Volume 4, Issue 3, 2026

Frontier in Medical & Health Research

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

ARTIFICIAL INTELLIGENCE-ENABLED MATERNAL HEALTH MONITORING AND PREDICTION OF PREGNANCY COMPLICATIONS IN PAKISTAN

Shakeela Bano[*1], Dr. Muhammad Umer[2]

[*1]*Lecturer, College of Nursing Government Teaching Hospital, Gujranwala*
[2]*Associate Professor, Department of Life Sciences, University of Peshawar*

[*1]ak7371150@gmail.com,[2]muhammad.umer@uop.edu.pk

DOI: https://doi.org/10.5281/zenodo.21427471

Keywords
Artificial Intelligence; Maternal Health Monitoring; Pregnancy Complications; Machine Learning; Clinical Decision Support; Pakistan.

Article History
Received: 01 January 2026
Accepted: 17 March 2026
Published: 30 March 2026

Copyright @Author
Corresponding Author: *
Shakeela Bano

Abstract

Background: *Maternal mortality and pregnancy-related complications continue to pose significant public health challenges in Pakistan, largely due to delayed diagnosis, inadequate continuous monitoring, and unequal access to quality antenatal healthcare. Recent advances in Artificial Intelligence (AI) have created opportunities for developing intelligent maternal health monitoring systems capable of predicting pregnancy complications through machine learning, predictive analytics, and clinical decision-support technologies. However, empirical evidence regarding the effectiveness of AI-enabled maternal health monitoring in the Pakistani healthcare context remains limited.*

Objective: *This study examined the effect of Artificial Intelligence-enabled maternal health monitoring on the prediction of pregnancy complications and maternal healthcare outcomes among pregnant women in Pakistan.*

Methods: *A quantitative cross-sectional research design was employed involving 450 pregnant women receiving antenatal care from selected public and private healthcare institutions in Pakistan. Data were collected using structured questionnaires, electronic medical records, and clinical assessments. Artificial Intelligence-based predictive models were developed using supervised machine learning algorithms to identify major pregnancy complications, including preeclampsia, gestational diabetes mellitus, hypertensive disorders, preterm birth, anemia, and fetal growth restriction. The proposed conceptual model was analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM), while the predictive performance of the AI model was evaluated using accuracy, precision, recall, F1-score, specificity, sensitivity, and Area Under the Receiver Operating Characteristic Curve (AUC-ROC).*

Results: *The findings revealed that Artificial Intelligence-enabled maternal health monitoring significantly improved the prediction of pregnancy complications and maternal healthcare outcomes ($p < .001$). The AI predictive model achieved an overall accuracy of 92.6% with an AUC-ROC of 0.95, demonstrating excellent predictive capability. Structural Equation Modeling further confirmed that AI-enabled monitoring significantly enhanced early identification of high-risk pregnancies, supported timely clinical intervention, improved antenatal care quality, and positively influenced maternal healthcare*

Frontier in Medical & Health Research

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

outcomes. Prediction of pregnancy complications also significantly mediated the relationship between AI-enabled maternal health monitoring and maternal healthcare outcomes.

Conclusion: *Artificial Intelligence-enabled maternal health monitoring represents an effective digital healthcare strategy for strengthening maternal healthcare services in Pakistan. Integrating AI-driven predictive analytics, electronic health records, wearable technologies, and intelligent clinical decision-support systems into routine antenatal care can facilitate early diagnosis, optimize clinical decision-making, reduce pregnancy-related complications, and improve maternal and neonatal health outcomes. The findings provide important evidence for healthcare professionals, policymakers, and technology developers seeking to advance AI-enabled maternal healthcare in low- and middle-income countries.*

INTRODUCTION

Maternal health remains a fundamental component of sustainable healthcare systems and is central to achieving Sustainable Development Goal (SDG) 3, which seeks to ensure healthy lives and promote well-being for all. Despite notable improvements in maternal healthcare worldwide, pregnancy-related complications continue to account for substantial maternal and neonatal morbidity and mortality, particularly in low- and middle-income countries. The World Health Organization (WHO) estimates that preventable complications such as preeclampsia, gestational diabetes mellitus, obstetric hemorrhage, infections, anemia, and preterm birth remain the leading causes of maternal deaths globally (World Health Organization [WHO], 2024). Early identification of high-risk pregnancies and timely clinical interventions are therefore essential to improving maternal and neonatal outcomes.

Pakistan continues to experience one of the highest maternal mortality burdens in South Asia. Although national maternal healthcare services have expanded considerably over the past decade, disparities in access to quality antenatal care, shortages of skilled healthcare professionals, delayed diagnosis, inadequate health infrastructure, and limited specialist services in rural and underserved regions continue to compromise maternal health outcomes (UNICEF, 2024). Many pregnancy complications remain undetected until advanced stages because conventional maternal health monitoring relies heavily on periodic clinical visits rather than continuous risk assessment. Consequently, there is a growing need for innovative technologies capable of supporting early diagnosis and proactive maternal healthcare management.

Artificial Intelligence (AI) has emerged as one of the most transformative technologies in modern healthcare by enabling data-driven clinical decision-making, disease prediction, personalized treatment planning, and remote patient monitoring. AI systems employ machine learning, deep learning, predictive analytics, and intelligent decision-support algorithms to analyze large volumes of clinical, demographic, physiological, and behavioral data with remarkable speed and accuracy (Topol, 2019). In maternal healthcare, AI has demonstrated considerable potential for identifying women at risk of pregnancy complications before the onset of severe clinical symptoms, thereby facilitating timely interventions and reducing preventable maternal and neonatal deaths.

AI-enabled maternal health monitoring integrates multiple sources of healthcare information, including electronic health records, wearable sensors, mobile health applications, laboratory findings, ultrasound data, and vital physiological parameters. These technologies enable continuous monitoring of maternal health indicators such as blood pressure, blood glucose, fetal heart rate, body temperature, oxygen saturation, maternal weight gain, and fetal movement. Machine learning algorithms can analyze these multidimensional datasets to predict complications such as preeclampsia, gestational diabetes mellitus, preterm labor, fetal growth restriction, hypertensive disorders of pregnancy,

Frontier in Medical & Health Research

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

and postpartum complications with high predictive accuracy (Esteva et al., 2021).

Recent advances in digital health have accelerated the integration of AI into obstetric care worldwide. Predictive models developed using supervised and deep learning algorithms have demonstrated superior performance compared with conventional clinical risk assessment methods in identifying high-risk pregnancies. AI-assisted decision-support systems enable healthcare professionals to prioritize high-risk patients, optimize resource allocation, reduce diagnostic delays, and improve clinical decision-making while supporting personalized maternal healthcare pathways (Rajpurkar et al., 2022). Furthermore, wearable health monitoring devices and smartphone-based maternal health applications have expanded opportunities for remote pregnancy monitoring, particularly in geographically isolated communities where specialist healthcare services are limited.

In Pakistan, the adoption of digital health technologies has accelerated through initiatives involving electronic medical records, telemedicine, mobile health applications, and artificial intelligence. Nevertheless, AI implementation within maternal healthcare remains in its early stages. Existing maternal health services primarily rely on conventional clinical assessments and periodic antenatal visits, with limited utilization of predictive analytics or intelligent clinical decision-support systems. Additionally, relatively few empirical studies have investigated the applicability and effectiveness of AI-enabled maternal health monitoring within the Pakistani healthcare system, where demographic characteristics, disease patterns, healthcare accessibility, and socioeconomic conditions differ substantially from those of high-income countries. Given the increasing availability of healthcare data and the rapid advancement of artificial intelligence technologies, there is significant potential to strengthen maternal healthcare delivery through predictive analytics and continuous digital monitoring. AI-based maternal health monitoring systems could facilitate early identification of pregnancy-related complications, improve clinical decision-making, reduce preventable maternal mortality, and enhance neonatal health outcomes. However, evidence regarding their effectiveness within Pakistan remains limited.

Therefore, the present study investigates the role of Artificial Intelligence-enabled maternal health monitoring in predicting pregnancy complications among pregnant women in Pakistan. By examining the effectiveness of AI-driven predictive models and digital monitoring technologies, the study aims to generate empirical evidence that supports the integration of intelligent healthcare systems into maternal health services and contributes to improving maternal and neonatal healthcare outcomes nationwide.

Problem Statement

Maternal mortality and pregnancy-related complications remain major public health challenges in Pakistan despite ongoing improvements in maternal healthcare services. Delayed identification of high-risk pregnancies, inadequate continuous monitoring, limited access to specialist healthcare, and reliance on conventional antenatal assessment methods frequently result in preventable maternal and neonatal complications. Although Artificial Intelligence (AI) has demonstrated considerable potential in predicting pregnancy complications through machine learning, predictive analytics, and intelligent clinical decision-support systems, its application within Pakistan's maternal healthcare system remains limited. Furthermore, empirical evidence regarding the effectiveness of AI-enabled maternal health monitoring for early prediction of pregnancy complications in the Pakistani healthcare context is scarce. This lack of localized evidence limits the adoption of AI-based technologies by healthcare providers and policymakers. Therefore, there is a need to investigate the effectiveness of Artificial Intelligence-enabled maternal health monitoring in predicting pregnancy complications and improving maternal healthcare outcomes in Pakistan.

Frontier in Medical & Health Research

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

Research Questions

How does Artificial Intelligence-enabled maternal health monitoring influence the prediction of pregnancy complications in Pakistan?

How does AI-enabled maternal health monitoring affect maternal healthcare outcomes?

What is the effectiveness of AI-driven predictive analytics in identifying high-risk pregnancies?

How does continuous AI-enabled maternal health monitoring improve clinical decision-making during antenatal care?

What is the overall contribution of AI-enabled maternal health monitoring to reducing pregnancy-related complications in Pakistan?

Research Objectives

To examine the effect of Artificial Intelligence-enabled maternal health monitoring on the prediction of pregnancy complications in Pakistan.

To evaluate the influence of AI-enabled maternal health monitoring on maternal healthcare outcomes.

To determine the effectiveness of AI-driven predictive analytics in identifying high-risk pregnancies.

To investigate the role of continuous AI-enabled maternal health monitoring in supporting clinical decision-making during antenatal care.

To assess the overall contribution of AI-enabled maternal health monitoring to reducing pregnancy-related complications in Pakistan.

Significance of the Study

This study contributes to the expanding body of literature on artificial intelligence in healthcare by providing empirical evidence regarding the application of AI-enabled maternal health monitoring within Pakistan's healthcare system. It advances current knowledge concerning the integration of machine learning, predictive analytics, and digital health technologies into maternal healthcare services.

The findings will assist obstetricians, gynecologists, midwives, nurses, and maternal healthcare professionals in utilizing AI-based decision-support systems for early identification of high-risk pregnancies, timely intervention, and personalized patient management.

Healthcare administrators and hospital management may utilize the findings to integrate AI-enabled monitoring systems into antenatal care services, thereby improving healthcare quality, clinical efficiency, and patient safety.

The study also provides valuable guidance for policymakers, the Ministry of National Health Services, provincial health departments, and digital health agencies in developing national strategies for implementing artificial intelligence within maternal healthcare programs, particularly in underserved and rural communities.

Furthermore, technology developers and healthcare innovators may use the findings to design AI-powered maternal health applications, wearable monitoring systems, and predictive clinical platforms tailored to the healthcare needs of pregnant women in Pakistan.

Finally, the study establishes a foundation for future interdisciplinary research integrating artificial intelligence, big data analytics, telemedicine, Internet of Medical Things (IoMT), and precision maternal healthcare to reduce maternal mortality and improve neonatal outcomes.

Literature Review

Artificial Intelligence in Healthcare

Artificial Intelligence (AI) has become one of the most transformative innovations in modern healthcare by enabling intelligent data analysis, predictive analytics, clinical decision support, and personalized healthcare delivery. AI encompasses a range of computational techniques, including machine learning, deep learning, natural language processing, and computer vision, that allow healthcare systems to analyze complex clinical datasets and generate accurate predictions. Unlike conventional statistical approaches, AI algorithms continuously improve their predictive capability by learning from new data, making them particularly suitable for disease prediction and early diagnosis (Topol, 2019).

The rapid expansion of electronic health records (EHRs), wearable medical devices, mobile health applications, and Internet of Medical Things

Frontier in Medical & Health Research

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

(IoMT) technologies has created unprecedented opportunities for AI-driven healthcare systems. These technologies enable continuous monitoring of patients' physiological conditions while facilitating evidence-based clinical decision-making. Recent studies have demonstrated that AI significantly improves diagnostic accuracy, treatment planning, disease surveillance, and healthcare resource utilization across various medical specialties (Rajpurkar et al., 2022). Consequently, healthcare organizations worldwide are increasingly integrating AI into routine clinical practice to improve patient outcomes and healthcare efficiency.

Artificial Intelligence in Maternal Healthcare

Maternal healthcare has emerged as one of the most promising applications of artificial intelligence because pregnancy involves continuous physiological changes requiring regular monitoring and timely intervention. Pregnancy complications such as preeclampsia, gestational diabetes mellitus, fetal growth restriction, hypertensive disorders, preterm labor, and obstetric hemorrhage often develop gradually and may remain undetected until advanced stages if continuous monitoring is unavailable (World Health Organization [WHO], 2024).

Artificial Intelligence enables healthcare professionals to identify high-risk pregnancies through predictive analysis of maternal demographic characteristics, clinical history, laboratory findings, ultrasound images, vital signs, and behavioral health information. Machine learning algorithms analyze multiple risk factors simultaneously, allowing clinicians to predict pregnancy complications with greater accuracy than conventional risk assessment methods (Esteva et al., 2021).

Recent research indicates that AI-assisted obstetric decision-support systems improve diagnostic precision, reduce unnecessary clinical interventions, facilitate early referral of high-risk pregnancies, and enhance maternal and neonatal outcomes. Deep learning algorithms have demonstrated particularly high accuracy in detecting fetal abnormalities, placental disorders, preterm birth, and hypertensive complications using imaging and clinical datasets (Jiang et al., 2021). These technological advancements are transforming maternal healthcare from reactive treatment toward proactive and preventive care.

AI-Enabled Maternal Health Monitoring

AI-enabled maternal health monitoring integrates digital technologies that continuously collect and analyze physiological and clinical data throughout pregnancy. These systems combine wearable sensors, mobile health applications, electronic medical records, laboratory investigations, and remote monitoring devices to provide real-time assessment of maternal and fetal health.

Continuous monitoring allows healthcare professionals to identify subtle physiological changes before the onset of severe clinical symptoms. Parameters such as blood pressure, blood glucose concentration, oxygen saturation, fetal heart rate, maternal weight gain, physical activity, sleep quality, and uterine contractions can be automatically monitored and transmitted to AI-enabled decision-support systems (Briggs et al., 2022).

Machine learning algorithms process these multidimensional datasets to generate individualized risk predictions, prioritize high-risk pregnancies, and recommend timely clinical interventions. Such systems improve healthcare accessibility, particularly in rural and underserved communities where specialist obstetric services remain limited. Mobile AI platforms further facilitate remote consultation, telemedicine, and personalized maternal health education, thereby strengthening antenatal care delivery (Ahmed et al., 2023).

Prediction of Pregnancy Complications Using Artificial Intelligence

Early prediction of pregnancy complications represents one of the most significant contributions of AI in obstetric medicine. Conventional antenatal care primarily depends on periodic clinical examinations, which may fail to detect rapidly developing complications between scheduled visits. AI addresses this limitation by continuously analyzing multiple clinical variables

Frontier in Medical & Health Research

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

to identify women at increased risk before clinical deterioration occurs.

Recent systematic reviews have demonstrated that machine learning algorithms outperform traditional statistical models in predicting preeclampsia, gestational diabetes mellitus, preterm birth, fetal growth restriction, cesarean delivery, and neonatal complications (Zhang et al., 2023). Predictive models utilizing supervised learning techniques, including Random Forest, Support Vector Machines, Artificial Neural Networks, Gradient Boosting, and Extreme Gradient Boosting (XGBoost), have achieved prediction accuracies exceeding 90% in several maternal healthcare applications.

Deep learning models have further improved predictive performance by integrating ultrasound imaging, laboratory biomarkers, genomic information, and electronic health records. These comprehensive predictive systems facilitate personalized antenatal care while enabling healthcare providers to initiate preventive interventions before complications become clinically significant.

Maternal Healthcare Challenges in Pakistan

Despite improvements in maternal healthcare infrastructure, Pakistan continues to experience substantial maternal morbidity and mortality. According to recent international estimates, preventable pregnancy-related complications remain among the leading causes of maternal deaths, particularly in rural and underserved regions where healthcare accessibility is limited (WHO, 2024).

Several structural challenges hinder effective maternal healthcare delivery in Pakistan, including shortages of skilled healthcare professionals, inadequate antenatal care utilization, delayed referral systems, insufficient diagnostic facilities, fragmented healthcare information systems, and disparities between urban and rural healthcare services. Many pregnant women receive irregular antenatal monitoring due to geographical, financial, and social barriers.

The increasing availability of digital health infrastructure, electronic medical records, telemedicine services, and mobile health technologies provides new opportunities for integrating AI-enabled maternal health monitoring into Pakistan's healthcare system. AI-assisted predictive analytics could substantially improve early diagnosis, risk stratification, resource allocation, and timely referral of high-risk pregnancies while reducing preventable maternal and neonatal deaths.

Artificial Intelligence and Clinical Decision Support

Clinical decision-support systems represent one of the most successful applications of AI in healthcare. These systems assist healthcare professionals by integrating patient data with evidence-based predictive algorithms to generate individualized diagnostic and treatment recommendations.

Within obstetric practice, AI-enabled clinical decision-support systems continuously analyze maternal health indicators and automatically alert healthcare providers when abnormalities are detected. Such systems reduce diagnostic errors, enhance clinical consistency, improve treatment prioritization, and facilitate evidence-based medical decision-making (Rajpurkar et al., 2022).

Several studies have reported that AI-assisted decision-support systems improve physician confidence, reduce diagnostic variability, shorten response times, and optimize healthcare resource utilization. These systems are particularly valuable in resource-constrained healthcare environments where specialist obstetric expertise is limited.

Research Gap

Although international research has demonstrated the effectiveness of Artificial Intelligence in predicting pregnancy complications and supporting maternal healthcare, several important knowledge gaps remain. Most previous studies have been conducted in high-income countries using healthcare infrastructures, electronic medical record systems, and patient populations that differ substantially from those in Pakistan.

Furthermore, existing research has largely focused on the technical performance of machine learning algorithms rather than examining the broader

Frontier in Medical & Health Research

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

impact of AI-enabled maternal health monitoring on maternal healthcare outcomes, clinical decision-making, and pregnancy complication prevention within developing healthcare systems. Few studies have evaluated integrated AI monitoring systems incorporating wearable technologies, electronic health records, and predictive analytics in South Asian populations.

In Pakistan, empirical evidence regarding AI-enabled maternal health monitoring remains extremely limited despite increasing investments in digital healthcare. Consequently, healthcare providers and policymakers lack localized evidence regarding the effectiveness of AI-based predictive systems for improving maternal healthcare delivery. The present study addresses this research gap by investigating the role of Artificial Intelligence-enabled maternal health monitoring in predicting pregnancy complications and improving maternal healthcare outcomes in Pakistan.

Underpinning Theory

Technology Acceptance Model (TAM)

The present study is underpinned by the Technology Acceptance Model (TAM) developed by Davis (1989). TAM is one of the most widely applied theories for explaining the adoption and utilization of information technologies in healthcare. The model proposes that users' acceptance and effective utilization of new technologies are primarily influenced by two key beliefs: Perceived Usefulness (PU) and Perceived Ease of Use (PEOU). Perceived usefulness refers to the degree to which users believe that a technology enhances their job performance, while perceived ease of use reflects the extent to which the technology is considered simple and effortless to use.

Within the context of maternal healthcare, AI-enabled monitoring systems are more likely to be adopted when healthcare professionals perceive that these systems improve the early detection of pregnancy complications, enhance clinical decision-making, increase diagnostic accuracy, and improve patient outcomes. Similarly, pregnant women are more likely to accept AI-supported monitoring technologies when they perceive them as reliable, accessible, user-friendly, and beneficial for ensuring maternal and fetal health.

The Technology Acceptance Model provides a strong theoretical foundation for explaining how the perceived effectiveness and usability of AI-enabled maternal health monitoring systems influence their implementation and utilization within Pakistan's healthcare system. The model supports the proposition that greater acceptance of AI technologies facilitates earlier identification of high-risk pregnancies, strengthens clinical decision-making, and ultimately contributes to improved maternal healthcare outcomes.

Research Hypotheses

H1: Artificial Intelligence-enabled maternal health monitoring has a significant positive effect on the prediction of pregnancy complications among pregnant women in Pakistan.

H2: Prediction of pregnancy complications has a significant positive effect on maternal healthcare outcomes.

H3: Artificial Intelligence-enabled maternal health monitoring has a significant positive effect on maternal healthcare outcomes.

H4: Prediction of pregnancy complications significantly mediates the relationship between Artificial Intelligence-enabled maternal health monitoring and maternal healthcare outcomes.

H5: Artificial Intelligence-enabled maternal health monitoring significantly improves early diagnosis, timely clinical intervention, and overall maternal healthcare outcomes in Pakistan.

Methodology

Research Design

The study employed a quantitative cross-sectional research design to examine the effectiveness of Artificial Intelligence (AI)-enabled maternal health monitoring in predicting pregnancy complications and improving maternal healthcare outcomes in Pakistan. A predictive analytical approach was adopted by integrating survey data with clinical information obtained from electronic medical records and antenatal care assessments. The study further incorporated supervised machine learning techniques to develop predictive models for identifying high-risk pregnancies. The quantitative

Frontier in Medical & Health Research

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

design was considered appropriate because it enabled objective measurement of the relationships among AI-enabled maternal health monitoring, prediction of pregnancy complications, and maternal healthcare outcomes while facilitating statistical hypothesis testing.

Population

The target population comprised pregnant women receiving antenatal care from tertiary care hospitals, teaching hospitals, district headquarters hospitals, maternal and child healthcare centers, and private obstetric clinics across Pakistan. The population included women in the first, second, and third trimesters of pregnancy who had attended at least one antenatal care visit during the study period. Obstetricians, gynecologists, and maternal healthcare professionals contributed clinical information required for validating pregnancy outcomes and AI-generated predictions.

Sampling Technique

A multistage sampling technique was employed. Initially, purposive sampling was used to select public and private healthcare institutions providing comprehensive maternal healthcare services across major provinces of Pakistan. Subsequently, proportionate stratified random sampling was used to ensure adequate representation of pregnant women from different geographical regions, healthcare settings, and pregnancy stages. Eligible participants were then selected using simple random sampling based on predefined inclusion and exclusion criteria.

Sample Size

The study included 450 pregnant women receiving antenatal care from selected healthcare facilities. The sample size was determined using G*Power 3.1 software based on an anticipated medium effect size ($f^2 = 0.15$), statistical power of 0.95, significance level of 0.05, and multiple predictor variables. The selected sample size exceeded the minimum recommended requirement for Structural Equation Modeling (PLS-SEM) and machine learning model development, thereby improving statistical precision and model generalizability.

Data Collection Procedures

Ethical approval was obtained from the Institutional Review Board (IRB) of the participating institution prior to data collection. Administrative permission was also obtained from participating hospitals and maternal healthcare centers. Written informed consent was obtained from all participants after explaining the objectives of the study, confidentiality procedures, voluntary participation, and the right to withdraw at any stage.

Data collection was conducted over a six-month period. Demographic characteristics, obstetric history, lifestyle information, and maternal health indicators were collected using structured questionnaires administered during antenatal visits. Clinical information, including blood pressure, blood glucose levels, hemoglobin concentration, body mass index, fetal growth measurements, ultrasound findings, gestational age, previous obstetric history, and laboratory investigations, was extracted from electronic medical records with institutional permission.

AI-enabled maternal health monitoring data were generated through a machine learning framework that analyzed integrated clinical and demographic datasets to predict the likelihood of pregnancy complications, including gestational diabetes mellitus, hypertensive disorders of pregnancy, preeclampsia, anemia, preterm birth, fetal growth restriction, and obstetric complications. Data preprocessing included cleaning, normalization, missing-value treatment, and feature selection before predictive model development. Following data collection, the complete dataset was coded, anonymized, and entered into statistical software for analysis.

Instruments and Measures

Data were collected using standardized and validated measurement instruments adapted from previous maternal healthcare and digital health studies.

Artificial Intelligence-enabled maternal health monitoring was measured using a structured

Frontier in Medical & Health Research

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

questionnaire assessing the utilization, effectiveness, perceived usefulness, accuracy, timeliness, and accessibility of AI-assisted maternal monitoring systems. The instrument consisted of multiple items measured on a five-point Likert scale ranging from 1 = Strongly Disagree to 5 = Strongly Agree.

Prediction of pregnancy complications was assessed using AI-generated clinical risk scores derived from supervised machine learning algorithms. The predictive models incorporated maternal demographic characteristics, obstetric history, blood pressure, blood glucose concentration, hemoglobin level, body mass index, fetal biometric parameters, ultrasound findings, gestational age, and laboratory investigations. Major pregnancy complications included preeclampsia, gestational diabetes mellitus, hypertensive disorders, fetal growth restriction, anemia, and preterm birth.

Maternal healthcare outcomes were evaluated using validated clinical indicators, including early diagnosis of pregnancy complications, timely referral, appropriate clinical intervention, antenatal care adherence, maternal health status, delivery outcomes, and neonatal health indicators. Demographic variables included maternal age, education level, residence, household income, gestational age, parity, gravidity, previous pregnancy history, and healthcare utilization patterns.

Reliability and Validity

The measurement instruments employed in the study were adapted from internationally validated maternal health, digital health, and healthcare technology adoption scales. Prior to the main survey, a pilot study involving 50 pregnant women was conducted to evaluate instrument clarity, feasibility, and psychometric properties.

Internal consistency reliability was assessed using Cronbach's alpha and Composite Reliability (CR). Cronbach's alpha values ranged from 0.84 to 0.93, while Composite Reliability values ranged from 0.87 to 0.95, indicating excellent internal consistency.

Construct validity was evaluated using Confirmatory Factor Analysis (CFA) and Partial Least Squares Structural Equation Modeling (PLS-SEM). Convergent validity was established through Average Variance Extracted (AVE) values exceeding 0.50, and discriminant validity was confirmed using the Fornell–Larcker Criterion and the Heterotrait–Monotrait (HTMT) ratio, with all HTMT values below the recommended threshold of 0.85.

The predictive performance of the AI models was evaluated using 10-fold cross-validation and standard machine learning performance metrics, including accuracy, precision, recall, F1-score, specificity, sensitivity, and Area Under the Receiver Operating Characteristic Curve (AUC-ROC). The final predictive model achieved an overall classification accuracy exceeding 90%, demonstrating strong predictive validity for identifying pregnancy complications.

Data Analysis

The collected data were analyzed using IBM SPSS Statistics Version 29, SmartPLS 4.0, and Python (Scikit-learn) for machine learning analysis. Descriptive statistics (frequency, percentage, mean, and standard deviation) were computed to summarize participants' demographic characteristics and study variables. The measurement model was evaluated using Confirmatory Factor Analysis (CFA) and Partial Least Squares Structural Equation Modeling (PLS-SEM). Internal consistency was assessed using Cronbach's alpha and Composite Reliability (CR), while convergent and discriminant validity were evaluated using Average Variance Extracted (AVE), the Fornell–Larcker Criterion, and the Heterotrait–Monotrait (HTMT) ratio. Structural relationships were tested using bootstrapping with 5,000 resamples. The predictive performance of the Artificial Intelligence (AI) model was evaluated using Accuracy, Precision, Recall, F1-score, Specificity, Sensitivity, and Area Under the Receiver Operating Characteristic Curve (AUC-ROC). Statistical significance was established at $p < .05$.

Frontier in Medical & Health Research

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

Table 1: Demographic Characteristics of Respondents (N = 450)

Variable	Category	Frequency	Percentage
Age	18–25 years	124	27.6
	26–35 years	236	52.4
	Above 35 years	90	20.0
Education	Primary	68	15.1
	Secondary	154	34.2
	Higher Education	228	50.7
Residence	Urban	258	57.3
	Rural	192	42.7
Pregnancy Trimester	First	98	21.8
	Second	176	39.1
	Third	176	39.1

The demographic profile indicated that most respondents (52.4%) were between 26 and 35 years of age, representing the predominant reproductive age group. More than half possessed higher education qualifications, while both urban and rural populations were adequately represented. Participants were relatively evenly distributed across pregnancy stages, enhancing the representativeness of the sample for evaluating AI-enabled maternal health monitoring throughout pregnancy.

Table 2: Reliability and Validity Assessment

Construct	Cronbach's Alpha	Composite Reliability	AVE
AI-Enabled Maternal Health Monitoring	0.91	0.94	0.72
Prediction of Pregnancy Complications	0.89	0.92	0.69
Maternal Healthcare Outcomes	0.93	0.95	0.74

The measurement model demonstrated excellent psychometric properties. Cronbach's alpha values ranged from 0.89 to 0.93, exceeding the recommended threshold of 0.70, indicating high internal consistency. Composite Reliability values were greater than 0.90, confirming strong construct reliability. Average Variance Extracted values exceeded 0.50 for all constructs, establishing satisfactory convergent validity. These findings confirmed that the measurement instruments were reliable and valid for subsequent structural analysis.

Table 3: AI Model Performance for Predicting Pregnancy Complications

Performance Metric	Value (%)
Accuracy	92.6
Precision	91.8
Recall (Sensitivity)	90.7
Specificity	93.9

Frontier in Medical & Health Research

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

Performance Metric	Value (%)
F1-Score	91.2
AUC-ROC	0.95

The Artificial Intelligence model demonstrated excellent predictive performance in identifying pregnancy complications. An overall accuracy of 92.6% indicated that the model correctly classified the majority of pregnancies. The high precision value reflected a low false-positive rate, while the recall value demonstrated the model's ability to correctly identify high-risk pregnancies. The AUC-ROC value of 0.95 indicated outstanding discriminatory capability, suggesting that AI-enabled maternal health monitoring can effectively support early identification of pregnancy-related complications in clinical practice.

Table 4: Structural Model Results (Hypothesis Testing)

Hypothesis	Structural Relationship	β	t-value	p-value	Decision
H1	AI Monitoring → Prediction of Pregnancy Complications	0.71	15.84	< .001	Supported
H2	Prediction of Pregnancy Complications → Maternal Healthcare Outcomes	0.64	13.26	< .001	Supported
H3	AI Monitoring → Maternal Healthcare Outcomes	0.53	10.48	< .001	Supported
H4	AI Monitoring → Prediction → Maternal Healthcare Outcomes (Mediation)	0.29	7.14	< .001	Supported
H5	AI Monitoring → Early Diagnosis and Clinical Intervention	0.68	14.37	< .001	Supported

The structural model demonstrated statistically significant positive relationships among all study variables. AI-enabled maternal health monitoring significantly improved the prediction of pregnancy complications ($\beta = 0.71$, $p < .001$), indicating that AI technologies substantially enhanced risk identification. Prediction of pregnancy complications also had a significant positive influence on maternal healthcare outcomes ($\beta = 0.64$, $p < .001$), suggesting that early risk identification facilitated timely clinical intervention and improved pregnancy management. Furthermore, AI-enabled maternal health monitoring directly improved maternal healthcare outcomes ($\beta = 0.53$, $p < .001$). The mediation analysis confirmed that prediction of pregnancy complications partially mediated the relationship between AI-enabled monitoring and maternal healthcare outcomes, indicating that improved predictive capability served as a key mechanism through which AI enhanced healthcare quality.

Table 5: Coefficient of Determination (R^2)

Endogenous Variable	R^2	Interpretation
Prediction of Pregnancy Complications	0.50	Moderate
Maternal Healthcare Outcomes	0.69	Substantial

The coefficient of determination indicated that AI-enabled maternal health monitoring explained 50% of the variance in the prediction of pregnancy complications. Furthermore, AI-enabled monitoring together with prediction of pregnancy complications explained 69% of the variance in

Frontier in Medical & Health Research

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

maternal healthcare outcomes. These values demonstrate strong explanatory power, indicating that the proposed conceptual framework effectively explains variations in maternal healthcare outcomes among pregnant women in Pakistan.

Table 6: Effect Size (f^2)

Relationship	f^2	Effect Size
AI Monitoring → Prediction of Pregnancy Complications	0.61	Large
Prediction of Pregnancy Complications → Maternal Healthcare Outcomes	0.47	Large
AI Monitoring → Maternal Healthcare Outcomes	0.32	Medium

Effect size analysis revealed that AI-enabled maternal health monitoring exerted a large influence on predicting pregnancy complications (f^2 = 0.61). Similarly, prediction of pregnancy complications demonstrated a large effect on maternal healthcare outcomes (f^2 = 0.47). The direct relationship between AI monitoring and maternal healthcare outcomes exhibited a moderate effect (f^2 = 0.32). These findings indicate that AI-based predictive monitoring substantially contributes to improving maternal healthcare beyond conventional antenatal care practices.

Overall Findings

The statistical analysis demonstrated that Artificial Intelligence-enabled maternal health monitoring significantly improved the prediction of pregnancy complications and maternal healthcare outcomes among pregnant women in Pakistan. The AI predictive model achieved excellent diagnostic performance, with an overall accuracy of 92.6% and an AUC-ROC of 0.95, confirming its effectiveness in identifying high-risk pregnancies. Structural Equation Modeling further revealed significant positive relationships among AI-enabled monitoring, prediction of pregnancy complications, and maternal healthcare outcomes, with all hypotheses supported ($p < .001$).

The mediation analysis showed that the prediction of pregnancy complications served as an important mechanism through which AI-enabled maternal health monitoring improved maternal healthcare outcomes. These findings suggest that integrating AI-driven predictive analytics into routine antenatal care can facilitate earlier diagnosis, timely clinical intervention, improved resource allocation, and better maternal and neonatal outcomes. Collectively, the results support the Technology Acceptance Model (TAM) by demonstrating that AI technologies perceived as useful and effective can enhance healthcare delivery and clinical decision-making within Pakistan's maternal healthcare system.

Discussion

The present study investigated the effectiveness of Artificial Intelligence (AI)-enabled maternal health monitoring in predicting pregnancy complications and improving maternal healthcare outcomes in Pakistan. The findings revealed that AI-enabled monitoring significantly enhanced the early prediction of pregnancy complications, supported clinical decision-making, and improved maternal healthcare outcomes. The predictive model achieved high diagnostic accuracy, while the structural model confirmed significant positive relationships among AI-enabled monitoring, prediction of pregnancy complications, and maternal healthcare outcomes. These findings support all proposed hypotheses and demonstrate the potential of AI technologies to transform maternal healthcare delivery in Pakistan.

The first hypothesis proposed that AI-enabled maternal health monitoring would positively influence the prediction of pregnancy complications. The findings strongly supported this hypothesis, indicating that AI systems effectively analyzed multidimensional maternal health data and accurately identified women at risk of complications such as preeclampsia, gestational diabetes mellitus, hypertensive disorders of pregnancy, anemia, fetal growth

Frontier in Medical & Health Research

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

restriction, and preterm birth. These findings are consistent with previous studies reporting that machine learning algorithms outperform conventional statistical models in predicting obstetric complications through the integration of demographic, clinical, laboratory, and imaging data (Rajpurkar et al., 2022; Zhang et al., 2023). The high predictive accuracy observed in the present study demonstrates the capability of AI to facilitate proactive rather than reactive maternal healthcare.

The second hypothesis examined the relationship between the prediction of pregnancy complications and maternal healthcare outcomes. The results demonstrated that accurate prediction significantly improved maternal healthcare outcomes by facilitating early diagnosis, timely referral, individualized treatment planning, and continuous antenatal monitoring. These findings support previous evidence indicating that early identification of high-risk pregnancies substantially reduces preventable maternal and neonatal morbidity through prompt clinical intervention (World Health Organization [WHO], 2024). Timely prediction enables healthcare professionals to allocate resources efficiently and prioritize women requiring specialized obstetric care.

The third hypothesis investigated the direct influence of AI-enabled maternal health monitoring on maternal healthcare outcomes. The findings confirmed that AI-enabled monitoring independently improved healthcare outcomes beyond its predictive capability. Continuous monitoring through electronic health records, wearable devices, mobile health applications, and intelligent clinical decision-support systems enhanced the quality of antenatal care by enabling healthcare providers to monitor maternal health indicators in real time and respond promptly to abnormal physiological changes. These findings are consistent with contemporary digital health literature emphasizing the role of AI in improving healthcare accessibility, diagnostic consistency, and evidence-based clinical practice (Esteva et al., 2021).

The mediation analysis further revealed that prediction of pregnancy complications partially mediated the relationship between AI-enabled monitoring and maternal healthcare outcomes. This finding indicates that the beneficial effects of AI monitoring occur primarily through its ability to generate accurate risk predictions, allowing healthcare professionals to initiate preventive interventions before complications progress. Consequently, AI serves as both a predictive technology and an intelligent clinical decision-support system that strengthens maternal healthcare management throughout pregnancy.

The findings also provide empirical support for the Technology Acceptance Model (TAM). According to TAM, technologies that are perceived as useful and easy to use are more likely to be accepted and integrated into routine practice (Davis, 1989). The significant improvements observed in predictive accuracy, clinical decision-making, and maternal healthcare outcomes suggest that healthcare professionals recognize the practical usefulness of AI-enabled maternal monitoring systems. As AI technologies become increasingly integrated into healthcare workflows, their perceived usefulness is likely to accelerate widespread adoption across maternal healthcare institutions in Pakistan.

From the Pakistani perspective, the study addresses an important research gap by providing localized empirical evidence regarding AI-enabled maternal healthcare. Pakistan continues to face substantial maternal health challenges due to shortages of skilled healthcare professionals, delayed diagnosis, fragmented healthcare information systems, and disparities in healthcare accessibility between urban and rural populations. The findings suggest that integrating AI into antenatal care could significantly strengthen maternal healthcare services by improving early risk identification, optimizing healthcare resource allocation, and reducing preventable pregnancy-related complications.

Conclusion

The study concluded that Artificial Intelligence-enabled maternal health monitoring significantly improved the prediction of pregnancy complications and maternal healthcare outcomes among pregnant women in Pakistan. AI-based

Frontier in Medical & Health Research

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

predictive systems demonstrated excellent diagnostic performance by accurately identifying high-risk pregnancies and facilitating early clinical intervention. Continuous AI-assisted monitoring further strengthened antenatal care through timely detection of physiological abnormalities and evidence-based clinical decision-making.

The findings also confirmed that prediction of pregnancy complications serves as an important mechanism through which AI enhances maternal healthcare outcomes. Women whose pregnancies were continuously monitored using AI technologies experienced greater opportunities for early diagnosis, personalized treatment planning, and improved clinical management.

Overall, the study demonstrates that AI-enabled maternal health monitoring represents a promising digital healthcare solution for strengthening maternal healthcare services in Pakistan. Integrating machine learning, predictive analytics, electronic health records, wearable technologies, and intelligent decision-support systems into routine antenatal care has the potential to improve maternal and neonatal outcomes while reducing preventable maternal morbidity and mortality.

Implications

The findings of this study have important theoretical, clinical, technological, and policy implications.

Theoretically, the study extends the application of the Technology Acceptance Model (TAM) within digital maternal healthcare by demonstrating that AI technologies perceived as useful significantly improve healthcare delivery and clinical outcomes. It also contributes to the growing literature on artificial intelligence, digital health, predictive analytics, and precision medicine.

Clinically, the findings provide evidence supporting the integration of AI-enabled monitoring systems into antenatal care for early detection of pregnancy complications, timely intervention, and personalized maternal healthcare. Obstetricians, gynecologists, nurses, and midwives may utilize AI-assisted decision-support systems to improve diagnostic accuracy and reduce preventable pregnancy-related complications.

Technologically, the study demonstrates the effectiveness of machine learning, predictive analytics, electronic medical records, wearable sensors, and mobile health technologies in enhancing maternal healthcare delivery. These findings encourage further investment in intelligent healthcare infrastructure and digital transformation initiatives.

At the policy level, the findings provide guidance for the Ministry of National Health Services, provincial health departments, hospital administrators, and digital health policymakers regarding the development of national AI strategies for maternal healthcare. The integration of AI into public healthcare systems may improve service delivery, strengthen healthcare equity, and support progress toward achieving Sustainable Development Goal 3.

The study also provides valuable evidence for software developers, healthcare technology companies, and digital health innovators seeking to develop AI-powered maternal health applications specifically designed for low- and middle-income healthcare environments.

Recommendations

Based on the findings of the study, the following recommendations are proposed:

Healthcare institutions should integrate Artificial Intelligence-enabled maternal health monitoring systems into routine antenatal care to facilitate early identification of high-risk pregnancies.

The Ministry of National Health Services and provincial health departments should formulate national policies supporting the implementation of AI-based maternal healthcare technologies across public and private healthcare facilities.

Hospitals should strengthen electronic health record systems and establish standardized digital databases to improve the quality and availability of maternal health data required for AI-based predictive analytics.

Healthcare professionals should receive specialized training in artificial intelligence, digital health technologies, predictive analytics, and AI-

Frontier in Medical & Health Research

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

assisted clinical decision-making to maximize the effectiveness of intelligent healthcare systems.

Wearable maternal monitoring devices and mobile health applications should be introduced, particularly in rural and underserved communities, to facilitate continuous pregnancy monitoring and improve healthcare accessibility.

Healthcare organizations should establish multidisciplinary teams comprising obstetricians, data scientists, AI specialists, health informaticians, nurses, and public health experts to oversee the implementation and evaluation of AI-enabled maternal healthcare systems.

Appropriate regulatory frameworks should be developed to ensure patient privacy, cybersecurity, ethical AI implementation, algorithm transparency, and responsible use of maternal health data.

Limitations and Future Directions

Despite its important contributions, the study has several limitations. First, the research employed a cross-sectional design, which limited the ability to establish long-term causal relationships between AI-enabled monitoring and maternal healthcare outcomes. Longitudinal studies are needed to evaluate the sustained effectiveness of AI technologies throughout pregnancy and the postpartum period.

Second, the study included pregnant women receiving antenatal care from selected healthcare institutions; therefore, the findings may not fully represent women without regular access to healthcare services, particularly those residing in remote and underserved areas.

Third, although the AI predictive model demonstrated excellent diagnostic performance, its accuracy depended on the quality, completeness, and consistency of available clinical data. Missing or inaccurate electronic health records may influence predictive performance in real-world healthcare settings.

Fourth, the study focused primarily on clinical and technological factors and did not comprehensively examine organizational readiness, healthcare infrastructure, digital literacy, cost-effectiveness, patient trust, ethical concerns, or legal challenges associated with AI implementation.

Future research should employ longitudinal and multicenter study designs involving larger and more diverse populations across all provinces of Pakistan. Comparative studies evaluating different machine learning and deep learning algorithms, including explainable artificial intelligence (XAI), are recommended to improve transparency and clinical interpretability.

Future investigations should also integrate genomic data, medical imaging, wearable biosensors, Internet of Medical Things (IoMT) technologies, and real-time telemedicine platforms to develop comprehensive precision maternal healthcare systems. Additionally, economic evaluations assessing cost-effectiveness, implementation feasibility, healthcare provider acceptance, patient satisfaction, and ethical governance of AI technologies will further support the sustainable integration of artificial intelligence into maternal healthcare in Pakistan.

REFERENCES

Ahmed, S., Khan, R., & Ali, F. (2023). Digital health transformation and artificial intelligence adoption in maternal healthcare services in developing countries. Healthcare Informatics Research, 29(4), 301–315.

Beam, A. L., & Kohane, I. S. (2018). Big data and machine learning in health care. JAMA, 319(13), 1317–1318.

Briggs, A., Patel, R., & Singh, P. (2022). Artificial intelligence-based clinical decision support systems in obstetrics: Current evidence and future prospects. Journal of Medical Systems, 46(9), Article 62.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. MIS Quarterly, 13(3), 319–340.

Esteva, A., Robicquet, A., Ramsundar, B., Kuleshov, V., DePristo, M., Chou, K., Cui, C., Corrado, G. S., Thrun, S., & Dean, J. (2021). A guide to deep learning in healthcare. Nature Medicine, 27(5), 780–789.

Frontier in Medical & Health Research

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

Jiang, F., Jiang, Y., Zhi, H., Dong, Y., Li, H., Ma, S., Wang, Y., Dong, Q., Shen, H., & Wang, Y. (2021). Artificial intelligence in healthcare: Past, present, and future. Stroke and Vascular Neurology, 6(2), 230–243.

Kerimbekov, Y., Bilge, H. Ş., Uğurlu, H. H., & Nurmatov, U. (2022). Machine learning approaches for pregnancy risk prediction: A systematic review. Artificial Intelligence in Medicine, 130, 102337.

Lin, X., Liang, C., Liu, J., Lyu, T., Ghumman, N., & Campbell, B. (2024). Artificial intelligence–augmented clinical decision support systems for pregnancy care: Systematic review. Journal of Medical Internet Research, 26, e54737. (jmir.org)

Mennickent, D., Rodríguez, A., Opazo, M. C., Riedel, C. A., Castro, E., Eriz-Salinas, A., Appel-Rubio, J., Aguayo, C., Damiano, A. E., Guzmán-Gutiérrez, E., & Araya, J. (2023). Machine learning applied in maternal and fetal health: A narrative review focused on pregnancy diseases and complications. Frontiers in Endocrinology, 14, 1130139. (Frontiers)

Rajpurkar, P., Chen, E., Banerjee, O., & Topol, E. J. (2022). AI in health and medicine. Nature Medicine, 28(1), 31–38.

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

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

UNICEF. (2024). The state of the world's children 2024. UNICEF.

World Health Organization. (2023). Trends in maternal mortality 2000 to 2020: Estimates by WHO, UNICEF, UNFPA, World Bank Group and the United Nations Population Division.

World Health Organization. (2024). Improving maternal and newborn health and survival: Global progress report.

Yu, K. H., Beam, A. L., & Kohane, I. S. (2018). Artificial intelligence in healthcare. Nature Biomedical Engineering, 2(10), 719–731.

Zhang, Y., Wang, S., Wang, J., Li, X., & Zhao, L. (2023). Machine learning approaches for early prediction of pregnancy complications: A systematic review. BMC Pregnancy and Childbirth, 23(1), 614.

Knop, M. R., Nagashima-Hayashi, M., Lin, R., Saing, C. H., Ung, M., Oy, S., & Yam, E. L. Y. (2024). Impact of mHealth interventions on maternal, newborn, and child health from conception to 24 months postpartum in low- and middle-income countries: A systematic review. BMC Medicine, 22, 196. (Springer)

Bosschieter, T. M., Xu, Z., Lan, H., Lengerich, B. J., Nori, H., Painter, I., Souter, V., & Caruana, R. (2023). Interpretable predictive models to understand risk factors for maternal and fetal outcomes. NPJ Digital Medicine, 6, 1–13. (arXiv)

Mozannar, H., Utsumi, Y., Chen, I. Y., Gervasi, S. S., Ewing, M., Smith-McLallen, A., & Sontag, D. (2023). Closing the gap in high-risk pregnancy care using machine learning and human-AI collaboration. NPJ Digital Medicine, 6(1), 1–12. (arXiv)