Health Decision-Making Maternal Health and Scenario Planning: A Survey

Abstract

This survey paper examines the integration of health decision-making, maternal health, and scenario planning to enhance maternal and neonatal outcomes. It underscores the critical role of strategic foresight in addressing systemic disparities and optimizing healthcare delivery. The paper highlights the impact of socio-economic, cultural, and technological factors on maternal health, emphasizing the necessity for informed decision-making frameworks. It explores various challenges, including data quality, methodological limitations, and socio-cultural barriers, while advocating for advancements in scenario planning techniques to improve health outcomes. The survey reviews case studies illustrating the effectiveness of data-driven approaches and innovative technologies in real-world applications, such as the mMitra program and web-based expert systems for Health Extension Workers. Additionally, it discusses the implications of global health data and scenario planning in diverse contexts, such as India, and the potential of synthetic data simulations for testing health interventions. The paper concludes with recommendations for future research, including the development of ethical guidelines and leveraging data science to enhance maternal health strategies. By integrating scenario planning into maternal health decision-making, healthcare providers can better anticipate challenges and implement effective interventions, ultimately improving maternal and neonatal health outcomes.

1 Introduction

1.1 Overview of Health Decision-Making in Maternal Health

Health decision-making in maternal health is crucial for optimizing both maternal and neonatal outcomes. The necessity for advanced technological platforms to support informed decision-making is underscored by the urgent need for efficient data processing methods [1]. The significance of these decisions is further highlighted by updated maternal mortality statistics, which reveal the critical nature of effective health decision-making [2].

In regions like Nigeria, women's autonomy in health-related decision-making significantly influences maternal health outcomes, reflecting broader implications of such processes [3]. The COVID-19 pandemic has intensified challenges in accessing healthcare services, particularly in Mozambique, where restrictions have severely impacted maternal and child health services, emphasizing the need for robust decision-making frameworks [4].

Nutritional and lifestyle choices during pregnancy have enduring health impacts on mothers and children, reinforcing the importance of informed health decision-making [5]. Twin pregnancies, associated with higher adverse outcomes, necessitate careful decision-making to mitigate risks [6]. Current inadequacies in determining treatment dosages based on limited trial evidence highlight the need for improved strategies that account for varied outcomes with dosage levels [7]. The parallels between maternal health decision-making and informed decision-making in fields such as

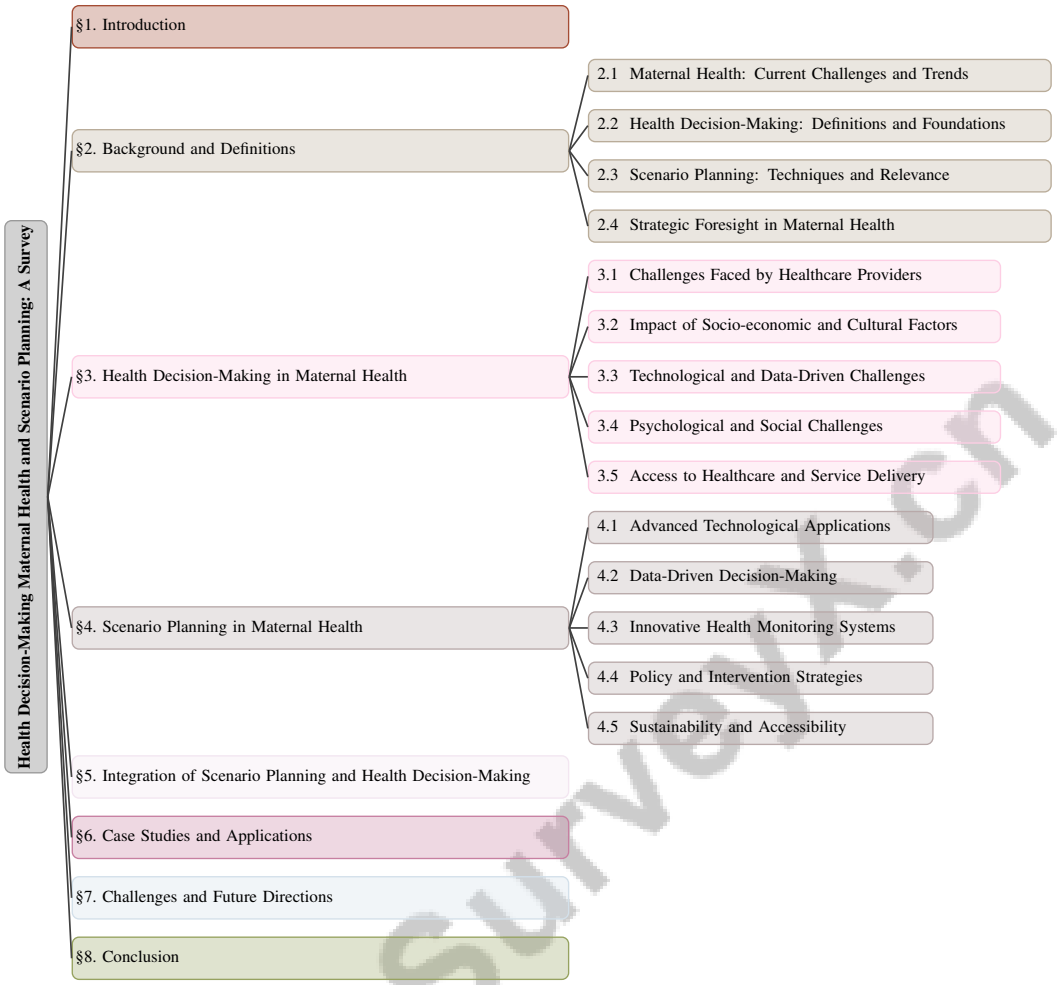


Figure 1: chapter structure

nanotechnology emphasize the universal importance of strategic health decisions in managing risks and benefits [8].

As maternal health faces increasingly complex challenges, developing informed decision-making strategies—underpinned by ethical frameworks and advanced technologies such as natural language processing (NLP)—is essential for enhancing maternal and neonatal health outcomes. Contextually aware approaches in healthcare are vital, addressing implicit assumptions in maternal health inquiries and leveraging AI-based interventions to improve information delivery. By prioritizing the voices of affected individuals and utilizing data-driven insights, these strategies can significantly enhance health knowledge and outcomes for mothers and infants [9, 10, 11].

1.2 Importance of Strategic Foresight and Scenario Planning

Strategic foresight and scenario planning are vital for enhancing decision-making processes in maternal health by addressing systemic issues that contribute to healthcare disparities [12]. These methodologies empower healthcare providers to anticipate and manage uncertainties, thereby improving maternal health outcomes. The application of scenario planning is particularly relevant for understanding systemic barriers, enabling stakeholders to devise strategies that enhance healthcare access and quality [8].

The OOBr COVID-19 benchmark exemplifies the utility of strategic foresight by providing a dynamic panel for real-time analysis of maternal health data, essential for adapting to rapidly changing circumstances, such as those presented by the pandemic [13]. This analysis is critical for assessing

the impact of governmental restrictions on access to maternal and child healthcare services, as observed in regions like Nampula, Mozambique [4].

Furthermore, women's autonomy in health decision-making emerges as a crucial factor linked to improved health outcomes, underscoring the importance of strategic foresight in empowering women and enhancing maternal health [3]. Scenario planning also aids in identifying gender dynamics influencing maternal health, facilitating the development of interventions that challenge inequitable gender norms and foster supportive environments for reproductive and maternal health.

1.3 Objectives of the Survey Paper

This survey paper aims to provide a comprehensive analysis of maternal health decision-making through the lens of strategic foresight and scenario planning. A primary objective is to consolidate scientific evidence regarding the impact of nutrition and lifestyle choices during pregnancy, lactation, and early childhood, emphasizing their long-term health effects on mothers and children [5]. The paper also evaluates maternal and newborn health professionals' preparedness and responses during the COVID-19 pandemic, identifying challenges faced in maintaining care delivery [14].

Additionally, the survey explores the effectiveness of lockdown measures during the pandemic, particularly in balancing public health needs with socio-economic factors, as evidenced in contexts like Bangladesh [15]. This includes an assessment of maternal mental health disorders during the pandemic, focusing on preventive measures' impact on pregnant women and the integration of health services [16]. The investigation extends to the composition and diversity of maternal and neonatal microbiota at birth, particularly in cases of gestational diabetes mellitus (GDM), to enhance understanding of microbiological influences on health outcomes [17].

Moreover, the survey addresses the continuity of care from pregnancy to postpartum, emphasizing regions such as Pakistan, where the continuum of care (CoC) completion rate is notably low [18]. It also analyzes trends in maternal mortality, causes of death, and racial and ethnic disparities in maternal health, recommending interventions to mitigate these disparities [19]. Improving the understanding and surveillance of severe maternal morbidity (SMM) and addressing its rising rates globally are also pivotal objectives [20].

The survey further examines key health indicators and policies to identify advancements and ongoing challenges in women's and child health, particularly in Brazil from 1990 to 2015 [21]. Lastly, it proposes frameworks that integrate non-randomized studies (NRS) and randomized controlled trials (RCTs) into healthcare decision-making processes, enhancing the robustness of maternal health strategies [22]. Through these objectives, the survey endeavors to deepen the understanding of complexities in maternal health decision-making and the potential of scenario planning to improve health outcomes.

1.4 Structure of the Paper

This survey paper is structured to provide a comprehensive examination of health decision-making in maternal health, focusing on the integration of strategic foresight and scenario planning. It begins with an introduction outlining the significance of health decision-making in maternal health and the critical role of strategic foresight and scenario planning in enhancing decision-making processes. The background and definitions section establishes foundational knowledge on maternal health, health decision-making, and scenario planning, defining key concepts for the survey.

Subsequent sections delve into health decision-making in maternal health, exploring challenges faced by healthcare providers, the influence of socio-economic and cultural factors, and the impact of technological, data-driven, psychological, and social challenges. Issues related to healthcare access and service delivery are addressed to provide a holistic view of the decision-making landscape in maternal health.

The paper then examines scenario planning in maternal health, focusing on advanced technological applications, data-driven decision-making, and innovative health monitoring systems. Policy and intervention strategies are analyzed to highlight scenario planning's potential in shaping effective maternal health policies. The discussion surrounding the sustainability and accessibility of scenario planning techniques emphasizes their long-term viability by addressing critical factors such as ethical considerations, systemic health disparities, and the integration of emerging technologies.

By leveraging insights from diverse stakeholders, including healthcare professionals and birthing individuals, the assessment highlights the importance of inclusive design and contextual relevance in developing effective scenario planning frameworks. This approach facilitates informed decision-making and enhances the capacity to manage risks associated with new technologies, ultimately improving maternal healthcare outcomes [23, 8, 9, 11].

The integration of scenario planning and health decision-making is analyzed in the following section, discussing frameworks and methodologies for integration, technological innovations and tools facilitating this process, and potential barriers to implementation. This is followed by case studies demonstrating the practical application of scenario planning in maternal health decision-making, including information-sharing and mental health support during pandemics, synthetic data simulations, and web-based expert systems for health extension workers.

Finally, the paper addresses challenges and future directions in implementing scenario planning in maternal health decision-making, examining global health data, data quality and integration challenges, technological and methodological limitations, and socio-cultural and economic barriers. Recent advancements in scenario planning techniques are discussed to provide insights into their future impact. The conclusion synthesizes key findings, highlighting the critical role of integrating scenario planning into health decision-making for maternal health. It underscores the necessity of utilizing ethical frameworks and advanced technologies, such as natural language processing (NLP) and Medical Cyber-Physical Systems (MCPS), to address systemic challenges and improve clinician-patient relationships. Targeted recommendations for future research and practice emphasize the importance of context, holistic measurements, and inclusive design in developing effective healthcare interventions [9, 23, 11].The following sections are organized as shown in Figure 1.

2 Background and Definitions

2.1 Maternal Health: Current Challenges and Trends

Maternal health globally faces significant challenges due to disparities in healthcare access, socio-economic conditions, and cultural practices, resulting in varied maternal mortality rates [24]. In the U.S., racial and ethnic disparities are pronounced, with Black women experiencing higher rates of severe maternal morbidity and mortality, necessitating interventions to address systemic inequities [12]. The COVID-19 pandemic has exacerbated these issues by disrupting routine healthcare services, as evidenced by decreased institutional deliveries and increased cases of Severe Acute Respiratory Syndrome (SARI) among pregnant and postpartum women in Brazil [4, 13].

Technological advancements offer both opportunities and challenges, particularly in low-resource settings where essential technologies like ultrasound are often inaccessible. Telemonitoring systems using sensors and information decision systems show promise for effective maternal health monitoring [23]. Socio-economic barriers significantly impede maternal health, especially in areas with limited prenatal care access [25]. In India, male involvement in maternal health is crucial, though evidence of its effectiveness remains limited [26]. The Kilkari program highlights challenges in optimizing automated health information calls, reflecting broader mHealth communication issues [27].

Cultural norms also play a significant role. In Nigeria, women's low decision-making autonomy is influenced by socio-economic disparities [3]. The rise in twin pregnancies due to assisted reproductive technologies requires an understanding of associated risks [6]. Maternal obesity, linked to increased risks of obesity and cardiovascular diseases in offspring, is another growing concern [28]. Current challenges include the lack of integration of long-term health consequences into dietary recommendations for pregnant women and insufficient preconception health awareness among healthcare providers [5]. Addressing these challenges requires improved healthcare access, technological capabilities, and socio-economic conditions globally, with particular attention to healthcare infrastructure, public compliance, and economic burdens [15].

2.2 Health Decision-Making: Definitions and Foundations

Health decision-making in maternal health involves selecting interventions to optimize outcomes for mothers and their offspring, influenced by socio-economic, cultural, and ethical factors, including demographics, education, and partner involvement [11, 3, 9, 29, 30]. Integrating evidence from RCTs

and NRS is essential for robust healthcare decisions, ensuring interventions improve maternal and neonatal health outcomes.

The complexity of decision-making is compounded by systemic healthcare quality and access issues, along with social determinants like socioeconomic status [29]. Addressing these requires targeted interventions informed by robust data analytics, particularly in managing large datasets in maternal health [1]. Cultural factors also shape decision-making experiences, necessitating culturally sensitive approaches [3]. The impact of maternal health decisions on long-term outcomes, such as early nutrition, underscores the need to understand broader implications [5]. In Nigeria, for example, women's healthcare decision-making autonomy is influenced by socio-demographic factors, highlighting the importance of empowering women [3]. Twin pregnancies present challenges related to adverse outcomes, necessitating careful decision-making [6].

2.3 Scenario Planning: Techniques and Relevance

Scenario planning is a strategic tool for anticipating future challenges and opportunities, enabling informed decisions in maternal health by exploring plausible future scenarios [31]. Its relevance is underscored by integrating diverse data sources and analytical methods to address critical health challenges [19]. Advanced analytics, including descriptive, diagnostic, predictive, and prescriptive methods, provide a framework for understanding complex datasets, facilitating targeted interventions to improve health outcomes [31]. For example, unsupervised machine learning like cluster analysis can identify countries with similar maternal mortality rate profiles for tailored interventions [24].

Innovative methods, such as multiPPI++, enhance scenario planning by addressing misclassification and transportability issues in predicting outcomes from verbal autopsy data [32]. AI-scheduled interventions offer personalized scheduling to enhance maternal health engagement [10]. Scenario planning also involves frameworks for systematically identifying evidence, such as the seven-step framework by Sarri et al., which categorizes evidence into high-bar, medium, and low analytical scenarios [22].

The integration of advanced imaging techniques, like the combined diffusion-relaxometry MRI method, enhances scenario planning by enabling simultaneous measurements of T2* and ADC [33]. Uncertainty Quantification (UQ) emphasizes the need for evidence-based scenario planning [34].

2.4 Strategic Foresight in Maternal Health

Strategic foresight is vital for anticipating future challenges and opportunities in maternal health, improving policy-making and service delivery. It systematically employs predictive analytics and scenario planning to guide decision-making, particularly in bridging knowledge and preparedness gaps between high-income and low- and middle-income countries [14].

Innovative technologies, such as the Passive Wearable Inertia Sensor (PWIS), exemplify strategic foresight by providing cost-effective health monitoring solutions [35]. Initiatives emphasize proactive measures in screening and managing maternal mental health disorders during crises [16]. The shift towards data-driven approaches, termed 'Googlization', highlights strategic foresight's potential to leverage big data for informed decision-making in maternal health [36]. The integration of dynamic programming and AI in optimizing vaccination policies illustrates strategic foresight's role in real-time policy adjustments [37].

Gestational diabetes is reconceptualized as having broader implications than a short-term complication, emphasizing the need for strategic foresight in maternal health policy [38]. Data-driven quality improvement initiatives are crucial for enhancing outcomes and service delivery, underscoring strategic foresight's role in continuous improvement [39]. The introduction of Medical Cyber-Physical Systems (MCPS) represents a novel telemonitoring framework, categorizing research based on technology and application [23]. This framework highlights strategic foresight's potential in enhancing maternal health predictions by addressing data reporting system limitations and temporal trends [40].

Brazil's Unified Health System (SUS) is a significant policy development aimed at improving maternal health delivery [21]. Strategic foresight's importance is further underscored by its capacity to predict beneficiary engagement, improving health outcomes [10]. The impact of maternal obesity on offspring in metabolic, immunological, and neurodevelopmental domains underscores the necessity of strategic foresight in informing maternal health policy [28].

In examining the multifaceted nature of health decision-making in maternal health, it is essential to consider the various challenges and factors that come into play. Figure 2 illustrates the hierarchical structure of these key challenges, categorizing them into systemic, socio-economic, technological, psychological, and access-related domains. Each of these categories is further delineated into specific challenges and influences, thereby providing a comprehensive overview of the complexities involved in maternal health decision-making. This structured representation not only enhances our understanding of the interconnected factors but also highlights the need for a holistic approach in addressing the challenges faced by individuals in this critical area of health.

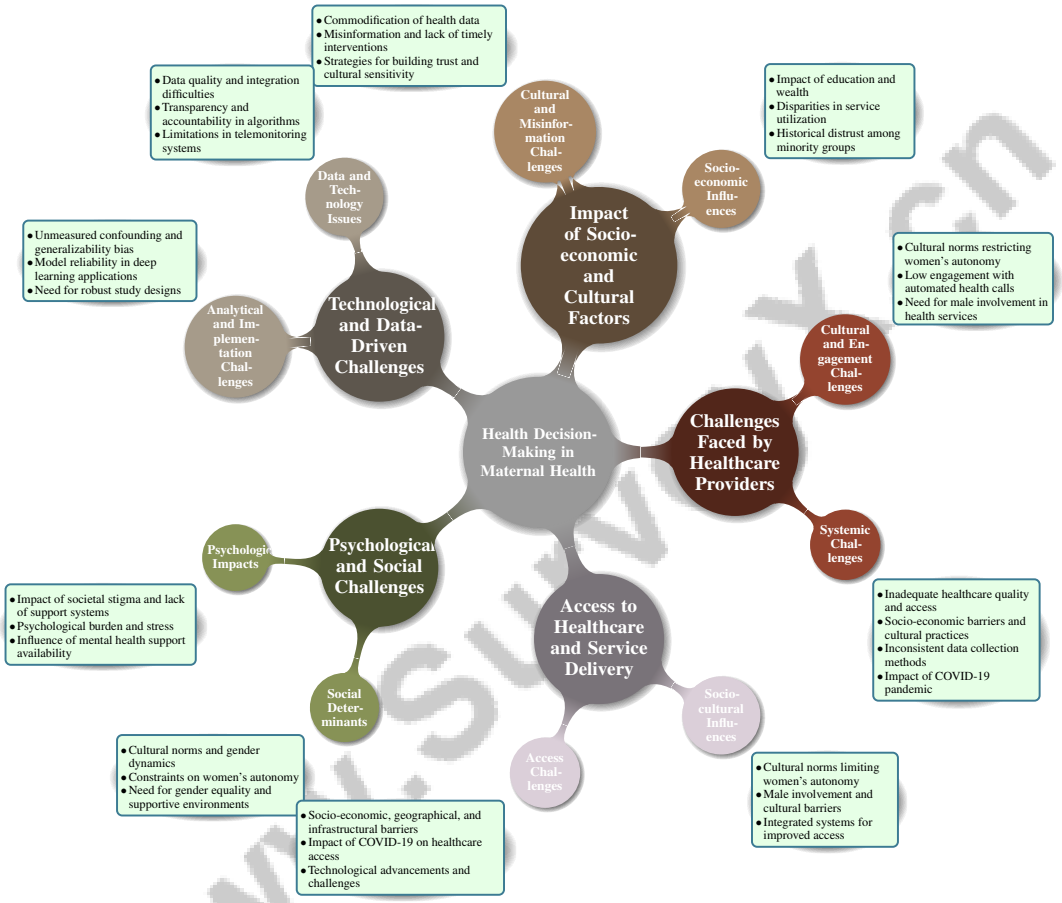


Figure 2: This figure illustrates the hierarchical structure of key challenges and factors influencing health decision-making in maternal health, categorized into systemic, socio-economic, technological, psychological, and access-related domains. Each category is further detailed into specific challenges and influences, providing a comprehensive overview of the complexities involved in maternal health decision-making.

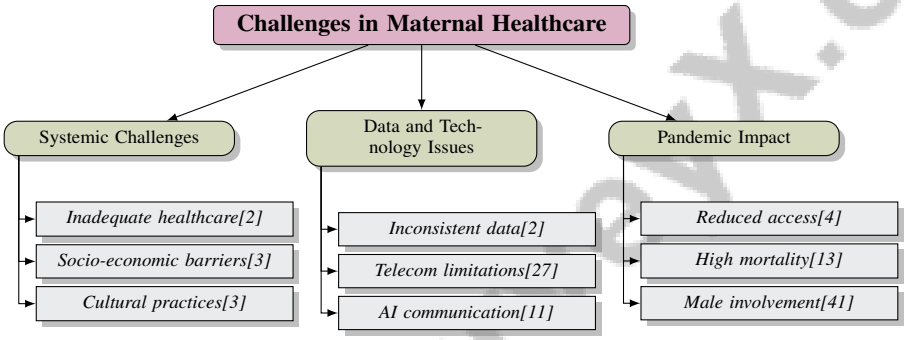
3 Health Decision-Making in Maternal Health

3.1 Challenges Faced by Healthcare Providers

Healthcare providers in maternal health face systemic challenges, including inadequate healthcare quality and access, compounded by socio-economic barriers and cultural practices. These issues are exacerbated by inconsistent data collection methods, which hinder the accurate capture of maternal deaths and obstruct informed decision-making [2]. The COVID-19 pandemic has further strained healthcare delivery by reducing access to maternal and child healthcare services [4]. The lack of comprehensive data during such crises complicates the management of these challenges [13]. Additionally, low engagement with automated health calls, influenced by beneficiary preferences, limits the effectiveness of telecommunication technologies [27].

As illustrated in Figure 3, the primary challenges faced in maternal healthcare can be categorized into systemic challenges, data and technology issues, and the impact of the pandemic. This figure highlights key issues such as inadequate healthcare, socio-economic barriers, cultural practices, inconsistent data, telecom limitations, AI communication, reduced access during pandemics, high mortality rates, and the role of male involvement. Cultural norms and regional differences restrict women's autonomy in accessing education and health resources [3]. The absence of effective risk management mechanisms further complicates healthcare provision in maternal health, where uncertainties are prevalent [8]. Trial designs often fall short in providing comprehensive information on treatment outcomes, complicating the optimization of interventions [7].

Male involvement in health service utilization has shown potential in improving maternal and newborn outcomes, particularly in low- and middle-income countries. However, the effectiveness of such interventions needs further exploration to establish best practices [26, 29, 10, 41]. Addressing these challenges requires enhancing healthcare infrastructure, improving data quality, and developing guidelines that support informed decision-making. Tackling systemic issues like racial and ethnic disparities can lead to tailored interventions, such as AI-driven communication strategies, that improve health outcomes for underserved communities [12, 9, 10, 11].



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3.2 Impact of Socio-economic and Cultural Factors

Socio-economic and cultural factors critically shape decision-making in maternal health, influencing healthcare access and outcomes. Socioeconomic status, including education and wealth, significantly impacts health-related choices, as seen in Nigerian women [3]. Disparities in service utilization and mortality rates are tied to socio-economic status, caste, education, and gender [29]. Historical distrust of the healthcare system among minority groups complicates delivery, as cultural differences and communication barriers hinder access [30]. Maternal mortality disparities among racial groups, exacerbated by socio-economic and cultural factors, necessitate targeted interventions [2].

The commodification of health data by technology companies poses risks, potentially eroding trust and complicating decision-making [36]. Misinformation and lack of timely interventions are core obstacles within the socio-cultural context, impacting engagement with health programs [25]. Strategies to address these challenges should include improving education, equitable wealth distribution, and building trust in healthcare systems while fostering culturally sensitive communication. This approach can enhance patient engagement in decision-making, particularly among underrepresented groups, and address systemic disparities in healthcare access and quality [18, 11, 14, 9, 30].

3.3 Technological and Data-Driven Challenges

Technological and data-driven challenges in maternal health encompass issues of data quality and the integration of advanced monitoring systems. Innovations like the T2*-diffusivity MRI technique enhance health assessments but face implementation hurdles due to complexity and cost [33]. The E-textile system addresses traditional monitoring challenges such as poor signal quality [42]. Data

quality issues, including missing values and integration difficulties, complicate decision-making [31]. Transparency, accountability, and privacy protection in algorithmic applications further complicate decision-making [43]. Telemonitoring systems face limitations in real-time processing capabilities [23].

Challenges like unmeasured confounding in observational studies and generalizability bias in trials affect decision reliability [44]. Ensuring model reliability in deep learning applications remains a significant hurdle [34]. Slow processing of large datasets can impede timely decision-making [1]. In health communication, the inability to collect individual preferences for optimal call scheduling presents a technological challenge [27]. The lack of robust study designs to measure male involvement impacts underscores the need for rigorous methodologies [26].

Addressing these challenges requires strategies focused on enhancing data quality, improving real-time processing, and establishing robust analytical frameworks. Integrating advanced analytics methods can drive innovation and improve outcomes in diverse application areas [36, 31]. Overcoming these obstacles will enable informed decision-making, ultimately improving maternal and neonatal health outcomes.

3.4 Psychological and Social Challenges

Psychological and social challenges significantly impact maternal health decision-making, particularly where mortality is influenced by unsafe abortions [21]. Societal stigma and lack of support systems for unwanted pregnancies exacerbate these challenges. The psychological burden of navigating complex healthcare systems, coupled with societal pressures, increases stress among pregnant women, complicating informed decision-making.

Social determinants, including cultural norms and gender dynamics, critically shape health outcomes. Women's autonomy in decision-making is often constrained by patriarchal structures, as seen in Nigerian women, where only 6.2% report making their own healthcare decisions [3, 11]. This lack of autonomy is compounded by psychological stressors, deterring necessary medical interventions.

The availability of mental health support influences decision-making, with crises like the COVID-19 pandemic heightening depressive and anxiety symptoms [45, 10]. Inadequate mental health resources and stigma contribute to reluctance in seeking support. Addressing these challenges requires enhancing mental health services, promoting gender equality, and fostering supportive environments for informed decision-making.

3.5 Access to Healthcare and Service Delivery

Access to healthcare services and effective delivery systems are crucial for maternal and neonatal outcomes. Social determinants, care continuum, and ethical technology application play significant roles in improving health services. Enhanced access to antenatal care, skilled delivery, and postpartum support can reduce mortality rates, as evidenced in studies from India and Pakistan [18, 29, 11]. Disparities in access are driven by socio-economic, geographical, and infrastructural challenges, particularly in LMICs.

The COVID-19 pandemic has exposed vulnerabilities in healthcare access, with disruptions increasing morbidity and mortality [13]. In Mozambique, restrictions have limited service access, highlighting the need for resilient systems [4]. Technological advancements, such as AI and mobile health services, offer opportunities for enhanced access and service delivery. However, challenges like standardization, bias in AI decision-making, and economic sustainability in LMICs must be addressed [36, 46, 11].

Socio-cultural factors also influence access. Cultural norms and gender dynamics limit women's autonomy, leading to delayed or inadequate services [3]. Male involvement can improve service utilization, but cultural barriers often restrict this, necessitating targeted interventions for gender-inclusive practices [26]. Improving access and delivery requires integrated systems addressing technological and socio-cultural barriers. This includes enhancing infrastructure, promoting digital literacy, and empowering women in decision-making, addressing disparities and fostering engagement in maternal health [22, 9, 10, 11]. Addressing these challenges can improve access to services and enhance maternal and neonatal outcomes.

4 Scenario Planning in Maternal Health

Scenario planning is crucial in maternal health to foresee and address the multifaceted challenges in healthcare delivery. This approach aids in identifying potential health crises and crafting strategic interventions for diverse populations. A key aspect involves integrating advanced technological applications that are transforming maternal health, enhancing monitoring and predictive capabilities for better decision-making. The following subsection explores the role of advanced technologies in scenario planning and their influence on maternal health outcomes.

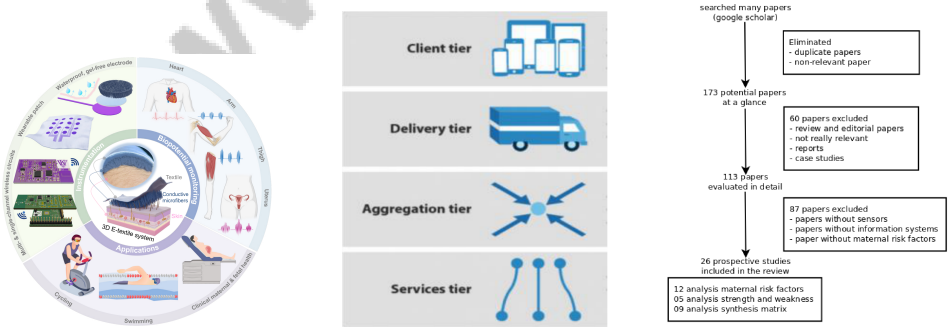
4.1 Advanced Technological Applications

Advanced technological applications significantly enhance scenario planning in maternal health, improving monitoring, prediction, and response to health challenges. AI technologies exemplify this integration by personalizing maternal health interventions to boost engagement and outcomes [10]. The Brazilian Obstetric Observatory is a model for analyzing maternal health data using statistical models like descriptive statistics and regression analyses, identifying trends that guide targeted interventions and policy formulation [13].

Innovations such as the 3D E-textile system allow real-time monitoring of electrophysiological signals, addressing traditional challenges in maternal health assessments. This wearable device records maternal and fetal health data continuously, providing critical insights often missed in sporadic assessments [9, 35]. Advanced clustering methods, like K-Means and Hierarchical Clustering, refine scenario planning by grouping countries based on maternal mortality rates, enabling tailored interventions for specific regions.

Incorporating stakeholder perspectives, including healthcare providers and patients, is essential in designing technologies like Natural Language Processing (NLP) tools to address systemic disparities and enhance clinician-patient relationships. Engaging affected individuals ensures that NLP applications meet practical needs while promoting ethical use and contextual understanding [11, 32, 9, 36, 22]. A participatory design framework enhances the development of NLP tools that improve communication and decision-making processes in maternal health.

Despite AI advancements, challenges remain in its integration into medical consultations, potentially complicating shared decision-making. AI's role can delay clinical decisions when recommendations are opaque to patients, risking symptom misinterpretation and confusion about professional responsibilities. Health professionals must adapt their decision-making strategies to incorporate AI effectively while maintaining clear communication with patients [36, 47]. This underscores the need for careful consideration of AI's role in maternal health scenarios to support effective decision-making.



(a) 3D E-textile System for Biopotential Monitoring[42]

(b) Network architecture diagram showing client, delivery, aggregation, and services tiers.[46]

(c) Flowchart detailing the selection and evaluation process for prospective studies.[23]

Figure 4: Examples of Advanced Technological Applications

As illustrated in Figure 4, scenario planning in maternal health increasingly incorporates advanced technological applications to enhance monitoring and decision-making. The 3D E-textile system for biopotential monitoring exemplifies this innovation, featuring a sophisticated textile structure

embedded with conductive microfibers that connect to a waterproof, gel-free wearable patch for multi-channel wireless communication. Additionally, network architecture diagrams showcase the complex data handling layers from client devices to aggregation and services tiers. The flowchart for selecting and evaluating studies highlights the meticulous process of research synthesis, ensuring the inclusion of studies addressing key maternal health factors. These advancements exemplify the potential of scenario planning in maternal health, paving the way for precise and responsive healthcare solutions [42, 46, 23].

4.2 Data-Driven Decision-Making

Data-driven decision-making is essential in scenario planning for maternal health, enabling effective resource allocation and targeted interventions. By incorporating advanced analytical techniques, data-driven approaches enhance the ability to anticipate and respond to health challenges. The Bayesian Spatial Functional Clustering (BSFC) method, for instance, uses random spanning trees for spatial partitioning and latent Gaussian models to provide nuanced insights into maternal health patterns [48].

Data-driven methods, such as the Bayesian approach with Thompson Sampling, facilitate inference of optimal call times based on limited data, showcasing their potential to improve health intervention engagement [27]. This is particularly relevant in maternal health, where timely interventions can significantly impact outcomes. Instance-Based Learning Theory (IBLT) models individual beneficiaries' engagement dynamics, emphasizing the importance of personalized data-driven approaches in scenario planning [49].

The Causal Datasheet Generation Tool (CDG-T) evaluates Bayesian network structural learning algorithms on synthetic datasets mimicking real-world properties, underscoring the role of data-driven decision-making in refining predictive models [50]. These tools provide a robust framework for understanding complex data and informing strategic decisions.

Data-driven approaches extend beyond maternal health, as seen in their application in nanotechnology scenario planning, highlighting their broad relevance [8]. By enhancing public services through improved resource allocation, data-driven decision-making significantly contributes to effective scenario planning, ultimately leading to better health outcomes [43].

4.3 Innovative Health Monitoring Systems

Innovative health monitoring systems are pivotal for improving maternal health outcomes through scenario planning techniques. These systems utilize cutting-edge technologies, including AI and machine learning, alongside data-driven methodologies, to deliver robust monitoring and predictive analytics. This capability empowers healthcare providers to proactively identify and address potential health issues, enhancing disease detection and chronic condition management [36, 11].

A maternal health awareness program involving 2,252 participants over 31 weeks demonstrates the potential of scenario planning in optimizing health monitoring systems through synthetic data simulations [51]. These simulations test various scenarios and assess system performance under different conditions, providing valuable insights into health interventions' effectiveness.

Key innovations in health monitoring systems include real-time data collection and analysis, facilitating timely decision-making and intervention. Wearable sensors and mobile health applications enable continuous monitoring of maternal health indicators, offering a proactive approach to risk management. Advanced technologies, such as NLP and Medical Cyber-Physical Systems (MCPS), equip healthcare providers with essential data to develop personalized care plans, addressing maternal health complexities and significantly improving health outcomes for mothers. By incorporating insights from healthcare workers and birthing individuals, these technologies aim to overcome systemic disparities and enhance clinician-patient interactions, fostering a more inclusive and effective maternal healthcare environment [23, 11].

The integration of advanced algorithms and machine learning techniques enhances the predictive capabilities of health monitoring systems, enabling accurate disease detection and improved health outcome management, as evidenced by their successful application in analyzing medical images and optimizing intervention strategies in maternal health programs [36, 52, 11, 10]. By analyzing historical and real-time data, these systems can identify trends that may indicate potential health

issues, allowing for early intervention strategies. This proactive approach is essential in reducing maternal morbidity and mortality rates, particularly in low-resource settings where healthcare access may be limited.

Incorporating stakeholder feedback and user-centered design principles in developing health monitoring systems ensures alignment with the needs of healthcare providers and patients. This participatory approach enhances usability and effectiveness by integrating insights from healthcare providers and beneficiaries. It not only improves the delivery of critical health information—such as maternal and child health education—but also fosters engagement through tailored interventions, ultimately leading to improved health outcomes for mothers and their infants [11, 25, 9, 10].

4.4 Policy and Intervention Strategies

Policy and intervention strategies in maternal health are crucial for enhancing healthcare delivery and outcomes, particularly when informed by scenario planning techniques. Strategies must address diverse needs and challenges across regions, including both high-income countries (HICs) and low- and middle-income countries (LMICs). This survey introduces a framework for understanding severe maternal morbidity (SMM), emphasizing the importance of categorizing its definitions, prevalence, and contributing factors to develop region-specific interventions [20]. This approach ensures that policy strategies are contextually relevant and effective in addressing unique regional challenges.

An innovative strategy involves integrating SMS advertising into an M-Service platform, providing free access to maternal health information while generating revenue from advertisers [46]. This method enhances access to essential health information and ensures the sustainability of health services through commercial partnerships, particularly beneficial in resource-limited settings.

Intervention strategies must also focus on improving the quality of maternal health care, as highlighted by the need to reduce unnecessary surgical interventions [21]. By implementing evidence-based guidelines and monitoring systems, healthcare providers can ensure that interventions are effective and appropriate, minimizing adverse outcomes. Unique stratification of outcomes by maternal morbidity and birth order offers a nuanced understanding of challenges, allowing for targeted policy interventions [6].

The intergenerational concordance of microbial variation associated with gestational diabetes mellitus (GDM) underscores the need for policies addressing the long-term health effects of maternal conditions on neonatal microbiota [17]. Incorporating insights from microbiome research into maternal health policies enables healthcare systems to develop comprehensive strategies that consider both immediate and future health impacts.

Future research should prioritize developing comprehensive emergency response strategies that integrate public health and economic recovery efforts while exploring community-driven solutions [15]. These strategies are crucial for building resilient healthcare systems capable of effectively responding to crises, such as pandemics, which disproportionately affect maternal health services.

4.5 Sustainability and Accessibility

Sustainability and accessibility are critical considerations in applying scenario planning for maternal health, ensuring interventions are enduring and universally available. The MatES web-based expert system exemplifies a sustainable approach to enhancing maternal health services by providing decision support based on symptoms and diseases. This system facilitates training and consultation for Health Extension Workers (HEWs), improving their capacity to deliver quality healthcare [52]. By leveraging web-based platforms, such systems offer scalable solutions adaptable to various contexts and resource levels, enhancing the sustainability of maternal health interventions.

Accessibility in maternal health is often hindered by socio-economic and geographical barriers, especially in LMICs. Integrating scenario planning techniques in healthcare can effectively address access challenges by equipping providers with tools to foresee potential barriers, such as systemic health disparities and economic constraints, and develop proactive strategies to mitigate these obstacles. Employing data-driven decision-making and ethical frameworks enables healthcare practitioners to better understand diverse populations' needs, ultimately improving access to care [36, 11]. For instance, mobile health applications and telehealth services can extend maternal health services' reach to remote and underserved areas, ensuring essential healthcare access for all women.

The sustainability of scenario planning in maternal health also relies on integrating community-driven approaches that empower local populations to participate actively in health decision-making. Involving community members in planning and implementing health interventions ensures that services are culturally appropriate and responsive to specific needs. This participatory approach enhances accessibility to maternal health services by incorporating the voices and needs of both healthcare workers and birthing individuals, fostering community ownership and promoting long-term sustainability by addressing systemic health disparities and encouraging inclusive design in healthcare technologies [9, 11].

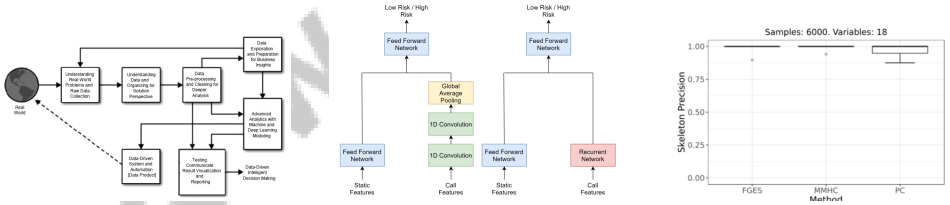
Moreover, innovative funding models, such as public-private partnerships and the integration of commercial services, can support the financial sustainability of maternal health interventions, as demonstrated by the SMS advertising strategy in M-Service platforms. These models create diversified revenue streams that enhance health services' sustainability while ensuring accessibility remains a priority, addressing systemic disparities and the need for ethical frameworks in healthcare technology [36, 11].

5 Integration of Scenario Planning and Health Decision-Making

5.1 Frameworks and Methodologies for Integration

Integrating scenario planning into maternal health decision-making requires comprehensive frameworks that address healthcare delivery complexities. Farber's framework for integrating scenario planning into technoscientific education provides a foundational model, emphasizing strategic foresight in managing risks and benefits [8]. Embedding scenario planning in educational curricula enhances healthcare professionals' decision-making capabilities.

Shammi et al. categorize methods into stages of lockdown strategies, assessing socio-economic impacts, which offers a framework for understanding the socio-economic effects of health interventions [15]. This approach helps develop interventions that balance public health needs with socio-economic factors. Sarri et al. highlight the importance of synthesizing evidence from non-randomized studies (NRS) and randomized controlled trials (RCTs) to enhance health strategies' validity [22, 44, 10, 11]. This synthesis leverages innovative methodologies like matching algorithms and sensitivity analyses, producing robust causal estimates to guide effective interventions and improve maternal health outcomes.



(a) Understanding Data-Driven Intelligent Decision Making Process[31]

(b) Deep Learning Network Architecture for Risk Classification[25]

(c) Comparison of Skeleton Precision Across Different Methods[50]

Figure 5: Examples of Frameworks and Methodologies for Integration

As shown in Figure 5, integrating scenario planning and health decision-making requires robust frameworks. The "Understanding Data-Driven Intelligent Decision Making Process" outlines steps from data collection to analytics, emphasizing data organization for insights. The "Deep Learning Network Architecture for Risk Classification" uses static features in a feed-forward network to classify risk scenarios. The "Comparison of Skeleton Precision Across Different Methods" visually compares methodologies, highlighting structured methodologies' role in informed, data-driven healthcare decisions [31, 25, 50].

5.2 Technological Innovations and Tools

Technological innovations are crucial for integrating scenario planning into health decision-making, particularly in maternal health. The 3D E-textile system exemplifies technology's potential by

providing real-time data for clinical applications [42]. This non-invasive monitoring improves maternal health assessments' accuracy and timeliness.

Web-based expert systems, like MatES, support healthcare providers by assisting Health Extension Workers (HEWs) in diagnosing and managing maternal health issues [52]. These systems enhance HEWs' capacity to deliver quality healthcare, especially in resource-limited settings. The Adaptive Distributed Processing Framework (ADPF) optimizes data processing, facilitating scenario planning integration into health decision-making [1]. This framework ensures timely and accurate information access, essential for effective maternal health strategies.

Advanced algorithms, such as Bayesian collaborative bandits with Thompson Sampling, demonstrate technology's potential to improve health interventions [27]. This method optimizes call scheduling in mHealth programs, maximizing engagement and impact. Leveraging these technological tools enhances maternal health programs' effectiveness and outcomes for mothers and children.

5.3 Barriers to Implementation

Implementing integrated approaches in maternal health decision-making faces methodological, data-related, and systemic challenges. A significant barrier is the reliance on limited ground truth labels for prediction, hindering robust predictive models for maternal health outcomes [32]. This dependency complicates model validation, affecting scenario planning techniques' reliability in real-world settings.

Confounding in exposure-mediator or mediator-outcome relationships introduces biases, compromising health decision-making validity [53]. Addressing these confounding factors is crucial for evidence-based health interventions. Data completeness and real-time reporting challenges further complicate integrated approaches' implementation. Incomplete data can lead to inaccurate analyses, hindering informed decision-making [13]. Comprehensive data is critical for successful scenario planning integration into health decision-making.

Systemic barriers, such as inadequate infrastructure and resources in low- and middle-income countries (LMICs), also impede implementation. These limitations restrict healthcare systems' capacity to adopt advanced technologies and methodologies essential for improving maternal health outcomes. Addressing systemic challenges requires targeted investments in healthcare infrastructure and capacity-building, enabling the adoption of integrated approaches that enhance service delivery, improve patient engagement, and ensure equitable health outcomes. Such investments are vital for fostering healthcare system resilience, as evidenced by strategic planning needs to manage public health crises like the COVID-19 pandemic, enhancing maternal and child health outcomes [18, 39, 36, 15, 30].

6 Case Studies and Applications

6.1 Case Studies and Practical Applications

The integration of scenario planning in maternal health decision-making is demonstrated through case studies that highlight its role in improving health outcomes. The mMitra program, which utilizes automated health calls, significantly enhances maternal health awareness among women. Analysis of call records from over 300,000 participants revealed improved engagement compared to traditional methods like random forests [25]. This underscores the efficacy of data-driven strategies in optimizing health communication.

Another application involves cluster analysis to identify countries with similar maternal mortality rates, as demonstrated by Nandini et al. These methods offer valuable insights for policymakers and healthcare providers, enabling targeted interventions tailored to specific regional needs [24]. By integrating scenario planning with advanced analytical techniques, decision-making processes in maternal health are enhanced. Emphasizing ethical frameworks and principles, these methods ensure the effective integration of natural language processing tools, focusing on contextual relevance, comprehensive measurements, and inclusive design. AI-based interventions, such as automated voice calls, significantly improve health knowledge and outcomes in underserved communities, illustrating the tangible benefits of technology in maternal health programs [10, 11].

6.2 Information-Sharing and Mental Health Support During Pandemic

Scenario planning is vital for enhancing information-sharing and mental health support during pandemics, enabling healthcare systems to anticipate and address complex challenges. The COVID-19 pandemic underscored the need for robust information-sharing mechanisms to ensure timely dissemination of critical health information, essential for effective public health responses [4]. Scenario planning aids in developing strategic frameworks for information dissemination, identifying communication barriers, and optimizing health message delivery, as demonstrated by the mMitra program [25].

Additionally, scenario planning is essential for mental health support during pandemics, addressing psychological impacts such as heightened anxiety and stress. It enables healthcare providers to anticipate mental health needs and design proactive interventions, particularly for maternal mental health, as evidenced by significant psychological distress among mothers during the COVID-19 pandemic [16, 14, 45, 54, 15]. This approach enhances healthcare system resilience, ensuring uninterrupted mental health service provision and timely support for vulnerable populations [16, 14, 45, 4, 15].

6.3 Synthetic Data Simulations and Real-World Applications

Synthetic data simulations are crucial for enhancing real-world scenario planning applications, particularly in maternal health. These simulations evaluate health interventions, allowing researchers to analyze scenarios and assess potential impacts on outcomes. By integrating advanced methodologies, such as AI-based scheduling and natural language processing for verbal autopsy data, simulations improve understanding of strategies to enhance maternal and child health knowledge [22, 32, 9, 10]. They support informed decision-making by integrating evidence from randomized controlled trials and non-randomized studies, enhancing reliability and applicability in real-world settings.

Synthetic data simulations facilitate testing intervention strategies in controlled environments. For instance, Bayesian network structural learning algorithms on synthetic datasets allow robust evaluation of predictive models [50]. This approach refines strategies, ensuring they are evidence-based and tailored to specific population needs. Moreover, simulations explore potential impacts of health policies, enabling anticipation and mitigation of challenges. By simulating diverse scenarios, researchers evaluate intervention feasibility and effectiveness, ensuring solutions are sustainable, accessible, and tailored to unique challenges [9, 44, 10].

6.4 Monetary Saving Recommendations in Tanzania

Scenario planning in maternal health decision-making is exemplified by a case study on monetary saving recommendations in Tanzania, highlighting strategic foresight's potential to improve resource allocation and health outcomes. This approach empowers policymakers to address current challenges and future uncertainties in maternal healthcare [11, 9, 8, 23, 10]. Financial constraints limit access to essential services, necessitating innovative approaches to maximize resource impact. Scenario planning explores financial strategies, enabling effective anticipation and addressing of economic challenges.

Integrating community savings groups is a key strategy, pooling resources to fund maternal health initiatives. These groups provide financial support for pregnant women, ensuring access to healthcare services. Scenario planning techniques assess financial models, determining sustainable strategies for enhancing outcomes while addressing social determinants and systemic challenges [11, 8, 23, 9, 29].

Scenario planning also identifies economic barriers and formulates interventions. By analyzing future scenarios, decision-makers understand socio-economic implications of emerging technologies and public health crises. This foresight enables informed decision-making, anticipating risks and aligning resources to promote sustainable development [8, 15, 9, 11]. Simulating economic scenarios assesses health insurance or subsidy feasibility, ensuring interventions are tailored to Tanzania's economic context.

In addition to financial strategies, scenario planning supports educational programs to improve women's financial literacy. These programs foster financial stability and enhance maternal health outcomes, addressing high morbidity and mortality rates. Empowering women with financial management skills improves healthcare decisions and practices during pregnancy and infancy

[11, 52, 9, 25, 10]. Scenario planning customizes educational initiatives, ensuring cultural appropriateness and responsiveness to target population needs.

6.5 Web-Based Expert System for Health Extension Workers

The development of a web-based expert system for Health Extension Workers (HEWs) represents a significant advancement in maternal health, leveraging scenario planning to enhance healthcare delivery and decision-making. These systems use forward chaining rule-based methodologies for decision support, training, and consultation, improving HEWs' capacity to deliver quality maternal healthcare [52]. By integrating scenario planning, expert systems anticipate health challenges and provide tailored recommendations, equipping HEWs with necessary tools and knowledge for diverse scenarios.

The MatES web-based expert system exemplifies this by offering a platform for diagnosing and managing maternal health issues based on symptoms and diseases. It enhances HEWs' decision-making by providing timely, evidence-based recommendations, ensuring services align with medical guidelines and best practices. Addressing the knowledge gap in resource-limited settings like Ethiopia, this system facilitates better maternal health outcomes and effective management of pregnancy and childbirth complications [52, 36, 11]. Real-time access to information and decision support empowers HEWs, improving maternal and neonatal health outcomes.

Integrating scenario planning into expert systems customizes interventions, responding to regional and population needs. By simulating health scenarios, systems identify barriers to access and devise strategies, improving service accessibility and sustainability. Leveraging AI-driven interventions, such as automated voice calls, enhances knowledge and engagement, reducing maternal morbidity and mortality in low-income communities [11, 52, 9, 25, 10].

7 Challenges and Future Directions

The integration of global health data within scenario planning frameworks in India presents both challenges and opportunities for enhancing maternal healthcare delivery. This section delves into these dynamics, emphasizing the role of global health data in addressing the diverse socio-economic and cultural landscape of India.

7.1 Global Health Data and Scenario Planning in India

Incorporating global health data into scenario planning for maternal health in India entails both challenges and opportunities. A significant challenge is the skepticism from regulators regarding the methodological validity of using global health data, particularly from non-randomized studies, which complicates the adoption of comprehensive data-driven strategies [22]. Developing robust frameworks to synthesize diverse data sources is essential for evidence-based, contextually relevant decision-making. India's socio-economic and cultural diversity necessitates interventions tailored to address regional disparities in healthcare access and socio-economic determinants [19]. The COVID-19 pandemic further highlighted the importance of global health data in understanding long-term impacts on maternal health, especially among high-risk groups [4]. Future research should focus on longitudinal studies to assess these impacts and inform policies promoting equitable healthcare access and maternal mental health.

Opportunities in scenario planning for maternal health in India include innovative models for delivering essential health information. The integration of SMS advertising into M-Services has proven effective in enhancing health information dissemination, a particularly beneficial approach in India given the widespread accessibility of mobile technology [46]. Emphasizing optimal nutrition before and during pregnancy, as well as in early childhood, is vital for addressing the diverse needs of India's demographic groups, with future interventions focusing on these nutritional aspects to improve maternal and child health outcomes [5].

7.2 Challenges in Data Quality and Integration

Effective scenario planning in maternal health is hindered by challenges in data quality and integration. Inconsistencies in data collection and reporting, particularly regarding neonatal mortality rates, arise

from a lack of standardized definitions and methodologies across countries, complicating data quality and integration efforts [2]. Verbal autopsy narratives, while useful, often struggle with real-world complexities, such as missing values and mixed data types, highlighting data quality concerns. Limitations in randomized controlled trials (RCTs) and observational studies further complicate data reliability in maternal health [44]. Understanding the effects of maternal obesity on offspring health outcomes, as well as social determinants of health, requires comprehensive data to capture these complex relationships [28, 12].

Current systems, such as the MatES web-based expert system, which focuses on only 10 major diseases, underscore limitations in data scope and integration [52]. Addressing these challenges involves improving data collection methodologies, establishing robust ethical frameworks, and enhancing data integration strategies. Overcoming these barriers will improve the reliability and applicability of scenario planning in maternal health, ultimately enhancing outcomes for mothers and children [8].

7.3 Technological and Methodological Limitations

Maternal health practices face significant technological and methodological challenges. Low-resource settings often find traditional methods like Passive Wearable Inertia Sensors (PWIS) and E-textile methods for real-time monitoring difficult to implement due to costs and signal quality issues [35, 42]. Advanced techniques, such as combined diffusion-relaxometry MRI, require regularization for effective assessments [42, 35, 48]. Computational methodologies, such as Bayesian Spatial Functional Clustering (BSFC) and Partially Observable Markov Decision Processes (POMDPs), pose challenges due to computational intensity and potential biases in data sampling [48, 37, 27, 7].

Telemonitoring systems face research gaps related to data filtering, security, and effectiveness in diverse environments, necessitating further investigation [23]. The lack of comprehensive theoretical foundations for Uncertainty Quantification (UQ) in medical AI also presents significant challenges [34]. Empirical studies are crucial to validate the effectiveness of AI in healthcare, highlighting a gap in current technological applications [47].

7.4 Socio-Cultural and Economic Barriers

Socio-cultural and economic barriers significantly impede the effective implementation of maternal health services, influencing healthcare access and decision-making. In regions like Nigeria, cultural norms and regional disparities present formidable challenges, affecting women's autonomy in health decisions [3]. Economic disparities further limit access to healthcare resources and services, particularly in underserved areas [29]. Culturally sensitive interventions are crucial to addressing these inequities [30]. Male involvement in maternal health decisions also plays a critical role, with gaps in understanding its effects on women's autonomy and couple dynamics [26].

The COVID-19 pandemic has exacerbated socio-cultural and economic barriers, creating significant gaps in understanding the long-term impacts on maternal and newborn health outcomes. The effectiveness of new care models is crucial in addressing these challenges [14]. The continuum of care (CoC) for maternal health is often disrupted by socio-cultural barriers, underscoring the need for improved health education and targeted interventions in underserved regions [18]. Robust methodological approaches to unmeasured confounding offer potential solutions, providing a more accurate assessment of maternal health interventions [53]. However, biases due to dataset limitations, such as a focus on higher maternal morbidity and mortality rates in underserved areas, need to be addressed [6].

7.5 Advancements in Scenario Planning Techniques

Advancements in scenario planning techniques have significantly enhanced the capacity to address complex maternal health challenges. The multiPPI++ method exemplifies these advancements, improving accuracy in predicting health outcomes through the integration of diverse data sources and analytical frameworks [32]. This method enables healthcare providers to make informed decisions by offering evidence-based recommendations for maternal care, ensuring healthcare services are consistent and aligned with the latest medical guidelines and best practices.

Ethical considerations are increasingly important in scenario planning, particularly regarding patient rights and societal norms. The use of data-driven algorithms necessitates careful consideration of data ownership and privacy issues, highlighting the potential long-term implications of tech-driven health research [36]. Addressing these ethical concerns is crucial for ensuring that scenario planning techniques are both effective and respectful of individual rights.

The adaptability and interoperability of telemonitoring systems are critical areas for future research, as these systems play a vital role in enhancing maternal healthcare [23]. Integrating innovative methodologies and technologies, such as mobile health applications, can provide comprehensive and real-time data, facilitating timely interventions and improving health outcomes. State-specific and community-specific studies are essential for informing policy and program interventions aimed at reducing maternal health inequities [29]. These studies offer valuable insights into the unique challenges and opportunities within different regions, enabling the development of targeted strategies that address the specific needs of diverse populations.

8 Conclusion

Integrating scenario planning into health decision-making is crucial for advancing maternal health outcomes. By anticipating and addressing potential challenges, scenario planning enables the development of proactive strategies that can mitigate systemic disparities in maternal healthcare. The insights gained from the OOBr COVID-19 benchmark highlight the pandemic's profound impact on maternal health, emphasizing the need for targeted public health interventions. Technological advancements, such as web-based expert systems, demonstrate the potential for expanding healthcare delivery beyond traditional settings, paving the way for innovative research and practice in maternal health monitoring. Implementing AI-driven interventions can optimize resource allocation and prevent disengagement, thereby enhancing maternal health outcomes. Ethical leadership and informed decision-making, as seen in scenario planning for emerging technologies, remain essential for improving maternal health. Programs promoting male engagement in reproductive health, like Bandebereho, show promise, though further research is needed to confirm their impact on mortality and morbidity. The association between twin pregnancies and adverse perinatal outcomes underscores the necessity for specialized maternal and neonatal care. Enhancing women's autonomy in healthcare decisions is critical, with only a small fraction currently making independent decisions. Updated nutritional guidelines are vital for preventing obesity and related conditions during pregnancy. Incorporating Uncertainty Quantification (UQ) into AI-driven medical decision-making can improve the reliability and effectiveness of healthcare interventions. Additionally, advancements in dosage selection methodologies contribute significantly to patient care, underscoring the importance of evidence-based decision-making in maternal health.

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