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REVIEW

Leveraging Artificial Intelligence to Achieve Sustainable Public Healthcare Services in Saudi Arabia: A Systematic Literature Review of Critical Success Factors

Rakesh Kumar[1,*], Ajay Singh[2], Ahmed Subahi Ahmed Kassar[3], Mohammed Ismail Humaida[3], Sudhanshu Joshi[4] and Manu Sharma[5]

[1]Department of Health Management, College of Public Health and Health Informatics, University of Ha'il, Ha'il, 81451, Saudi Arabia
[2]Department of Management & Information Systems, College of Business Administration, University of Ha'il, Ha'il, 81451, Saudi Arabia
[3]Department of Public Health, College of Public Health and Health Informatics, University of Ha'il, Ha'il, 81451, Saudi Arabia
[4]School of Management, Doon University, Dehradun, Uttarakhand, 248001, India
[5]Department of Management Studies, Graphic Era University, Dehradun, Uttarakhand, 248002, India

*Corresponding Author: Rakesh Kumar. Email: ra.kumar@uoh.edu.sa

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ABSTRACT: This review aims to analyze the development and impact of Artificial Intelligence (AI) in the context of Saudi Arabia's public healthcare system to fulfill Vision 2030 objectives. It is extensively devoted to AI technology deployment relevant to disease management, healthcare delivery, epidemiology, and policy-making. However, its AI is culturally sensitive and ethically grounded in Islam. Based on the PRISMA framework, an SLR evaluated primary academic literature, cases, and practices of Saudi Arabia's AI implementation in the public healthcare sector. Instead, it categorizes prior research based on how AI can work, the issues it poses, and its implications for the Kingdom's healthcare system. The Saudi Arabian context analyses show that AI has increased the discreet prediction of diseases, resource management, and monitoring outbreaks during mass congregations such as hajj. Therefore, the study outlines critical areas for defining the potential for artificial intelligence and areas for enhancing digital development to support global healthcare progress. The key themes emerging from the review include Saudi Arabia: (i) the effectiveness of AI with human interaction for sustainable health services; (ii) conditions and quality control to enhance the quality of health care services using AI; (iii) environmental factors as influencing factors for public health care; (iv) Artificial Intelligence, and advanced decision-making technology for Middle Eastern health care systems. For policymakers, healthcare managers, and researchers who will engage with AI innovation, the review proclaims that AI applications should respect the country's socio-cultural and ethical practices and pave the way for sustainable healthcare provision. More empirical research is needed on the implementation issues with AI, creating culturally appropriate models of AI, and finding new applications of AI to address the increasing demand for healthcare services in Saudi Arabia.

KEYWORDS: Artificial intelligence; public health services; sustainability; healthcare; Saudi Arabia; PRISMA

1 Introduction

Artificial Intelligence (AI) rapidly improves the healthcare industry across the global frontier with innovations designed to improve public healthcare [1]. In the international landscape, artificial intelligence enhances disease monitoring, data predicting, patient care, health and service organization, and aids policy decisions [2]. AI is employed in Saudi Arabia to improve health care and supports the Vision 2030 project [3].

AI strengthens epidemiology by estimating the occurrence of diseases using forecasting and defining the existing threats concerning the generally prevalent and typical regional genetic and lifestyle diseases [4]. In environmental health, AI tracks and controls the ecological impacts of influx and increase in urban and industrialization processes to promote safer living standards. AI significantly affects health services administration in the Kingdom as it helps solve administrative issues, distribute resources, and increase effectiveness while providing services to clients [5]. It also supports social and behavioral sciences by analyzing data to develop culturally appropriate interventions for public health problems [6,7]. In addition, AI enhances effective and timely formulation of preventive measures, eventually leading to effective health policies and fortification of the international health care systems, particularly for mass events like pilgrimage, hajj, and community as well as occupational health by enhancing personalized health care delivery and quality occupational health [8]. As remarkable as the advancements in AI are practical, the integration of these advances in Saudi Arabia is based on tenets derived from Islamic ethical standards that mandate pertinent AI applications to be free from bias, opaque, and culturally insensitive [9]. With the further advancement of AI, improving public health in Saudi Arabia would be more profound, which would help Saudi Arabia achieve the set healthcare objectives and fight future sicknesses more efficiently. Various factors play critical roles in addressing public health concerns in Saudi Arabia, viz., effective healthcare policies, investment in medical infrastructure, access to quality healthcare services, public awareness, and education while integrating with AI, data governance, and cultural sensitivity in healthcare delivery [10,11]. The healthcare system is also responsible for countering communicable and non-communicable diseases, with significant emphasis on diseases prevailing in the region [12].

Environmental health is essential to an increased rate of urbanization, industrialization, and climate change, which calls for attention to safe water supply, pollution, and waste disposal [13]. Health services administration aims to enhance the quality of health services across the country using advanced technologies such as telecommunications to deliver health services [6]. In addition, the ethical principles of public health connected with the Islamic culture and Tradition of locality ensure human rights for the benefit of the majority of the population. This review focuses on how Saudi Arabia applies and adapts the international concept of public health to fit its uniquely designed system [14]. Based on the identified research gap from the previous research, there is a dearth of relevant literature on public health and the relevance, scope, and usage of AI specific to Saudi Arabia. Thus, conducting a systematic literature review on leveraging Artificial Intelligence plays a critical role in improving public health performance in Saudi Arabia from the perspective of both academics and industry [15]. AI integration in Saudi Arabia's healthcare system must align with Islamic values and cultural norms, emphasizing privacy, dignity, equity, and community welfare. AI should uphold patient privacy while using a patient's data, which should be masked and stored securely and ethically to conform to halal standards. Patients' self-determination must be served using AI. AI-driven telemedicine maintains justice and equitable access to practice quality-generated medical instructions to remote and underserved clients. Explainability reduces accountability and maintains transparency. The concept of maslaha as community well-being is maintained through prediction, disease watchdog, and resource management for social health welfare. Gender sensitivity is integrated into creating AI applications to adapt to such cultural norms, including same-gender calls in telemedicine. These principles combine to establish AI's set Norms and Values to conform with Islam and Culture, Vision 2030 objectives, and Intent to develop trust and improve healthcare [16].

The research review is crucial as it aims to fill some existing research gaps. Firstly, the application of AI is becoming paramount in Saudi Arabia's healthcare sector, acting as a force multiplier with significant capacity in data, diagnosis of diseases, and improvement of the service delivery process [17]. Second is Saudi Arabia's public health concern, which is experiencing changes in its public health systems due to Vision

2030. Thus, this study will seek to discover how AI can be the most effective when applied in public health, the unique capabilities, and the phases that can benefit most from AI applications [18,19]. This systematic literature review provides a thorough and linear evaluation of past research, analysis of existing research, and perception of the lack of knowledge of AI applications in public health entities in Saudi Arabia. The research outcomes help tailor AI solutions to a more sustainable, socio-economic, and culturally viable healthcare environment in Saudi Arabia [20,21]. In addition, it is a scientific contribution to healthcare industry-specific recommendations based on secondary research documents that can be helpful for policymakers, healthcare managers, and researchers embarking on the systematic review process [22]. Thus, the systematic review can be described as an important scholarly work contributing to the role and development of AI within Saudi Arabia's public health sector more efficiently and ethically.

2 Review of Literature

2.1 Artificial Intelligence and Public Health in Saudi Arabia

Globally, Artificial Intelligence (AI) integration into public health is an emerging field that can transform health systems. AI is highly relevant to public health in Saudi Arabia, as the country is currently revitalizing its healthcare sector in alignment with the Vision 2030 plan [23,24].

This review aims to discover the state and the use of artificial intelligence for public health in Saudi Arabia with a perspective on the specificities of the Saudi environment. Healthcare and epidemiology are the fields in which AI is applied in Saudi Arabia. The Kingdom of Saudi Arabia (KSA) encounters numerous public health challenges, some unique to the nation due to the millions of people who enter the country annually for pilgrimage during hajj, which is a significant concern [25]. Actions such as remote health surveillance, advanced epidemiological modeling, and local and regional outbreak prediction are currently utilized to aid in planning and executing large-scale health interventions, often during mass congregations [26]. These models increase Saudi Arabia's capacity to prevent and control infections and diseases and strengthen the health system responses [27]. Thus, AI is transforming the public healthcare systems in Saudi Arabia [28]. AI technologies contribute greatly to improving the performance of operations and resource utilization in healthcare by tackling key sectors. Patient inflow, seasonal demand, and resources are predicted using predictive analytics to optimally address staff, bed, and equipment usage during surges such as Hajj. AI improves the staff schedule by detecting busy hours and work on the shift so that it will not be overstaffed or understaffed. Materials management systems forecast scarcity of inventory and alert purchasing to reorder material to ensure patients get needed supplies without overstocking. Patients are properly managed using scheduling and queueing services from the AI utility, and the patients' waiting time is also reduced. Information technologies in imaging diagnostics help speed up the analysis of cases so that specialists concentrate on complicated cases. AI equally reduces the idle time in the operating room and improves the efficiency of the surgeons' time in the operating room. Smart energy consumption systems lower overhead expenses by efficiently regulating climate by controlling a facility's needs towards sustainable practices [29]. In emergencies, AI learns how much resource is required and helps match ICUs, ventilators, and staff in a shorter time. Predictive maintenance helps avoid equipment failure, and important devices are always on and ready to use [30]. Electronic health records enhanced by artificial intelligence enhance case categorization and data retrieval and automation of redundant administrative procedures, such as billing and coding, that are time-consuming and likely to contain errors at a substantial cost. All these applications improve healthcare delivery and the effectiveness and sustainability of healthcare systems. Saudi Arabia's public healthcare system can increase efficiency, reduce costs, and improve the quality of care provided to patients by incorporating these AI-powered resource management strategies, all of which are crucial for achieving the goals of Vision 2030. AI models rely on data from Electronic

Health Records (EHRs) and other macro/micro databases to recognize high-risk populations and quickly address every community's needs [31,32]. This approach is beneficial for chronic diseases, which remain the primary health concern in Saudi Arabia. For instance, AI can be employed to develop effective promotional strategies to address issues such as diabetes and obesity in specific countries relative to their diet, which can encourage those diseases [33]. The utilization of AI in Saudi Arabian health policy decision-making has increased. Decision-makers use AI analysis to make more intelligent choices about where to invest, what healthcare services to offer, and which public health issues should be addressed [34]. Using such an approach, AI helps be more proactive regarding collaborative planning and forecasting the future demand in public health enterprises [35]. Given various operational and strategic challenges, it helps to prepare and plan an extension of the healthcare delivery system. Thus, this study review uses systematic analysis of the role of Artificial Intelligence in advancing public healthcare performance in Saudi Arabia. It critically reviews the pivoting contribution of AI in leveraging public health in Saudi Arabia using past studies broadly covering use cases, best practices, academic research papers, and reviews of AI disruption in the public healthcare domain. Considering the emerging usage of AI across various industries, its application, implementation challenges, and strategic solutions for public healthcare should be thoroughly reviewed. Although extending previous literature, this review has many unique contributions. Firstly, it provides a logical, well-structured, and innovative categorization of past research according to its potential uses, limitations, and recommendations. Secondly, the authors proposed a framework for information synthesis to highlight potential AI implementation challenges that require scholarly investigation to enhance the state of knowledge at this time based on the results of the systematic literature review (SLR). The review will endeavor to give a comprehensive view of how AI is applied to provide added value to domains such as disease monitoring, healthcare delivery, and services, parallel with assessing the usefulness of such applications from a perspective of meeting the requirements of Saudi Arabia's population in terms of public health.

Integrating AI in Saudi Arabia's healthcare system requires addressing several critical research gaps to align with cultural, ethical, and practical needs. Literature often neglects the development of culturally sensitive AI models that respect Saudi Arabian values and Islamic ethics, which is essential for fostering trust and acceptance in AI-driven healthcare solutions. In addition, there is a lack of comprehensive ethical frameworks designed for the Saudi context, including considerations of data confidentiality, algorithmic transparency, and patient autonomy. Empirical studies specific to Saudi Arabia's healthcare infrastructure and workforce readiness are scarce, with most research focusing on Western contexts, leaving significant gaps in understanding the unique challenges and success factors of AI adoption in the Kingdom. In addition, aligning AI applications with Vision 2030's objectives, such as enhancing healthcare accessibility, efficiency, and quality, remains underexplored. Another critical issue is the reliance on non-local training data, which limits AI models' accuracy and relevance for the Saudi population. This review aims to bridge these gaps by proposing culturally sensitive, ethically grounded, and context-specific AI frameworks, offering insights into localized data requirements and strategic alignment with national healthcare goals to support effective AI integration in Saudi Arabia.

The review article primarily aims to investigate three research questions to understand the research progress in this area, including:

RQ1: *To what extent and in what ways are AI applications being used for the public healthcare sector in Saudi Arabia?*

RO1: *To investigate the extent of AI adoption in Saudi Arabia's public healthcare sector and explore how AI technologies are utilized to enhance public healthcare services.*

RQ2: *What are the critical areas in public healthcare in Saudi Arabia where AI has been deployed?*

RO2: *To systematically identify and categorize the critical areas within Saudi Arabia's public healthcare sector where AI technologies have been deployed, providing insights into AI integration's leading applications and domains.*

RQ3: *What future opportunities exist for AI applications that could enhance the sustainability of Saudi Arabia's public healthcare system by integrating digital technologies?*

RO3: *To explore and define future opportunities for AI applications that can contribute to building a sustainable public healthcare system in Saudi Arabia, focusing on how digital technologies can enhance these opportunities.*

Fig. 1 demonstrates the Review Framework adopted [36,37] for the review article. Sections 2.2 to 2.6 detail the process used for the systematic literature review by the authors, including data selection, keyword selection, acceptance and rejection criteria, and inclusion and exclusion.

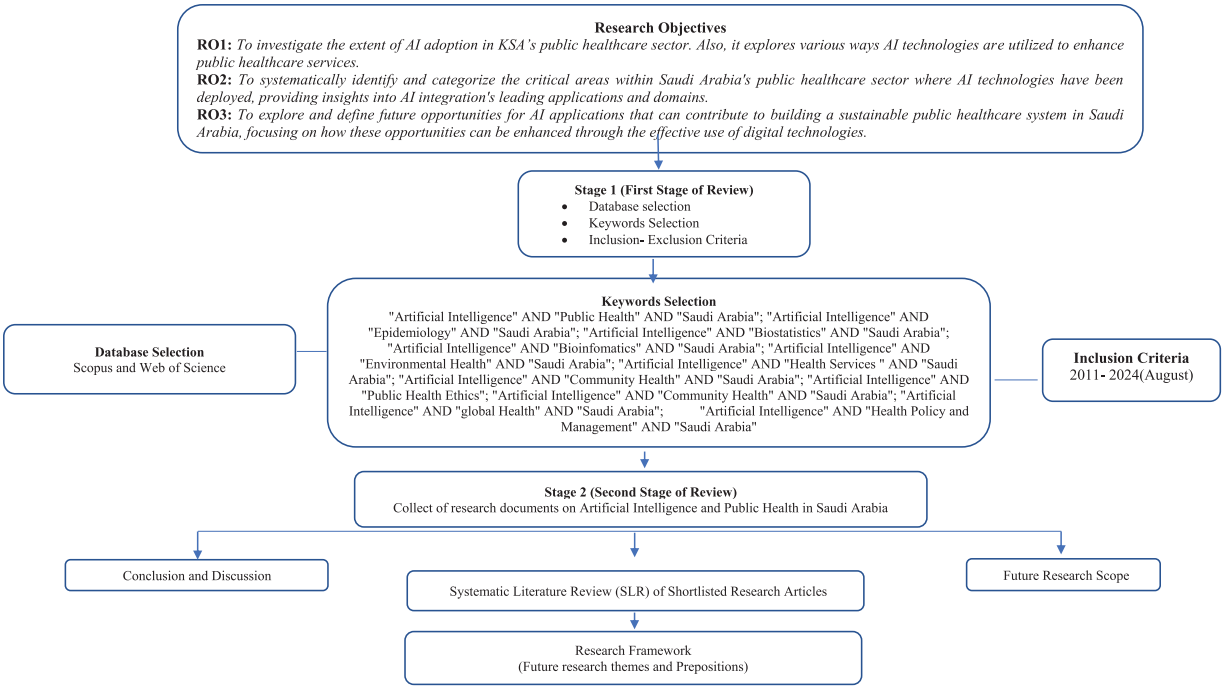

Figure 1: Review methodology using PRISMA framework (Adopted from [36,37])

2.2 Systematic Literature Review

A systematic literature review is a meticulous procedure that comprehensively evaluates and analyzes current and past research in a specific domain or region [38]. In addition, it enables the assessment and further exploration of the dominant trends in a specific field of study [39].

Adopting this approach streamlines the process of identifying constraints and possible directions for future investigation. Through evaluating and investigating previous research efforts, this study applies the concepts of SLR to gain a thorough grasp of the previously established research subject [37]. This review used the PRISMA approach for SLR [36].

2.3 Database Selection

The initial stage of starting a literature review is selecting a database to retrieve. The present research includes articles from Emerald Publishing, Taylor & Francis, Elsevier, Springer, and IEEE, which have been included in the SCOPUS and Web of Science databases. The study adheres to the timeline from 2011 till 2024 (August).

2.4 Choosing Keywords

Based on previous literature, the study analyses the practices and strategies for deploying Artificial Intelligence in advancing public health performance in Saudi Arabia using SLR. Appropriate selection of keywords is crucial for curating articles in all fields. For the present study, secondary data is searched using keywords from the Web of Science and Scopus databases. Keywords strings include: "Artificial Intelligence" AND "Public Health" AND "Saudi Arabia"; "Artificial Intelligence" AND "Epidemiology" AND "Saudi Arabia"; "Artificial Intelligence" AND "Biostatistics" AND "Saudi Arabia"; "Artificial Intelligence" AND "Bioinformatics" AND "Saudi Arabia"; "Artificial Intelligence" AND "Environmental Health" AND "Saudi Arabia"; "Artificial Intelligence" AND "Health Services" AND "Saudi Arabia"; "Artificial Intelligence" AND "Community Health" AND "Saudi Arabia"; "Artificial Intelligence" AND "Public Health Ethics"; "Artificial Intelligence" AND "Community Health" AND "Saudi Arabia"; "Artificial Intelligence" AND "global Health" AND "Saudi Arabia"; "Artificial Intelligence" AND "Health Policy and Management" AND "Saudi Arabia". The search items and systematic literature review carried out in the present research are listed in Table 1.

Table 1: Search criteria

Search terms	Initial search	First screening	Second screening	Final screening
"Artificial Intelligence" AND "Public Health" AND "Saudi Arabia"	28	24	23	21
"Artificial Intelligence," AND "Epidemiology" AND "Saudi Arabia"	37	12	8	5
"Artificial Intelligence" AND "Biostatistics" AND "Saudi Arabia"	22	18	6	4
"Artificial Intelligence" AND "Bioinformatics" AND "Saudi Arabia"	12	4	2	2
"Artificial Intelligence," "Environmental Health" AND "Saudi Arabia"	7	6	4	3
"Artificial Intelligence" AND "Health Services " AND "Saudi Arabia"	12	8	6	4
"Artificial Intelligence" AND "Community Health" AND "Saudi Arabia"	4	2	2	2

(Continued)

Table 1 (continued)

Search terms	Initial search	First screening	Second screening	Final screening
"Artificial Intelligence" AND "Public Health Ethics"	3	2	1	1
"Artificial Intelligence" AND "Community Health" AND "Saudi Arabia"	5	3	3	3
"Artificial Intelligence" AND "global Health" AND "Saudi Arabia"	12	7	5	4
"Artificial Intelligence" AND "Health Policy and Management" AND "Saudi Arabia"	8	6	4	2
	150	92	64	**51**

The search criteria for the study are described below, along with the help of Table 1. This study has made the final selections of the 51 articles to be subjected to final review at the end of the search for articles based on the prescribed systematic literature review across the four-documented process. By the PRISMA approach, the literature review was performed concerning a series of inclusion criteria that reduced the number of analyzed studies in several stages. Table 1 lists the search criteria employed to establish literature on the application of Artificial Intelligence (AI) across different domains of public health in Saudi Arabia. First, a preliminary and general search was made using some keywords linked to AI and its use in the fields of Epidemiology, Biostatistics, Bioinformatics, Environmental Health, Health Services, Community Health, Health and Global Health, Ethics, and Policy in Health and Health Administration and all relevant to Saudi Arabia. An initial search of the articles gave 150 sources to be reviewed. The first step was narrowing down these results to embrace only articles that dealt with Saudi Arabia, bringing the number down to 92. The second screening made the studies more specific by removing conference papers, thus leaving 64 studies on the list. Last, the study utilized a rigorous selection criterion to screen all the identified articles systematically, and only 51 articles were deemed fit for detailed review. These last 51 articles from which the research was conducted serve as the source of the current state of AI applications in public health within Saudi Arabia, which gave the topic a focused and solid groundwork.

2.5 Acceptance and Rejection Criteria

Based on PRISMA methodology, the only items provided are the subjects specified (Business, Management, and Accounting) and the calendar year (2011: 2024). A total of 150 documents were discovered. The 'Scopus' and 'Web of Science' databases will be queried using every search parameter for future research.

2.6 Inclusion and Exclusion Criteria

English-language inclusion criteria include conferences, peer-reviewed journals, and book chapters. The exclusion criteria encompass articles that have been published in conferences, Non-refereed journals and magazines.

3 Artificial Intelligence Applications

Artificial Intelligence (AI) rapidly transforms public healthcare by improving diagnosis accuracy, personalizing treatment plans, and enhancing operational efficiencies [86]. This review explores AI's current and potential applications in public healthcare systems, focusing on its impact on diagnostic processes, treatment personalization, patient management, and resource allocation. In addition, it examines the ethical implications, challenges, and prospects of integrating AI into public healthcare, emphasizing the balance between technological advancements and human-centric care [87]. AI transforms public healthcare while advancing diagnostic accuracy, personalized health plans, and operational efficiencies [28]. The review explores existing and future uses of AI, especially in diagnosing and treating diseases, patient care services, and, more importantly, resource allocation in Saudi Arabia's healthcare sector. In addition, it analyses the ethical concerns, benefits, and disadvantages of AI adaptation to Saudi public health care, focusing mainly on the aspects of technology and patients. Table 2 discusses past research on topics relevant to AI in public healthcare.

Table 2: Past research relevant to artificial intelligence in public healthcare

S. No.	Authors	Sub-research areas	Methodology	Techniques	Keywords
1	Albahri et al. [40]	AI in predictive analytics for disease outbreaks	Systematic review	Machine Learning, Data Mining	Predictive Analytics, Disease Outbreak, AI
2	Abdo [15]	AI-driven patient monitoring systems in Saudi hospitals	Case study	IoT, Machine Learning	Patient Monitoring, IoT, AI, Saudi Healthcare
3	Kumar et al. [41]	AI in personalized medicine and treatment plans	Empirical study	Neural Networks, Deep Learning	Personalized Medicine, AI, Deep Learning
4	Chang et al. [42]	Implementation of AI for public health surveillance	Mixed-methods study	Natural Language Processing (NLP)	Public Health Surveillance, NLP, AI
5	Mizan et al. [43]	AI for optimizing resource allocation in healthcare	Experimental research	Optimization Algorithms, AI	Resource Allocation, AI, Healthcare Optimization
6	Arbelaez Ossa et al. [44]	Ethical challenges of AI integration in public health	Qualitative analysis	Ethical Analysis, AI Policy	Ethics, AI, Public Health, Saudi Arabia
7	Sangaiah et al. [45]	Explainable AI in healthcare	Explorative analysis	Ethical Analysis, AI Policy	Privacy, dignity, Community Detection
8	Morgenstern et al. [46]	AI and big data in epidemiology and disease prevention	Longitudinal study	Big Data Analytics, Machine Learning	Epidemiology, AI, Big Data, Disease Prevention
9	Sharma et al. [47]	Role of IoT-driven systems in predicting COVID-19 spread in Saudi Arabia	Qualitative study	AI Algorithms, Decision Support Systems	Chronic Disease Management, AI, Saudi Healthcare
10	Joshi et al. [48]	Conceptual Framework for assessing implementing barriers in AI public health systems	Survey-based research	Statistical Analysis, AI Adoption	Operational Excellence, Public Health, Developing countries
11	Joshi and Sharma [37]	Barriers to Blockchain technology in public healthcare	Qualitative Study	AI and Blockchain Adoption	Blockchain, Public Healthcare
12	Youssef & Mahfouz [49]	AI applications in improving mental health services	Systematic literature review	Sentiment Analysis, Machine Learning	Mental Health, AI, Sentiment Analysis, Saudi Healthcare

(Continued)

Table 2 (continued)

S. No.	Authors	Sub-research areas	Methodology	Techniques	Keywords
13	Junaid et al. [50]	Modeling conceptual framework for implementing barriers of AI in public healthcare for improving operational excellence	Literature Survey	PRISMA Method	Internet of Things, Artificial Intelligence, Blockchain, Healthcare
14	Noorbakhsh-Sabet et al. [51]	Review applications of Machine Learning in Healthcare	Review Articles	Content Analysis Using Systematic Literature Review	Integrated Healthcare Systems, Machine Learning, Medical Informatics, Precision Medicine, AI, Public Healthcare
15	Min et al. [52]	AI in Predicting Patient Readmission Rates	Cohort study	Predictive Modeling, Data Mining	Patient Readmission, AI, Predictive Analytics
16	Ahmed et al. [53]	AI and its impact on reducing healthcare costs	Economic analysis	Cost-Benefit Analysis, AI Models	Healthcare Costs, AI, Economic Impact
17	Li et al. [54]	AI in Enhancing Public Health Emergency Responses	Case study	AI Algorithms, Decision Trees	Emergency Response, AI, Public Health
18	Alhuwaydi [55]	AI for mental health monitoring and support	Qualitative study	Sentiment Analysis, Machine Learning	Mental Health, AI, Support Systems
19	Alhumaid et al. [56]	AI's role in combating infectious diseases in Saudi Arabia	Systematic review	AI Algorithms, Predictive Analytics	Infectious Diseases, AI, Saudi Arabia
20	Murtaza et al. [57]	Medical Imaging and Diagnostics	Literature Review	Deep Learning	Diagnostics Support, Image Improvement, AI
21	Castiglioni et al. [58]	AI in Medical Imaging for Tumor Detection	Empirical Study	Deep Learning	Tumor Detection, AI, Medical Imaging
22	Rodríguez-Ruiz et al. [59]	AI in Diagnostic Support	Case Study	Machine Learning	Diagnostic Support, AI, Patient Information Analysis
23	Parvathaneni et al. [60]	AI in Drug Discovery and Development	Review Paper	Predictive Modeling, Data Analysis	Drug Discovery, AI, Predictive Modeling
24	Paul et al. [61]	Cost Efficiency in Drug Discovery	Systematic Review	Data Scanning, Predictive Modeling	Cost Efficiency, Drug Development, AI
25	Makridakis [62]	AI in Drug Candidate Identification	Experimental Research	Data Mining, Predictive Analysis	Drug Candidates, AI, Data Mining
26	Vamathevan et al. [63]	Patient Reaction Prediction in Drug Development	Empirical Study	Learning Algorithms	Patient Reactions, AI, Drug Development
27	Ahmed et al. [53]	AI in Personalized Medicine	Case Study	Genetic Profiling, Behavioral Analysis	Personalized Medicine, AI, Genetic Profiling
28	Zahra et al. [64]	AI in Medication Effectiveness	Empirical Study	Genetic Analysis	Medication Effectiveness, AI, Genetic Response
29	Curtis et al. [65]	Virtual Health Assistants and Chatbots	Case Study	AI Algorithms, Natural Language Processing	Virtual Health Assistants, AI, Chatbots
30	Thai et al. [66]	AI in Robotic Surgery	Experimental Research	Robotic Systems, Precision Surgery	Robotic Surgery, AI, Precision, Minimally Invasive Surgery
31	Viglialoro et al. [67]	AI and VR in Surgeon Training	Qualitative Analysis	Virtual Reality, AI Simulators	Surgeon Training, AI, Virtual Reality
32	Kansagara et al. [68]	Predictive Analytics in Patient Care	Systematic Review	Risk Assessment Models, Predictive Algorithms	Patient Care, Predictive Analytics, AI

(Continued)

Table 2 (continued)

S. No.	Authors	Sub-research areas	Methodology	Techniques	Keywords
33	Prabhod [69]	AI in Hospital Resource Management	Case Study	Forecasting Algorithms, Resource Management	Hospital Management, AI, Resource Optimization
34	Pillai [70]	AI in Administrative Workflow Optimization	Review Paper	Natural Language Processing, Data Capture	Workflow Optimization, AI, EHR, Medical Coding
35	Chan et al. [71]	AI in Remote Monitoring and Telehealth	Empirical Study	Smart Wearables, Health Tracking	Remote Monitoring, AI, Telehealth
36	Amjad et al. [72]	AI-Backed Telehealth Platforms	Systematic Review	Telehealth Systems, AI Algorithms	Telehealth, AI, Patient Monitoring, Rural Healthcare
37	Dino et al. [73]	AI in Mental Health Support	Qualitative Analysis	Cognitive Behavioral Therapy, Mood Monitoring	Mental Health Support, AI, Cognitive Behavioral Therapy
38	Quazi [74]	AI in Genome Analysis	Systematic Review	Genomic Data Analysis, Predictive Algorithms	Genome Analysis, AI, Genetic Risk Factors
39	Vilhekar et al. [75]	AI for Personalized Treatment Based on DNA	Empirical Study	DNA Analysis, Treatment Suggestion Algorithms	Personalized Treatment, AI, DNA-Based Treatment
40	Rahman et al. [76]	role of Vision 2030 in strengthening the healthcare system	Systematic review and document analysis	Thematic data analysis	Saudi Arabia, Healthcare, privatization
41	Reddy et al. [77]	Framework to assess 'Translational Evaluation of Healthcare AI (TEHAI)	Systematic Review	Data Mining, Predictive Analysis	Healthcare, Artificial Intelligence
42	Ryan [78]	Trust in AI, Moral and Ethical Implications of AI, AI Responsibility and Accountability	Conceptual Analysis, Critical Review of Ethical Guidelines	Philosophical Argumentation, Comparative Analysis	Trust, Human-AI Relationships
43	Saati et al. [25]	Tuberculosis and Migrant Health in Saudi Arabia, Impact of Religious Pilgrimage on Disease Spread, Antibiotic Resistance in Tuberculosis, Public Health Challenges in Saudi Arabia	Public Health Analysis, Epidemiological Overview, Global Health Contextualization	Risk Identification, Situational Analysis, Global Health Perspective	hajj; umrah; pilgrims; MDR; XDR; TDR
44	Saeed et al. [79]	Challenges in Saudi Arabia's Healthcare System, Healthcare Infrastructure Development, Role of AI in Healthcare, Regulatory and Data Challenges for AI in Healthcare	Descriptive Analysis, Policy and Technology Review, Challenges and Opportunities Framework	Problem-Solution Approach, Technology Integration, Policy Recommendation	Saudi Arabia, Healthcare Challenges, Artificial Intelligence
45	Said [80]	Challenges in Arabic Chatbot Development, Arabic NLP, Arabic Chatbot Evaluation, Resources for Arabic NLP	Systematic Literature Review (SLR), Study Selection and Quality Assessment, Snowballing Technique	Rule-Based and Generative Approaches, Human-based evaluation metrics	Arabic Dialogue System, Arabic Conversational Agent, Chatbots, Arabic Natural Language Processing

(Continued)

Table 2 (continued)

S. No.	Authors	Sub-research areas	Methodology	Techniques	Keywords
46	Saraswat et al. [32]	Healthcare 5.0 and Digital Transformation; Challenges in Healthcare 5.0; Explainable AI (EXAI) and Federated Learning in Healthcare	Systematic Literature Review, Proposed Architecture, Case Study and Experimental Validation	Explainability in AI, Federated Learning for Data Privacy, CT Image Classification and Segmentation, Solution Taxonomy and Operational Challenges	Healthcare 5.0, Patient-Centric Digital Wellness, Explainable AI (EXAI), ECG Monitoring, Data Privacy
47	Scheinker et al. [81]	Operational Analytics in Healthcare, Machine Learning and Optimization in Healthcare, Factors for Sustained Value in Healthcare Analytics Projects, Challenges in Implementing Healthcare Analytics	Case Study Approach, Project Evaluation Framework	Optimization and Machine Learning, Stakeholder Engagement, Implementation Strategies	Healthcare Operational Analytics, Machine Learning in Healthcare, Optimization Techniques, Stakeholder Engagement in Healthcare, Technical Performance in Healthcare Analytics, Analytical Projects
48	Serbaya et al. [82]	AI Awareness in Healthcare, Attitudes Toward AI in Healthcare, Behavioral Practices Related to AI in Healthcare, Sociodemographic Factors, and AI Perceptions	Cross-Sectional Study, Data Collection via Structured Questionnaire, Multiple Linear Regression	Survey Questionnaire, Descriptive Statistics, Multiple Linear Regression	Artificial Intelligence, Awareness, Attitude, Practice, Healthcare Workers, Saudi Arabia
49	Sheerah et al. [83]	Knowledge, Attitudes, and Practices (KAP), Psychological Impact, Vaccine Hesitancy, Management of Religious Gatherings During COVID-19, Travel Regulations and Pandemic Control	Evidence Review, Contextual Analysis	KAP Analysis, Psychological Assessment, Mass Gathering Management	Public health; Saudi Arabia; COVID-19; Health Regulations; Psychological impacts; vaccination; Hajj and Umrah; travel regulations
50	Sheerah et al. [84]	Virtual Healthcare Adoption, Impact of Digital Technologies on Healthcare, COVID-19 and Digital Transformation, Seha Virtual Hospital, Roadmap for Virtual Healthcare	Narrative Review, Case Study	Literature Review, Case Study Analysis	Virtual Healthcare, Digital Health Transformation, Vision 2030 Saudi Arabia
51	Sheikh et al. [85]	Learning Health and Care Systems, Impact of COVID-19 on Digital Health Strategies, Interoperability of Electronic Health Records, Data Management and Analysis in Healthcare, Ethical and Regulatory Challenges	Assessment and Re-evaluation	Strategic Analysis, Framework Development	Health Information Technology, National Learning Health Systems, COVID-19 and Digital Health, Ethical Challenges in Healthcare Technology

3.1 Public Healthcare and AI Applications

With the use of AI in the healthcare industry, the prospects have revolutionized how difficult precipitations were tackled in the past [88]. In diagnostics onwards right up to patient care, artificial intelligence is redefining how it plays in the field of health care professionals and patients [86]. Table 3 illustrates some AI applications in public health systems.

Table 3: AI-driven public health systems best practices

AI application area	Description	Best practices
1. Medical Imaging and Diagnostics	***Enhanced Image Analysis:*** AI in health care, specifically deep learning, can interpret medical images and identify issues such as tumors, bone fractures, and lesions, among others. Most diseases like breast cancer through mammography are detected using some of these AI tools [89].	• Diversify and qualify the raw data sets to be utilized in the training process to minimize bias in image identification. This way, models must be updated with new data to be as accurate as possible [90].
	Diagnostic Assistance: The use of AI in diagnosis makes it easier for physicians to get probable diagnoses from patient information, lab tests, and imaging, thus minimizing the chances of making wrong diagnoses and missing valuable opportunities for intervention [91].	• Connect with EHRs to feed and retrieve the data and incorporate AI tools into administrative processes to process the data in real-time. Ensure enhanced knowledge for practicing doctors and health care practitioners concerning the application of AI [92].
2. Drug Discovery and Development	***Accelerated Research:*** AI can fine-tune large databases, look for drug possibilities, determine the likelihood of effectiveness and virtual interactions, and save time and money [93].	• Cross-collaboration with other specialists, such as those specializing in artificial intelligence and pharmacologists. Have proper verification of the AI predictions by carrying out clinical trials [94].
	Predictive Modeling: It has also been utilized to forecast patient response to new drugs to target therapies and assess possible side effects [95].	• Base and enrich models with solid and various patient information; constantly test and update the models to minimize prediction errors [96].

(Continued)

Table 3 (continued)

AI application area	Description	Best practices
3. Personalized Medicine	***Tailored Treatment Plans:*** AI synthesizes genetic makeup, daily activity, and other factors. The treatment models devised for each patient indicate that the medical intervention therapies are more aligned for treatment success [97].	• Adopt Safe data management practices that will safeguard genetic and other personal information. Hopefully, they will liaise with genetic counselors to engage in decoding the insights made available by applying artificial intelligence [98].
	Pharmacogenomics: AI plays a role in choosing the right medicine with fewer side effects and knowing how genetics contributes to drug metabolisms in patients [99].	• Always feed AI models with fresh pharmacogenomics information and comply with the laws governing the use of genetic information [100].
4. Virtual Health Assistants and Chatbots	***Patient Engagement:*** This system automates essential patient interactions by answering commonly asked questions, setting appointments, and providing timely prescription alerts to improve patients' compliance [101].	• Public Healthcare systems should make the design of chatbots very friendly, with a user-friendly interface and an ability to support different languages to address a pool of different patients. Periodically assess the content of the chatbot and adjust it if necessary [102].
	Symptom Checking: Patients are being led and supported on their own. Symptom checkers provide first-line advice [103].	• Ensure these virtual assistants are trained to occasionally follow current medical norms and trends. Human intervention should be employed to determine the best action where the algorithms are complex [84].

(Continued)

Table 3 (continued)

AI application area	Description	Best practices
5. Robotic Surgery	***Precision and Efficiency:*** Robotic systems operated with the integration of artificial intelligence help surgeons in intricate procedures that are precise, less invasive, and have hastened recovery [104].	• Ensure that surgeons are adequately trained on the use of robotic systems and should adhere to high maintenance checks on the equipment. Use measures should be implemented to protect the patients' lives during the various procedures [105].
	Training and Simulation: When integrated with AI, virtual reality allows surgeons to be trained and use the training models in risk-free practice [106].	• Employment of realistic simulation of various probable incidences on the field and frequent revision of the training courses due to the changes in surgery techniques. Promote keeping of skills constant check for the surgeons [105].
6. Predictive Analytics for Patient Care	***Risk Assessment:*** Machine learning algorithms estimate the risks that patients can face, for example, readmission at the hospital, the development of other illnesses, the worsening of the current condition, and others, so that proper preventive measures can be taken [107].	• Assure adequate predictive models with accurate data and time-checked evaluation of the models. Engage the healthcare providers when developing and fine-tuning such models to be relevant [108].
	Resource Allocation: One of the applications of AI in the healthcare sector is to forecast the number of patients that would present themselves to the various hospitals so that human resources and the rest of the resources can be well distributed [109,110].	• Integrate the use of AI in approaches to managing the hospital and make individuals understand when and how decisions are made using data processed by AI algorithms: review periodically and modify the same in line with the existing results [40,53].

(Continued)

Table 3 (continued)

AI application area	Description	Best practices
7. Administrative Workflow Optimization	***Efficient Data Management:*** AI tasks such as medical coding, billing, and appointment setting eliminate human error and relieve employees so that they can concentrate on patient care [69].	• Ensure that all AI-driven health systems comply with healthcare regulations, like HIPAA [111]. Health data should be encrypted, and access restrictions should be enforced to prevent the leakage of patient information [112]
	Electronic Health Records (EHR) Management: NLP in EHRs makes data capturing and entering easier, improving EHR quality [107].	• Medical personnel should be regularly informed to verify the precision of electronic health record (EHR) systems and guarantee the absence of any errors triggered by human factors [113]. Health systems must guarantee that healthcare facility representatives can create and carry out hands-on training sessions for other staff members on using electronic health record (EHR) systems with the integration of artificial intelligence (AI) [51].
8. Remote Monitoring and Telehealth	***Continuous Health Monitoring:*** Wearable gadgets with AI technologies track the user's vital signs, diagnose pathophysiologic changes, and notify clinicians to take needed actions on time [114].	• Health data communication should be accomplished via defined, enhanced, or approved methods tailored for this purpose. The equipment should be designed to be easily used by all patients, including those with mobility problems [115].

(Continued)

Table 3 (continued)

AI application area	Description	Best practices
	Telemedicine Enhancement: Artificial intelligence (AI) facilitates the development of telehealth offerings, diagnostic tools, patient condition monitoring, and online consultations, enabling healthcare delivery to target regions [72].	• Encourage the implementation of integrated artificial intelligence (AI) technologies in telehealth solutions that are allowed by the applicable legislation in the country [115]. Provide healthcare professionals with instruction on the proper analysis and interpretation of data generated by artificial intelligence during virtual consultations [116].
9. Mental Health Support	***AI Therapists:*** Intelligent applications provide users with Cognitive Behavioral Therapy (CBT), mood reporting, and coping processes, thus enhancing mental health care [117].	• AI tools are developed with ethical concerns and are to have human input for higher-level decisions. AI models should occasionally be updated with fresh data from psychological studies [118].
	Sentiment Analysis: Machine learning algorithms applied to the speech and text data identify early symptoms of depression, anxiety, or any other mental disorder among the patients [119].	• Always get different datasets to train the sentiment analysis models to avoid bias. Artificial intelligence, alongside professionals and doctors, can be used as a tool for diagnosing and resolving issues [91].
10. Genome Analysis	***Disease Prediction:*** AI uses massive genetic databases to find genes linked to some diseases and to assist in prevention by early diagnosis [120].	• Adhere to the laid down ethical standards and the law on the use of genetic data. Involve genetics and healthcare practitioners in confirming the proposed AI findings [121].

(Continued)

Table 3 (continued)

AI application area	Description	Best practices
	Tailored Treatments: AI promptly suggests treatment courses that are likely to work based on a patient's genetic makeup, therefore reducing cases of applying trial-and-error methods [122].	• Incorporate the newest information regarding the genetic analysis results and treatment methods in AI models. Fully explain to the patients how AI-derived information is applied to manage their ailments [123].

As explained in Table 2, various applications of AI in public Healthcare systems play critical roles. AI, intense learning, enhances diagnostics by analyzing medical images for conditions like tumors and fractures [124]. AI has significantly improved mammography for breast cancer detection, assisting doctors by reviewing patient information and test results [125]. AI accelerates drug discovery by scanning large datasets to determine drug candidates and their effectiveness [62]. AI can also predict patient reactions to new drugs, making the process faster and cheaper [63]. AI helps craft personalized treatments by analyzing a patient's genetic and behavioral data [126].

It can also ascertain how patients react to the medications [64]. These AI-based platforms engage with patients, schedule appointments, and even offer first-line diagnosis [65]. Robotic systems powered by artificial intelligence make it possible to perform delicate operations with minimal intrusiveness, which results in shorter recovery times [66]. They are also applied in surgical training [127]. Risk assessment is assisted by AI in that it can predict patient readmission rates, progression of diseases, and complications, thus indicating where intervention is needed [68]. It can also predict patient volume in hospitals and deal with available stocks better [68,128]. Automated tasks such as medical coding, billing, and scheduling take much time and require many personnel who can otherwise be dedicated to patient care [70]. Natural language processing further reinforces the quality and utility of electronic health records. In wearable technology, AI will track a patient's condition and immediately inform the relevant doctor if the patient is in critical condition to prevent severe illness [129]. Nwankwo et al. [130] noted that telehealth platforms provide the needed care through AI, especially for rural areas. It knows that it can diagnose depression and anxiety presence based on patients' voices [73]. AI also analyses genetic data and contributes to prescribing the proper treatment options, which minimizes cross-attempts [74,75].

3.2 Public Healthcare in Saudi Arabia and AI Applications

In line with RO1, this study examines how Saudi Arabia's public healthcare sector integrates AI in delivering public healthcare services. AI is now a crucial tool in managing Saudi Arabia's healthcare challenges. Such AI approaches, such as machine learning, natural language processing, and computer vision, are applied in healthcare and become a reaction to challenges like scarcity of resources, increasing costs, and a need for an individual approach to all processes concerning healthcare [131]. In Saudi Arabia, AI was planned through Vision 2030: The government has revealed plans to achieve intentional AI in the country through Vision 2030, which stresses how AI is vital in engineering superior, more innovative, and more effective service delivery for patients [132]. RQ1 explains how AI is applied in the Saudi Arabian

public healthcare sector. Table 4 also represents the indicators of diagnosis, treatment, management, and care using AI applications with instances from Saudi Arabia to substantiate the flexibility of AI in healthcare administrations. Using advanced data analysis, predictive modeling, and real-time data monitoring, AI can effectively enhance disease prediction and management in Saudi Arabia. AI can improve disease prevention in various forms, including (a) Early detection and diagnosis, (b) Personalised treatment, (c) Predictive Epidemiology, (d) Remote Monitoring and Chronic Disease Management, and (e) Resource Allocation and Management. The detailed discussion is as follows:

(a) Early Detection and Diagnosis: AI-enabled algorithms can analyze large amounts of medical data (for instance, patient histories, laboratory results, and others), contributing to early disease diagnosis [133]. For nonsporadic diseases, including diabetes and cardiovascular diseases, AI can point out risk factors and early distributor notice for suitable actions [134]. However, in the Saudi context, when chronic disease becomes dominant, AI can predict diseases and assist in early diagnosis, decreasing overall health costs and improving patients' health [135].

(b) Personalised Treatment: AI can create a personalized health plan proposed based on the specific EHR of each of the patients [136]. AI models can be implemented to derive and suggest specific procedures for numerous chronic diseases. The patient develops plans based on their requirements, thus enhancing the recovery periods and health management [137].

(c) Predictive Epidemiology: AI-assisted analysis can be used for epidemiologic data to predict disease occurrences and events of large assemblies in tracking disease spread [138]. Healthcare planners in Saudi Arabia can use AI-led predictive models to forecast infectious disease trends [15]. It can easily result in accurate targeted vaccination, resource designation, and well-timed public health measures undertaken. AI can analyze wearable devices or mobile health applications to monitor health status remotely. These aids enable early interventions if some errors are detected [139]. AI can revolutionize Saudi Arabia's healthcare sector regarding resource allocation, genomic studies, and mental health analytics [140]. Using analysis of large patient data and forecasts of future inflow of patients and resource use, coupled with worker productivity, AI is capable of optimizing healthcare delivery, especially in high population mobility events such as stigmatization whereby the spiritual event of Hajj poses a great challenge in disease control and management as well as emergency preparedness [141]. In addition, AI's efficiency in analyzing genetics data plays a vital role in defining the risk factors for hereditary diseases caused by marriage within Saudi Arabia, which is the term for early diagnosis through genetic testing programs [142]. In mental health, AI-powered tools can detect patterns associated with mental health conditions using patient interactions, digital health platform responses, and voice or text analysis, fostering early detection and effective support [143]. In addition, AI-driven analysis of population-level health data from electronic health records reveals trends, risk factors, and outcomes, guiding public health planning and initiatives, particularly for non-communicable diseases [144]. Collectively, these applications contribute to more efficient disease management, improved healthcare quality, and better health outcomes across the population [145].

Table 4: Indicators of diagnosis, treatment, management, and care using AI applications

Applications	Description	Examples	Impact	Use cases in Saudi Arabia
Medical Imaging and Diagnostics	AI algorithms accurately interpret medical images [146]	AI tools analyze X-rays, MRIs, and CT scans [140] and detect cancer and diabetic retinopathy [68]	Faster, more accurate diagnoses [147]; early disease detection [148]	King Faisal Specialist Hospital: AI for breast cancer detection [149]; Saudi Aramco: AI for respiratory condition detection [150]
Predictive Analytics	It learns to forecast diseases and advisable patient readmission [151]	Predicting outbreaks [152]; identifying high-risk readmission patients [153]	Early interventions and improved outcomes [154]	Ministry of Health: AI for managing COVID-19 [155]; SFDA: AI predicting adverse drug reactions [156]
Personalized Treatment	AI uses both genomic and clinical information for treatment plans and therapy [142]	Precision medicine for cancer [157]; tailored drug prescriptions [158]	More effective treatments reduced adverse reactions and improved outcomes [159]	Saudi Human Genome Program: AI for personalized treatments [160]; King et al.: AI for precision oncology [161]
Virtual Health Assistants and Telemedicine	AI-driven virtual assistants provide remote consultations and manage appointments [162]	AI chatbots for patient queries [163]; AI in telemedicine for remote diagnosis [164]	Increased accessibility, reduced healthcare costs, and enhanced patient engagement [165]	Seha Virtual Hospital: AI telemedicine for remote regions [84,50]; Tawakkalna App: AI virtual health assistance during COVID-19 [166]
Remote Monitoring and Wearables	AI wearables track vital signs and detect anomalies in real-time [167]	Continuous monitoring of heart rate and blood pressure [168]; early detection of health issues [143]	Timely interventions, reduced hospital admissions, and improved chronic disease management [169]	Saudi Ministry of Health: AI-enabled wearables for diabetic patients [170]; KAUST: AI wearables for cardiovascular [171]

This table and discussion directly address RQ1 by examining the extent and diverse ways AI applications are being implemented to enhance healthcare services in Saudi Arabia, driving the nation's public healthcare system towards its Vision 2030 objectives.

3.3 Potential Barriers to AI Implementation in Saudi Arabia's Public Health System

Adopting AI in Saudi Arabia leads to innovative and sustainable transformation in the public healthcare system [172]. However, this transformation is witnessing various barriers that must promptly be addressed to ensure integrated development and societal acceptance [173]. The critical barriers include data privacy and security, workforce management, high implementation costs, cultural concerns related to AI adoption, and interoperability with existing healthcare infrastructure [174,175]. Addressing these challenges requires a strategic integrated approach. The approach helps improve the digital infrastructure to support a sustainable AI ecosystem in the healthcare domain. Overcoming these barriers enables Saudi Arabia to harness the potential of AI in public health in alignment with Saudi Arabian Vision 2030. The potential Barriers to AI implementation in the Saudi Arabian Public Healthcare System include (a) Data Privacy and Security Concerns, (b) Lack of Skilled Manpower, (c) Cost of Implementation, (d) Change Resistance, (e) Interoperationability, (f) Regulatory and Ethical Challenges, (g) Algorithmic Bias and Local Relevance, and (h) Infrastructure and Technology Gaps.' The detailed description is as follows:

(a) Data Privacy and Security Concerns: Misuse of health information can influence patient trust [176]. Strategically, Saudi Arabia should consider implementing privacy-preserving AI techniques like federated learning, which allows AI models to be trained on decentralized data without centralizing sensitive information and fortifying privacy laws [177]. This method reassures patients about the security of their data while improving privacy and compliance with data protection laws.

(b) Lack of Skilled Manpower: Deploying AI in healthcare needs employees who lack expertise in data analytics, AI, and healthcare application skills, which Saudi Arabia currently lacks [178]. Along with training initiatives, Saudi Healthcare institutions can establish academic tracks focused on AI to encourage the growth of a regional talent pool [132]. The government might also create partnerships with global AI research institutions to promote exchange programs, knowledge sharing, and collaborative research initiatives and provide career development grants as incentives for healthcare professionals to specialize in AI [179].

(c) Cost of Implementation: Some healthcare facilities might discover the initial setup costs of AI exorbitant, especially for smaller facilities [180]. The government can establish a fund that focuses on the use of AI in healthcare, offering preference to initiatives that assist in accomplishing Vision 2030 targets, such as preventive care and managing chronic illnesses [181]. In addition, healthcare organizations can see immediate advantages without experiencing significant financial burdens by using AI modularly, starting with smaller, scalable AI systems [182].

(d) Change Resistance: Patients' and healthcare providers' unwillingness to use AI technology can result from concerns about replacing human workers and their lack of familiarity [183]. This fear can be alleviated by establishing change management initiatives and displaying case studies demonstrating AI's beneficial effect in healthcare. Establishing "AI Champions" in healthcare organizations, reliable people with AI training who advocate its advantages can help improve colleagues' and patients' views of AI [184].

(e) Inter-operationability: Legacy systems have limited data sharing and integration capabilities [185]. Along with adopting standardized data protocols, Saudi Arabia can emphasize investments in middleware solutions that facilitate data transfer from legacy systems to AI-enabled platforms [186]. Another way to guarantee seamless integration is to form alliances with technology service providers to explore interoperability as a design element [187].

(f) Regulatory and Ethical Challenges: Without regulatory guidelines specific to AI in healthcare, healthcare Supply Chain partners often face uncertainty around AI applications [188]. Establishing a regulatory body of various healthcare stakeholders aims to streamline the development and deployment of AI-specific healthcare regulations to develop comprehensive, culturally aligned AI guidelines.

(g) Algorithmic Bias and Local Relevance: AI models trained on non-regional data are likely unsuccessful due to unique demographical and health-related patterns in Saudi Arabia that can lead to biased results [189]. To address this barrier, policymakers can develop guidelines encouraging AI developers to conduct bias audits and fairness testing for AI models [190]. Another strategy can be to conduct collaborative research with Saudi Arabian health institutions, as the research partnership can improve AI models' accuracy, fairness, and relevance [191].

(h) Infrastructure and Technology Gaps: Digital infrastructure, such as high-speed internet services and storage capabilities, is an elementary requirement for AI implementation. This challenge is catered to by expanding the existing digital infrastructure for healthcare AI [8]. Thus, strategic solutions can help Saudi Arabia address AI implementation challenges while creating a supportive environment for AI in healthcare [192]. By strategically coping with these implementation barriers, Saudi Arabia can position itself as a leader in culturally sensitive, secure, and effective AI-driven healthcare innovation to support Saudi Arabian Vision 2030. Fig. 2 demonstrate the potential barriers to AI implementation in Saudi Arabia.

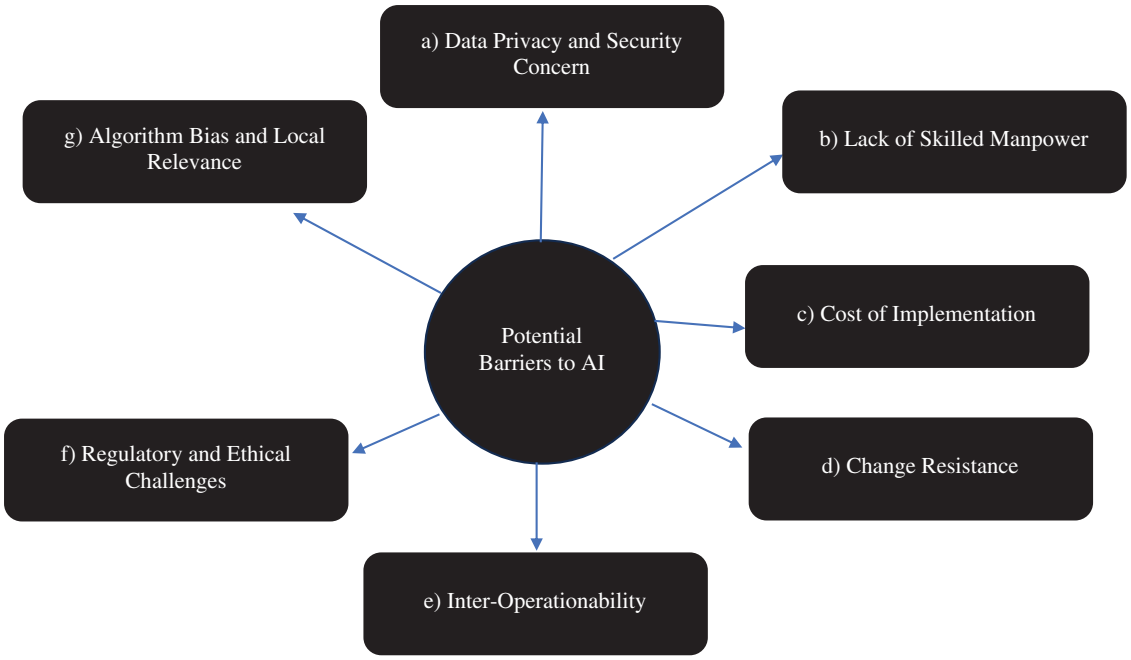

Figure 2: Demonstrates the potential barriers to AI implementation in Saudi Arabia

4 Critical Success Factors (CSFs) of AI Integration in Public Healthcare in Saudi Arabia

4.1 Critical Areas of AI Deployment in Public Healthcare

In alignment with RO2, which aims to systematically identify and categorize the critical areas within Saudi Arabia's public healthcare sector where AI technologies have been deployed, several key domains have emerged as focal points for AI integration. These key areas illustrate AI's transformative potential and provide insights into the leading applications in Saudi healthcare [193]. As RQ2 aims to identify these deployment areas, the following section identifies key challenges, opportunities, and Critical Success Factors (CSFs) that affect AI applications in the Kingdom of Saudi Arabia's public healthcare facilities. AI proves to be an essential element in improving public healthcare services at different levels. However, its integration is

conditioned to some extent by CSFs that are technological, ethical, organizational, and regulatory [194]. Implementing these analytics in Saudi Arabia is critical to addressing cultural, social, and infrastructural peculiarities [173]. CSFs that span technological, ethical, organizational, and regulatory challenges [195]. These CSFs are especially important when addressing cultural, social, and infrastructural contexts unique to Saudi Arabia [83]. Table 5 illustrates Critical Success Factors (CSFs) and their impact from the perspective of Saudi Arabia's AI integration into public healthcare. The critical areas for AI deployment (in Fig. 3), along with their respective challenges, include:

i) ***Data Privacy and Security:*** As AI technologies involve massive datasets for operations emphasizing health sectors, data protection and security remain aspects of significant value [196]. In Saudi Arabia, AI in healthcare means processing patient data and, therefore, must follow the PDPL. Following these standards is necessary to maintain patients' trust and safeguard their personal information because privacy is susceptible in Saudi Arabia. AI solutions must also consider a data breach and a hostile takeover of healthcare systems [197].

ii) ***Algorithmic Bias and Fairness:*** If trained on inadequate or limited datasets, AI decision-making systems create discriminative models, resulting in discriminating patient treatment. This issue especially is arousing in Saudi Arabia since the country is ethnically mixed, with citizens and a strong presence of immigrant workers. Large-scale disparities in the ability and opportunity to receive healthcare and treatments can worsen if some AI algorithms are programmed to perform better with specific population segments [198]. For accuracy and non-discrimination, AI systems should be put back with approaches that reduce prejudice and satisfy each cohort's demand for health care [199].

iii) ***Lack of Interoperability:*** The structure of both the public and private sectors of healthcare organizations in Saudi Arabia is presently relatively decentralized, and the implementation of numerous EHR platforms and systems differ from each other in their data representation. A lack of integration between systems causes many problems that hinder AI integration and prevent the effective exchange of information and integration between healthcare entities [200]. The necessity for increased AI effectiveness in public healthcare means that standardizing the IT structure and the type of data involved is essential [51].

iv) ***Regulatory and Legal Challenges:*** There is still an emerging set of rules relating to the use of AI in Saudi Arabia's healthcare sector [92]. There are initiatives to develop guidelines that embrace Vision 2030 of the Kingdom of Saudi Arabia. However, the emerging issues include liability of the AI outward form, patient consent, and accountability in healthcare AI decisions [201]. There have to be policies that will encourage innovation in the best interest of the patients; there have to be measures regarding how the ethical and legal standards must be followed:

v) ***Cultural Sensitivity and Ethical Concerns:*** In Saudi Arabia, AI-enabled technological usage in products and services can align with cultural sensitivities and ethical considerations [178]. During the design phase, Islamic ethical principles (including patient privacy, autonomy, and dignity) can be incorporated through the engagement of local healthcare professionals [202]. The AI models are built to alert users about privacy policies in a culturally accepted manner to maintain Islamic patients' autonomy [203]. In addition, developing AI interfaces through digital assistance and chatbots in modern standard Arabic and regional dialects can ensure effective human-medical device interfaces while adapting local idiomatic expressions and culturally viable health communication language [204]. In addition, an Islamic ethical framework can be developed to cover guidelines related to data privacy, consent, transparency, and patient welfare in AI applications [205]. The ethical framework should align with regulations specific to AI in healthcare to supervise sensitive data related to data privacy, gender sensitivity, and public trust [202]. Using epidemiological Saudi-specific health data to train AI models can enhance disease prediction accuracy. Also, it improves the reliability of AI models for local health needs [206]. In the context of Saudi cultural norms,

AI-enabled telemedicine platforms can offer customized gender-specific interfaces and solutions to ensure seamless experiences [207]. Community engagement through workshops and outreach sessions educates the public about AI benefits in healthcare in Saudi Arabia [208]. In addition, AI-enabled hospitals should undergo monthly, biannual, and annual reviews, where patients' feedback and cultural experts' comments and feedback can help identify, assess, and contribute to developing and restructuring cultural values and ethical guidelines [209].

These cultural and ethical issues resulting from the adoption of AI in healthcare include whether a patient has permission to be treated using an AI model, how much information should be provided to the patient, and how much human intervention should be allowed during the use of AI models [210]. These concerns are further magnified in Saudi Arabia by the Islamic medical culture of ethical norms and protocols rooted in patient rights, self-respect, and dignity [211]. AI applications must conform to these cultural and religious sentiments to be acceptable across the globe; at the same time, healthcare decisions must be made wisely and with a visible ethical backbone [212].

vi) ***Infrastructure and Workforce Readiness:*** AI deployment in Saudi Arabia's public healthcare delivery also requires the proper infrastructure and a competent human resource. It can be understood that AI applications in healthcare now depend on high-performance computing spaces and both advanced networking and storage facilities. In addition, investment in the education and training of healthcare professionals in using AI tools is insufficient, which poses a significant challenge for enhancing the use of AI tools [213]. Though successive Kingdom governments have sought to develop the country's digital infrastructure, more infrastructure and human capital are needed to advance AI adoption [214].

vii) ***Trust and Acceptance:*** Healthcare professionals and patients must trust AI technologies to enhance adoption. Accordingly, based on RQ2, Saudi Arabian culture and religion play an important and extensive role in perceiving AI in healthcare. They should isolate themselves culturally and demonstrate how they can enhance patients' comfort without negating the Saudi culture to make the principles of AI acceptable for adoption [215]. It is high time to increase people's awareness and understanding of AI drivers and constraints through obligatory public education and clear and persistent information sharing [216]. Table 5 illustrates the Critical Success Factors (CSFs) and their impact from the perspective of Saudi Arabia's AI integration into public healthcare.

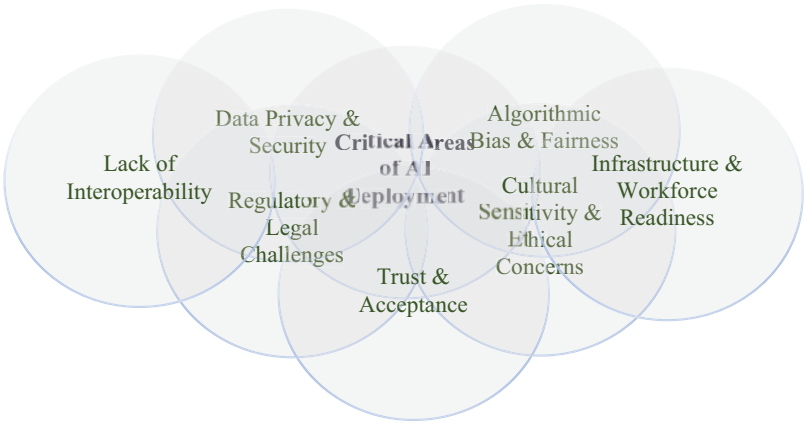

Figure 3: Critical areas of AI deployment in public healthcare

Table 5: Critical success factors (CSFs) and their impact from the perspective of Saudi Arabia's AI integration into public healthcare

CSFs	Description	Impact	Context in Saudi Arabia	Use cases in Saudi Arabia
CSF1: Data Privacy and Security	Ensuring the protection of sensitive patient data against breaches and unauthorized access [217].	Compliance with data protection laws is crucial for maintaining patient trust and safeguarding health information [218].	Saudi Arabia's Personal Data Protection Law (PDPL) requires stringent data handling practices. Ensuring AI compliance with PDPL is essential [219].	• *King Faisal Specialist Hospital and Research Centre (KFSHRC):* Implements robust data security measures for AI systems to comply with PDPL [220]. • *Saudi Data and Artificial Intelligence Authority (SDAIA):* Promotes data protection standards for AI applications in healthcare [221].
CSF2: Algorithmic Bias and Fairness	AI models can reflect biases from training data, leading to unequal treatment of different demographic groups [222]	Bias in AI can exacerbate healthcare disparities and undermine trust in AI systems [223].	AI systems must be trained on diverse and representative data to address the needs of Saudi Arabia's diverse population [34].	• *Saudi Health Council:* Conducts studies to ensure AI models are tested for fairness and accuracy across different demographic groups [92]. • *King Saud University Medical City:* Develops AI algorithms with diverse datasets to mitigate biases in healthcare delivery [135].
CSF3: Interoperability	Difficulty integrating AI solutions with existing healthcare IT systems and data formats.	Fragmentation can limit the effectiveness and efficiency of AI applications.	Standardizing data formats and ensuring compatibility across public and private healthcare providers is needed.	• *Ministry of Health:* Working on integrating AI tools with national health information systems for better interoperability [85]. • *Health Information and Management Systems Society (HIMSS):* Supports the development of interoperability standards for AI in Saudi healthcare [224].
CSF4: Regulatory and Legal Issues	Developing clear regulations and guidelines for AI in healthcare, including liability and compliance issues [225].	Regulation uncertainty can hinder AI adoption and implementation [226].	Saudi Arabia is working on developing comprehensive regulations for AI in healthcare as part of Vision 2030 [227].	• *Saudi Food and Drug Authority (SFDA):* Drafts guidelines for regulating AI medical devices and software [221]. • *Saudi Data and Artificial Intelligence Authority (SDAIA):* Provides regulatory frameworks and guidelines for AI applications in healthcare [228].
CSF5: Ethical Concerns	Addressing issues related to patient consent, transparency, and human oversight in AI-driven decisions [134].	Maintaining trust and ensuring the ethical use of AI is critical for public acceptance [229].	Aligning AI applications with Islamic ethical principles and providing transparent information about AI decisions is crucial [230].	• *King Abdulaziz Medical City:* Ensures AI applications align with Islamic ethical standards and include patient consent protocols [231]. • Saudi Health Council: Develops ethical guidelines for AI use in healthcare, reflecting Islamic values [232].
CSF6: Infrastructure and Workforce Readiness	Investing in necessary infrastructure and upskilling healthcare professionals to use AI tools effectively [233].	Inadequate infrastructure and a lack of trained personnel can slow AI integration [234].	Saudi Arabia invests in healthcare infrastructure and workforce development under Vision 2030, but gaps remain [76].	• *Vision 2030 Health Transformation Program:* Invests in upgrading healthcare infrastructure and training programs for AI integration [192,235]. • *King Saud University:* Provides specialized training for healthcare professionals on AI tools and technologies [236].
CSF7: Trust and Acceptance	Building trust among patients and healthcare professionals regarding the reliability and accuracy of AI systems [237].	Increased trust and acceptance are necessary for successful AI adoption.	AI solutions must be culturally sensitive and aligned with Saudi values. Educational initiatives and clear communication are key.	• *Seha Virtual Hospital:* Uses AI-powered telemedicine to build trust through reliable and transparent services [84]. • *Tawakkalna App:* Educates users about AI-driven health services and ensures transparency to build acceptance [238].

4.2 Strategic Action Plan for CSF Implementation

In order to effectively address the implementation of CSFs of AI in Saudi Arabia's public healthcare system, a strategic action plan can be developed focusing on the critical areas including:

i. ***Strengthening Data Privacy and Security:*** It is necessary to adopt and apply strict policies that protect the received data based on HIPAA and other USA and UK legislation requirements to protect the collected and stored information [239]. Strengthening data privacy and security involves investing in the tools to achieve cybersecurity and applying the latest features, such as encryption methods, second-factor authentication, and security scanning. From the healthcare perspective of Saudi Arabia, it preserves the security of patients' health information and patients' identity to build confidence [240].

ii. ***Mitigating Bias in AI Models:*** The action plan targets reducing Biased AI by employing multiple data sources to train AI models, making the AI use balanced [241]. This will be undertaken by working with global and national bodies to collect structured information to capture the diversity of people in the Kingdom of Saudi Arabia. Validation and testing techniques will also be applied to diagnose and eliminate bias where necessary. Therefore, the expected outcome is reducing healthcare disparities. AI models should provide equally good solutions for people of all categories [242].

iii. ***Navigating Regulatory Approvals:*** In executing this plan to advance the growth and use of AI in healthcare, the plan will include setting up a regulatory agenda specific to Saudi Arabia that involves working with the regulatory authorities, those in the sector, and AI solution providers to create a more efficient approval process and coming up with set standard in guidelines that will foster AI innovation without jeopardizing patient safety or ethical issues [243,244].

iv. ***Facilitating Integration with Existing Healthcare Systems:*** As a result of the sequential implementation, there shall be a planned approach to the stages at which the application of AI tools will occur, then pilot implementation at hospitals, training of the working professionals and provision of the resources required for such change without compromising on efficiency, workflow or even patient care for the improvement of health care delivery systems [245].

v. ***Cooperation and Disruptive Thinking:*** It means supporting partnerships between the public and private sectors and, more importantly, grabbing international relationships to advance the use of AI in healthcare [179]. This can be undertaken by developing innovation zones in health care and ensuring the provision of incentives to undertake research and development in the areas, including grants and tax credits to attract the right talent and capital [246]. The goal of AI adoption is to advance Saudi Arabian healthcare to be at par with other countries' AI-driven health systems for the improvement of public healthcare and the economy's growth [79].

vi. ***Enhancing Public Awareness and Trust in AI:*** Public awareness campaigns are critical in enhancing the public understanding and awareness of AI in healthcare [247]. The awareness campaigns are mainly that of health promotion, safety of AI and applying uses of AI in the public care system, communication through social media, and the promotion concerning the usage of AI applications in the public care context [248,249].

vii. ***Establishing Innovation Zones:*** Saudi Arabia should also develop innovation zones or centers to enhance the application of AI in health care and promote its use [192]. Most of these hubs will focus on conducting research, development, public-private partnerships, and international links. Offering grants and tax credits encourages talent attraction and investments, making Saudi Arabia the preferred hub for AI healthcare [84].

viii. ***Monitoring and Evaluation of AI Implementation:*** Benchmarking is necessary to control and assess the application of AI in healthcare and its success [139]. This entails utilizing the already set key performance indicators (KPIs) that will be employed to determine the extent of implementation, the result,

and the outcome achieved to identify areas for adjustments. AI implementation review cycles must be set up to achieve the desired objectives without negative implications to patient safety or ethics [250]. Ongoing assessment will enable the development of relevant changing strategies to keep the integration of artificial intelligence pertinent to the current needs of the healthcare system [251]. Relating to the measures that can be taken to ensure public awareness and acceptance of their use in health care, there is a need to launch public awareness campaigns for health literacy. This means launching public awareness campaigns on the safety and possibility of using artificial intelligence in the health care system.

This can be done through social media to post success stories, sometimes address concerns, and post information regarding AI's application in healthcare. In addition, community leaders and healthcare professionals should be encouraged to support AI development. The idea is to create commonly recognized trust in AI technologies to achieve support for their application. Fig. 4 demonstrates the Strategic Action Plan for CSF implementation. Table 6 lists the Strategic Action Plan, Implementation Steps, and Outcomes.

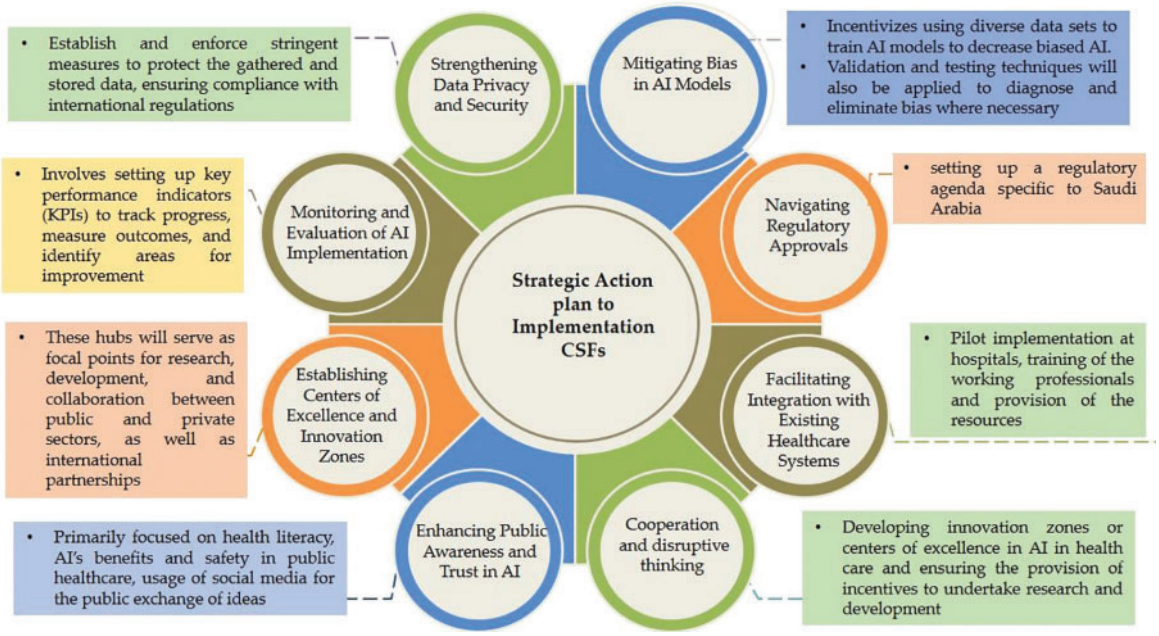

Figure 4: Strategic action plan

Table 6: Strategic action plan, implementation steps and outcomes

S. No.	Perspective(s)	Strategic action	Implementation steps	Outcomes
1	**Strengthening Data Privacy and Security [239,240]**	Increase data protection and confidentiality provisions [252]	• Adopt and standard high levels of data protection policies [253]. • Ensure implementation of higher levels of cyberspace security [254]. • Increase the awareness of the healthcare profession regarding the best practice [104].	Preserve privacy and sanctity of persons' essential health-related information [255].

(Continued)

Table 6 (continued)

S. No.	Perspective(s)	Strategic action	Implementation steps	Outcomes
2	**Mitigating Bias in AI Models [241,242]**	Mitigate bias in AI models [89,256]	• Collaboratively improve the incorporation of various, balanced data samples [253]. • Co-operate with international organizations [104]. • Rigorous validation and testing should be conducted [257].	Eliminating disparity in health literate to determine fair outcomes for all demographical groups [258].
3	**Navigating Regulatory Approvals [78,232]**	Navigate the regulatory approval process [78]	• Establish a clear regulatory framework [259]. • Engage with regulatory bodies and AI developers [260] to develop balanced guidelines for innovation and safety.	Accelerate AI adoption by providing a clear path for regulatory approval [261].
4	**Facilitating Integration with Existing Healthcare Systems [110,245]**	Support using AI as a tool that can be incorporated easily [262]	• Pilot implementation should be in a few hospitals that have agreed early to be part of the project [263]. • Promote and provide suitable knowledge for healthcare workers [264].	Invest in technical support Modernization of the service delivery system of the healthcare sector with an AI-based technique [265].
5	**Cooperation and disruptive thinking [79,179]**	Foster collaboration and innovation [170]	• Promote public/private partnerships as well as worldwide associations [266] • Develop centers of excellence for AI in healthcare. • Provide R&D incentives [267].	Promote Saudi Arabia as one country for top-tier healthcare innovation through AI [191].
6	**Enhancing Public Awareness and Trust in AI [248,249]**	Raise the prevalence and credibility of public knowledge [139]	• Launch public awareness campaigns [250]; • To share experiences about successes/failures and to answer concerns; • Involve those in leadership positions in the community and healthcare professionals.	Inform the public concerning the viability and value of AI technologies [268].
7	**Establishing Centers of Excellence and Innovation Zones [178]**	Develop dedicated innovation zones and centers of excellence for AI in healthcare [269]	• Allocate resources and funding for the development of AI research and innovation centers [81] • Collaborate with universities and tech firms to establish cutting-edge research facilities [270]. • Encourage cross-disciplinary collaboration within these centers [271].	Create a robust ecosystem for AI innovation in healthcare, driving technological advancements and attracting global talent [272].
8	**Monitoring and Evaluation of AI Implementation [139,250,251]**	Establish continuous monitoring and evaluation frameworks for AI integration [89]	• Set up an independent monitoring body to oversee AI implementation in healthcare [273]. • Develop key performance indicators (KPIs) for evaluating AI outcomes [274]. • Regularly review and update AI strategies based on feedback and performance data [40,275].	Ensure AI systems in healthcare are continuously optimized, addressing any emerging issues and improving overall effectiveness [8,276].

Table 5 details how addressing these strategic areas can help Saudi Arabia's public healthcare system effectively overcome the challenges of implementing AI, leading to improved healthcare outcomes and enhanced system efficiency.

4.3 Content Analysis for Themes Identified

In line with RO3, which seeks to explore and define future opportunities for AI applications to enhance the sustainability of Saudi Arabia's public healthcare system, this section focuses on integrating digital

technologies and their potential to drive these opportunities forward. The study identified key research themes related to the future deployment of AI in healthcare utilizing thematic analysis, highlighting the most promising areas for innovation and sustainability and addressing RQ3. The systematic literature review and thematic analysis conducted in R Studio reveal multiple themes based on their density (degree of development) and centrality (relevance), presented in a 2 × 2 matrix.

Fig. 5 depicts a thematic map that categorizes these research themes into four quadrants: Motor Themes, Niche Themes, Emerging or Declining Themes, and Basic Themes. Each quadrant represents different research clusters that guide the future development of AI applications in Saudi Arabia's public healthcare system, contributing to sustainability efforts.

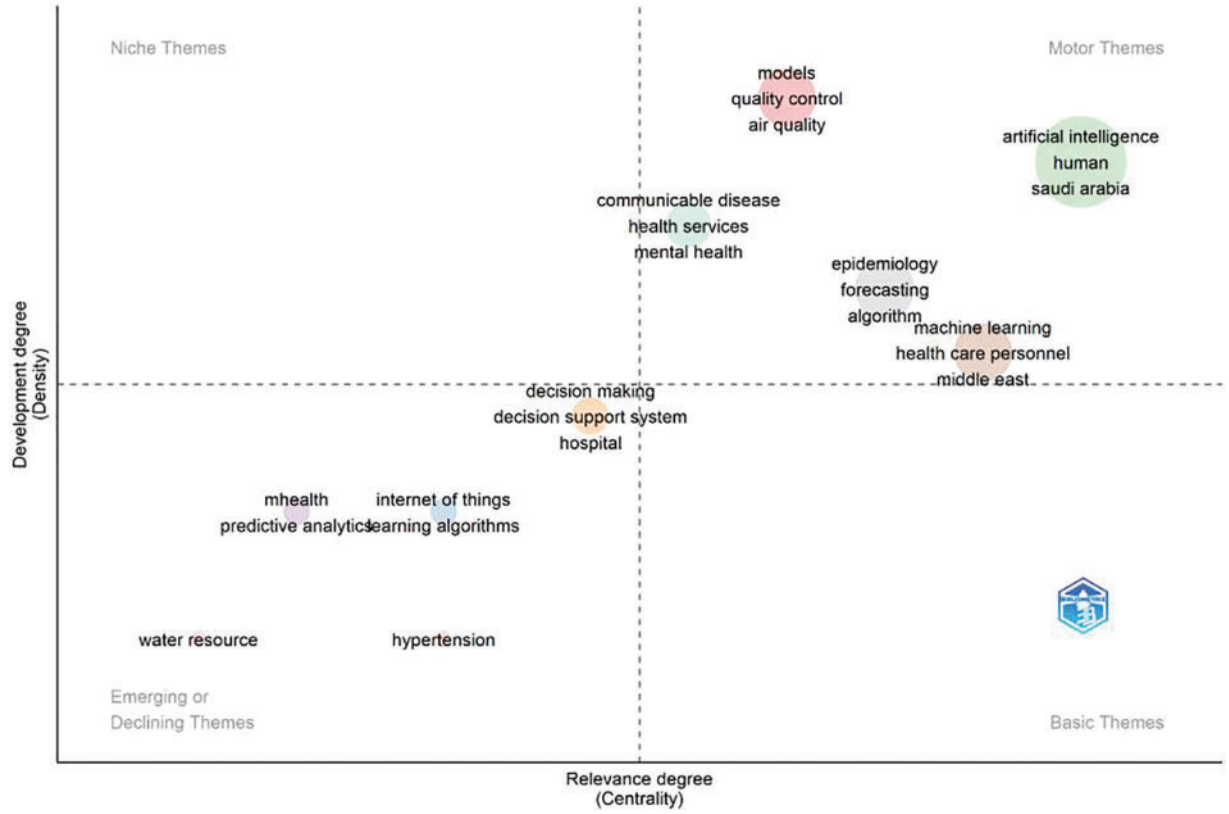

Figure 5: Thematic analysis

The analysis points to numerous future opportunities for AI-driven sustainability in Saudi Arabia's public healthcare system by addressing RQ3 and focusing on these identified themes. AI's integration with digital technologies, including predictive analytics, mHealth, and decision support systems, promises to enhance the system's overall efficiency, quality of care, and ability to meet public health demands, aligning with RO3's goal of promoting sustainable development through technology.

Theme 1: Artificial Intelligence-Human factors for sustainable public Health services in Saudi Arabia.

Fig. 5 indicates that Motor Themes are located in the upper-right quadrant, showing high density and centrality, meaning that they are widely used and essential to the field of study. This quadrant includes concepts like 'artificial intelligence,' 'human factors,' and 'Saudi Arabia.' Not only are these themes well-emerged, but they are also central to advancing knowledge in the overall field of study. The relevance of such

themes is evidenced by their prominence and significance to public health care, where the adoption of AI is viewed as disruptive. The positioning of 'Saudi Arabia' in this quadrant also reinforces its appropriateness because the region is leading in developing AI health solutions. The interrelation between Theme 1 and Proposition 1 is shown in Fig. 7.

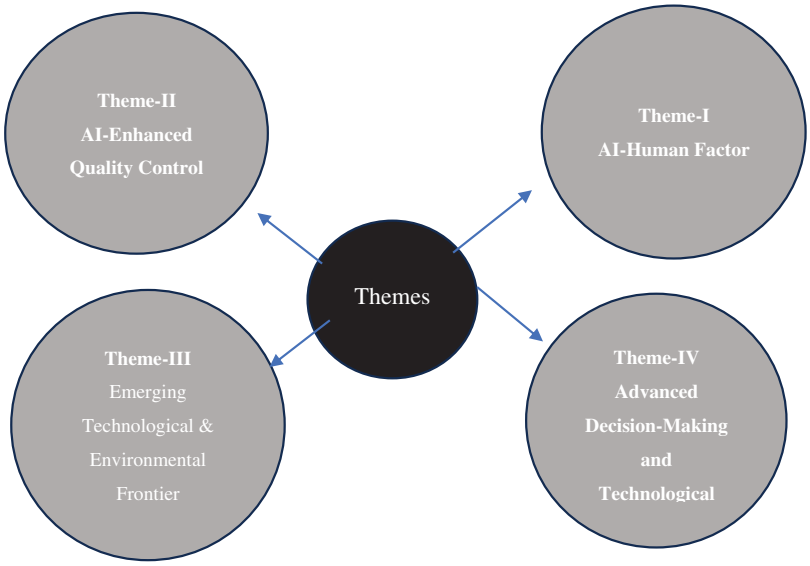

Figure 6: Various themes on public health services in Saudi Arabia

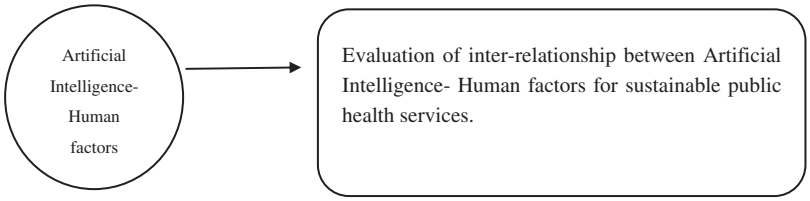

Figure 7: Theme 1 and Proposition 1

Proposition 1: *Evaluation of the inter-relationship between Artificial Intelligence-Human factors for sustainable public health services.*

Theme 2: AI-Enhanced Quality Control: Elevating Standards and Efficiency in Saudi Arabia.

This is classified as niche themes, which are highly developed but not so central and are addressed in the upper-left quadrant. Topics like models, quality control, air quality, communicable diseases, health services, and mental health are included in this category. Although these issues do not set a tendency that is popular and embraced throughout the field, they deal with specific areas of study and are highly complex and, in many cases, detailed. These themes probably serve interest-specific, specialized research specialists and can provide detailed, innovative methods or trends within a narrow sub-discipline.

Proposition 2: *Investigation of the potential of AI in improving quality assurance in Saudi Arabia's public healthcare systems and formulate operational, technical, and legal Strategies for its sustainable performance.*

The interrelation between Theme 2 and Proposition 2 is shown in Fig. 8.

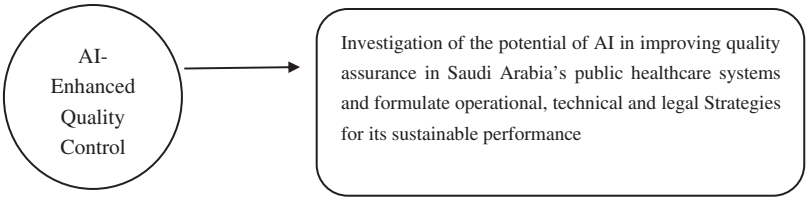

Figure 8: Theme 2 and Proposition 2

Theme 3: Emerging Technological and Environmental Frontiers in Public Healthcare System.

Water Resources, mHealth, Predictive Analytics, Learning Algorithms, IoT, and Hypertension. Low density and centrality characterize emerging or declining themes in the lower-left quadrant. This Cluster consists of themes: Water Resources, mHealth, Predictive Analytics, Learning Algorithms, Internet of Things (IoT), and Hypertension. These issues can be interdisciplinary fields that are still in the process of establishing the kind of acceptance within the scholarly world and academic circles, or they can be dwindling or stagnant disciplines. Both points indicate that the analyzed themes are still underdeveloped and do not occupy a central place in research. Thus, they can be classified as topics that are either in the process of evolving and, therefore, still being explored by researchers or gradually losing their significance in the context of the scientific investigation.

Proposition 3: *To investigate and implement the use of emerging technologies such as Mobile health, predictive analysis, learning algorithms, Internet of things (IoT), and environmental health system in Saudi Arabia, emphasizing the resource-scarce water supply and disease prevention, health facility access, and management of chronic diseases like hypertension.*

The interrelation between Theme 3 and Proposition 3 is shown in Fig. 9.

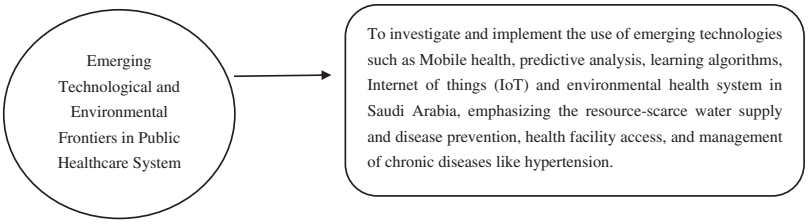

Figure 9: Theme 3 and Proposition 3

Theme 4: Advanced Decision-Making and Technological Integration in Middle Eastern Healthcare Systems. The identified cluster is Basic Themes: The lower right is divided into Basic Themes, and while being less dense, they are focused on the research domain. Some topics that can fall under this category include Decision Making, Decision Support Systems, Hospital Management, Epidemiology, Forecasting, Algorithms, Machine Learning, Healthcare Personnel, Middle East and all other related topics. These generic themes are part of the field's core, and the subsequent more specific and complex research is based on these themes. Despite being less developed, their importance suggests that these are key research directions that can provide a base for increasingly sophisticated and interdisciplinary investigations.

Fig. 6 explains Various themes of Public Health services in Saudi Arabia. Comparing AI implementation in healthcare indicates the situation in Saudi Arabia and prospects in the Middle East and globally, as well as its strengths and future improvements. They have constraints similar to those in Saudi Arabia, such as

data privacy, cultural integration, and a lack of AI talent, but they have a better AI-rooted environment than the UAE. The Global leaders are the United States and South Korea in AI diagnostic solutions, pharmacogenomics, and digital health supported by well-established regulatory legislation and public-private partnerships. These nations highlight the importance of effective data management and ethical-issue AI, the aspects Saudi Arabia is developing under Vision 2030. Saudi Arabia has been credited with handling unique demands, such as managing mega-demands such as the Hajj event. The issues connected with the development of the healthcare workforce, localized research, and data creation are still present to a greater or lesser extent. However, by strengthening international partnerships and enhancing the regulatory environment, Saudi Arabia has all the potential to become one of the leaders in a culturally appropriate, AI-based healthcare system in the Middle East and beyond.

Proposition 4: *To explore and model decision support systems (DSS), machine learning, and predictive analytical solutions that would affect the management of hospitals, the epidemiology of diseases, and the effectiveness of the healthcare personnel in countries of the Middle East with a purpose of solving Middle East's healthcare problems and improving the general performance of the healthcare systems.*

The interrelation between Theme 4 and Proposition 4 is shown in Fig. 10. Integrating sustainable and culturally sensitive AI in Saudi Arabia's healthcare system can significantly enhance the quality of care while aligning with Vision 2030 goals. Sustainable AI practices reduce environmental impact, conserve resources, and promote equitable healthcare, emphasizing energy-efficient models and eco-friendly operations to minimize the carbon footprint. Environmental factors like extreme heat and high foot traffic during events such as Hajj necessitate adaptive AI deployment, with region-specific solutions to ensure functionality under diverse conditions. Ensuring quality control through robust testing, validation, and updates is critical for AI reliability in diagnostic imaging and predictive modeling applications. Culturally and ethically sensitive AI integration, aligned with societal and religious values, fosters trust and public acceptance, requiring privacy protection, consent management, and adapted algorithms. In addition, AI's role in disease prediction and management can revolutionize chronic care through predictive analytics and personalized treatment, improving patient outcomes and healthcare accessibility. These insights provide actionable recommendations for healthcare providers and policymakers to adopt green AI technologies, develop quality assurance frameworks, and implement culturally aligned, patient-centric AI solutions to enhance healthcare sustainability and effectiveness in Saudi Arabia.

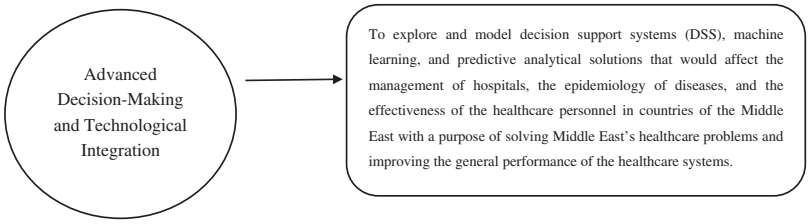

Figure 10: Theme 4 and Proposition 4

5 Discussion

Artificial Intelligence (AI) is transforming healthcare as a disruptive force, offering novel ways to enhance diagnostics, streamline administrative operations, and tailor therapeutic strategies [275]. In Saudi Arabia, AI has started its journey in harmony with the Kingdom's Vision 2030 Main Goals, technological development and better healthcare services. Thus, fundamental and practical issues are linked to the use of

AI in healthcare. For AI systems to reach their full use, they must be updated often, meaning addressing both technical and human elements that determine AI impact [203]. Accordingly, the qualitative thematic analysis carried out in this study reveals four areas where AI can make a significant contribution to sustainability in Saudi Arabia's public healthcare. First, integrating AI into the existing systems must involve collaborating with human beings in the health sector. This synergy intervention will be imperative for the practical realization of long-term goals in public health since AI can boost services. Still, human factors are vital in service delivery. Second, applying AI to quality assurance is another area where the technology can gain organizational, technical, and legal advancements, especially in disease transmission prevention and mental health intervention services. Third, future technologies, including mHealth, predictive analytics, and IoT, will probably provide insights into the scarcity of resources and chronic diseases and substantive approaches to a sustainable health system. Accordingly, this context indicates that such tools and models as decision support systems (DSS) and machine learning can complement the management, epidemiology, and healthcare workforce delivery in hospitals in Saudi Arabia and design the platform for further studies of the future complex roles of AI in the Kingdom's healthcare sector and beyond.

The research suggests specific measures to ensure the privacy and security of patient data when using AI in healthcare. Table 7 demonstrates specific measures to ensure privacy and security of patient data using AI in Healthcare.

Table 7: Security measures towards AI in Saudi Arabian healthcare system

Security measure	Description	Implementation	Saudi Arabian context
Data Encryption	Encrypt all patient data, both in transit and at rest, to prevent unauthorized access [251].	Apply Advanced Encryption Standards (AES-256) to data in databases and during network transfers, ensuring only authorized users can decrypt sensitive information [252].	Compliance with Saudi regulations like the Saudi Health Information Exchange (SHIE) requires strict encryption standards for all healthcare data to protect patient privacy [277].
De-Identification and Anonymization	Remove or mask identifiable information in patient data to protect privacy during AI model training [159].	Use anonymization techniques, such as removing or generalizing identifiers, to prevent patient re-identification while retaining data integrity for AI analysis [278].	De-identification aligns with Saudi patient privacy norms, ensuring data cannot be traced back to individuals while supporting AI-driven healthcare improvements [228].

(Continued)

Table 7 (continued)

Security measure	Description	Implementation	Saudi Arabian context
Strict Access Control and Role-Based Permissions	Implement strict access controls, allowing only authorized personnel access to sensitive healthcare data [279].	Use Role-Based Access Controls (RBAC) to limit access based on roles, enforce Multi-Factor Authentication (MFA), and conduct regular audits of access logs to enhance security [280].	Saudi healthcare facilities can follow the SHIE framework to set robust access controls, meeting national healthcare data protection and confidentiality standards [94].
Compliance with Regulatory Standards	Follow local and international data protection laws, like Saudi Health Information Exchange Policies (SHIE) Policies and the General Data Protection Regulation (GDPR) [281].	Conduct regular compliance audits and update privacy policies to meet regulatory requirements, developing frameworks that align with Saudi standards to build trust and ensure legal compliance [282].	Saudi-specific regulations, including SHIE, outline strict requirements for data handling, ensuring AI healthcare solutions adhere to national legal and privacy standards [283].
AI Model Security Audits	Conduct regular security audits and vulnerability assessments on AI models to identify and address risks [280].	Perform routine assessments, including penetration testing, to detect AI system vulnerabilities and improve defenses against breaches [23].	Routine audits are necessary to comply with Saudi guidelines, reinforcing system security and mitigating AI model vulnerabilities in alignment with local regulations [284]
Data Minimization	Collect and retain only the minimal necessary data to accomplish AI tasks, reducing sensitive information risk exposure [285].	Limit data to essential parameters for AI analysis, reducing potential data breach impact and supporting data protection principles [286].	Saudi policies encourage data minimization, requiring healthcare providers to handle only necessary patient data, thus lowering the exposure risk for sensitive information [287].

(Continued)

Table 7 (continued)

Security measure	Description	Implementation	Saudi Arabian context
Federated Learning and Edge Computing	Use federated learning or edge computing to keep data localized, reducing centralized storage risks [288].	Federated learning enables AI training on decentralized data sources, keeping data at local sites and reducing centralized exposure, which is especially beneficial for healthcare facilities handling extensive patient data [289].	Using federated learning can align with Saudi data sovereignty concerns, allowing AI training without centralizing patient data, which meets local data privacy expectations [290].
Regular Privacy Impact Assessments (PIAs)	Conduct PIAs to evaluate and mitigate privacy risks before deploying AI applications [291].	Perform assessments to identify risks related to data handling within AI systems, informing necessary adjustments to prioritize privacy and security [292].	PIAs are essential in Saudi Arabia for evaluating data protection strategies, as SHIE compliance mandates proactive measures to identify and mitigate risks in AI deployment [293].
Audit Trails and Activity Monitoring	Maintain audit trails and continuously monitor AI system activity to detect unusual access patterns [294].	Implement automated monitoring systems to flag suspicious activity; maintain audit logs for transparency, enabling quick investigations and responses to unauthorized access [295].	Saudi guidelines advocate for stringent activity monitoring in healthcare, ensuring that unusual data access patterns are promptly detected and addressed to secure patient information [296].
Education and Training for Healthcare Staff	Educate healthcare personnel on data privacy best practices and security protocols for AI systems [297].	Conduct training sessions on secure data handling, access management, and patient confidentiality to ensure staff are well-equipped to uphold privacy standards.	In Saudi Arabia, healthcare providers are encouraged to train staff on SHIE data protection standards, promoting awareness of national privacy requirements and secure data handling practices.

(Continued)

Table 7 (continued)

Security measure	Description	Implementation	Saudi Arabian context
Establishing a Data Governance Framework	Develop a governance framework with clear policies for data handling, security, and compliance.	Create data classification policies, retention schedules, and secure disposal procedures, ensuring consistent privacy and security measures.	Saudi healthcare entities benefit from implementing data governance in line with SHIE and other local standards, fostering consistency in data handling, retention, and disposal.
Patient Consent and Transparency	Obtain informed consent from patients before using their data in AI applications, providing transparency on data usage.	Inform patients about data usage, storage, and protection, empowering them with knowledge and fostering trust in AI-enabled healthcare.	Saudi regulations emphasize patient consent and transparency, requiring that patients are fully informed about data use in AI applications to maintain trust and compliance with SHIE policies.

Ensuring the privacy and security of patient data in AI-powered healthcare, particularly in Saudi Arabia's sensitive public healthcare sector, requires comprehensive measures. The Saudi Health Information Exchange (SHIE) policies must be followed, and regular security assessments must be conducted to identify potential breaches of GDPR. Eliminating or limiting the amassment of data and using federative learning or edge computing reduce exposure to centralized processes. The healthcare staff should be trained on privacy issues, data management policies, and decision-making related to patient trust. In alignment, these strategies enable Saudi Arabia's healthcare system to use AI effectively while risking patient privacy and creating a safe and reliable healthcare atmosphere. The other implication of the findings of this research is the policy implications and usage of AI in catering to mass gatherings and delivering public healthcare. AI has a tremendous possibility to transform the availability of health care services and their results during such an event as Hajj; therefore, millions exert pressure on the health care system in the process [298]. Table 8 depicts the various AI applications which are implemented in public healthcare and patient care during mass gatherings.

AI technologies can provide innovative systems to address crowd health amidst gatherings such as Hajj by providing better healthcare, thus supporting Vision 2030. Predictive modeling includes processing past and present claims and other relevant information to predict future healthcare demands, like the possible occurrence of an epidemic or exploration of risks and preparedness for their realization to optimize resource allocation. AI-terminals and cameras observe crowd density in real-time and identify early signs of illness; wearables monitor stars and raise alarms to healthcare teams due to symptoms, such as heat stress or first signs of restricted breathing. AI also helps reduce response time in an emergency through triage that separates severe conditions and predicts when medical equipment and personnel will be needed. Data analysis in contact tracing contains an outbreak, movement data to prevent disease spread, and language

translation for non-English-speaking pilgrims. Telemedicine applications based on artificial intelligence enable remote consultations, which help relieve stress for onsite workers, while environmental measuring systems evaluate threats associated with air quality or temperature and then contribute to taking preventive actions. AI processes aggregated data to identify potential public health risks to enhance readiness during subsequent events.

Table 8: AI applications in public healthcare delivery and patient care in mass gatherings

AI application	Description	Example
Predictive Modeling for Crowd Health Management	Real-time information assists AI in analyzing and combining historical patterns at mass gathering and current information to forecast the demands for health care, new diseases, cases of injuries, and risks during large crowds.	Predict conditions including heat exhaustion, respiratory disorders, and infections and assist in determining which healthcare requires resources.
Real-Time Monitoring and Surveillance	Security cam/sensors monitor crowd density, suspicious behavior, and patients with the illness.	At the Hajj event, AI will detect conditions such as flu and other related diseases in congregation areas and alert health workers to attend to the sick to contain the spread.
Disease Detection Using Wearable Devices	Smart clothing features sensors that track different parameters (heart rate, temperature, blood oxygen) and how AI processes this data in identifying pathological values or the first symptoms of a disease.	AI can recognize people who can have respiratory issues so the healthcare staff can intercede before extremes escalate, especially during extreme weather conditions during the Hajj pilgrimage.
Enhanced Emergency Response and Triage	AI streamlines emergency cases by prioritizing them based on their criticality.	In medical tents and clinics, AI triage algorithms rapidly sort patient symptoms and medical histories to support the correct treatment decisions by health care providers.
Resource Allocation and Management	AI predicts demand for medical supplies, staff, and facilities, ensuring optimal resource allocation to areas of greatest need.	During Hajj, AI algorithms first process real-time data to allocate medical teams and equipment (for instance, mobile clinics) in the best way so that there will be no overload and patients will not have to wait a lot.

(Continued)

Table 8 (continued)

AI application	Description	Example
Contact Tracing and Outbreak Control	AI identifies the pattern of movement as well as interactions prevailing within a particular region, meaning that it, as a tool helps to identify people who can be potentially infected promptly and isolate them.	AI contact tracing apps monitor the contacts the pilgrim has been in touch with and help the authorities inform those contacts, leading to isolation or other containment procedures when an infected case is detected.
Natural Language Processing for Multilingual Communication	Using AI translation to help the healthcare staff when it comes to interacting with the multilingual pilgrims and ensuring that the latter fully understand the former.	AI audibly translates languages to inform the hajj travelers of necessary health information and instructions in their understanding of cultural languages, enhancing health compliance during the Hajj pilgrimage.
AI-Powered Telemedicine Support	Telemedicine platforms to integrate AI, these platforms will link pilgrims to remote healthcare service providers in most cases and relieve on-site medical teams in many ways.	Decentralized AI chatbots and m-health teleconferencing relieve onsite medical personnel of non-emergency patients pilgrims with manageable pre-existing conditions.
Environmental Monitoring for Health Hazards	AI helps to read the consequences of weather conditions or pollution for health by tracking air quality, temperature, and humidity.	Formerly, AI systems provide the corresponding signal for hazardous levels of the pollutant or temperature: supplying measures such as water points, umbrellas, and temporary purification of the air.
Data-Driven Public Health Insights and Reporting	AI gathers large amounts of data from different resources to classify disease patterns within a society and enhance preventive steps and policies.	Post-Hajj analysis enabled data to forecast the health needs of attendees or patterns related to previous hajj gatherings, which would be useful soon, making pilgrims safer in the process.

AI is central in actualizing Saudi Arabia's Vision 2030 goals, and enhancing the availability, quality, and uptake of improved technology is significant to Saudi Arabia's Vision 2030 work plans, mainly information to the healthcare sector, its availability, quality, and use of advanced technology. Specifically, predicting the healthcare demand makes work more efficient, along with the proper use of infrastructures; thus, it contributes to the sustainable growth of healthcare outsourcing. Increasing the efficiency of drug discovery, genomics, and individualized treatment paves the way for enhancing new medical research and development

hubs in Saudi Arabia. AI ensures patient satisfaction by paying individual attention to their condition and ensuring that they receive their health administrative goals. It ensures that administrative goals are achieved and served through surveillance during phases such as Hajj. It also promotes the financial stability of healthcare since jobs performed get done automatically, on diagnoses, there are high chances of getting it right, and operational costs are overcome. In addition, training the employees' human capital through AI will be knowledge-based in the transformation agenda of Vision 2030. The aid of AI enhances relevant decision-making and policymaking in Saudi culture. Table 9 discusses healthcare applications that enhance responsiveness and improve innovative health systems in light of Vision 2030.

Table 9: AI in healthcare and Saudi Arabia's Vision 2030

Healthcare enhancement focus	Role in Vision 2030	AI application
Enhancing Healthcare Accessibility and Quality	Promotes equal and efficient delivery of health care services to clients in Saudi Arabia, mainly with low health care access.	Telemedicine and Virtual Health Assistants increase access in remote or rural areas, hence making it possible to achieve Goals 3A and 3C of Vision 2030 related to reach and inclusiveness.
Improving Disease Prevention and Management	Enhance disease prevention and control to help decrease a nation's burden of chronic disease.	Using patients' data, the AI algorithms diagnose and forecast frequent populace diseases such as diabetes and heart diseases, constraining healthcare expenses and enhancing populace health, which is in tandem with Vision 2030 health agenda.
Optimizing Healthcare Infrastructure and Resource Management	Streamlines resource allocation and optimizes infrastructure use within Saudi Arabia's healthcare sector.	AI models predict service demand, aiding staff, facility, and supply planning, enhancing operational efficiency, and supporting Vision 2030's emphasis on efficient resource utilization and sustainable healthcare expansion.
Accelerating Medical Research and Innovation	Boosts Saudi Arabia's capacity for medical research, advancing healthcare and pharmaceutical innovations.	AI assists in drug discovery, genomic analysis, and personalized medicine, positioning Saudi Arabia as a Middle Eastern leader in medical research, aligning with Vision 2030's goal of diversifying the economy through science and technology.

(Continued)

Table 9 (continued)

Healthcare enhancement focus	Role in Vision 2030	AI application
Enhancing Patient Experience and Satisfaction	Improves the patient experience by making healthcare more personalized, responsive, and convenient.	AI-driven applications manage appointments, reduce wait times, and offer personalized treatment plans, supporting Vision 2030's goal to raise patient satisfaction and make healthcare more consumer-focused.
Supporting Public Health Initiatives and Epidemiology	Manages public health data, detects trends, and prevents infectious disease outbreaks, critical for mass gatherings like Hajj.	AI-enabled surveillance and predictive tools monitor health trends and provide timely interventions during events like Hajj, contributing to Vision 2030's focus on safeguarding public health and ensuring preparedness.
Reducing Healthcare Costs and Increasing Efficiency	Reduces costs by automating tasks and improving diagnostic accuracy, increasing healthcare delivery efficiency.	AI streamlines administrative processes, minimizes errors, and automates tasks (*e.g.*, medical image analysis), lowering operational costs, which aligns with Vision 2030's goal of a financially sustainable healthcare system.
Empowering Healthcare Workforce Development	Assists in training and upskilling healthcare professionals to use advanced tools effectively.	AI-driven training, simulations, and VR enhance skill development, ensuring healthcare providers are well-prepared for AI integration, aligning with Vision 2030's goal of creating a knowledge-driven, skilled workforce.
Promoting a Data-Driven Healthcare System	Supports a data-centric healthcare ecosystem, using data insights for decision-making and quality improvement.	AI analyzes vast healthcare data to identify patterns, optimize care pathways, and inform policies, aligning with Vision 2030's commitment to digital technologies for improving healthcare delivery and decision-making.

(Continued)

Table 9 (continued)

Healthcare enhancement focus	Role in Vision 2030	AI application
Ensuring Culturally Sensitive and Ethical AI Solutions	Develops AI solutions that respect Saudi Arabia's cultural and ethical values, enhancing public trust and adoption in healthcare.	Culturally sensitive AI models ensure that healthcare technologies respect the privacy, values, and beliefs of the Saudi population, supporting Vision 2030's commitment to cultural sensitivity and ethical integrity.

Policymakers and healthcare managers in Saudi Arabia foster an environment that encourages the adoption and innovation of AI in healthcare. Establishing a robust foundation for AI in Saudi Arabia's healthcare system requires a multi-faceted approach involving clear regulatory frameworks, prioritized data privacy, and strong public-private partnerships (PPPs). Comprehensive guidelines addressing ethical considerations, patient safety, and data protection aligned with standards such as SHIE and GDPR will reduce uncertainty and build stakeholder trust. Promoting PPPs and international collaborations will accelerate innovation through shared expertise and resources. Dedicated AI training programs and education initiatives will create a skilled workforce capable of leveraging AI effectively. Establishing innovation hubs and research centers will foster cutting-edge development tailored to Saudi Arabia's healthcare needs, while financial incentives, such as grants and subsidies, will lower barriers to adoption. AI ethics committees will ensure cultural alignment and uphold patient rights while focusing on digitizing and standardizing health data, which will improve AI accuracy and relevance. Pilot projects can demonstrate AI's value in diverse healthcare settings, encouraging widespread adoption. Public awareness campaigns will engage and educate citizens, fostering acceptance and trust in AI technologies. Dedicated funding for AI research in areas such as chronic disease management and resource optimization will drive innovation, and fostering collaborative ecosystems among healthcare providers, startups, academia, and government will accelerate the integration of AI solutions into Saudi Arabia's healthcare system.

The research gives broad implications of AI for healthcare workforce development and training in Saudi Arabia. AI integration in the assessment of health services in Saudi Arabia is transforming the context of workforce promotion and preparing. It affects the competencies care workers should possess and the structural changes that healthcare education requires. Health workers need to become knowledgeable in the concepts, tools, and processes surrounding AI to work effectively with AI systems; these include specific programs on AI basics to interpret results and decision-making under AI augmentation. AI implementation leads to many new job avenues, such as clinical data analysts, AI ethicists, and healthcare tech, which provides educational institutions with Health informatics and digital certifications. Machine learning and predictive analytics have become part of medical programs and offer requisite courses to sharpen the future workforce alongside mandatory continuing education programs for the current workforce. The focus on data protection, ethical deployment of AI, and constructing critical thinking and interdisciplinary teamwork will significantly add to readiness. Experience with virtual health communications or limited and thus learning focused on interacting with both AI tools and, ultimately, patients through simulation-based means will prove advantageous. Further, breaking tedious administrative work will allow Health service providers to focus more on patient-centered care. Thus, promoting an AI culture aligned with Saudi Arabia's Vision 2030 confirms sustainable and efficient healthcare services.

6 Future Research Directions

A large-scale research agenda on integrating AI into Saudi Arabia's healthcare system can help fill the cultural nuances of AI adherence and outcome research. Future empirical studies can examine how AI applications in Saudi Arabia are compatible with Saudi culture and Islamic belief, introducing practical recommendations from qualitative interviews or surveys based on privacy protection, gender, and cultural sensitivity. Self-administered, cross-sectional surveys and interviews with healthcare workers would ascertain factors affecting AI acceptance, including work pressures, ethical considerations, and patients' consequences for acceptance of AI by developing protocols for training specifically to help healthcare workers match their willingness to accept help from AI with their conceptual model of how patients and healthcare should work. Surveys measuring patient attitudes towards AI-based healthcare solutions can identify aspects that build trust, thus making AI systems culturally palatable. Longitudinal research that chronologically captures the trends of implementation of AI in the healthcare regime, the outcome modifier, or the patients' benefactor would help to establish solid empirical evidence for the steady use of AI. Exploratory qualitative case studies using AI-based health programs during hajj can provide broadly applicable culturally appropriate solutions for crowd health in high-risk environments. Collectively, these studies would develop a body of knowledge needed for culturally appropriate and sustainable integration of AI in the kingdom's health care sector. Table 10 explains the research thrust areas and methodology of future studies.

Table 10: Future research directions

Study	Research focus	Methodology	Research outcome
Healthcare AI: Cultural Adaptation	Examines opportunity to identify how AI tools can be integrated into the Saudi context, which has apparent cultural Islamic values.	Self-administered questionnaires, health care worker interviews and focus groups, Islamic scholar interviews and patient focus groups, and a survey to assess the degree of acceptance and perceived efficacy.	Recommendations for enhancing AI in healthcare and developing culturally appropriate algorithms and interfaces for clients from Saudi Arabia and nearby countries, using information about acute patient confidentiality and gender and cultural sensitivity.

(Continued)

Table 10 (continued)

Study	Research focus	Methodology	Research outcome
AI Acceptance from the Healthcare Workers' Perspective	Examines the status of the population's perceptions towards AI in the healthcare industry and their adoption behaviors.	Questionnaires with cross-sectional samples of healthcare staff using the Technology Acceptance Model (TAM) plus qualitative interviews to afford deeper insights into AI in clinical settings.	Provides an understanding of perceived advantages and disadvantages, such as workload and ethical issues, that will inform specific training and IT support interventions to ensure a positive perception of AI by healthcare workers.
Experimental Study on Patient Response to AI-based Health Care Intervention	Evaluates patients' response to AI-based diagnosis/therapeutic and prescribe adherence alternatives based on trust and cultural relevance.	Patients are given recommendations with and without AI; responses involving written questionnaires and interviews to assess trust and acceptance.	Evaluates aspects of patient nurturance to understand culturally sensitive approaches to introduce an AI-supported healthcare solution.
Longitudinal Study on AI Impact on Healthcare Delivery and Patient Outcomes	Measures long-term effects of AI on healthcare quality, efficiency, and patient outcomes in Saudi facilities.	Longitudinal study across hospitals and clinics, tracking metrics like diagnosis accuracy, patient satisfaction, and workflow efficiency using EHRs, surveys, and staff feedback.	Provides evidence on the effectiveness and challenges of AI over time, enabling adjustments in AI usage and data-driven insights for optimizing sustainable healthcare improvements
AI Ethical Frameworks	Compares Saudi Arabian ethical AI framework against that of Western countries in terms of privacy and transparency.	Qualitative research involves comparing ethical AI guidelines in Saudi Arabia with some Western systems, using data interviews of healthcare ethics committees and policymakers to capture rationale.	Global guidelines with Saudi's local cultural considerations established an ethical map to foster innovative healthcare while maintaining cultural sensibilities.

(Continued)

Table 10 (continued)

Study	Research focus	Methodology	Research outcome
AI-Driven Health Programs for Hajj pilgrims	AI for health monitoring for pilgrims during Hajj and assessment of health measure effectiveness and culture.	Qualitative research using focus group discussion and questionnaires with health care practitioners involved in managing the health of pilgrims and Hajj organizers, and participant observation to assess the physical health of the crown during the journey.	AI concerning health issues in religious, historical, or other important spaces and jurisdictions as a service to population health administration and an ethically appropriate course of action.

The research directions offer a balanced approach that seems to call for additional focused empirical research addressing the issues arising from culture and the practicality of the theories.

Tools and models such as decision support systems (DSS) and machine learning can complement the management, epidemiology, and healthcare workforce delivery in hospitals in Saudi Arabia and design the platform for further studies of the future complex roles of AI in the Kingdom's healthcare sector and beyond. Finally, investing in technology and human capital is vital. This includes upgrading technological platforms and ensuring that healthcare practitioners are well-trained in AI applications. AI can enhance the efficiency, effectiveness, and equity of Saudi Arabia's public healthcare system, ultimately contributing to the nation's goal of achieving Vision 2030.

The government should adopt a policy on AI good practices that encourage the ethical and culturally appropriate, promotion of AI policies that focus on data protection, user consent, and algorithmization and execution regulation. The healthcare sector should have a separate AI governance committee that will maintain compliance with the above policies in relation to Islamic values and Vision 2030. Specifically, AI education and training for healthcare professionals should be performed to improve AI literacy, practical aspects of AI, and ethical concerns that allow AI to be easily integrated into a working environment. There are ways to finance the inclusion of AI to extend and improve these services to areas where facilities and qualified staff are scarce. Incentives and subsidies will play the most important part in getting there. Governments and private sectors should collaborate to co-design AI solutions suitable for Saudi Arabia's environment. Promising sectors, such as smart healthcare and disease prognosis, should advance rapidly. Culture and ethics-specific solutions created with the help of cultural and religious advisors integrate Islamic ethics and form the base for AI solutions that the public will trust. Pilot projects for AI solutions such as diagnostics and telemedicine, combined with the availability of massive data for future application to serve public health surveillance and mass gatherings like Hajj, will position Saudi Arabia as a pioneer in adopting AI in the healthcare sector, including resource allocation, health risk monitoring in real-time and disease prevention.

Table 11 lists the policy recommendations and future implications for healthcare practitioners and policymakers to have a clear pathway for adopting AI that aligns with Vision 2030 [299,300]. These

strategies will help Saudi Arabia achieve a sustainable, culturally responsive, and technologically advanced healthcare system.

Table 11: Policy recommendations and future implications

Policy recommendation	Implication	Recommendation
Develop and Enforce a Comprehensive AI Policy Framework	There is a need for a proper framework for policies that would set out the general issues of ethical and culturally correct use of AI in medical services.	Form an AI-specific governing board in the health sector that would have the duty of overseeing and setting policies for the application of AI besides giving ethical clues for local and Islamic standards.
Invest in AI Education and Training	AI implementation means that healthcare practitioners need to know and be ready to interface with AI systems.	Setting of specific and measurable continuing professional development for the Healthcare Workers (HCWs) on how to start incorporating these concepts of AI in practice, namely practical AI, ethical issues involved, practical application of AI, application of AI in support of decision making and how the organizational processes can better fit with AI systems.
Create Incentive Programs to Encourage AI Adoption in Underserved Areas	AI can potentially enhance equal healthcare provision in remote areas, a key focus of Vision 2030.	AI can potentially enhance equal healthcare provision in remote areas, a key focus of Vision 2030.
Public-Private Partnerships (PPPs) for AI Development and Implementation	Engagement with the private sector can complement advances in AI to public endeavors by offering more talent, tools, and cash, which are needed.	Support PPPs from partnerships to co-design AI solutions for Saudi specific diseases or patient care.
Culturally and Ethically Sensitive Artificial Intelligence Systems	Public is willing to embrace and accept healthcare AI systems, which is where the software being employed corresponds to the Saudi culture, for example, respecting privacy and or acquiring a prior consent.	AI individuals must engage cultural relation experts, Islamic scholars, and other related healthcare specialists to ensure that AI systems share Islamic culture and ethical background.

(Continued)

Table 11 (continued)

Policy recommendation	Implication	Recommendation
Implement Pilot Programs and Scale Successful AI Applications	Field trials of AI technologies show working prototypes, regional effectiveness, and the reaction of patients.	The use of diagnostics via artificial intelligence and telemedicine to collect data on the effects for future research. Extend innovative services to serve as a template throughout the healthcare system to address Vision 2030 obligations according to available AI capabilities.
Processes standardized for the training of models in AI	Local data is essential for AI training as Saudi Arabia's healthcare demands are quite different from those of most parts of the world.	Set up "health data referential" and data hub to offer de-identified, high-quality data on any region for AI training, backed up by rigorous data management protocols to prevent breach of privacy.
AI in surveillance and mass gathering activities in the public health context	AI can assist in public health management during mass events such as the Hajj, as well as in health needs prediction and outbreaks.	Design AI guidelines and applications for mega-conferences, including forecasting models for infrastructure and healthcare resources. These measures will strengthen public health capacities to improve healthcare sectors' safety during mass gatherings.

7 Conclusion

AI has started its journey harmoniously in Saudi Arabia with Vision 2030's primary goals: technological development and better healthcare services. Thus, fundamental and practical issues are linked to the use of AI in healthcare. For AI systems to reach their full use, they must be updated often, meaning addressing both technical and human elements that determine AI impact. Accordingly, the qualitative thematic analysis conducted in this study reveals four areas where AI can significantly contribute to sustainability in Saudi Arabia's public healthcare. First, integrating AI into the existing systems must involve collaborating with human beings in the health sector. This synergy intervention will be imperative for the practical realization of long-term goals in public health since AI can boost services. However, human factors are vital in service delivery. Second, applying AI to quality assurance is another area where the technology can gain organizational, technical, and legal advancements, especially in disease transmission prevention and mental health intervention services. Third, future technologies, including mHealth, predictive analytics, and IoT, will probably provide insights into the scarcity of resources and chronic diseases and substantive approaches to a sustainable health system. Developing AI frameworks to suit Saudi Arabia's cultural, ethical, and healthcare

needs can revolutionize the sector, aligning with Vision 2030's goals. Culturally-aware AI ensures adoption and public trust by respecting societal values in data collection, patient interactions, and ethical applications. AI-driven predictive models enable early detection and preventive care for chronic diseases, easing the burden on healthcare systems. Integrating genomics with AI fosters personalized medicine, offering targeted therapies for hereditary conditions common in the region. Fourth, Advanced AI tools for telemedicine and remote monitoring improve healthcare accessibility in underserved areas, while epidemic prediction models enhance public health safety during mass events like Hajj. Decision support systems empower clinicians with accurate diagnostics and treatment recommendations, while multilingual NLP bridges language gaps, enriching patient-provider communication. AI optimizes resource allocation, streamlining supply chains and staff scheduling for greater efficiency. Mental health support systems use AI to provide early interventions and monitor high-risk individuals. Robust data privacy frameworks and explainable AI models build trust and transparency, ensuring patient confidentiality and confidence in AI-assisted care. AI accelerates drug discovery, offers personalized treatment protocols, and monitors environmental health impacts, addressing climate-related health risks.

Collaborative research networks drive innovation and skill development, establishing a self-sustaining AI ecosystem tailored to Saudi healthcare needs. Investing in these key areas of AI research and development can create a more efficient, responsive, and accessible healthcare system in Saudi Arabia. These advancements will support the Kingdom's Vision 2030 goals, positioning Saudi Arabia as a leader in AI-driven healthcare transformation and sustainable public health innovation.

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Abbreviations

AI	Artificial Intelligence
KSA	Kingdom of Saudi Arabia
EHRs	Electronic Health Records
SLR	Systematic Literature Review
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
NLP	Natural Language Processing
EXAI	Explainable AI
IoT	Internet of Things
KAP	Knowledge, Attitudes, and Practices

HIPAA	Health Insurance Portability and Accountability Act
CSFs	Critical Success Factors
PDPL	Personal Data Protection Law
KFSHRC	King Faisal Specialist Hospital and Research Centre
HIMSS	Health Information and Management Systems Society
GDPR	General Data Protection Regulation
SFDA	Saudi Food and Drug Authority
SDAIA	Saudi Data and Artificial Intelligence Authority
SHIE	Saudi Health Information Exchange
DSS	Decision Support Systems

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