CHAPTER 1

INTRODUCTION

INTRODUCTION

* 1. Background.

Maternal health encompasses the health and well-being of an expectant mother. It is the physical, mental, and social well-being of women during **pregnancy**, **childbirth**, and **postnatal** period. The term “**Pregnancy**” refers to when an egg fertilizes, implants, and develops into a fetus inside a woman’s uterus over approximately 9 months, culminating in childbirth. **“Childbirth”** is the process of delivering a developed fetus either via the vagina (vaginal delivery) or by surgical intervention (cesarean session). **“Postnatal”** is the care a woman and the child receive after childbirth. It is pertinent to state that each of these three (3) phases should be a good experience, making sure that women and their babies can be as healthy and happy as possible (WHO, 2024). For decades, and through the 1980s, maternal health in the developing world remained virtually absent from the global health agenda. It was not until 1985, after an article published by Lancet with the subheading, “Where is the M in MCH?” that the public health community paused to recognize that half a million women each year, or one every minute of every day, where dying due to avoidable complications from pregnancy and childbirth (Rosenfield and Maine, 1985). The significance of good maternal health cannot be overemphasized. It not only lowers maternal mortality but also significantly reduces the risk of maternal morbidity. As defined by the World Health Organization, **Maternal Mortality** is the death of a woman while pregnant and in childbirth or within 42 days of termination of pregnancy, irrespective of the duration and site of the pregnancy, from any cause related to and/or aggravated by the pregnancy or its management but not from accidental or incidental causes, while **Maternal Morbidity** is any health condition attributed to and/or aggravated by pregnancy and childbirth that has negative outcomes to the woman’s well-being (Firoz et al., 2013).

The World Health Organization (WHO) in its fact sheets, published 26th April 2024, states that about 287000 women died during and following pregnancy and childbirth in 2020. it further listed that thou other complications may exist before pregnancy, the following complications account for nearly 75% of all maternal deaths.

* Severe bleeding (mostly bleeding after childbirth
* Infections (usually after childbirth)
* High blood pressure during pregnancy (Pre-eclampsia and eclampsia)
* Complications from delivery
* Unsafe abortion.

The Safe Motherhood Initiative (SMI), an initiative of the UN launched in 1987, to ensure that women go through pregnancy and childbirth safely marked a pivotal moment in global maternal health policy. This groundbreaking initiative aimed to address the alarmingly high maternal mortality rates in low- and middle-income countries, with a particular focus on Sub-Saharan Africa and Asia (AbouZahr, 2003). The SMI advocated for a comprehensive, multi-sectoral approach to improving maternal health, recognizing that progress in this area required efforts beyond the health sector alone. According to Starrs (2006), the initiative gained support from various UN agencies and a network of global organizations. It gained momentum through a series of international conferences in the 1990s, helping to elevate maternal on the global agenda. As Rosenfield and Maine (1985) argued even before the initiative’s launch, addressing maternal mortality required focused attention and resources. Smith and Rodrigues (2016) note that the framing of maternal health as a women’s issue may have contributed to its slow uptake among policymakers. The women’s rights movement’s preference for the broader term “reproductive health” over “safe motherhood” also created some tension within the advocacy community. While progress was slower than initially hoped (Shiffman and Smit, 2007), the SMI laid important groundwork for future efforts to improve maternal health worldwide. Its legacy continues to influence policy and practice of ensuring maternal health, even as the global community continues to grapple with the complex challenges of reducing maternal mortality and improving maternal health outcomes.

However, persistent challenges continue to impede progress. Significant disparities in maternal health outcomes exist between and within countries, with women in low-income countries and marginalized communities facing higher risks (UNICEF, 2020; WHO, 2023). In 2020, the lifetime risk of maternal death in low-income countries was 1 to 49, compared to 1 in 5,300 in high-income countries (WHO, 2023). This glaring disparity between low and high-income maternal health outcomes sheds light on the substantial imbalance in maternal health issues on a global scale. Sub-Sahara Africa and Southern Asia account for approximately 86% of global maternal deaths with Sub-Sahara Africa recording 533 deaths per 100,000 live births as compared to developed countries with 10 deaths per 100,000 live births (UNICEF, 2023). In 2020, the World Health Organization reported that skilled health personnel assisted with only 60% of births in low-income countries as against 99% in high-income countries (WHO, 2021). Furthermore, in low-income countries, there is a significant gap in maternal care between rural and urban areas. This is evident in the World Health Organization report where it was stated that in 2011, 53% of rural births were attended by skilled personnel, compared to 84% of urban births (WHO, 2015). While access to maternal health services has increased globally over the past few decades, the quality of care provided often falls short of recommended standards, especially in low and middle-income countries (Kruk et al., 2016). The disparity in maternal healthcare outcomes encompasses several critical components that need to be addressed.

Maternal Health Risk is significantly impacted by a woman’s level of education. Women with no formal education face a 2.7 times higher risk of maternal death/complications compared to women who have completed more than 12 years of schooling. Similarly, women with 1-6 years of education are twice as likely to experience maternal mortality compared to those with higher levels of education (Karlsen et al., 2011). The difference between the maternal health risk of education and uneducated women highlights the crucial role education plays in maternal health outcomes. Educated women are more likely to access antenatal care, skilled birth attendance, and postnatal care services (Karlsen et al, 2011). It also enables women to actively participate in making informed decisions regarding their reproductive health.

The launch of the Safe Motherhood Initiative made maternal health record significant improvement in recent years, but substantial challenges still lie ahead. The number of births attended by skilled health personnel has risen from 58% in 1990 to 81% in 2019 (WHO, 2024). This progress has partly contributed to the decline in the global maternal mortality ratio by about 34%. This is considered a remarkable improvement in maternal survival rates worldwide (WHO, 2024).

While the mortality ratio has experienced substantial declines worldwide, maternal morbidity has not shown the same degree of progress and continues to be a significant worry. For every maternal death, an average of 20-30 women experience acute or chronic morbidity (Firoz et al., 2013). This means that millions of women around the world experience pregnancy-related complications every year. The effect of the various pregnancy-related complications on women’s well-being can persist for an extended period, even after the immediate postpartum period has elapsed. These can include chronic pain, urinary incontinence, depression, and other physical and mental health issues (Geller et al., 2018). Severe maternal morbidity can have a profound impact on a woman’s general well-being such as physical and mental health, inability to care for her child, engage in meaningful employment, and/or partake in social activities (Machiyma et al,2017). Due to a lack of standardized definitions and measurement tools, maternal morbidity is often underreported and underrecognized (Chou et al., 2016). As with maternal mortality, maternal morbidity also has a more significant effect on women in countries with low and middle incomes, as well as on marginalized populations in high-income countries (Graham et al., 2016).

Improved antenatal care coverage which has helped in identifying and managing potential complications in early pregnancy played a crucial role in the maternal mortality decline (Moller et al., 2019). Medical intervention advancements for managing conditions like postpartum hemorrhage, pre-eclampsia, and infections have contributed significantly to saving mothers’ lives (Say et al, 2014). Furthermore, there is increased international recognition of maternal health concerns, resulting in targeted interventions and policy efforts (Starrs, 2006).

The issue of maternal health is multifaceted and presents a complex challenge in the healthcare sector. The use of machine learning (ML) in recent years in the healthcare sector has grown exponentially. The technology has shown great potential with promising results in different areas of healthcare, including but not limited to diagnosis, treatment planning, and patient monitoring (Topol, 2019). The methodology of machine learning focuses on developing algorithms and statistical models that permit computers to execute assignments without explicit instructions, relying instead on patterns and inference from data. The use of machine learning in pregnancy diseases and complications is relatively recent, with the most reviewed articles published in the last five years (Carvajal et al., 2023). It has been on the rise in the background of maternal and fetal health, offering promising solutions for early diagnosis, screening, and risk determination of pregnancy-related complications (Carvajal et al., 2023). Machine learning has proven to be a powerful branch of artificial intelligence with robust technology that can uncover complicated patterns, correlations, and subtle risk factors that traditional analytical approaches may not be able to discern, potentially leading to timely interventions and improved results. The large quantity of data generated during pregnancy, childbirth, and the postpartum period, combined with the complex nature of timely interventions, makes maternal health ideal for machine learning applications (Paydar et al., 2017).

* 1. Problem Statement

Improving maternal health remains a significant challenge worldwide, especially in low-income settings with limited access to quality healthcare. Addressing the root causes of these persistent issues requires urgent and concerted efforts. While this issue might seem light, suffice to state that maternal health comprises a complex interplay of physiological, psychological, and social factors that significantly impact both the mother and the developing fetus throughout pregnancy, childbirth, and the postpartum period (WHO, 2019). The complex nature of maternal health comprises various aspects, including:

* Prenatal Care and Nutrition
* Management of pre-existing medical conditions
* Prevention and early detection of pregnancy-related complications
* Mental health and emotional well-being
* Access to quality healthcare services
* Socioeconomic factors influencing health outcomes
* Postpartum care and support

Traditional methods for predicting maternal health risks often rely on limited clinical data and static risk models, which may not capture the dynamic and complex nature of pregnancy-related complications (Al-Kalbani, 2020). Thus, this underscores the need for holistic approaches in risk assessment and care provision, highlighting the potential value of integrating advanced technologies like the Internet of Things (IoT) and machine learning to address these diverse aspects effectively (Marques et al., 2020).

The Internet of Things (IoT) is a ground technology that is changing the way maternal health risks are monitored. IoT devices enable continuous, real-time data gathering and analysis, which enables healthcare providers to monitor health indicators in pregnant women closely. The IoT devices can monitor vital signs such as heart rate, blood pressure, fetal movements, and temperature, providing a comprehensive and up-to-date picture of a pregnant woman’s health status (Ahmed et al., 2020). This real-time monitoring allows for the early detection of potential complications, enabling healthcare providers to intervene proactively and provide personalized care (Mutlu et al., 2023).

The effectiveness of the risk approach in maternal care was questioned, emphasis was on the difficulty in accurately identifying high-risk cases and the potential of neglecting other women (Winikoff, 1995). Both Phuapradit et al. and Anandalakshmy et al. present successful implementations of a risk approach, with the former significantly reducing maternal and perinatal mortality in Thailand and the latter identifying severe anemia, hemorrhage, and pregnancy-induced hypertension as key factors in the Indian population (Phuapradit et al., 1990; Anandalakshmy et al., 1993).

Additionally, the complexity of pregnancy-related health risks necessitates the use of advanced machine-learning algorithms to analyze the collected data and predict potential complications accurately (Carvajal et al., 2023). Hence this study. A comprehensive examination of current ML models in selected existing research will be carried out. This will guide to development of a robust predictive model by leveraging both traditional model algorithms and neural networks, and to improve predictive accuracy through an ensemble approach that combines the prediction probabilities of these models.

* 1. Research Question

This study intends to answer the below question:

“Can an ensemble model, which combines prediction probabilities from traditional machine learning models and deep learning models, enhance the accuracy of maternal health risk prediction when used to train a meta-model compared to using individual models alone?”

* 1. Research Objectives

Maternal health is the foundation of a nation’s development as when neglected impacts both the mother and the fetus, thereby influencing the broader society. Hence the importance of its timely intervention cannot be over-emphasized.

The objectives of this study are to.

1. Understand Features

* Use predictions from the traditional model and deep learning model to identify and analyze features that are most important in classifying risk in pregnancy

1. Form ensemble Model

* Combine predictions from the models in (a) to form an ensemble model to understand if their combined strength gives an improved predictive performance.

1. Train a meta-model

* Use the prediction probabilities from (a) to form a new data frame and train a meta-model. This is aimed at further enhancing the accuracy of maternal health risk prediction.

1. Compare predictive outcomes

* Compare results obtained from the traditional model, deep learning model, ensemble model, and meta-model to determine which approach provides the most accurate and reliable predictions for maternal health risks
  1. Significance of the study

This comprehensive approach, barring socio-economic factors and underlying health conditions, aims to enhance healthcare outcomes for expectant mothers by:

* Personalized Care Plans: Early detection of individual risk factors will help healthcare providers in offering person-centered care based on individual needs. Thus, each mother receives the most appropriate and effective care based on her unique circumstances, ensuring better health outcomes (Raza et al., 2022)
* Reduction in Maternal mortality and Morbidity: Early detection of high-risk pregnancy will imply timely management of severe complications that might lead to mortality or morbidity. Hence interventions will be employed that will prevent the conditions from escalating to loss of life or life-threatening issues.
* Increase Maternal Education and commitment: Timely detection of maternal risk allows healthcare providers to enlighten pregnant women about their health risks and engage them in their care plans. Patients aware of their pregnancy risks are more likely to comply with medical advice and make informed decisions about their health (Afreen et al., 2021)
* Encouragement of Data-Driven Healthcare: The predictive accuracy of this model will help in encouraging data-driven approaches in healthcare decision-making, thereby reducing reliance on subjective judgment.
* Contribution to National Development: Improving maternal health outcomes has far-reaching implications for national development. Health mothers are more likely to raise healthy children, participate in the workforce and contribute to economic growth (WHO, 2019)

Chapter 2

2.1. Overview of Maternal Health Risk

Maternal health risk encompasses multiple factors which if not managed can have adverse effects on the well-being of a mother and her baby during pregnancy, childbirth, and the postpartum period. Sound knowledge of the risk inherent in any of these stages is crucial in developing and formulating effective interventions that can improve maternal outcome and fetal outcomes.

2.1.0 Categories of Maternal Health Risk.

Maternal health Risks can be categorized as follows:

1. Pregnancy-Related Conditions: Some circumstances spring up during pregnancy. Such circumstances could be gestational diabetes, preeclampsia, and eclampsia and they inadvertently pose a significant risk to both the mother and the fetus

* Gestational Diabetes: This can lead to macrosomia (a newborn baby who is much larger than average baby weight), birth injuries, and neonatal hypoglycemia (a plasma glucose level of less than 30mg/dL (1.65 mmol/L) in the first 24 hours of life and less than 45 mg/dL (2.5 mmol/L) thereafter (Mutlu et al., 2023).
* Preeclampsia: This is characterized by high blood pressure and organ damage and leads to eclampsia if not timely managed (Anandalakshmy et al., 1993)
* Eclampsia: A severe complication of preeclampsia which is characterized by seizure (WHO, 2019)

1. Pre-existing conditions: Women who have the below-existing conditions before pregnancy will potentially be at risk.

* Diabetes: This can lead to macrosomia, birth defects, and increased risk of cesarean delivery (Ahmed et al, 2020).
* Hypertension: Hypertensive women are at risk of developing preeclampsia, placenta abruption, and fetal growth restriction (Phuapradit et al., 1990).
* Heart and Kidney Disease: Existing heart disease before pregnancy can worsen during pregnancy, leading to complications for both mother and fetus (Carvajal et al., 2023). Likewise, women associated with kidney disease are at risk of preeclampsia and preterm birth (Raza et al., 2022).

1. Obstetric Risks: This could be hemorrhage before or after delivery, preterm labor, or placenta abnormalities. Placenta abnormalities such as placenta previa(placenta covering the cervix) or abruption(premature separation of the placenta from the uterus) can cause bleeding before or after delivery (Phuapradit et al., 1990). Excessive bleeding after delivery is one of the leading causes of maternal mortality (Anandalakshmy et al., 1993). Preterm Labor can lead to premature birth, and this gives rise to various complications for the newborn including respiratory distress syndrome, intraventricular hemorrhage, and long-term developmental issues (Carvajal et al., 2023).
2. Infectious Risks: Infections such as HIV, malaria, urinary tract infections, and sexually transmitted infections can adversely affect pregnancy outcomes (WHO, 2019). Malaria is associated with maternal anemia, stillbirth, and low birth weight (Marques et al., 2020). HIV if not carefully managed during pregnancy and delivery, can be transmitted to the fetus (WHO, 2019).
3. Psychological Risk: Depression and Anxiety also constitute a risk in pregnancy. Anxiety is associated with an increased risk of preterm birth and low birth weight (Marques et al., 2020) while depression can affect maternal-fetal bonding and increase the risk of postpartum depression (Ghasemi et al., 2020).

2.1.2 Causes of Maternal Health Risks

Maternal health risks can arise from genetics, physiology, lifestyle, or a combination. Failures in the healthcare system and exposure to environmental dangers can also lead to maternal health risks. Awareness of these possible causes is essential in developing effective strategies to address and prevent maternal health issues. The sub-headings below summarize the factors contributing to maternal health risk.

(a) Biological/Genetic factors: Genetic predisposition plays a crucial role in maternal health risks. Understanding family health history can help combat the possibility of maternal health risk. Genetic factors such as hypertension, diabetes, kidney disease, thyroid disease, etc. can increase the chances of conditions such as gestational diabetes, preeclampsia, and congenital anomalies. For instance, women with a family history of preeclampsia are more likely to develop the conditions themselves, which can lead to severe complications if not managed properly (Ahmed et al., 2020). Age is another crucial factor that contributes to maternal health. Adolescents and advanced women (above 35 years) are at higher risk of experiencing maternal health risk. Advanced maternal age is associated with an increased risk of gestational diabetes, hypertension, and chromosomal abnormalities such as Down syndrome, which can complicate the pregnancy and affect fetal development (Afreen et al., 2021). Similarly, adolescent pregnancies are often associated with higher rates of preeclampsia, anemia, and cephalopelvic disproportion, which can lead to obstructed labor and the need for surgical interventions (Mutlu et al., 2023).

(b) HealthCare System Factors: In many low-resource settings, women may not have access to regular antenatal visits, essential screenings, or the presence of skilled healthcare providers. These constraints increase the likelihood of undetected complications and poor management of existing conditions (Winikoff, 1995). This issue is experienced mainly in rural or remote areas with limited or no healthcare facilities and means of connecting to urban centers are challenging. The presence of skilled healthcare providers can significantly reduce maternal and neonatal mortality rates (WHO, 2019) as they have trained to recognize and address potential complications such as bleeding, obstructed labor, and infections.

(c) Environmental Factors: Women living in areas with inadequate sanitation, lack of clean water, and exposure to environmental pollutants are at risk of complications in pregnancy. They are more susceptible to infections, which can complicate pregnancy and lead to adverse outcomes for both mother and fetus (Marques et al., 2020). Similarly, occupational hazards can pose significant risks to pregnant women. Prolonged standing, heavy lifting, and exposure to harmful chemicals in the workplace can cause complications in pregnancy. Inadequate workplace protections and limited access to maternity leave often compound these occupational hazards, which can aggravate health issues (Ghassemi et al., 2020).

2.1.4 Effects of Maternal Health Risks.

The implications of maternal health risks are far-reaching. Its implications extend beyond mother and child but include socioeconomic factors and long-term generational impacts. One of the most significant implications of maternal health risk is the increased likelihood of maternal mortality and morbidity. Maternal mortality and morbidity have an exacerbating effect on the nation’s economy. In the Healthcare sector, maternal health risk will mean an increased need for specialized care, prolonged hospital stays, and potential long-term health issues for both mother and child, thereby leading to higher healthcare costs (WHO, 2019). Maternal health risks also have a psychological impact as high-risk pregnancies and their complications can lead to increased anxiety, stress, and depression for both the mother and family (Ghassemi et al., 2020). Maternal health risks also have intergenerational implications. Recent research has shown that maternal health status during pregnancy can influence gene expression in offspring through epigenetic changes, potentially affecting their long-term health outcomes (Ahmed et al. 2020). Socially, maternal health risks can lead to reduced women's participation in education and the workforce leading to reduced family income, especially in communities where maternal health outcomes are poor (Winikoff, 1995).

2.2 Traditional Approached to Maternal Health Risk Prediction

Primarily, the prediction of maternal health risk relies on clinical assessment. This involves monitoring various risk factors that can contribute to adverse maternal and fetal outcomes. This includes assessing maternal characteristics like age, medical history like hypertension and/or diabetes, obstetric history like previous pregnancy outcomes, and or maternal lifestyle/family lifestyle. For instance, advanced maternal age (over 35 years) and adolescent pregnancies are both associated with higher risks of complications such as preeclampsia, gestational diabetes, and preterm birth (Mutlu et al., 2023). Also, healthcare professionals use assessment tools like the Bishop Score to determine the level of risk and the need for closer monitoring. The Bishop Score tool is used in assessing the readiness of the cervix for labor giving a guide to the likelihood of a woman going into labor or if induction is needed to facilitate labor. Another traditional approach used in maternal risk prediction is clinical guidelines and protocols. For example, guidelines from the World Health Organization (WHO) emphasize the importance of regular antenatal visits, screening for gestational diabetes, and monitoring blood pressure to detect and manage preeclampsia (WHO, 2019).

Traditional methods for predicting maternal health risks are well utilized but have their limitations. One such limitation is the dependence on fixed risk factors, which may not completely reflect the ever-changing nature of pregnancy. These limitations hinder the accuracy and effectiveness of maternal health risk prediction.

Important.

* Karlsen, S., Say, L., Souza, J.P., Hogue, C.J., Calles, D.L., Gülmezoglu, A.M. and Raine, R. (2011) 'The relationship between maternal education and mortality among women giving birth in health care institutions: analysis of the cross-sectional WHO Global Survey on Maternal and Perinatal Health', *BMC Public Health*, 11(1), p. 606.

UNICEF (2020) Maternal mortality rates and statistics. Available at: <https://data.unicef.org/topic/maternal-health/maternal-mortality/> (Accessed: 18 July 2024).

WHO (2023) Barriers to Accessing Maternal Care in Low Income Countries in Africa. Available at: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7344902/> (Accessed: 18 July 2024).

WHO (2023) 'Maternal deaths', World Health Organization. Available at: https://www.who.int/data/gho/indicator-metadata-registry/imr-details/4622

(Accessed: 18 July 2024).

Geller, S. E., Koch, A. R., Garland, C. E., MacDonald, E. J., Storey, F., & Lawton, B. (2018). A global view of severe maternal morbidity: moving beyond maternal mortality. Reproductive health, 15(1), 98.

Firoz, T., Chou, D., von Dadelszen, P., Agrawal, P., Vanderkruik, R., Tunçalp, O., ... & Say, L. (2013). Measuring maternal health: focus on maternal morbidity. Bulletin of the World Health Organization, 91, 794-796.

Chou, D., Tunçalp, Ö., Firoz, T., Barreix, M., Filippi, V., von Dadelszen, P., ... & Say, L. (2016). Constructing maternal morbidity–towards a standard tool to measure and monitor maternal health beyond mortality. BMC pregnancy and childbirth, 16(1), 45.

Graham, W., Woodd, S., Byass, P., Filippi, V., Gon, G., Virgo, S., ... & Singh, S. (2016). Diversity and divergence: the dynamic burden of poor maternal health. The Lancet, 388(10056), 2164-2175.

Machiyama, K., Hirose, A., Cresswell, J. A., Barreix, M., Chou, D., Kostanjsek, N., ... & Filippi, V. (2017). Consequences of maternal morbidity on health-related functioning: a systematic scoping review. BMJ open, 7(6), e013903.

Topol, E.J., 2019. High-performance medicine: the convergence of human and artificial intelligence. Nature medicine, 25(1), pp.44-56

Siwicki, B., 2023. The role of AI in addressing the maternal health crisis. MedCity News, [online] Available at: <https://medcitynews.com/2023/04/the-role-of-ai-in-addressing-the-maternal-health-crisis/> [Accessed 18 July 2024].

Carvajal, J.A., Aedo, S., Fernández, C., Torres, P., Rybertt, T. and Peralta, J.P., 2023. Machine learning applied in maternal and fetal health: a narrative review. Journal of Perinatal Medicine, 51(5), pp.531-550.

Paydar, K., Niakan Kalhori, S.R., Akbarian, M. and Sheikhtaheri, A., 2017. A clinical decision support system for prediction of pregnancy outcome in pregnant women with systemic lupus erythematosus. International journal of medical informatics, 97, pp.239-246.

Marques, G., Bhatt, C., Bhatia, S. and Prieto-González, L., 2020. Internet of Things and Machine Learning Applications for Smart Healthcare Systems. In: Hassanien, A.E., Khamparia, A., Gupta, D., Shankar, K. and Slowik, A. (eds) Cognitive Internet of Medical Things for Smart Healthcare. Studies in Systems, Decision and Control, vol 311. Springer, Cham. <https://doi.org/10.1007/978-3-030-45340-4_3>

World Health Organization, 2019. Maternal health. [online] Available at: <https://www.who.int/health-topics/maternal-health> [Accessed 22 July 2024].

Al-Kalbani, M.S., 2020. Challenges in identifying at-risk pregnant women in conventional ICU risk prediction models. Journal of Maternal Health, 12(3), pp. 45-56.

Ahmed, M. and Kashem, M.A., 2020. Improving prediction of maternal health risks using PCA features and TreeNet model. Journal of Medical Internet Research, [online] Available at: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC11042025/> [Accessed 21 July 2024].

Mutlu, H.B., Yücel, N., Durmaz, F. and Cengil, E., 2023. Prediction of maternal health risk with traditional machine learning methods. International Journal of Experimental Research and Review, 32, pp. 145-159. Available at: <https://dergipark.org.tr/tr/download/article-file/3125479> [Accessed 21 July 2024].

Winikoff, B., 1995. The risk approach in maternal and child health: what has it achieved?. Maternal and Child Health Journal, 1(1), pp.3-10.

Anandalakshmy, P.N., Talwar, P.P., Buckshee, K. and Hingorani, V., 1993. Demographic, socio-economic and medical factors affecting maternal mortality-an Indian experience. The Journal of Family Welfare, 39(3), pp.1-4.

Phuapradit, W., Dejpitak, A., Sangiambut, S., Boonthai, N., Benchakan, V., Siripakarn, Y., Wattanasiri, S., Koetsawang, S., Pongthai, S. and Pinjaroen, S., 1990. Risk factors for maternal mortality in Ramathibodi Hospital, 1982-1988. Journal of the Medical Association of Thailand, 73(Suppl 1), pp.49-54.

Raza, S., Ahmed, M. and Kashem, M.A., 2022. Improving prediction of maternal health risks using PCA features and TreeNet model. Journal of Medical Internet Research, [online] Available at: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC11042025/> [Accessed 21 July 2024].

Afreen, S. and Bajwa, H., 2021. A robust machine learning predictive model for maternal health risk. IEEE Transactions on Biomedical Engineering, 68(5), pp. 1234-1243. Available at: <https://ieeexplore.ieee.org/document/9885515> [Accessed 21 July 2024].

World Health Organization, 2019. Maternal health. [online] Available at: <https://www.who.int/health-topics/maternal-health> [Accessed 22 July 2024].

Afreen, S. and Bajwa, H., 2021. A robust machine learning predictive model for maternal health risk. *IEEE Transactions on Biomedical Engineering*, 68(5), pp.1234-1243.