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Enhancing Healthcare Information Systems in Ethiopian Hospitals: Exploring Challenges and Prospects of a Cloud-based Model for Smart and Sustainable Information Services

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Abstract: Hospitals are the primary hubs for healthcare service providers in Ethiopia; however, hospitals face significant challenges in adopting digital health information systems solutions due to disparate, non-interoperable systems and limited access. Information technology, especially via cloud computing, is crucial in healthcare for efficient data management, secure storage, real-time access to critical information, seamless provider communication, enhanced collaboration, and scalable IT infrastructure. This study investigated the challenges to standardizing smart and green healthcare information services and proposed a cloud-based model for overcoming them. We conducted a mixed-methods study in 11 public hospitals, employing quantitative and qualitative approaches with diverse stakeholders (N = 103). The data was collected through surveys, interviews, and technical observations by purposive quota sampling with the Raosoft platform and analyzed using IBM SPSS. Findings revealed several shortcomings in existing information systems, including limited storage, scalability, and security; impaired data sharing and collaboration; accessibility issues; no interoperability; ownership ambiguity; unreliable data recovery; environmental concerns; affordability challenges; and inadequate policy enforcement. Notably, hospitals lacked a centralized data management system, cloud-enabled systems for remote access, and modern data recovery strategies. Despite these challenges, 90.3% of respondents expressed interest in adopting cloud-enabled data recovery systems. However, infrastructure limitations, inadequate cloud computing/IT knowledge, lack of top management support, digital illiteracy, limited innovation, and data security concerns were identified as challenges to cloud adoption. The study further identified three existing healthcare information systems: paper-based methods, electronic medical catalog systems, and district health information systems2. Limitations of the paper-based method include error-proneness, significant cost, data fragmentation, and restricted remote access. Growing hospital congestion and carbon footprint highlighted the need for sustainable solutions. Based on these findings, we proposed a cloud-based model tailored to the Ethiopian context. This six-layered model, delivered as a Software-as-a-Service within a community cloud deployment, aims to improve healthcare services through instant access, unified data management, and evidence-based medical practices. The model demonstrates high acceptability and potential for improving healthcare delivery, and implementation recommendations are suggested based on the proposed model.

Index Terms: Healthcare Information Systems, Cloud-based Model, Interoperability, Sustainability, Information Technology, Cloud Computing.

1. Introduction

In the 21st century, digital transformation has cleaned across industries, with healthcare grappling with the profound challenges posed by pandemics like COVID-19. This has underscored the urgent need for digital solutions. Organizations increasingly adopt cloud-based information systems to enhance data management, improve efficiency, and promote

environmental sustainability in autonomous environments such as IoT and smart hospitals. However, Ethiopian healthcare institutions confront significant obstacles, including the lack of a unified system for integrating, information systems, sustainability concerns, and easy access to healthcare data for stakeholders [1,2]. Information and communication technologies (ICT), including cloud computing, have revolutionized multiple industries, yet their ability to unlock healthcare data in Ethiopian hospitals remains largely unfulfilled. This study explores numerous research questions such as what challenges hinder the standardization of smart and green features in healthcare information services within Ethiopian hospitals? A study [3] reveals Ethiopia's healthcare challenges, such as medication accuracy, and patient treatment delays leading to complications and fatalities. Accordingly, these challenges stem from health data complexities, failure in collaboration in data sharing, ethical and legal issues, system interoperability gaps, insufficient knowledge, and infrastructure deficiencies. Research suggests that digital health solutions can transform Ethiopia's healthcare system and societal well-being [4]. Challenges such as infrastructure, training, device access, and hesitancies among patients however to date healthcare service providers are far away from full adoption and implementation of technological solutions. However, challenges such as infrastructure, training, device access, and hesitancies among patients and healthcare service providers are far from fully adopting and implementing technological solutions.

Recent studies [5,6] highlight Ethiopia's proactive efforts to advance ICT adoption through various initiatives such as the national data set, the national enterprise service bus (NESB), EthioICT-Village, WoredaNet, the integrated financial management information systems, the ICT business incubation centers, and SchoolNet. These efforts are intended to create integrated networks connecting institutions across regions and bridging digital divides between urban and rural areas, focusing primarily on capital expenditure (CapEx) rather than operational expenditure (OpEx). A notable research study [7] highlighted that digital transformation can significantly improve healthcare workflows through technology implementation. However, this potential has yet to be fully explored in Ethiopia.

The Ethiopian Ministry of Health (MoH) [8], states that hospitals are primary healthcare service providers and are categorized into primary, secondary, and tertiary levels of healthcare, as depicted in Fig.1. However, these hospitals lack modern facilities and ICT-enabled systems, including Internet of things (IoT), smart systems, and cloud computing. Limited technology-driven healthcare systems in Ethiopia impede access to crucial patient medical histories essential for holistic care, highlighting the urgent need to address these shortcomings for improved health outcomes.

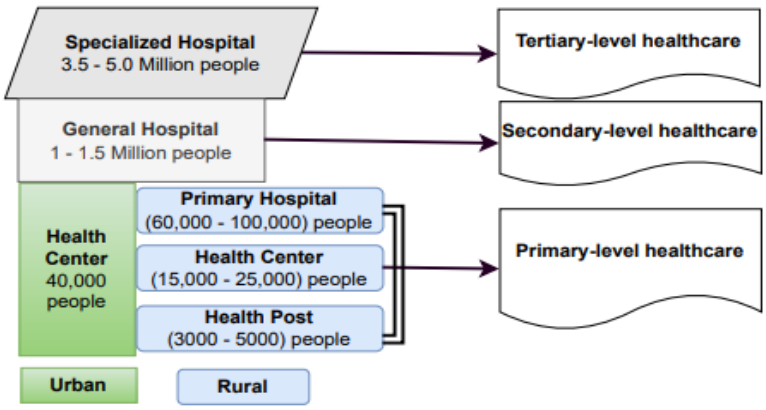

Fig.1. Ethiopian health Tier system [8]

The prevalence of disparate, non-integrated, and non-interoperable health information systems poses a major challenge in the Ethiopian healthcare sector. In the current state, the healthcare data collected by one system is often unusable by another due to a lack of integration framework or policy, and there are no standard procedures governing information exchange among health information systems (HIS) [9]. A study [10] demonstrates the substantial benefits of incorporating ICT in healthcare, including enhancing the coverage and quality of healthcare services. Computing systems, information technology (IT), and the wide adoption of digitalization have been playing a vital role in transforming existing systems towards better information systems accessibility approaches. Studies [11,12] disclosed cloud computing as a dynamic ICT trend providing cost efficiencies, time savings, enhanced features, and continuous service availability (i.e., 24/7), while also contributing to energy conservation. However, widespread adoption remains a significant challenge in the Ethiopian healthcare sector. Health records are only one of the innovations on the Gartner emergence cycle for cloud-based solutions[13], as depicted in Fig.2.

Numerous studies have highlighted cloud computing's capability to offer comprehensive ICT services, including hardware, software, networks, storage, virtualization, and applications, thereby establishing a robust global platform. Despite its increasing adoption across various sectors, healthcare remains notably behind in embracing cloud-based solutions, particularly in Ethiopian public hospitals. Efficient healthcare data sharing within and between hospitals is critical for enhancing service quality. In this regard, a cloud-based solution can enhance efficiency, reduce costs, and facilitate secure, shareable access to patient data, transforming traditional data handling through remote access, retrieval, and enhanced security and privacy measures. However, Ethiopian hospitals currently lack systematic adoption and

exploration of cloud computing, which could enable secure, ubiquitous access to health data across any device. This gap hinders the improvement of service quality within the Ethiopian healthcare system.

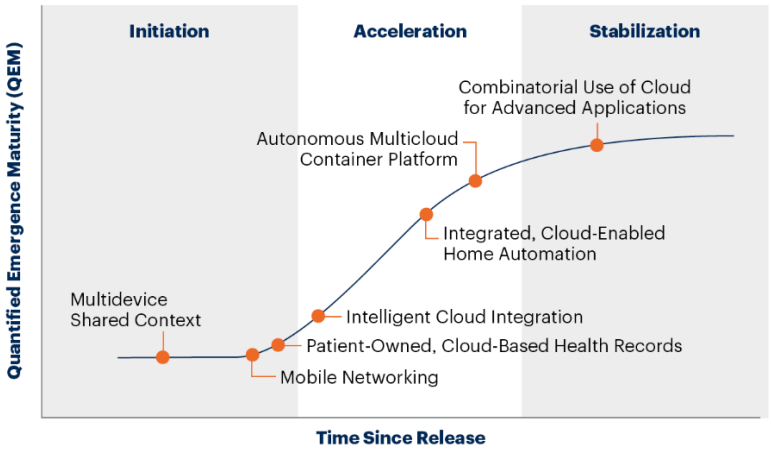

Fig.2. Gartner emergency cycle for cloud-based solutions [13]

Objective: This study aims to investigate and analyze the challenges in healthcare-related data and information hindering the standardization of smart and green healthcare services in the Ethiopian healthcare system and design a suitable cloud-based contextualized model.

Hypothesis: The adoption of a cloud-based solution in Ethiopian healthcare institutions can address the current challenges related to data standardization, integration, and access, leading to improved healthcare service quality and efficiency. This hypothesis suggests that the proposed cloud-based model can overcome the existing barriers and provide a more effective and sustainable approach to managing healthcare data in Ethiopia.

This study's scope encompasses an in-depth analysis of existing issues within 11 selected government hospitals (primary, general, and specialized hospitals), but it does not include health centers and health posts. These hospitals under the MoH affiliation were selected purposefully based on proximity to research institutions, adherence to a three-tier healthcare delivery model (as shown in Fig.1), and specific ICT infrastructure challenges such as availability, capacity, data consolidation, and cost.

A comprehensive literature review, related works, and surveys are conducted to analyze current challenges in Ethiopian healthcare information systems, explore the prospects of cloud computing in healthcare, and propose a cloud-based model to address research gaps identified in existing literature, models, frameworks, and survey data.

2. Literature Review of Related Works

The digital era has revolutionized healthcare services by introducing technologies that enhance patient access to healthcare services, such as IoT, smart devices, and cloud computing. Cloud computing, as defined by research [14], involves delivering services via Internet-based technologies, symbolized by the cloud metaphor. A study [12] categorizes the cloud computing model into four deployment models, three service delivery models, and five essential characteristics. The comparison of cloud computing services and deployment models is shown in Table 1 and Table 2, respectively. Comparing models is crucial for selecting the most suitable one for healthcare services, and optimizing the use of computing resources effectively. Studies [15,16] indicate that Cloud computing consists of two parts: a pool of computing resources, i.e., provided by cloud service providers (CSPs), and cloud service consumers (CSCs), i.e., users who are accessing these resources through networked access. Amazon Web Services, Microsoft Azure, Google Cloud Platform, IBM Cloud, and Verizon Cloud are examples of cloud service providers [15,16].

In addition to the service delivery models in Table 1., cloud computing extends beyond traditional service delivery models to include Recovery as a Service (RaaS) solutions) [17]. Accordingly, RaaS solutions help organizations consolidate data backup, archiving, disaster recovery, and business continuity on a unified platform, mitigating data loss risks and facilitating rapid recovery. Unlike traditional IT, where users manage these aspects, cloud services offer these critical functions as managed services, enhancing efficiency and reliability.

Table 1. Comparison of cloud computing service delivery models

Cloud Service models	Provided by-	Delivers/ provides-	Managed by users (i.e. infrastructure)	Flexibility for users	Possible intervention in healthcare	Ref.
Infrastructure as a service (IaaS)	CSPs	Virtualized computing resources (CPU, Servers, VMs, Storage, etc.)	High	High	Infrastructure/resources provisions	[12,17]
Platform as a service (PaaS)	CSPs	Computing Platforms: Operating systems, programming languages, Libraries, Databases, execution environment etc.)	Medium	Medium (control over deployed applications)	Developing the solution model /application	[12,17]
Software as a service (SaaS)	CSPs	Applications (i.e., (Software)	No/low	Low/Limited	End-users' app provision	[12,17]

Table 2. Comparison of cloud computing deployment models

Cloud deployment models-	Available to-	Security level-	Control by user(s)-	Cost	Suitability remark(s) in healthcare	Ref.
Private cloud	A single organization	High	High	High	Suitable for security & privacy	[12,18–20]
Public cloud	General public/ industries	Low	Low	Pay-Per-Use	Suitable for open access announcements	[18–20]
Hybrid cloud	Public and organizations; Individuals, & companies	Medium	Medium	Pay-Per-Use	Suitable for classified HC info. services	[18–20]
Community cloud	A specific community (i.e., organizations having shared concerns)	High	High	Medium	Suitable for clustered organizations under a unified umbrella	[12,18–20]

A recent study [21] reveals that cloud computing offers numerous benefits, features, and users' pay-per-use access to services such as shared virtual infrastructures. A research study [22] states that cloud technology is a virtualized, off-premise rent-based service model that offers high-end uptime, scalability, availability, reliability, and on-demand services over networks via the Internet. Thus, federated health data, facilitated by shared virtual resources, can effectively overcome healthcare service challenges like resource limitations, and costs.

Related studies [23–25] firmly suggest that cloud-based solutions have the potential to enhance the quality of healthcare services. In this regard, reviewing previous studies related to the healthcare system is crucial for understanding the models, frameworks, and architectures used in cloud-based healthcare systems. Hence, selected related works and the most relevant models, frameworks, and architectures employed in a cloud-based healthcare system in prior research studies are selected and reviewed as follows:

A Cloud-based Smart Home Environment: The dramatic increase in the aging population worldwide poses significant challenges to existing healthcare systems [26]. Accordingly, recent technological advancements in smart sensors, cloud computing, and big data analysis have opened new avenues for home-based healthcare delivery. The research study [26] developed a cloud-based smart home environment (CoSHE) comprising a smart home setup, wearable unit, private cloud infrastructure, and home service robot. A smart home, equipped with environmental sensors, mobile devices, and a home gateway, is in a mock apartment, whereas wearable units worn by humans collect physiological signals and activity data. CoSHE was set up using a private cloud platform and utilized OpenStack Juno, an open-source cloud orchestration tool, and adopts a SaaS model with a four-tiered architecture: service presentation, cloud engine, data processing, and cloud storage. Accordingly, the service presentation layer acts as an interface for wireless applications, APIs, and web services, enabling remote data access. The cloud engine leverages a message queue cluster to distribute tasks between data processing and storage clusters using message-driven scheduling. Data processing uses the data processing cluster to implement data mining algorithms on physiological and contextual data. Cloud storage serves as data resources for the cloud using storage clusters. A study [26] utilized a hybrid data storage model, i.e., combining a relational database (MySQL) for storing structured data and a non-relational database (NoSQL) for unstructured data (sensor data). However, the model fails to include essential elements such as unified integration, federation, and collaboration of health data across hospital systems, highlighting a critical gap that needs addressing for comprehensive and coordinated healthcare systems.

Cloud-based Hospital Information Systems: A study [27] states that healthcare information systems (HIS) have low interoperability due to the heterogeneity of architectures, models, and tools used. The authors suggest that a cloud-based hospital information system (cHIS) can be designed to provide smart healthcare services by optimizing IT environments and reducing operating costs through resource pooling and technological convergence. The suggested solution, i.e., cHIS, is comprised of cloud-based HIS, mobile EMR, personal biological records, and healthcare big data services. In this research, the cloud platform-based HIS service is divided into virtual machine technology (to maximize shared computing resources), grid computing technology (to support service stability), security-related technology, and application programs. The VM system was adopted and set up to provide SaaS-type services. The cHIS application utilized service-

oriented architecture (SOA) and component-based design (CBD) principles, and an experiment was conducted on the CloudSim simulator to evaluate its efficacy in delivering smart healthcare services. Finally, the study [27] revealed that an increase in cloud storage disk and network bandwidth allows more users to be served and improves efficiency in handling unpredictable scalability and processing huge amounts of data. Similarly, several other studies emphasized the economic benefits of cloud computing, such as resource sharing, cost reduction, real-time health data exchange, and the necessity of federated healthcare information systems. The study [27] does not share or allow access to the patient's health data among hospitals, along with service collaboration and energy-aware solutions.

A Cloud-based Secured Healthcare Framework: Another study [11] proposed a cloud-based secured healthcare framework (SecHC). The authors enhanced the cipher-text policy attribute-based encryption (CP-ABE) scheme to provide safe access to health care and medical data. The study suggests a solution through electronic health records (EHRs) that include patient data, laboratory results, medication lists, diagnostic tests, etc., but the privacy and integrity of healthcare and medical data remain significant challenges while data sharing and outsourcing over the cloud [11]. In this EHR framework, the scheme introduced two additional modules, a hashing module in the encryption phase and a hashing verification module in the decryption phase, to provide fine-grained access control and offer data privacy and integrity. The framework involved four entities: data owner, data user, attribute authority, and secure health cloud. On the other hand, the general framework for the CP-ABE scheme has four modules: setup, key generation, encryption, and decryption. The hashing module was introduced as a new module in the SecHC framework, and attributes of access policy were hashed using the message digest algorithm 5 (MD5). Advanced Encryption Standard (AES) was used as an encryption algorithm to convert data into unreadable forms. The hashing module is used to ensure data integrity, whereas the hashing verification module is used to verify the authenticity of the access policy during the decryption phase. According to a study [11], data security requirements such as privacy, integrity, and fine-grained access control are essential for data sharing in the cloud environment. However, the framework lacks consideration for secure sharing of health data across hospitals, data ownership, and control by patients.

A Secure and Robust Healthcare over Blockchain Approach: Another important study [28] suggests that cloud-based patient information sharing can enhance service quality and reduce healthcare costs by enabling seamless communication between patients, hospitals, and insurance agents. The shift to cloud-based storage for sensitive health information opens up vulnerabilities in both data privacy (patient control and confidentiality) and secure data transformation (protecting data during transfer and storage). The study [28] proposed secure and robust healthcare over Blockchain (SRHB) approach with attribute-based encryption (ABE). The SRHB module includes doctors, patients, and insurance agents with a workflow-oriented approach using advanced encryption techniques to ensure data security. The study [28] states that companies and research institutions, namely Phillips, Gem Health, Google, and IBM, have recently built healthcare applications based on Blockchain techniques. Another related study [29] states that Blockchain technology offers secure cloud-based medical data transformation. Accordingly, the expansion of Blockchain technology has prompted researchers to explore innovative applications in various sectors, including healthcare. The schemes in the studies [11,28] have their cons and pros. The SecHC with CP-ABE scheme in [11] explains the economic and convenient benefits of cloud-based healthcare services. However, SecHC lacks green and energy-saving practices, secure shareability, service collaboration, and accessibility across hospitals. The decentralized nature of Blockchain enhances security and reliability, but when the number of blocks grows, it may cause delays in information delivery. On the other hand, the SRHB [28] approach with ABE ensures secure health data transmission in a centralized healthcare system, reducing delays and providing flexibility and privacy for patients in a cloud environment. However, it lacks energy-saving, service collaboration across hospitals, and Blockchain techniques.

A Cloud-based Healthcare System Model: The authors of [30] emphasized the challenges posed by inadequate health institutions, a shortage of healthcare professionals, and IT resources in rural and remote villages. The study suggested that efficient utilization of ICTs in healthcare offers a solution to address healthcare service problems. The study [30] proposed a cloud-based healthcare system model (CBHS), which is a client-server architecture application using a MySQL database, PHP, and various technologies like JQuery, HTML, CSS, and Ajax for server and frontend scripting languages. Accordingly, the model's remote accessibility in real-time reduces medical tourism, pressure on healthcare professionals, and patient waiting time with a unified login form for all users, facilitating access to their respective interfaces. In this model, the primary stakeholders include community healthcare workers, doctors, and patients, and the application automatically generates a unique username and default password for new patients upon successful registration. This model is limited to community health centers, lacking information accessibility. Also, the study primarily considered rural community dwellers, but the actual data were collected from institutions situated in urban areas that did not consider rural dwellers as the owners of the challenges.

A Blockchain-based Healthcare System: Another study [31] says that data written in paper form is difficult to fetch in digital form as it needs extra manpower, costs to archive, and leads to data entry errors. However, digitization of health data is a key for remote access by experts, health professionals, and patients. Also, authors argue that Cloud-based eHealth systems face challenges in security and privacy while protecting sensitive and personal data from hackers. According to [31], the emergence of healthcare 4.0, such as using the IoT, cloud computing, Big data, and Blockchain, requires dealing with security challenges for medical data protection. Numerous studies have stated that Blockchain technology has the potential to address security issues by enabling the provision of secure eHealth services. Thus, the study [31] proposed a

Blockchain-based healthcare system (BHS) for storing and sharing health data, comprising IoT nodes, medical users, fog nodes, cloud storage, and a private Blockchain. The BHS is primarily focused on securing healthcare systems from unauthorized access, data leakages, and data loss issues, and Blockchain technology is being increasingly utilized to secure sensitive data in cloud-based environments.

A Healthcare Architecture using Cloud Computing: Another study [32] states that digitization of data and medical information can be better for processing, analyzing, and sharing through IoT-cloud collaboration in a real-time fashion. It says that secure connections should be established to ensure cost-effective communication between health professionals, patients, and healthcare institutions. In this research, cloud computing addresses resource limitations by enabling storage, servers, networking, and applications to cover large topographical areas, despite some affecting aspects. The study [32] proposed a healthcare architecture using cloud computing (HACC), consisting of different layers such as user interface, service, smart gateway, and public cloud computing. The proposed system's user interface layer includes ambulatory, emergency, location-based services, and recommendations. The service layer manages network security analysis and operations like protection, detection, and reaction services. The smart gateway oversees system operations, data handling, processing, management, and service execution. In this architecture, data collected from multiple hospitals is uploaded to a cloud infrastructure, potentially transforming to a paradigm shift in the working environment and culture. This architecture anticipated public cloud computing; however, a public cloud has numerous security and privacy issues and concerns [19,20].

A Green Computing System Architecture: A local study [33] explores the use of the cloud for sharing composite personal health information in Ethiopian healthcare centers. Accordingly, the global IT sector contributes to over 2% of the global carbon footprint, with key issues in green IT responsibilities such as high carbon dioxide (CO2) emissions. Thus, the author of [33] proposed a green computing system architecture (GCSA) that comprises users, public domain, emergency department, face recognition, private domain, personal health records, and a cloud server. It is intended to deliver secure patient-centric personal health record (PHR) access and effective key management. The study categorized users into public and private domains to address key management challenges. The architecture suggest a cloud server with a patient-centric approach where patients would have complete control over their privacy through encrypting personal health record files to allow fine-grained access. However, the architecture lacks practical demonstrations of its greenness and carbon emissions reduction. The author also did not incorporate up-to-date security measures or enhance the sharing of personal health records among hospitals.

3. Methodology

The Research Process Design

This study employed a mixed research design, combining exploratory and applied research methods and a mix of quantitative and qualitative approaches, as illustrated in Fig.3. Studies [34,35] suggest that employing a mixed research approach enhances the effectiveness of research outcomes and achieves quality results by combining multiple approaches. Further, an exploratory applied design is perceived as providing a clear view of the problems with multilateral explorations. This study used separate questionnaire with 17 common parameters in all fact-finding techniques and then data was analyzed using IBM's SPSS 23 for investigating detailed problems and challenges in the existing healthcare systems.

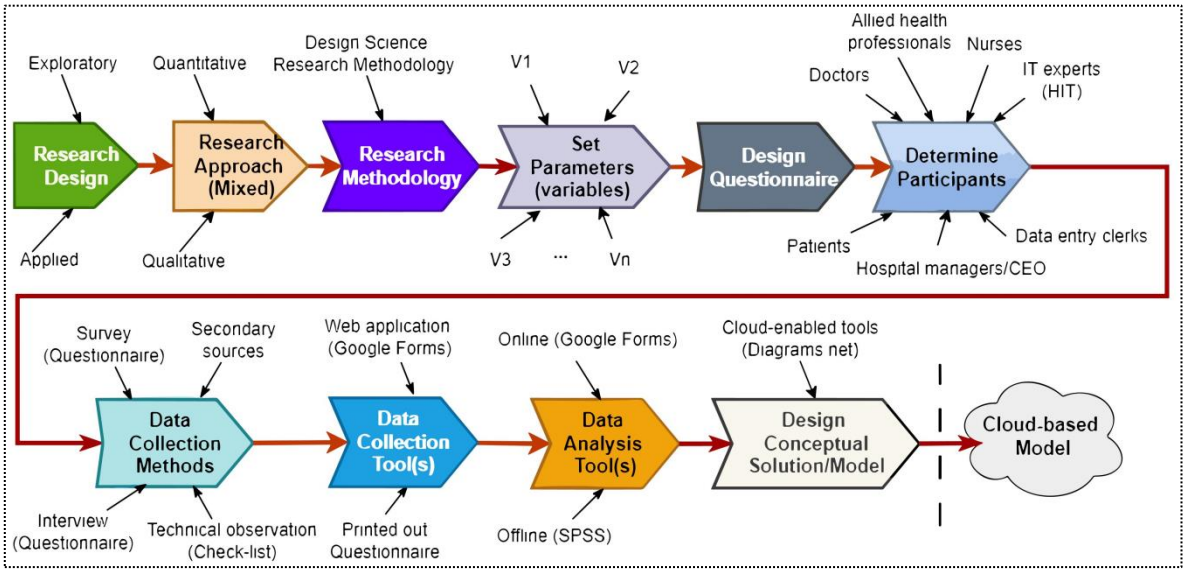

Fig.3. The general research design and methodology

As depicted in Fig.3., a design science research methodology (DSRM) [36] was used in the general research design and methodology to achieve the research objective and answer the research question. This study utilized three data-gathering techniques: 1) Surveys (questionnaires) were utilized to collect quantitative primary data using online (i.e., Google Forms) and offline (printed out) questionnaires. 2) Technical observations, refer to the researcher's observations of the real situations at the research sites, such as data handling, existing systems, and limits; hence, a checklist was used to conduct the observations. 3) Interviews (questionnaires) were used to collect facts from experts such as health information technicians (HIT). Primary data were collected from doctors, nurses, allied health professionals, IT experts/HIT, managers/CEOs, data entry clerks, and patients, as shown in Fig.4. Secondary data, including documents, reports, and related works, were utilized for qualitative data analysis and cross-data validation.

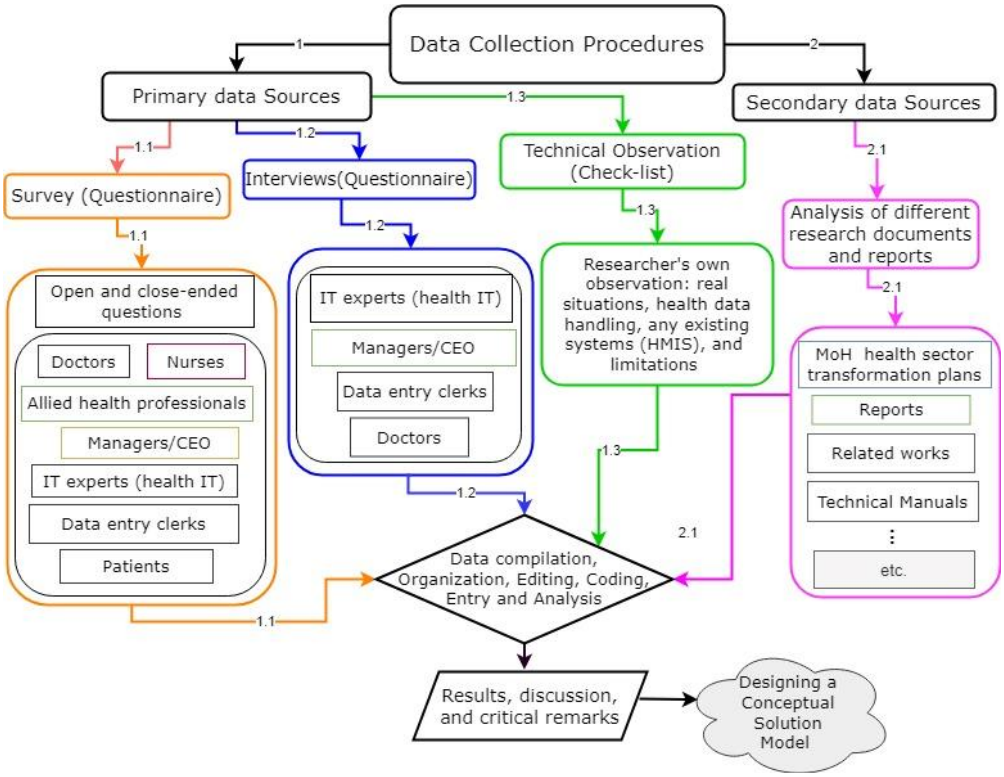

Fig.4. Data collection methods and sources

Data Sampling and Analysis

This study focused on selected government hospitals based on purposive quota sampling as the main goal of this data collection was to investigate and analyze the challenges related to healthcare data and information management in the selected Ethiopian hospitals. This method selected only representative healthcare institutions to ease the data problems and to get feedback of the competent stakeholders of all the levels of operations and administrations in these institutions.

The data were collected from eleven (11) hospitals, i.e., four primary hospitals, three general hospitals, and four specialized hospitals. The sampling size was calculated using Raosoft, an online sample size calculator, assuming a 5% margin of error, a 95% confidence level, and a 50% response distribution. The authors estimated a population of 165 participants, using 15 respondents from each hospital, and hence recommended a sample size of 116. Ultimately, 103 responses were received. Data processing is considered an essential process for researchers to make convincing analyses. Thus, this study utilized Google Forms/Spreadsheets for automatic response analysis, IBM SPSS 23 for statistical data analysis, and diagrams.net for designing the proposed model.

The Raosoft sample calculator used in this paper is significant in this research for the following reasons:

- Reduced Bias and Increased Generalizability: It helps ensure the sample is representative of the population of Ethiopian hospitals by suggesting a statistically relevant sample size.
- Increased Confidence in Findings: With a sample size of 116, the researchers can be 95% confident that their results are reliable and reflective of the Ethiopian healthcare system.
- Efficient Resource Allocation: By calculating a sample size of 116, the researchers could focus their resources on surveying a manageable number of hospitals while still obtaining statistically reliable data.

Here's a breakdown of the specific settings used in the Raosoft calculator:

- 5% Margin of Error: This means the researchers are comfortable with their results being within 5% of the true value for the population of hospitals.
- 95% Confidence Level: This indicates a 95% probability that the sample results accurately reflect the population.
- 50% Response Distribution: This is a common default setting as it represents the most uncertain scenario. With more knowledge about the expected response rate, the researchers could adjust this value.

Overall, the Raosoft sample calculator plays a crucial role in ensuring the research produces reliable and generalizable findings about the challenges faced by Ethiopian hospitals in adopting standardized, smart, and green healthcare services.

4. Data Analysis and Results

We surveyed to explore and apply technology-enhanced solutions to address existing challenges in healthcare information systems. To investigate existing challenges in hospital information management system, real primary data from selected hospitals was collected, organized, analyzed using statistical techniques, and presented in tables and charts to visualize the situations and draw meaningful inferences. The data was collected from 103 participants through a survey questionnaire (20.4% female and 79.6% male), as shown in Table 3. The participants consist of doctors (16.5%), nurses (19.5%), Allied health professionals (17%), managers/CEOs (1.9%), IT experts (3.9%), patients (11.7%), data entry clerks (4.9%), Health officers (6.8%), health information technicians (HIT) (9.8%), Epidemiologist (1.9%), lab technicians (2%), pharmacist (2%), project manager (1%) and Biomedical engineering (1%).

Table 3. Gender information

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Female	21	20.4	20.4	20.4
	Male	82	79.6	79.6	100.0
	Total	103	100.0	100.0	

As depicted in Fig.5., the study collected the data to examine the information system problems and challenges in 11 public hospitals, with 73% in the newly formed South Ethiopia regional state, 18% in Hawassa, and 9% in Addis Ababa.

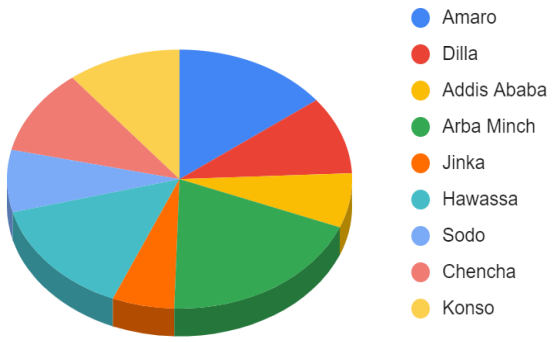

Fig.5. Locations of the hospitals

This study included primary, general, and specialized hospitals, along with their respective respondents as detailed in Table 4.

Table 4. Type of hospitals and frequency of respondents at each hospital

Types of hospitals (No.)		Frequency (respondents)	Percent	Valid Percent	Cumulative Percent
Valid	Primary Hospital (4)	48	46.6%	46.6%	46.6%
	General Hospital (3)	27	26.2%	26.2%	72.8%
	Specialized Hospital (4)	28	27.2%	27.2%	100.0%
	Total	103	100.0	100.0%	

As depicted in Fig.6., the majority, i.e., 68.0%, of respondents agreed that there is no centralized system to manage healthcare data or information from a single location where one patient has one health record at the national level; 23.3% of respondents disagreed; however, 8.7% were unaware of it.

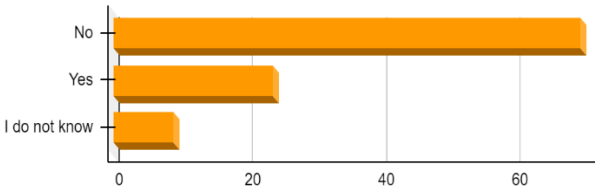

Fig.6. Status of centralized system to manage health care data from a single location

At this point, a question: How do you rate the aspects of the existing systems in the hospital? Was raised to assess the status of existing information systems in each hospital. This question was structured in 17 sub-questions considering 17 parameters: data standardization, storage capacity/on-demand scalability, data consolidation, security, regulated share-ability, interoperability, service collaboration, data ownership, accessibility, recoverability in disaster, system greenness, in-house data center affordability, reliability, improved QoS, common policy enforcement, smartness, and agility (i.e., cloud computing shares the resources among users and works very quickly). The responses were collected, analyzed, and summarized in Table 5.

Table 5. Rating the level of aspects of the existing systems in the hospital

Aspects of existing systems		**Very Poor**	**Poor**	**Good**	**Very Good**
Level of storage capacity and on-demand scalability	Frequency	9	33	51	10
	Percent	8.7%	32.0%	49.5%	9.7%
Level of promised security and privacy	Frequency	5	28	53	17
	Percent	4.9%	27.2%	51.5%	16.5%
Level of regulated sharing of health data among hospitals	Frequency	7	40	46	10
	Percent	6.8%	38.8%	44.7%	9.7%
Level of service collaboration (inter/intra)	Frequency	8	37	46	12
	Percent	7.8%	35.9%	44.7%	11.7%
Level of Timeliness accessibility	Frequency	14	45	38	6
	Percent	13.6%	43.7%	36.9%	5.8%
Level of access over any digital devices (interoperability)	Frequency	28	56	15	4
	Percent	27.2%	54.4%	14.6%	3.9%
Level of data ownership and access control	Frequency	31	53	17	2
	Percent	30.1%	51.5%	16.5%	1.9%
Level of data standardization	Frequency	11	42	42	8
	Percent	10.7%	40.8%	40.8%	7.8%
Level of data consolidation and repository provisions	Frequency	19	45	37	2
	Percent	18.4%	43.7%	35.9%	1.9%
Level of data recoverability in case of disaster	Frequency	19	54	27	3
	Percent	18.4%	52.4%	26.2%	2.9%
Level of systems greenness	Frequency	17	55	27	4
	Percent	16.5%	53.4%	26.2%	3.9%
Level of smartness	Frequency	13	63	25	2
	Percent	12.6%	61.2%	24.3%	1.9%
Level of in-house data center affordability	Frequency	12	69	24.3	3
	Percent	11.7%	67%	19%	2.9%
Level of in-house data center reliability	Frequency	17	65	18	3
	Percent	16.5%	63.1%	17.5%	2.9%
Level of in-house data center quality of service (QoS)	Frequency	23	55	22	3
	Percent	22.3%	53.4%	21.4%	2.9%
Level of common policy enforcement and control	Frequency	23	56	20	4
	Percent	22.3%	54.4%	19.4%	3.9%
Level of existing systems agility	Frequency	29	56	17	1
	Percent	28.2%	54.4%	16.5%	1.0%
	Total (for each aspect)			Frequency	103
				Percent	100.0%

As depicted in Fig.7., based on the survey results, 90.3% of the respondents agreed that these hospitals lack technology-enabled or online systems where patients, doctors, and health professionals can be enabled to access patients' health data or information from a remote location, whereas 5.8% disagreed and 3.9% were found unaware.

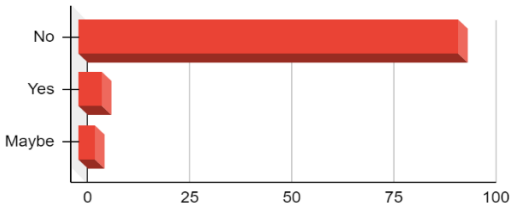

Fig.7. Technology-enabled or online system in these hospitals

As depicted in Fig.8., 83.5% of the respondents agreed (i.e., 53.4% strongly agreed and 30.1% agreed) that using centralized and modern technologies like cloud-based systems in healthcare data management can reduce typographical errors more than manual methods and the remaining 14.6% remained neutral, 1% disagreed, and 1% strongly disagreed.

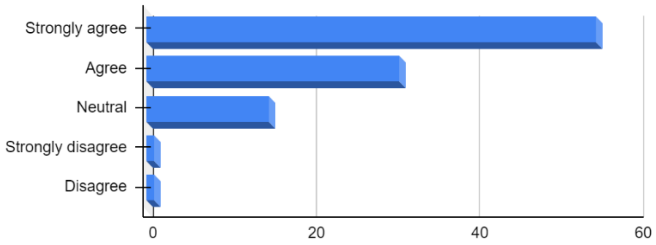

Fig.8. Using cloud-based systems in health data management can reduce typographical errors

Also, as detailed in Table 6, the majority of respondents (21.4 % strongly agreed and 54.4% agreed, i.e., 75.8) agreed that most medical errors occur due to poor access to patients' healthcare data or information in these hospitals.

Table 6. Medical errors happen due to poor access to patients' health care data

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly agree	22	21.4	21.4	21.4
	Agree	56	54.4	54.4	75.8
	Neutral	20	19.4	19.4	95.2
	Disagree	5	4.9	4.9	100.0
	Total	103	100.0	100.0	

As depicted in Fig.9., 67% of the respondents agreed that these hospitals handle patients' health care data using paper-based methods, while 33% disagreed, i.e., they use personal computer-centric (local, i.e., not networked with other hospitals).

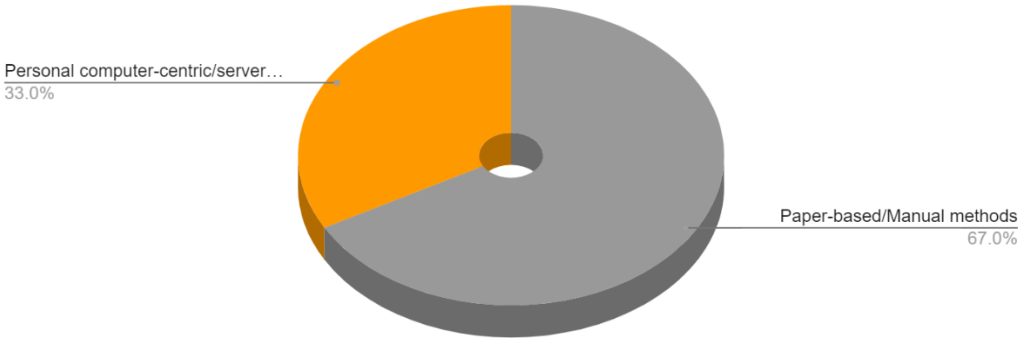

Fig.9. The hospitals handle patients' health care data

According to the survey results and technical observations, these hospitals lack a consolidated healthcare data repository system, which makes it difficult to seamlessly access, timely retrieve, and process healthcare data across different hospitals. As depicted in Fig.10., 81.6% of the respondents agreed there is no consolidated healthcare data repository system, while 11.7% disagreed and found themselves unaware.

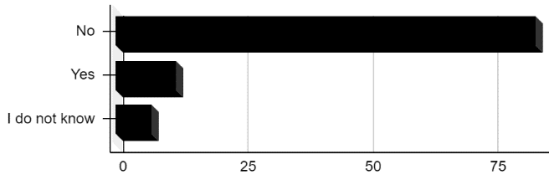

Fig.10. Hospitals connected by a consolidated health care data repository system

As depicted in Fig.11., 89.3% (i.e., 45.6% strongly agreed and 43.7% agreed) of the respondents agreed that cloud-based healthcare services are more easily accessible, available, scalable, and timely retrievable than manual methods, whereas 4.9% remained neutral and 5.9% disagreed.

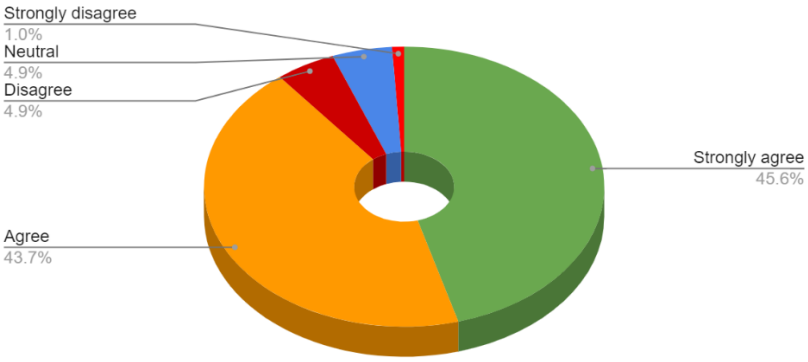

Fig.11. Healthcare services over the cloud can be more easily accessible than paper-based methods

The healthcare data in these hospitals is non-interoperable; 87.4% of respondents agreed that healthcare data is not digitally accessible via web browsers or links across multiple devices and various Ethiopian hospitals without installing specific software, whereas 12.6% disagreed. As depicted in Fig.12., 85.4% agreed (32.0% strongly agreed and 53.4% agreed) that cloud-based healthcare services can be more secure and prevent unauthorized access than paper-based, whereas 10.7% were neutral and 3.8% disagreed.

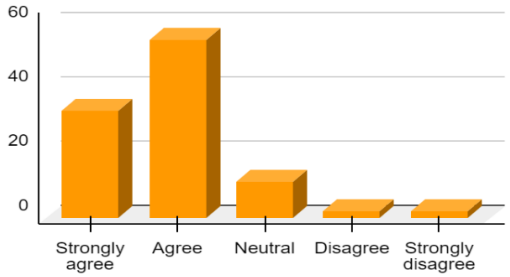

Fig.12. Healthcare services over the cloud can be more secure and prevent unauthorized access

However, Ethiopian hospitals still utilize paper forms to share patients' health care data among hospitals when patients are referred to another hospital for further or specialized treatment. As depicted in Fig.13., 96.1% of respondents agreed that these Ethiopian hospitals exchange patients' histories using paper-based or manual methods, whereas 1% agreed that digital media (CD/DVD, flash disk, etc.), 1.9% agreed over the cloud, and the remaining 1% agreed via email.

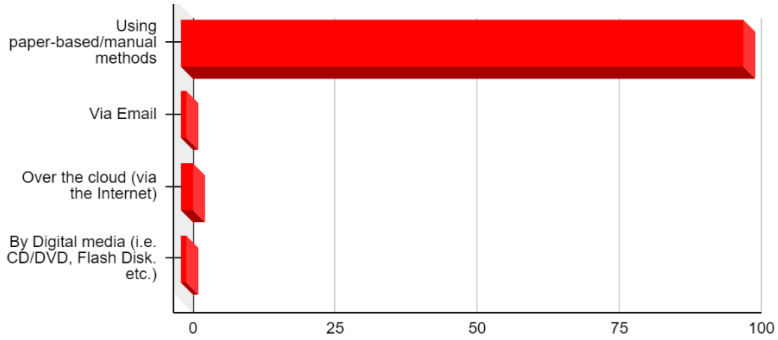

Fig.13. Hospitals share patients' health data when referred to another hospital

In cumulative percent, as depicted in Fig.14., 91.2% of respondents agreed that cloud-based healthcare services can enhance service collaboration among hospitals, patients, doctors, and allied health professionals.

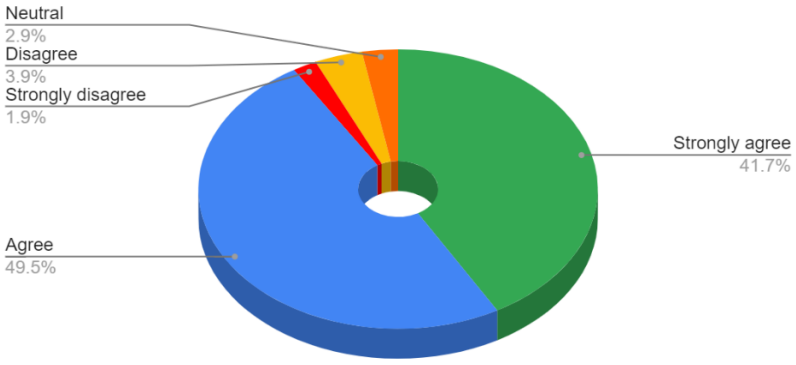

Fig.14. Healthcare services over cloud can enhance service collaboration

In these hospitals, patients check their health care data or information by physically visiting the hospital(s). There are no alternative digital solutions to check patients' health care data status online or get any reports. As shown in Table 7, 97.1% of respondents agreed that patients check their health care data/information by physically visiting the hospital(s); however, physically visiting hospitals leads to unnecessary congestion and increases carbon emissions from transportation methods like vehicles.

Table 7. Patients check their health data or information in the hospital(s)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	By physically visiting the hospital(s)	100	97.1	97.1	97.1
	Over the Cloud/online systems	3	2.9	2.9	100.0
	Total	103	100.0	100.0	

Meanwhile, as depicted in Fig.15., 91.3% of respondents agreed that there is no possibility that patients can access and control their healthcare data or information remotely, anytime, anywhere, over any digital device(s), whereas 8.7% disagreed from an accessibility point of view. Access to patients' health histories remotely is important, such as in an emergency.

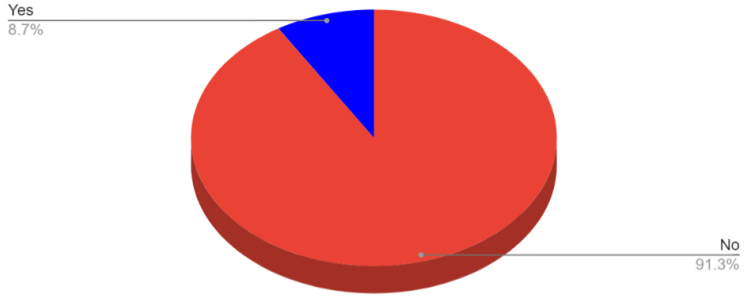

Fig.15. Patients access and control their health care data remotely

Based on the responses, 72.8% agreed that disasters such as earthquakes, fires, floods, etc. have not been experienced to destroy the hospitals' health care data or information. However, these hospitals lack modern data recovery systems in case of disaster, as shown in Table 8.

Following such issues: Which mechanism will provide a better solution to recover data if a disaster happens in the future? This question's responses were recorded, in which the majority, i.e., 90.3% of the respondents, agreed to opt for cloud-enabled/online data recovery systems, whereas 9.7% agreed to opt for traditional data backup mechanisms (CD/DVD, hard disk, etc.). Also, technical observation verified that none of the selected hospitals have online or cloud-based data recovery systems. As depicted in Fig.16., respondents agreed that cloud-enabled healthcare services can eliminate healthcare data redundancy, reduce unnecessary energy consumption from traditional IT data centers, reduce cost, and avoid manual workloads.

Table 8. Hospitals recover patients' health care data and related information if a disaster happens

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No system to recover	55	53.4%	53.4%	27.2%
	I do not know	28	27.2%	27.2%	80.6%
	Traditional data backup mechanisms (CD/DVD, hard disk, etc.)	17	16.5%	16.5%	97.1%
	Over the cloud/online data recovery systems	2	1.9%	1.9%	99.0%
	Paper-based	1	1.0%	1.0%	100.0
	Total	103	100.0	100.0	

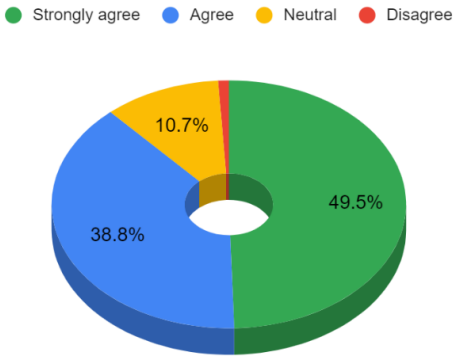

Fig.16. Cloud-enabled healthcare services can eliminate healthcare data redundancy

Cloud computing can offer patients' healthcare data accessibility from anywhere, improving hospitals' quality of service. On this concern, the majority of the respondents, i.e., 92.2% agreed that the hospitals' current systems lack agility, but the cloud offers better competitive advantages than traditional IT due to its agility. On the other side, the majority of respondents (91.2%) agreed that modern technologies, such as cloud services, can enhance healthcare services over traditional systems or manual methods, whereas 8.7% remained neutral. Further, a rating was asked about the greenness, security, interoperability, and centralization of a cloud-enabled healthcare service model to suggest a cloud-based smart and green hospital information management system. As depicted in Fig.17., the response ratings were very good (48.5%), good (36.9%), fair (8.7%), poor (3.9%), and not applicable (1.9%).

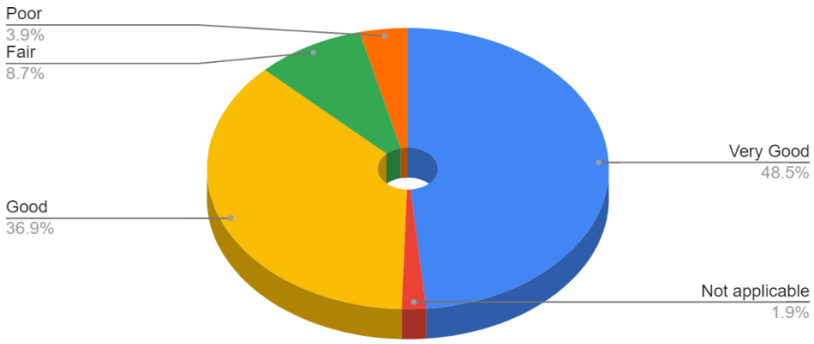

Fig.17. Rating cloud-enabled healthcare services model for the hospitals

However, as summarized in Table 9, in line with the technical observations and survey, challenges are influencing the adoption of cloud-based/online systems in hospitals.

When the question was raised about policy enforcement, the respondents confirmed that the role of policymakers is very important in addressing the aforementioned challenges. As depicted in Fig.18., 42.7% of respondents strongly agreed and 45.6% agreed that policymakers' common policy enforcement and control regarding cloud-enabled solutions in hospitals is necessary. The rest of the responses were neutral (5.8%), strongly disagreed (1.0%), and disagreed (4.9%), which were considered negligible.

Table 9. Challenges influencing the adoption of cloud-based systems in hospitals

		Responses		Percent of Cases
		N	Percent	
Challenges influencing adoption of Cloud in hospitals:	Acute shortage of infrastructure	93	20.3%	90.3%
	Data security and privacy concerns	31	6.8%	30.1%
	Digital illiteracy of the users/patients	68	14.8%	66.0%
	Lack of Cloud-based/IT health knowledge of the top management	64	13.9%	62.1%
	Lack of Cloud-based/IT health knowledge of the users/patients	82	17.9%	79.6%
	Lack of decision maker's innovativeness	50	10.9%	48.5%
	Lack of top management support	70	15.3%	68.0%
	Lack of immediate benefits	1	0.2%	1.0%
Total		459	100.0%	445.6%

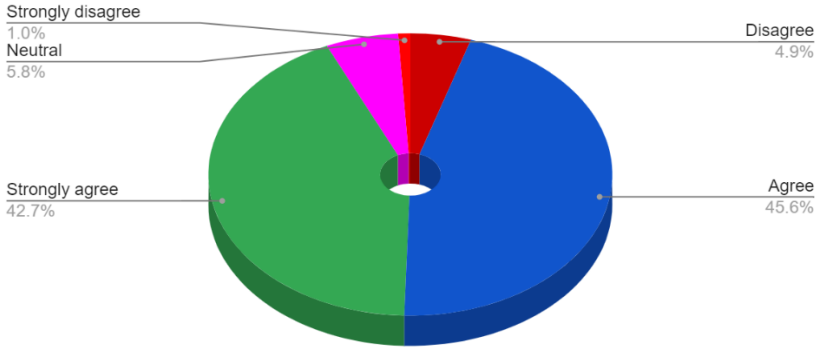

Fig.18. Policymakers' common policy enforcement regarding cloud-based solutions in hospitals

Finally, the survey results, technical observation, and interviews confirmed three existing systems in the selected hospitals: 1) paper-based methods or formats; 2) the electronic medical catalog system (eMCS); and 3) the district health information system 2 (DHiS2).

5. Discussion

The issues and challenges in the existing state-of-the-art systems in the Ethiopian healthcare systems:

Digital health data is crucial for remote healthcare access; however, ICT adoption in healthcare, including cloud services, remains nascent in developing countries like Ethiopia. Challenges include disparate, non-interoperable, non-integrated healthcare information systems, limited access to services, and remotely inaccessible patient histories across hospitals, leading to suboptimal/poor healthcare information delivery. This study reviewed related models, frameworks, and architectures, and conducted surveys, interviews, and technical observations in selected hospitals to assess existing systems. We gathered up-to-date data from selected hospitals to analyze their current situations. Data collected highlighted gender disparities among respondents (79.6% male, 20.4% female).

The survey, technical observations, and interviews indicated that these hospitals face significant challenges in integrating healthcare data and information systems for smart and sustainable management. Participants highlighted a pressing need for a new system enabling unified access to healthcare data nationwide. The results revealed a demand for next-generation technology capable of on-demand scalable data storage, robust security, inter/intra-hospital data sharing, and collaborative service delivery. The existing state-of-the-art systems at selected hospitals, i.e., in-house data center accessibility, interoperability, data ownership, data consolidation, recoverability, greenness, affordability, reliability, QoS, common policy enforcement, control, and agility were found inadequate and poor.

In current state-of-the-art systems, hospitals lack online systems for doctors, patients, and healthcare professionals to remotely retrieve patients' healthcare data. Patient histories, traditionally recorded but not digitized, remain seamlessly inaccessible across hospitals. Most respondents (72.8%) noted a lack of technology-enabled solutions for sharing patients' healthcare data among hospitals. However, the majority (83.5%) acknowledged that using modern technologies such as cloud-based systems in healthcare data management could reduce typographical and medical errors caused by poor access to patient data.

Notably, 60.2% of respondents were unaware if hospitals have plans to migrate patient healthcare data to alternative systems like the cloud. Hospitals still rely on cumbersome and outdated paper-based methods for patient data management. Hospitals typically use paper forms for patient referrals, which often lack crucial past medical histories, posing significant

risks, especially for allergic patients needing specific drugs or medications, potentially endangering their lives. These hospitals lack digital accessibility of healthcare data across multiple devices, resulting in non-interoperable systems. The absence of data consolidation and repositories hinders seamless operations. A survey found that 89.3% of respondents prefer cloud-based healthcare services for advanced features like high accessibility, availability, scalability, and timely processing.

Challenges and Opportunities for Cloud-Based Healthcare Services in Ethiopia:

The data analysis and reviews show that cloud-based healthcare services enable service collaboration, enhance security, and prevent unauthorized access compared to paper-based methods. However, current systems require patients to visit hospitals physically to check health information and obtain reports, causing congestion and greenhouse gas emissions from transportation, such as vehicles. The majority of the respondents i.e., 91.3% confirmed patients' inability to remotely access and control their healthcare data via digital devices, indicating the absence of alternative digital solutions or systems. Online access to health data is critical in current systems, particularly during emergencies. Disasters such as earthquakes, fires, and floods have not destroyed healthcare data in selected hospitals, as per data analysis results. However, these hospitals lack modern cloud-enabled data recovery systems, underscoring the need for technology-enhanced solutions for robust data recovery. Data analysis also shows current hospital systems lack agility, unlike the inherently agile nature of cloud computing, which offers competitive advantages over traditional IT and existing systems. 90.3% of respondents agreed to opt for cloud-enabled or online data recovery systems. Other studies show that cloud computing in healthcare reduces data redundancy, energy consumption, and costs while enhancing Quality of Service (QoS) by enabling universal patient data access. Additionally, 85.4% of respondents rated the idea of developing a cloud-based healthcare services model for hospitals as good, with 48.5% considering it very good and 36.9% good.

This study reveals challenges hindering the standardization of smart and green features in Ethiopian hospital information systems including lack of data consolidation and repositories, interoperability issues across digital devices, low energy efficiency, remotely inaccessible traditional data handling, high costs, carbon footprint concerns, lack of centralized and networked systems, lack of on-demand scalable data storage, security and privacy vulnerabilities, data recoverability and redundancy issues, data ownership issues, affordability challenges of in-house data centers, and existing systems agility limitations. Also, the study identified challenges influencing the adoption of cloud-based or online systems in hospitals: infrastructure shortages, users'/patients' IT knowledge gaps, lack of management support, digital illiteracy, lack of cloud-based or IT knowledge of top management, lack of decision-makers innovativeness, data security concerns, privacy issues, and lack of immediate benefits. Data analysis results and facts underline policymakers' pivotal role in addressing these challenges, with 88.3% of respondents advocating for policymakers to encourage next-generation systems like cloud-enabled solutions for easier healthcare data management in hospitals. Based on a comprehensive literature review, surveys, technical observations, and interviews, this study has identified/confirmed three existing data and information management systems in these hospitals, revealing their issues and challenges as follows:

5.1. The Current Paper-based Methods, Paper Formats, and Deficiencies

Patients' medical histories are paper-based and wrapped in dossiers (Fig.19.). This includes or is utilized for referrals, lab results, prescriptions, and more, housed in hardcopy folders on shelves. Retrieving these records is cumbersome, difficult to identify a patient's history on time, and lacks remote access. Paper-based health data handling faces numerous challenges, such as errors, high paper costs, scalability issues, reliability, greenness, vulnerable access, security concerns, maintainable storage, and collaboration. However, digitalizing the existing health care data faces challenges such as the existence of a huge amount of patients' histories kept in hardcopy formats, redundant and scattered patients' data in different hospitals (at distant geographical locations), unclear handwritten records, and a fear of privacy leakages (security and privacy concerns). In this regard, the researchers recommend digitalization for a centralized system where hospitals can store patient records and access data from the same system, with nationally unique card numbers for patient identification across the country.

5.2. The Current Electronic Medical Catalog System (eMCS) and Deficiencies

In these hospitals, eMCS is primarily used for efficient patient registration, advanced searching, appointment management, trace cards, and generating reports, but it does not store patients' health histories. Once a patient's record is identified in eMCS, their health history from paper dossiers is manually retrieved from shelves. As depicted in Fig.20., eMCS is designed to reduce duplication of records and card losses by ensuring one medical record number for each patient record. However, patients are registered with unique card numbers in each hospital, and they do not use the same card number across all hospitals, such as primary, general, and specialized hospitals. This system is isolated, i.e., not integrated or centralized. Still, patients' registration duplications persist, requiring the implementation of a unified national ID card to integrate patient records nationwide.

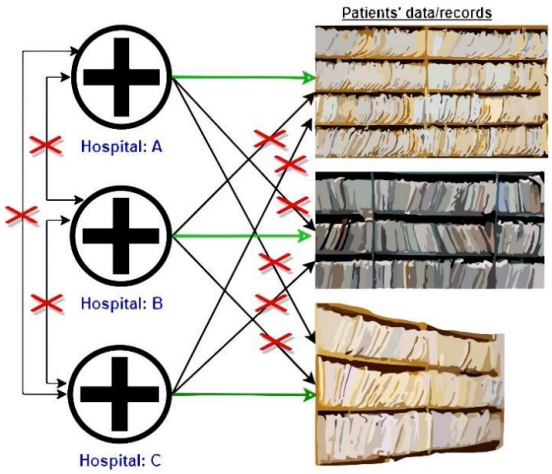

Fig.19. The conceptual model of existing paper-based methods (isolated data)

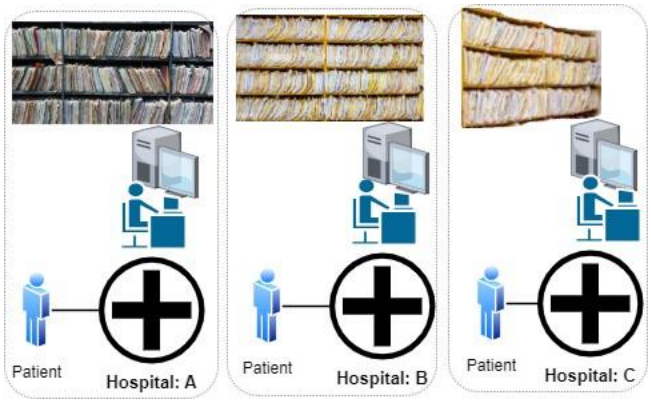

Fig.20. The conceptual model of existing eMCS

5.3. The Current District Health Information System 2 (DHiS2) and Deficiencies

DHiS2 is a web-based health information management system (HMIS) used in 80 low- and middle-income and 122 countries globally, including Ethiopia and other African nations like Burkina Faso, Ghana, Kenya, Tanzania, Uganda, and Zambia to facilitate data collection, processing, and analysis for health ministries' [37]. In Ethiopian hospitals, DHiS2 supports periodic reporting of disease statistics (i.e., mortality and morbidity), services like family planning, and key performance indicators (KPIs) at monthly, quarterly, biannual, and annual intervals. KPIs are defined at the MoH level and can be set at the regional and hospital levels. As depicted in Fig.21., DHiS2 allows online reporting to the MoH, accessible from anywhere with authorized access, but eMCS is hospital-specific and cannot be accessed remotely.

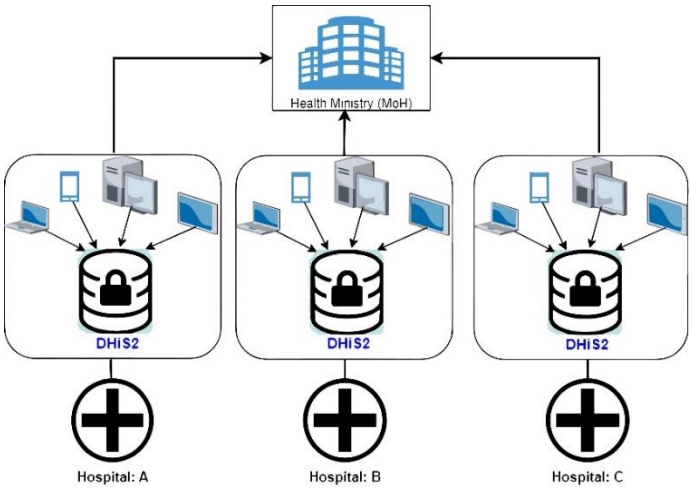

Fig.21. The conceptual model of existing DHiS2

The existence of multiple and varied systems in these hospitals shows the absence of an integrated and consolidated health data repository system at the national level. The study reveals challenges in Ethiopian hospitals for smart and green healthcare information services, such as the prevalence of disparate systems, limited access to healthcare services, remotely inaccessible patient histories, lack of a centralized system, storage scalability, in-house data center affordability, data ownership and control, data consolidation, data sharing, service collaboration, etc. Thus, the Ethiopian healthcare information system requires centralized and sustainable healthcare services delivery to enhance QoS however, none of the surveyed hospitals have implemented cloud services. Therefore, this study proposed a cloud-based contextualized model to address these challenges.

The Design of a Proposed Model

As illustrated in Fig.22., a cloud-based contextualized model is proposed for smart and sustainable healthcare information services for hospitals in general settings and Ethiopian hospitals in particular to address the identified challenges.

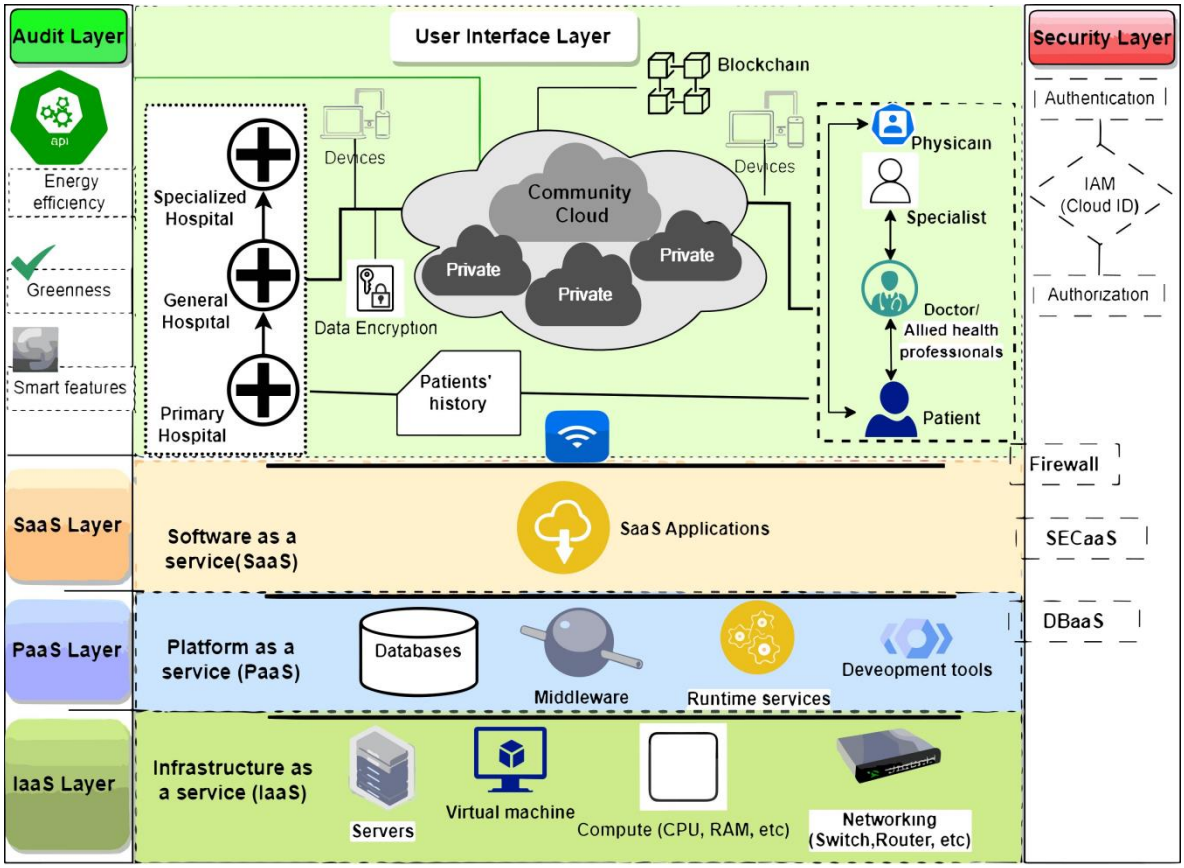

Fig.22. The proposed cloud-based contextualized model

The Model Description

This model is designed to enhance healthcare data/information access and service quality, focusing on smart and sustainable features of healthcare information systems. Cloud computing provides computing resources as a service [16,21]. Hence, the proposed model is delivered as a SaaS model within the community cloud deployment model. The model consists of six layers: the IaaS layer, the PaaS layer, the SaaS layer, the user interface layer, the security layer, and the audit layer.

- The ***IaaS layer***, the underlying infrastructure, provides computing infrastructures like computing, storage, and networking. The network is crucial for various tasks and activities, such as compute talks to storage and other computer-related tasks. These resources are scalable, cost-effective (costs depend on consumption), serve numerous users, and can be virtualized for enhanced flexibility. It provides scalable computing resources over the internet, allowing users to rent virtualized hardware on demand.
- The ***PaaS layer*** provides a computing platform with powerful tools and resources, such as operating systems, programming languages, databases, middleware, runtime services, and web servers, enabling quick and easy application development.

- The ***SaaS layer*** is a ready-to-use application that is accessible from any connected device over the Internet via a web browser or link, as long as a network connection is available, enabling hospitals (primary, general, and specialized) to access health care data from the same system at the national level.
- The ***User Interface layer*** offers an interface or dashboard for users, such as patients, doctors, specialists, nurses, and lab technicians, to interact with the system using multiple devices. Patients' histories are consolidated in a unified repository system, and all users, such as doctors, specialists, patients, physicians, etc., will be able to access all data from a single point of view via the cloud using multiple devices. Hospitals, primary, general, and specialized ones, access health data from a single location, and the patient's data will be encrypted while being shared with the cloud.
- The ***Security as a Service layer*** offers strong security filtration and measurements. The multitenant architecture of cloud applications poses significant data security issues. Several research studies have concluded that security, i.e., fear of cyber-security attacks, is the major issue that is hampering the potential growth of cloud computing. Despite numerous studies on security and privacy threats, current solutions lack the latest security solutions. Hence, this model incorporates an additional security layer, considering user authentication, authorization, Cloud ID, sensitive data encryption, firewalls, blockchain technology, and the cloud SECaaS option.
- The ***Audit layer*** is responsible for evaluating the energy efficiency, greenness, and smartness features of the proposed model.

User acceptance validation test

The proposed model underwent validation with a selected sample of users and stakeholders who participated in pre-research context analysis via survey and interview. Key parameters examined included security & privacy, storage capacity, on-demand scalability, data sharing, service collaboration, timely access, interoperability, data ownership & control, data consolidation, data recovery, greenness, smartness, in-house data center (DC) affordability and quality of service, common policy enforcement, and agility. Fig.23., illustrates responses from 48 participants (81.3% male, 18.8% female), comprising doctors (16.7%), HIT professionals (20.8%), nurses (16.7%), patients (10.4%), CEOs/managers (2.1%), allied health professionals (27.1%), and data entry clerks (6.3%).

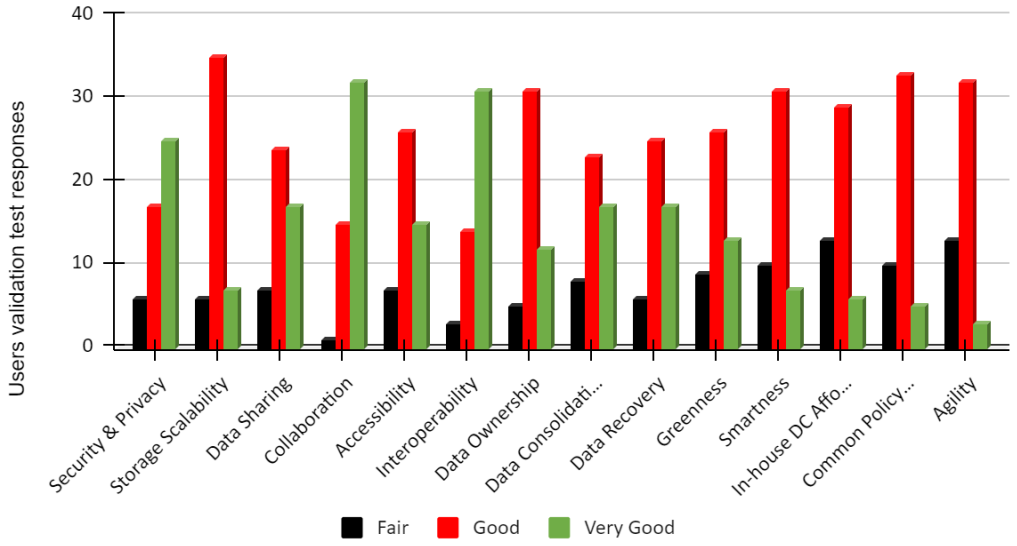

Fig.23. The proposed model's validation test

Fig.23., illustrates that 79% of respondents accepted the proposed model as good and promising for transforming health information systems towards the next generation. Specifically, security and privacy, service collaboration, and interoperability were accepted and rated as very good by 21%. The model's overall acceptability and usability were rated highly useful by 47.9%, moderately useful by 31.3%, and fairly useful by 20.8%. Consequently, it was concluded that the model should be developed and transformed into a functional prototype for validation in real system case scenarios.

Proposed Recommendations for Implementation of the Cloud-Based Healthcare Model:

Based on the research findings and the proposed model, the following recommendations are suggested for its implementation:

- Prioritize Security and Privacy: Implement robust security measures, including encryption, firewalls, and blockchain technology, to protect sensitive patient data from unauthorized access. Ensure compliance with relevant data privacy regulations and standards, such as the health insurance portability and accountability act (HIPAA) and general data protection regulation (GDPR).

- Adoptive Collaboration and Data Sharing: Establish clear guidelines and protocols for data sharing and collaboration among healthcare providers, ensuring seamless access to patient information across different hospitals. Promote interoperability between the proposed model and existing healthcare systems to facilitate data exchange and integration.
- Address Infrastructure Challenges: Invest in upgrading IT infrastructure to support the cloud-based model, including network connectivity, storage capacity, and computing power. Collaborate with technology providers to ensure the availability and affordability of cloud services in Ethiopia.
- Enhance User Training and Capacity Building: Provide comprehensive training to healthcare professionals, patients, and other stakeholders on how to effectively use the cloud-based platform and leverage its features. Address digital literacy gaps to ensure that all users can benefit from the technology.
- Develop a Robust Governance Framework: Establish clear governance policies and procedures to manage the cloud-based platform, including data ownership, access control, and decision-making processes. Appoint a responsible party to oversee the implementation and operation of the model.
- Ensure Sustainability and Scalability: Design the model to be scalable and adaptable to changing needs and technologies. Incorporate energy-efficient practices and technologies to reduce the environmental impact of the cloud-based platform.
- Monitor and Evaluate Performance: Continuously monitor the performance of the model, including its impact on healthcare service quality, efficiency, cost-effectiveness and service level agreements (SLAs). Collect feedback from users and stakeholders to identify areas for improvement and make necessary adjustments.

By implementing these recommendations, the proposed cloud-based model can help to improve healthcare delivery in Ethiopia by providing secure, accessible, and efficient data management solutions.

6. Conclusions

In conclusion, this research emphasizes the transformative prospects of the cloud in healthcare, particularly in Ethiopian public hospitals. Cloud infrastructure in healthcare consolidates data, fosters collaboration among professionals, enables efficient patient data storage and sharing across hospitals, and reduces redundancy, manual workloads, and interoperability issues as a new service delivery paradigm in the ICT sector, enhancing workplace flexibility and advancing medical discoveries. Centralized healthcare data repositories can significantly cut costs, eliminate tedious manual processes, and avoid redundant investigations for patients across multiple hospitals. This study examined 17 parameters of healthcare information systems in 11 selected public hospitals and rigorously analyzed them. Findings identified gaps in Ethiopia's healthcare information systems and proposed cloud computing solutions based on extensive literature, surveys, and related research. In Ethiopia, hospitals are the primary hubs for healthcare service providers; however, disparate, non-interoperable, non-integrated healthcare systems among hospitals, limited access, and remotely inaccessible patients' medical histories among hospitals hinder the standardization of smart and green healthcare information services, resulting in poor healthcare delivery. The study employed a mixed research design integrating exploratory and applied methods, using quantitative and qualitative approaches. Primary data collection involved surveys, interviews, and technical observations. We selected the hospitals using the purposive technique, with population sampling employing simple random and purposive quota sampling. A total of 103 participants (79.6% males, 20.4% females) provided responses, analyzed using Google Forms/Spreadsheets and IBM SPSS, and model design was facilitated with diagrams.net. The study reveals significant lagging in hospital integration of healthcare data and smart, green management systems for remote access and collaboration. Existing systems exhibit shortcomings in storage capacity, scalability, security, data sharing, collaboration, accessibility, interoperability, data ownership, data recovery capabilities, greenness, affordability of in-house data centers, reliability, quality of service, policy enforcement, and agility. Hospitals are notably behind in adopting advanced technology-enabled systems, like cloud-enabled systems and modern disaster recovery solutions. 90.3% of respondents opted for cloud-enabled data recovery and 85.4% favored centralized cloud-based healthcare services for hospitals. The challenges influencing cloud-based system adoption in hospitals include infrastructure shortages, cloud/IT knowledge gaps, lack of top management support, digital illiteracy, decision-makers' lack of innovativeness, and data security concerns. The study identified three existing systems in these hospitals: 1) paper-based methods; 2) eMCS; and 3) DHiS2. These varied systems reveal a lack of a unified nationwide healthcare data repository system. Additionally, none of these hospitals have implemented advanced technology-enabled systems like cloud services. Therefore, we proposed a cloud-based contextualized model comprising IaaS, PaaS, SaaS, User Interface, Security, and Audit layers, delivered as SaaS in a community cloud deployment. This model enhances healthcare services with instant access, centralized data management, reduced redundancy, and evidence-based medical services. The suggested model is considered a significant knowledge contribution to healthcare data and information management system transformation, based on comprehensive feedback from potential users and stakeholders. Future research should re-validate this model using an operational prototype, emphasizing interoperability, storage capacity, green energy efficiency, and smart features through simulations or real-world demonstrations.

Ethical Considerations

Given the sensitive nature of healthcare data and the potential impact of the proposed cloud-based model on the Ethiopian healthcare system, several ethical considerations were considered and proposed for future implementations:

Data Privacy and Security

- Informed consent: Ensure that all participants provide informed consent, clearly understanding the purpose of the research, the use of their data, and the potential risks and benefits.
- Data anonymization: Implement robust measures to anonymize and protect the privacy of patient data. This includes techniques such as data masking, and encryption.
- Data security: Establish strong security protocols to prevent unauthorized access, breaches, and data loss. Regularly update security measures and conduct vulnerability assessments.

Ethical Use of Data

- Purpose-bound use: Ensure that the data is used solely for the research purposes outlined in the study protocol and is not shared or used for other purposes without explicit consent.
- Data quality: Implement quality control measures to ensure the accuracy, completeness, and consistency of the data collected.
- Minimize harms: Identify and mitigate potential risks to participants, such as privacy breaches, psychological distress, or negative impacts on their healthcare.

Cultural Sensitivity

- Contextualization: Tailor the research methods and interventions to the cultural and social context of Ethiopia, respecting local customs, values, and beliefs.
- Language: Ensure that communication with participants is conducted in a language they understand and that culturally sensitive language is used. Other supports were provided to explain in the localized language.

Collaboration and Transparency

- Stakeholder involvement: Involve relevant stakeholders, including healthcare providers, patients, policymakers, and community representatives, in the research process to ensure that their needs and perspectives are considered.
- Transparency: Maintained transparency throughout the research process, from study design to dissemination of findings, to build trust and credibility.

By addressing these ethical considerations, the researchers can ensure that the study is conducted responsibly and ethically, contributing to the advancement of healthcare in Ethiopia while protecting the rights and well-being of participants.

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