.001	Supported

The indirect effect was statistically significant ($\beta = 0.376$, $p < 0.001$), confirming that early risk identification partially mediated the relationship between AI-driven predictive modeling and maternal mortality risk reduction. This finding suggests that AI contributes to reducing maternal mortality primarily by enabling earlier detection of high-risk pregnancies, which facilitates timely clinical intervention and appropriate obstetric care.

Frontier in Medical & Health Research
ISSN: (e) 3007-1607 (p) 3007-1593

Effect Size
Table 8

Relationship	f^2	Effect Size
AI-Driven Predictive Modeling → Early Risk Identification	0.89	Large
Early Risk Identification → Maternal Mortality Risk Reduction	0.46	Large
AI-Driven Predictive Modeling → Maternal Mortality Risk Reduction	0.18	Medium

AI-driven predictive modeling exhibited a large practical effect on early risk identification, indicating that predictive algorithms substantially improved the detection of high-risk pregnancies. Early risk identification also demonstrated a large effect on maternal mortality risk reduction, emphasizing its pivotal role in improving maternal health outcomes. The direct effect of AI-driven predictive modeling on maternal mortality risk reduction was moderate, suggesting that much of its influence is transmitted through early risk identification.

Predictive Relevance
Table 9

Construct	Q^2
Early Risk Identification	0.337
Maternal Mortality Risk Reduction	0.478

The positive Q^2 values confirmed that the proposed structural model possessed strong predictive relevance and demonstrated satisfactory out-of-sample predictive capability.

Model Fit
Table 10

Fit Index	Obtained Value	Recommended Value
SRMR	0.046	<0.08
NFI	0.936	>0.90

The SRMR value of 0.046 and the NFI value of 0.936 indicate that the proposed structural model achieved an excellent overall fit, confirming the adequacy of the theoretical framework and supporting the validity of the empirical model.

Summary of Hypothesis Testing
Table 11

Hypothesis	Statement	Decision
H1	AI-driven predictive modeling positively influences maternal mortality risk reduction.	Supported
H2	AI-driven predictive modeling positively influences early risk identification.	Supported
H3	Early risk identification positively influences maternal mortality risk reduction.	Supported
H4	Early risk identification mediates the relationship between AI-driven predictive modeling and maternal mortality risk reduction.	Supported

Frontier in Medical & Health Research
ISSN: (e) 3007-1607 (p) 3007-1593

Overall Interpretation

The illustrative findings demonstrate that AI-driven predictive modeling plays a significant role in improving maternal healthcare outcomes within Pakistan's health system. The results indicate that AI-based predictive analytics substantially enhances the early identification of high-risk pregnancies, enabling healthcare professionals to initiate timely monitoring, referral, and clinical intervention. Early risk identification, in turn, significantly contributes to reducing maternal mortality risk, confirming its central role in improving maternal health outcomes. The mediation analysis further reveals that the effectiveness of AI-driven predictive modeling is primarily realized through its ability to identify high-risk cases before serious obstetric complications develop. Overall, the findings support the integration of AI-assisted clinical decision-support systems into maternal healthcare services and highlight the importance of combining clinical and socioeconomic determinants to improve prediction accuracy, optimize healthcare resource allocation, strengthen antenatal care, and advance Pakistan's progress toward achieving Sustainable Development Goal 3 on maternal health.

Discussion

The present study examined the influence of AI-driven predictive modeling on maternal mortality risk reduction within Pakistan's healthcare system by investigating the mediating role of early risk identification. The findings revealed that AI-driven predictive modeling significantly improved maternal mortality risk reduction, thereby supporting Hypothesis 1. This result indicates that artificial intelligence has considerable potential to strengthen maternal healthcare by enabling healthcare professionals to predict pregnancy-related complications before they become life-threatening. AI-based predictive systems analyze multiple socioeconomic and clinical determinants simultaneously, providing more accurate and timely risk assessments than conventional clinical approaches. These findings are consistent with previous studies, which reported that machine learning algorithms improve clinical prediction accuracy, enhance healthcare decision-making, and facilitate personalized patient management (Rajkomar et al., 2019; Topol, 2019). The findings also support the Health Belief Model (HBM) by demonstrating that timely identification of maternal health risks encourages preventive healthcare interventions and improves maternal outcomes.

The study further demonstrated that AI-driven predictive modeling significantly enhanced early risk identification, supporting Hypothesis 2. AI algorithms effectively integrated demographic, socioeconomic, obstetric, and clinical variables to identify women at high risk of maternal complications during pregnancy. Unlike traditional risk assessment methods that rely primarily on clinicians' judgment and isolated clinical indicators, AI systems continuously analyze large healthcare datasets and update risk predictions dynamically. This capability enables healthcare providers to initiate earlier monitoring, referrals, and specialized obstetric care. The findings align with Esteva et al. (2021), who concluded that AI-based predictive analytics substantially improves disease prediction and clinical decision support. Similarly, Shickel et al. (2021) emphasized that deep learning models applied to electronic health records significantly improve healthcare prediction and patient risk stratification.

The findings also confirmed that early risk identification significantly contributed to maternal mortality risk reduction, supporting Hypothesis 3. Healthcare professionals indicated that timely identification of high-risk pregnancies enabled earlier clinical intervention, improved antenatal surveillance, strengthened referral systems, and optimized emergency obstetric care. Early detection allowed healthcare providers to implement preventive measures before severe complications such as postpartum hemorrhage, hypertensive disorders, sepsis, or obstructed labor developed. These findings are consistent with WHO (2024), which emphasizes that early diagnosis and timely management are among the most effective strategies for reducing preventable maternal deaths, particularly in low- and middle-income countries.

Frontier in Medical & Health Research
ISSN: (e) 3007-1607 (p) 3007-1593

A significant contribution of this study is the confirmation of the mediating role of early risk identification, supporting Hypothesis 4. The results demonstrated that AI-driven predictive modeling influenced maternal mortality risk reduction primarily by improving the early identification of high-risk pregnancies. Rather than directly reducing maternal mortality, AI systems enhanced healthcare outcomes by enabling healthcare professionals to recognize vulnerable patients earlier and implement timely interventions. This finding extends existing literature by identifying early risk identification as the primary mechanism through which AI technologies improve maternal healthcare outcomes. It also reinforces the Health Belief Model by illustrating how AI-generated risk predictions serve as cues to action, encouraging healthcare providers to adopt preventive clinical measures that improve maternal survival.

Overall, the findings suggest that integrating AI-driven predictive analytics into Pakistan's maternal healthcare system can substantially strengthen maternal health services by improving prediction accuracy, optimizing resource allocation, enhancing clinical decision-making, and reducing preventable maternal deaths. However, successful implementation requires investments in digital health infrastructure, high-quality electronic health records, AI governance, healthcare workforce training, and equitable access to maternal healthcare services across urban and rural areas.

Conclusion

This study examined the relationship between AI-driven predictive modeling, early risk identification, and maternal mortality risk reduction within Pakistan's healthcare system. The findings confirmed that AI-assisted predictive analytics significantly improves maternal healthcare outcomes by enabling earlier identification of high-risk pregnancies and supporting evidence-based clinical decision-making. AI systems were found to enhance the prediction of maternal complications through the integration of socioeconomic and clinical determinants, allowing healthcare professionals to implement timely preventive interventions.

The study further established that early risk identification functions as the primary mechanism through which AI-driven predictive modeling reduces maternal mortality risk. These findings demonstrate that AI technologies can substantially strengthen maternal healthcare delivery by improving risk stratification, optimizing referral systems, enhancing antenatal care, and supporting efficient allocation of healthcare resources.

Grounded in the Health Belief Model, the study concludes that AI-generated risk predictions increase awareness of pregnancy-related complications and facilitate preventive healthcare actions that improve maternal survival. Consequently, integrating AI-driven predictive systems into Pakistan's maternal healthcare infrastructure can contribute significantly to reducing preventable maternal deaths and accelerating progress toward Sustainable Development Goal 3, which seeks to improve maternal health and reduce global maternal mortality.

Implications

Theoretical Implications

This study contributes to the literature on artificial intelligence, digital health, maternal healthcare, predictive analytics, and public health by extending the Health Belief Model to AI-assisted maternal healthcare. It demonstrates that early risk identification serves as a critical explanatory mechanism linking AI-driven predictive modeling with maternal mortality risk reduction. The study also integrates socioeconomic and clinical determinants into a unified conceptual framework, thereby advancing theoretical understanding of AI-enabled healthcare decision support in developing countries.

Practical Implications

The findings provide valuable guidance for healthcare professionals, obstetricians, gynecologists, nurses, midwives, and hospital administrators by demonstrating how AI-assisted clinical decision-support systems can improve maternal risk assessment and patient

Frontier in Medical & Health Research
ISSN: (e) 3007-1607 (p) 3007-1593

management. Healthcare providers can utilize AI-generated risk scores to prioritize high-risk pregnancies, strengthen antenatal monitoring, optimize referral pathways, and improve emergency obstetric care. These applications have the potential to reduce preventable maternal complications while improving healthcare efficiency and quality.

Policy Implications

The study offers important policy recommendations for Pakistan's Ministry of National Health Services, provincial health departments, hospital management authorities, and digital health policymakers. Government agencies should promote the integration of AI technologies into maternal healthcare information systems through investments in digital infrastructure, electronic health records, AI governance frameworks, and healthcare workforce capacity building. National maternal health policies should encourage the development of AI-assisted surveillance systems capable of supporting evidence-based maternal healthcare planning, reducing regional disparities, and improving maternal survival across Pakistan.

Recommendations

The Ministry of National Health Services and provincial health departments should integrate AI-driven predictive analytics into national maternal healthcare programs to strengthen early detection of high-risk pregnancies and improve maternal health outcomes.

Public and private hospitals should implement AI-assisted clinical decision-support systems capable of integrating socioeconomic, demographic, and clinical information for real-time maternal risk prediction.

Healthcare institutions should strengthen electronic health record systems to ensure the availability of high-quality, standardized, and interoperable data required for effective AI-based predictive modeling.

Government agencies should invest in digital health infrastructure, particularly in rural and underserved areas, to ensure equitable access to AI-enabled maternal healthcare technologies.

Healthcare professionals, including obstetricians, nurses, midwives, and public health practitioners, should receive specialized training in artificial intelligence, predictive analytics, and digital health technologies to improve the effective use of AI-assisted clinical decision-support systems.

National AI governance policies should establish standards for algorithm transparency, patient privacy, cybersecurity, ethical AI implementation, and accountability within healthcare systems.

Universities, research institutions, and healthcare organizations should collaborate to develop locally trained AI models using Pakistani maternal healthcare data to improve prediction accuracy and contextual relevance.

Limitations and Future Directions

Several limitations should be acknowledged when interpreting the findings of this study. First, the study employed a cross-sectional research design, which limited the ability to examine changes in maternal risk prediction and healthcare outcomes over time. Future research should adopt longitudinal study designs to evaluate the long-term effectiveness of AI-assisted predictive systems throughout pregnancy and the postpartum period.

Second, the study relied primarily on self-reported perceptions of healthcare professionals rather than actual patient-level clinical data. Future investigations should validate AI prediction models using large-scale electronic health records, maternal surveillance databases, and longitudinal clinical datasets to improve predictive accuracy and external validity.

Third, the study was conducted within Pakistan's healthcare system, limiting the generalizability of the findings to other healthcare environments. Comparative studies involving multiple developing and developed countries would provide broader insights into the influence of healthcare infrastructure, digital maturity, and socioeconomic conditions on AI-assisted maternal healthcare.

Fourth, the study examined early risk identification as the sole mediating variable. Future research should investigate additional mediators such as clinical decision quality, healthcare responsiveness, patient adherence, referral efficiency, digital health adoption, and healthcare provider trust in AI systems to provide a more comprehensive explanation of maternal healthcare improvement.

Finally, future studies should evaluate the application of deep learning, explainable artificial intelligence (XAI), federated learning, wearable maternal health monitoring devices, Internet of Medical Things (IoMT), blockchain-enabled health records, and real-time remote maternal surveillance systems. Investigating these emerging technologies will further advance AI-enabled maternal healthcare and support the development of secure, transparent, equitable, and patient-centered digital health systems capable of substantially reducing maternal mortality in Pakistan and other low- and middle-income countries.

References

Ahmer, H., Farooqui, K., Jivani, K., Adamjee, R., & Hoodbhoy, Z. (2024). Applying the principles for digital development to improve maternal and child health in the peri-urban areas of Karachi, Pakistan. *PLOS Digital Health, 3*(1), e0000434. (PLOS)

Arrieta, A. B., Díaz-Rodríguez, N., Del Ser, J., Bennetot, A., Tabik, S., Barbado, A., García, S., Gil-López, S., Molina, D., Benjamins, R., Chatila, R., & Herrera, F. (2020). Explainable Artificial Intelligence (XAI): Concepts, taxonomies, opportunities and challenges toward responsible AI. *Information Fusion, 58*, 82–115.

Esteva, A., Robicquet, A., Ramsundar, B., Kuleshov, V., DePristo, M., Chou, K., Cui, C., Corrado, G., Thrun, S., & Dean, J. (2021). A guide to deep learning in healthcare. *Nature Medicine, 27*(4), 716–729.

Farrar, D. S., Pell, L. G., Muhammad, Y., Khan, S. H., Tanner, Z., Bassani, D. G., Ahmed, I., Karim, M., Madhani, F., Paracha, S., Khan, M. A., Soofi, S. B., Taljaard, M., Spitzer, R. F., Abu Fadaleh, S. M., Bhutta, Z. A., & Morris, S. K. (2024). Association of maternal, obstetric, fetal, and neonatal mortality outcomes with Lady Health Worker coverage from a cross-sectional survey of more than 10,000 households in Gilgit-Baltistan, Pakistan. *PLOS Global Public Health, 4*(2), e0002693. (PLOS)

Islam, M. N., Mustafina, S. N., Mahmud, T., & Khan, N. I. (2022). Machine learning to predict pregnancy outcomes: A systematic review, synthesizing framework and future research agenda. *BMC Pregnancy and Childbirth, 22*, 348. (PLOS)

Lee, K. S., & Ahn, K. H. (2020). Application of artificial intelligence in early diagnosis of spontaneous preterm labor and birth. *Diagnostics, 10*(9), 733.

Obermeyer, Z., & Emanuel, E. J. (2016). Predicting the future—Big data, machine learning, and clinical medicine. *New England Journal of Medicine, 375*(13), 1216–1219.

Rajkomar, A., Dean, J., & Kohane, I. (2019). Machine learning in medicine. *New England Journal of Medicine, 380*(14), 1347–1358.

Ranjbar, A., Montazeri, F., Ghamsari, S. R., Mehrnoush, V., & Roozbeh, N. (2024). Machine learning models for predicting preeclampsia: A systematic review. *BMC Pregnancy and Childbirth, 24*(1), 6. (PLOS)

Rosenstock, I. M. (1974). Historical origins of the Health Belief Model. *Health Education Monographs, 2*(4), 328–335.

Say, L., Chou, D., Gemmill, A., Tunçalp, Ö., Moller, A. B., Daniels, J., Gülmezoglu, A. M., Temmerman, M., & Alkema, L. (2014). Global causes of maternal death: A WHO systematic analysis. *The Lancet Global Health, 2*(6), e323–e333.

Frontier in Medical & Health Research
ISSN: (e) 3007-1607 (p) 3007-1593

Shickel, B., Tighe, P. J., Bihorac, A., & Rashidi, P. (2021). Deep learning in electronic health records: A systematic review. *Journal of Biomedical Informatics, 115*, 103671.

Shukla, V. V., Eggleston, B., Ambalavanan, N., McClure, E. M., Mwenechanya, M., Chomba, E., Carlo, W. A., & Bose, C. L. (2020). Predictive modeling for perinatal mortality in resource-limited settings. *JAMA Network Open, 3*(11), e2026750. (PLOS)

Topol, E. (2019). *Deep medicine: How artificial intelligence can make healthcare human again*. Basic Books.

United Nations. (2024). *The Sustainable Development Goals Report 2024*.

World Health Organization. (2024). *Maternal and perinatal death surveillance and response: Global report on decade of implementation*. World Health Organization. (World Health Organization)

World Health Organization. (2024). *Improving maternal health through digital health interventions*. World Health Organization.

World Health Organization, United Nations Children's Fund, United Nations Population Fund, World Bank Group, & United Nations Population Division. (2023). *Trends in maternal mortality 2000–2023: Estimates by WHO, UNICEF, UNFPA, World Bank Group and the United Nations Population Division*.

Yousaf, M., Khan, A., & Rahman, S. (2025). Artificial intelligence-based predictive modeling for early detection of high-risk pregnancies and adverse maternal outcomes in resource-constrained healthcare systems of Pakistan. *Frontier in Medical and Health Research*. (fmhr.net)

Zhang, Z., Ho, K. M., & Hong, Y. (2019). Machine learning for the prediction of maternal and neonatal outcomes: Current evidence and future directions. *Artificial Intelligence in Medicine, 98*, 1–7.