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Investigating the Use and Sustainable Adoption of Digital Health Tools for Public Health Emergencies in Primary Healthcare Centres in Northern Nigeria

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Abstract

There is a dearth of information on factors affecting the use and sustainable adoption of digital health tools by primary healthcare workers. Improved digital health frameworks require more field evidence. We assessed factors affecting the use and sustainable adoption of the digital health tools in primary healthcare centres in Northern Nigeria. A cross-sectional facility-based study was conducted among PHC staff in Abuja, Niger and Nasarawa States. Purposive and simple random sampling were used to collect data from healthcare practitioners using a pretested, semi-structured questionnaire. The study used a Chi-square test for bivariate analysis and Structural Equation Modeling (SEM) for complex relationships between variables. A p-value of less than 0.05 indicated statistical significance and a 95% confidence level. The results showed that age ($\chi^2 = 203.64$, $p < 0.001$), sex ($\chi^2 = 136.92$, $p < 0.001$), marital status ($\chi^2 = 44.64$, $p < 0.001$), education level ($\chi^2 = 8.37$, $p = 0.007$), rate of IT knowledge ($\chi^2 = 228.22$, $p < 0.001$), profession ($\chi^2 = 151.55$, $p < 0.001$), geographical location ($\chi^2 = 212.79$, $p < 0.001$) were factors that influenced adoption. There is a significant relationship between perceived usefulness, relative advantage, awareness, data security and the adoption of digital health tools ($\chi^2 = 39.57$, $p < 0.001$), ($\chi^2 = 123.55$, $p < 0.001$), ($\chi^2 = 102.29$, $p < 0.001$), ($\chi^2 = 48.26$, $p < 0.001$) respectively. This study found enabling and hindering elements affecting digital health systems. To promote use and sustainable adoption, all stakeholders must actively overcome challenges.

Keywords: *Adoption, Digital Health, Nigeria, Primary Healthcare.*

Introduction

The 2030 United Nations Sustainable Development Goals (SDGs) agenda serves as a blueprint for attaining improved health for all, therefore indicating a more sustainable future for worldwide population [1]. Target 3.8 of SDG 3 states, "Achieve universal health coverage, including financial risk protection, access to quality essential health-care services and access to safe, effective, quality and affordable essential medicines and vaccines for all" [2]. On the one hand, one way to make progress towards achieving universal health coverage (UHC) is through health systems strengthening and sustainable development, and this can be achieved through evidence informed decision-making via the use of innovative digital interventions in accordance with Target 3.9d of SDG 3 to "Strengthen the capacity of all countries, in particular developing countries, for early warning, risk reduction and management of national and global health risks" [1]. On the other hand, UHC contributes to the SDGs by promoting global public health security and it does so by increasing the comprehensiveness and resilience of health systems to respond to health threats that spread within as well as across national borders [3, 4, 5]. Currently, Africa has achieved only 5%–25% UHC coverage [6]. The WHO has developed a Global Strategy on

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Digital Health for the period 2020-2025, with the goal of promoting healthy living and wellbeing for everyone, everywhere, and at all ages [7].

Behind good health for every person is a health system reliant on information that is shared and used in a timely manner. The 75th World Health Assembly (WHA) has prioritized its drive towards UHC, and it has also renewed its commitment to strengthen the systems and tools for epidemic and pandemic preparedness and response at all levels [8]. Health information and service delivery systems facilitate the assessment and evaluation of health system performance and advancements towards UHC. Hence, it is imperative to enhance these two functions in order to attain universal health and optimize health outcomes. Employing contextual and data-driven evidence to bolster local health systems and advocate for policies that promote UHC is critical.

It is obvious that the health sector is becoming a fast-changing field with new technologies emerging with time. And the health workforce must be duly empowered in the digital health revolution which is fast becoming a norm and transforming the culture of traditional healthcare where disruptive innovation of any form of technology is causing radical changes in any existing public health system; coupled with the perceived reluctance of healthcare stakeholders in healthcare settings to change [9, 10].

The application of digital technologies to enhance health systems, health services, and health outcomes is referred to as digital health. It possesses the capacity to facilitate the achievement of universal health coverage, particularly in settings with limited resources [11]. Digital health is a dynamic domain within the health sector that has the potential to aid in achieving health objectives by providing timely, accurate, and comprehensive health information to inform decision-making and service provision.

Reference [12] conducted a scoping review which identified 983 digital health tools that have been implemented in sub-Saharan Africa to enhance health systems during the previous decade. However, the review also identified deficiencies in the region regarding investments in digital health, including coordination, integration, scalability, sustainability, and equitable distribution. Digital health interventions in Africa encounter several obstacles, including substandard infrastructure, insufficient digital literacy, inadequate policies and regulations, concerns regarding ethics and privacy, and a scarcity of evidence regarding their efficacy and cost-effectiveness [13].

Nevertheless, the implementation of digital health in Nigeria encounters numerous obstacles, including inadequate coordination of pilot initiatives, decrepit healthcare systems, insufficient awareness and understanding, substandard infrastructure, and non-compatibility [11, 12, 14]. To enhance healthcare services, the Federal government of Nigeria is working to enhance digital health technology applications. It is evident that Nigeria is currently grappling with fragmented digital health deployment endeavors. In order to effectively bridge this existing void, this research posits contextual, and practical strategies that delineates the intricate processes and factors influencing the use and sustainable adoption of digital health tools, especially in Northern Nigeria.

Primary Healthcare is the foundation of universal health coverage, and for Africa to achieve universal health coverage, it is crucial to introduce new and innovative approaches. Africa's grassroots use of digital health technologies is low, which hinders healthcare delivery. And access, quality, efficiency, and resilience of PHC in Africa, particularly for hard-to-reach populations and low-resource settings, could be enhanced through the use of digital health [15].

Given the above, understanding the landscapes, challenges, and barriers to digital

health use and adoption in primary care is critical. Yet, there is a dearth of data to assist evidence-based decision making about complete adoption of digital health services across the continent while taking into account country-specific factors [15]. So, primary healthcare providers across the continent must be assessed for their knowledge, abilities, attitude, practise, and preparedness to use digital health in service delivery. Despite the Northern region of Nigeria exhibiting favorable attitudes and perceptions towards digital health, health workers exhibited a pervasive lack of knowledge in this area [16].

In sub-Saharan Africa, digital health tools have not been widely adopted or implemented, according to a review of electronic health records (EHR) adoption in Africa [17].

Moreover, the community structure is mostly under tapped. Although communities are generally the focus of public health interventions, and they are rarely considered a valuable resource [18]. However, healthcare professionals voiced their concerns about not being sufficiently involved in the planning process of digital health interventions [19, 20]. We need to figure out how to do this, so that our programmes can more effectively involve potential users and reach the people who could benefit from them.

Large-scale, high-priority health care programmes need to be evaluated more thoroughly. It was at Alma-Ata that primary health care was established as a cornerstone tactic for enhancing people's health all over the world with greater understanding of the value of primary healthcare in international health and its potential to play an even larger role in enhancing population health [21], [22].

Yet, by of the end of 2021, it was estimated that almost 15 million people worldwide had died as a direct result of COVID-19. Several crucial health services were interrupted as global health systems were strained to their limits, creating serious health risks and damaging years of progress in the battle against other fatal diseases [23] The effective utilization and management of digital health epidemic tools is a vital public health skill to obtain and disseminate reliable, timely information [24]. To detect communicable diseases, we need a good surveillance system. If we don't detect these developing communicable diseases, we could have a huge outbreak and be unprepared to deal with its effects on the community [25].

Without a competent health care workforce, universal health coverage will not be realized, and without healthcare providers, health care systems would collapse. Inadequate skills are often cited as an impediment to effective ICT use by health and care workers, who continue to be at the forefront of epidemic or pandemic response [26], [27].

Health care delivery is being radically altered by a number of factors, including but not limited to globalization, deregulation, and technology advancement.

In instances where the efficacy of digital health systems has been demonstrated, the realization of their full potential in enhancing public health is contingent upon the willingness of individuals to embrace, place confidence in, and actively participate with these technological advancements [7]. Increased demands and issues with health resources may arise; hence, the system is designed to offer support to individuals through a universal coverage approach. This can be a serious issue in community settings. Northern Nigeria serves as an illustration of this, as internally displaced persons due to conflict and compromised security issues have high service needs but most of the nation's available health care services are heavily prioritized and competitive, especially at the community levels. It's immediately crucial that we gather data so that we can track the changing demands of people, and they will undoubtedly evolve as an emergency progresses. Nigeria may go forward by adopting and deploying a robust and custom-built digital health infrastructure that meets our

particular demands [28] also recounted that on November 20-30, 2019, Nigeria held a digital health capacity development workshop in Abuja-FCT, Nigeria and acros the country's six geo-political zones to examine these issues and provide solutions for the quick, sustainable, scalable, and cost-effective deployment of digital health in Nigeria. The digital health capacity building workshop provided a good platform to discuss stable and cost-effective digital health ideas that could scale to improve health service delivery in Nigeria. The workshop concluded that while digital health technologies might boost Nigerian health systems for UHC and the health SDGs, donor-driven pilot initiatives should then be replaced by resilient, sustainable, cost-effective, and nationally owned projects.

Too frequently, technical features of community-based digital interventions have received more attention than the approaches and support networks required to make them effective on-the-ground. It is obvious that new programmes and strategies are required in places where rates of public health emergencies and child mortality are still high, health systems are underdeveloped, and resources are scarce.

Epidemic, gross violations of human rights, economic instability, and war are just a few of the ever-evolving threats we face today. The threat posed by these factors fluctuates sporadically over time, and therefore, should be monitored in order to identify the tipping point when the risk becomes significant to trigger public health actions.

Primary healthcare professionals conveyed their concerns about not being sufficiently involved in the planning process coupled with the absence of a contextual and comprehensive national policy and plans for e-health, and down-sized implementation at the local levels, which also depends on the active participation of all stakeholders in the planning and implementation process [20]. In addition, there is a lack of information regarding the factors that influence the utilization and long-term adoption of digital health tools in primary healthcare settings in a sustainable manner, where they are intended to be utilized by healthcare professionals. Therefore, this research aimed at examining the factors that influence the utilization and sustainable adoption of digital health tools. It also aimed to provide practical suggestions for the effective and sustainable adoption of these tools in Nigeria. The research will contribute to the existing body of knowledge by identifying key areas where the findings can be beneficial to healthcare policymakers in Nigeria and other developing nations with similar settings. This can help individuals, and the government understand their areas of focus and weaknesses while planning for the use and sustainable adoption of digital health tools.

Ultimately, this will result in enhanced epidemic preparedness and response, at the zonal, State, LGA, PHC, and community levels settings.

This investigation is primary research that offers a more comprehensive understanding of the enablers and barriers to the utilization of digital health. This research can be highly beneficial in areas with weak health systems and high rates of child mortality, as earlier depicted in the Northern Nigeria setting.

Challenges, with respect to insecurity issues widespread in the Northcentral part of Nigeria affected on-the-ground logistics. For the purpose of gaining a more in-depth comprehension of the cultural and contextual factors that have an effect on the implementation and utilization of digital health tools, future research should aim to investigate the potential of qualitative research methods. This will allow for a more comprehensive understanding of the implementation and utilization of digital health tools in a variety of settings. Furthermore, the scope of our research was limited to Nigeria; consequently, its conclusions may not be applicable to other populations or sub-Saharan Africa.

Materials and Methods

Research Design

A cross-sectional facility-based study was conducted among PHC personnel drawn from Abuja (Federal Capital Territory), Niger and Nasarawa States. We utilized a multistage sampling technique, incorporating both purposive sampling and simple random sampling, in order to meticulously select a sample size that would aptly represent the entire population under study.

Study Area

This study was conducted in three States, namely, Nasarawa, Niger, and FCT-Abuja of the Northcentral region of Nigeria. This region exhibits a high degree of volatility and is particularly vulnerable to incursions by non-state armed groups as well as the emergence of conflicts along sectarian lines [29]

Study Population

The study's sample consisted of doctors/nurses, disease surveillance and notification officers (DSNOs), monitoring and evaluation Officers (M&EOs), record officers, community health extension workers (CHEWs), and community health workers (CHWs) within the State Primary Healthcare Development Agency (SPHCDA). These individuals are based within the jurisdiction of the SPHCDA located in the three States (Abuja-Federal Capital Territory, Niger, and Nasarawa) in the Northcentral region of Nigeria.

Sampling Technique

Stage 1: One geopolitical zone (Northcentral) was purposively selected from the six geopolitical zones in Nigeria considering the level of security risks, particularly armed insurgency.

Stage 2: Three States, namely, Abuja, Niger and Nasarawa States were selected from the seven States in the Northcentral geopolitical zone through a simple random sampling by balloting.

Stage 3: Two local government areas (LGAs) per senatorial district in each of the chosen State with the highest number of accessible PHCs where digital health tools for public health emergencies have been deployed and implemented were randomly selected by balloting, with the number of PHCs per LGA as the sampling frame. This process was repeated until the required sample size was obtained from each LGA.

Stage 4: A purposive sampling was used to select accessible PHCs where digital health tools are implemented from the selected LGAs.

Inclusion Criteria

Recruitment for the study was limited to healthcare professionals under the jurisdiction of the SPHCDA, who are 18 years and above and have given their consent to participate.

Study Instruments

The collection of quantitative data was conducted using a pretested, semi-structured questionnaire. The questionnaire was adapted in accordance with prior research [20]. The questionnaire constituted socio-demographic characteristics and assessed the participants' proficiency and implementation of digital health.

Theoretical Basis

The utilization of the Technology Acceptance Model (TAM) to forecast and elucidate end-user responses to health IT is among the most noteworthy [30].

The initial TAM constructs have undergone modifications and expansions through extensive research, involving the inclusion of additional variables. These variables can largely be categorized into two main groups: (1) perceived variables and (2) external variables [31].

These supplementary independent variables augment the predictive capability of the TAM. The theoretical model under consideration is a

straightforward flowchart that illustrates the correlation between several independent variables—perceived usefulness, attitude towards digital health, ease of use, awareness, risk, data security concerns, infrastructure, gender, age, experience, relative advantage, and critical success factors—and the dependent variable of intention to use and sustainably adopt e-health technology. The theoretical framework was the primary model for this investigation.

Perceived usefulness of digital health tools by healthcare workers, ease of use, relative advantage, awareness, risk, data security, infrastructure, critical success factors, staff IT experience, information sharing, and technical infrastructure were assessed.

Data Collection Methods and Procedure

The study data were collected from July 2024 to August 2024. Ethical clearance was obtained from the National Health Research Ethics Committee of Nigeria (NHREC), with the NHREC approval number: NHREC/01/01/2007-28/06/2024. From each state, research assistants were recruited and provided with training on the data collection instrument following the translation of the questionnaire into ODK (Open Data Kit). For effective data collection, each research assistant was equipped with an Android device with the ODK installed. The digital health survey instrument was validated using Cronbach's alpha. In general, the Cronbach alpha value range of the e-value scale demonstrated a satisfactory validation estimate of 0.93. In addition, the Cronbach alpha value was within a comparable range when an item is deleted.

The instrument's reliability was determined by utilizing a subset of the sample size, specifically 10% of it, and the questionnaire was administered to a population that is similar to the sample population in another State. Necessary adjustments were made after the pre-test.

Sample Size Determination

The sample size for the quantitative sample was calculated using the standard formula for estimating a single population proportion:

$$n = \frac{\left(Z_{1-\frac{\alpha}{2}}\right)^2 P(1-P)}{d^2}.$$

$Z_{1-\frac{\alpha}{2}}$= Standard normal variate (at 5% type 1 error ($\hat{P}$<0.05) is 1.96)

P = Expected proportion in population based on previous studies implementing digital health=27.3% [32]

d = Absolute error or precision=0.05

$$n = \frac{(1.96)^2 0.273 \times (0.727)}{0.05^2} = 305.$$

$$n = 113\ per\ group.$$

Non-response rate: Individuals may decline to participate while they have been selected through random methods.

By accounting for a 10% non-response rate:

Final sample size=Effective sample size/1-NR anticipated

$$n = \frac{305}{0.9} = 339.$$

Data Management and Analysis

Dependent Variable

The dependent variable or outcome includes "intent to use digital health tools" and "intent to adopt digital health tools."

Independent Variables

The independent variables include perceived usefulness, ease of use, awareness, risk, data security concerns, IT infrastructure, critical success factors, relative advantage, experience, age, and gender.

Analysis Methods/Data Collection Tools

The data underwent a thorough examination to verify their comprehensiveness and identify any error, assigned specific codes, and then entered into Statistical Package for the Social Sciences (SPSS) version 25.0. Data analyses involved the utilization of both descriptive and

inferential statistical methods. A Chi-square test was employed for the bivariate analysis. Structural Equation Modeling (SEM), a multi-variate technique was used to estimate and test complex relationships between the dependent and independent variables, as well as to show how different variables influence each other.

In this research, statistical significance was determined by a p-value of less than 0.05, indicating a 95% confidence level.

Ethical Considerations

Ethical clearance was obtained from the National Health Research Ethics Committee of Nigeria (NHREC) with the following approval number: NHREC/01/01/2007-28/06/2024. The study participants provided informed verbal and documented consents prior to the administration of the questionnaire. The objectives and significance of the study were effectively communicated to the participants. The information that was gathered was handled with the utmost confidentiality. In order to guarantee that the consenting participants had a comprehensive understanding of the research study's objectives, processes, and inquiries, all protocols utilized, including data collection procedures, were communicated to them in the language that was most easily comprehensible to them. Consequently, the questionnaire was composed in the English language, which is the language that is comprehensible to the participants of the study area. No individual names were recorded, and no publication or report resulting from this research will include any name or identifier. Code numbers were designated to all information gathered for this study.

Results

Table 1. Descriptive Statistics of the Respondents' Characteristics

Variable	Frequency	Percentage
Age		
21-30	57	18.4
31 – 40	105	34.0
41 – 50	101	32.7
51 Above	46	14.9
Sex		
Male	195	63.1
Female	114	36.9
Marital Status		
Single	63	20.4
Married	243	78.6
Separated/Divorced	3	1.0
Level Education		
Primary/secondary	4	1.3
Tertiary	305	98.7
Rate of IT Knowledge		
Fairly	109	35.3
Minimum	120	38.8
Maximum	77	24.9
None	3	1.0
Profession		
Doctor/Nurse	90	29.1
CHEW/DSNO	82	26.5

Record officers	137	44.3
PHC Location		
Rural	168	54.4
Semi-Urban	88	28.5
Urban	53	17.2

The majority of participants were aged between 31-40 years, totaling 105 (34.0%), and most health practitioners were male, accounting for 195 (63.1%). In addition, a significant number of participants were married, with 243 (78.6%), and 305 (98.7%) had attained at least tertiary education respectively. Furthermore, 109 (35.3%) demonstrated minimum knowledge of IT. Most PHCs were located in rural areas, with 168 (54.4%), and the majority of these health centers utilized one digital health tool.

In total, approximately 11 digital health tools have been utilized within the primary healthcare over the last five years. The primary tools utilized during this timeframe include: ODK 77 (24.9%), succeeded by OpenLMIS 70 (22.7%), then survey CTO 56 (18.1%), E-health card 34 (11.0%), NIPDS 29 (9.4%) and SORMAS 9 (2.9%). The tool that saw the least usage was RI SMS, accounting for only 0.6%.

Table 2. Socio-Demographic Factors that Influences The Adoption of Digital Health Tools

Variable	Logistics & Supply Chain Management n (%)	Disease Surveillance & Response Systems n (%)	Data Collection & Health Information Management n (%)	Chi-square	p-value
Age					
21-30	0 (0.0)	9 (22.0)	48 (25.5)	203.64	<0.001
31 – 40	10 (12.5)	32 (78.0)	63 (33.5)		
41 – 50	24 (30.0)	0 (0.0)	77 (41.0)		
51 Above	46 (57.5)	0 (0.0)	0 (0.0)		
Sex					
Male	10 (12.5)	41 (100.0)	144 (76.6)	136.92	<0.001
Female	70 (87.5)	0 (0.0)	44 (23.4)		
Marital Status					
Single	0 (0.0)	9 (22.0)	54 (27.7)	44.64	<0.001
Married	77 (96.3)	32 (78.0)	134 (71.3)		
Separated/Divorced	3 (3.8)	0 (0.0)	0 (0.0)		
Level of Education					
Primary/secondary	4 (5.0)	0 (0.0)	0 (0.0)	8.37	0.007
Tertiary	76 (95.0)	41 (100.0)	188 (100.0)		
Rate of IT Knowledge					
None	3 (3.8)	0 (0.0)	0 (0.0)	228.22	<0.001
Fairly	0 (0.0)	11 (26.8)	98 (52.1)		
Minimum	10 (12.5)	30 (73.2)	80 (42.6)		
Maximum	67 (83.8)	0 (0.0)	10 (5.3)		
Profession					

Doctor/Nurse	0 (0.0)	9 (22.0)	81 (43.1)	151.55	<0.001
CHEW/DSNO	10 (12.5)	32 (78.0)	40 (21.3)		
Record officers	70 (87.5)	0 (0.0)	67 (35.6)		
PHC location					
Rural	10 (12.5)	41 (100.0)	117 (62.2)	212.79	<0.001
Semi-Urban	17 (21.3)	0 (0.0)	71 (37.8)		
Urban	53 (66.3)	0 (0.0)	0 (0.0)		

Table 2 outlines the socio-demographic factors that affect the adoption of digital health tools, analyzed within three domains: Logistics & Supply Chain Management, Disease Surveillance & Response Systems, and Data Collection, analytics, visualization & use.

The analysis revealed a highly significant relationship between age and adoption across all three domains ($\chi^2 = 203.64$, $p < 0.001$). Within the Logistics & Supply Chain Management field, those aged 51 and older comprised the majority at 57.5%, whereas younger age groups, specifically those between 21 and 30, were not represented. Conversely, the Disease Surveillance & Response Systems saw a predominant adoption rate among respondents aged 31-40, reaching 78.0%. The tools for Data Collection & Health Information Management were mainly utilized by respondents in the 41-50 age range, accounting for 41.0% of users. The Disease Surveillance & Response Systems were entirely dominated by males (100.0%), who also constituted the majority of users in Data Collection & Health Information Management (76.6%).

In addition, sex had a significant effect on the adoption of digital health tools ($\chi^2 = 136.92$, $p < 0.001$). Individuals in marital relationships were the main users of all three systems, especially in Logistics & Supply Chain Management (96.3%) and Data Collection & Health Information Management (71.3%) ($\chi^2 = 44.64$, $p < 0.001$). The level of education emerged as a significant factor affecting adoption ($\chi^2 = 8.37$, $p = 0.007$). Those with tertiary education demonstrated nearly complete adoption in all areas, achieving 100% adoption in both Disease Surveillance & Response Systems and Data Collection & Health Information Management, along with 95.0% adoption in Logistics & Supply Chain Management. The respondents possessing the highest level of IT expertise were the primary adopters of Logistics & Supply Chain Management at 83.8%, whereas those with the least knowledge predominantly engaged in Disease surveillance and response, which was statistically significant ($\chi^2 = 228.22$, $p < 0.001$). The role of profession played a crucial part in influencing the adoption of digital health tools ($\chi^2 = 151.55$, $p < 0.001$). Record officers mainly utilized Logistics & Supply Chain Management (87.5%), whereas Disease Surveillance & Response Systems were chiefly adopted by CHEW/DSNO professionals (78.0%). Healthcare professionals showed a greater tendency towards utilizing Data Collection & Health Information Management (43.1%). Rural primary health centers were the leading implementers of Disease Surveillance & Response Systems (100.0%), whereas semi-urban regions showed a significant adoption of Data Collection & Health Information Management (37.8%). Urban centers showed a significant representation in the adoption of Logistics & Supply Chain Management, with a percentage of 66.3% and $p < 0.001$.

Table 3. Assessing the Relationship Between Responses From The Digital Health Survey and Digital Health Tools

Variable	Logistics & Supply Chain Management n (%)	Disease Surveillance & Response Systems n (%)	Data Collection & Health Information Management n (%)	Chi-square	p-value
Perceived Usefulness					
Not useful	13 (16.3)	28 (68.3)	98 (52.1)	39.57	<0.001
Useful	67 (83.8)	13 (31.7)	90 (47.9)		
Ease of use					
Not easy	12 (15.0)	13 (31.7)	98 (52.1)	33.57	<0.001
Easy to use	68 (85.0)	28 (68.3)	90 (47.9)		
Relative Advantage					
Not advantageous	41 (51.2)	0 (0.0)	0 (0.0)	123.55	<0.001
Advantageous	39 (48.8)	41 (100.0)	188 (100.0)		
Awareness					
Not aware	50 (62.5)	5 (12.2)	10 (5.3)	102.29	<0.001
Aware	30 (37.5)	36 (87.8)	178 (94.7)		
Risk					
High risk	0 (0.0)	9 (22.0)	55 (29.3)	40.71	<0.001
Low risk	80 (100.0)	32 (78.0)	133 (70.7)		
Data Security					
No data security	0 (0.0)	9 (22.0)	63 (33.5)	48.26	<0.001
Data security is available.	80 (100.0)	32 (78.0)	125 (66.5)		
Infrastructure					
Poor infrastructure	10 (12.5)	14 (34.1)	98 (52.1)	40.61	<0.001
Good infrastructure	70 (87.5)	27 (65.9)	90 (47.9)		
Critical Success					
Not successful	0 (0.0)	9 (22.0)	25 (13.3)	20.48	<0.001
Successful	80 (100.0)	32 (78.0)	163 (86.7)		
Staff IT					
Low experience	10 (12.5)	14 (34.1)	98 (52.1)	40.61	<0.001
High experience	70 (87.5)	27 (65.9)	90 (47.9)		
Information Sharing					
Does not enhance information sharing	50 (38.5)	32 (78.0)	48 (25.5)	57.34	<0.001
Enhance information sharing	30 (37.5)	9 (22.0)	140 (74.5)		
Technical Infrastructure					
Not Available	0 (0.0)	9 (22.0)	38 (20.2)	27.42	<0.001
Available	80 (100.0)	32 (78.0)	150 9.8)		

Table 3 shows the relationships between the digital health survey responses and the adoption of digital health tools.

There was a significant relationship between perceived usefulness and the adoption of digital health tools ($\chi^2 = 39.57$, $p < 0.001$). Most respondents found digital health tools useful for Logistics & Supply Chain Management (83.8%), but a smaller proportion (31.7%) their usefulness in Disease Surveillance & Response Systems. Also, awareness emerged as a significant factor ($\chi^2 = 102.29$, $p < 0.001$). A greater proportion of respondents were aware of the tools for Data Collection & Health Information Management (94.7%) compared to Logistics & Supply Chain Management (37.5%). In a similar vein, the perception of relative advantage strongly influenced adoption ($\chi^2 = 123.55$, $p < 0.001$). All respondents found digital health tools advantageous for Disease Surveillance & Response Systems (100%), while only 48.8% perceived them as advantageous for Logistics & Supply Chain Management. Moreover, the significance of data security was evident, and hence, considered an important factor ($\chi^2 = 48.26$, $p < 0.001$). All respondents reported data security was available for Logistics & Supply Chain Management (100%) in contrast to Disease Surveillance & Response Systems (78%).

Table 4. Association between the Digital Health Tools Domains and Adoption of Digital Health Tools

Independent variables	Dependent variables Digital health tools in used	Estimate	p-value
Perceived Usefulness	Disease Surveillance & Response Systems	.032	0.012
Perceived Usefulness	Data Collection & Health Information Management	-.054	<0.001
Perceived Usefulness	Logistics & Supply Chain Management	.021	0.005
Ease of Use	Disease Surveillance & Response Systems	.199	<0.001
Ease of Use	Data Collection & Health Information Management	-.129	<0.001
Ease of Use	Logistics & Supply Chain Management	-.051	<0.001
Awareness	Disease Surveillance & Response Systems	.000	0.988
Awareness	Data Collection & Health Information Management	.039	0.018
Awareness	Logistics & Supply Chain Management	-.022	<0.002
Risk	Disease Surveillance & Response Systems	.184	<0.001
Risk	Data Collection & Health Information Management	-.151	<0.001
Risk	Logistics & Supply Chain Management	-.033	<0.001
Data security	Disease Surveillance & Response Systems	.347	<0.001
Data security	Data Collection & Health Information Management	.709	<0.001
Data security	Logistics & Supply Chain Management	-.690	<0.001
Relative Advantage	Disease Surveillance & Response Systems	.209	<0.001
Relative Advantage	Data Collection & Health Information Management	.000	0.977
Relative Advantage	Logistics & Supply Chain Management	-.120	<0.001
Infrastructure	Disease Surveillance & Response Systems	-.694	<0.001
Infrastructure	Data Collection & Health Information Management	-.210	<0.001
Infrastructure	Logistics & Supply Chain Management	.550	<0.001
Critical Success	Disease Surveillance & Response Systems	-.070	<0.001
Critical Success	Data Collection & Health Information Management	-.108	<0.001
Critical Success	Logistics & Supply Chain Management	.107	<0.001
Staff IT Experience	Disease Surveillance & Response Systems	.370	<0.001
Staff IT Experience	Data Collection & Health Information Management	.402	<0.001
Staff IT Experience	Logistics & Supply Chain Management	-.226	<0.001
Information Sharing	Disease Surveillance & Response Systems	-.191	<0.001

Information Sharing	Data Collection & Health Information Management	.196	<0.001
Information Sharing	Logistics & Supply Chain Management	-.001	0.877
Technical Infrastructure	Disease Surveillance & Response Systems	-.229	<0.001
Technical Infrastructure	Data Collection & Health Information Management	-.336	<0.001
Technical Infrastructure	Logistics & Supply Chain Management	.351	<0.001

Table 4 presents the relationship between digital health tools and their usage across various domains of the digital health survey.

Perceived Usefulness was positively associated with Disease Surveillance & Response Systems (Estimate = 0.032, p = 0.012), indicating that higher perceived usefulness leads to greater utilization of these systems. Similarly, for Logistics & Supply Chain Management, a slight positive relationship was observed (Estimate = 0.021, p = 0.005).

Ease of Use demonstrated a strong positive relationship with Disease Surveillance & Response Systems (Estimate = 0.199, p < 0.001), emphasizing the importance of ease of use in adopting these systems. Conversely, there was a negative relationship with Data Collection & Health Information Management (Estimate = -0.129, p < 0.001) and Logistics & Supply Chain Management (Estimate = -0.051, p < 0.001), showing that simpler systems were less likely to be used in these domains.

Awareness had no significant association with Disease Surveillance & Response Systems (Estimate = 0.000, p = 0.988), but it was positively correlated with Data Collection & Health Information Management (Estimate = 0.039, p = 0.018) and negatively associated with Logistics & Supply Chain Management (Estimate = -0.022, p = 0.002), suggesting that increased awareness may lead to higher usage of data collection tools but decreasing the utilization of logistics & supply management tools.

Risk perception was positively associated with Disease Surveillance & Response Systems (Estimate = 0.184, p < 0.001), while negative associations were observed for Data Collection & Health Information Management (Estimate = -0.151, p < 0.001) and Logistics & Supply Chain Management (Estimate = -0.033, p < 0.001).

Data Security was a strong predictor of increased usage for Disease Surveillance & Response Systems (Estimate = 0.347, p < 0.001) and Data Collection & Health Information Management (Estimate = 0.709, p < 0.001), although a negative relationship was observed with Logistics & Supply Chain Management (Estimate = -0.690, p < 0.001).

Relative Advantage was positively associated with Disease Surveillance & Response Systems (Estimate = 0.209, p < 0.001), but it had no significant association with Data Collection & Health Information Management (Estimate = 0.000, p = 0.977). A negative relationship was found for Logistics & Supply Chain Management (Estimate = -0.120, p < 0.001).

Infrastructure emerged as a key barrier, showing a strong negative association with Disease Surveillance & Response Systems (Estimate = -0.694, p < 0.001) and Data Collection & Health Information Management (Estimate = -0.210, p < 0.001), while it was positively associated with Logistics & Supply Chain Management (Estimate = 0.550, p < 0.001).

Critical Success Factors were negatively associated with both Disease Surveillance & Response Systems (Estimate = -0.070, p < 0.001) and Data Collection & Health Information Management (Estimate = -0.108, p

< 0.001), but they were positively related to Logistics & Supply Chain Management (Estimate = 0.107, p < 0.001).

Staff IT Experience had a strong positive association with Disease Surveillance & Response Systems (Estimate = 0.370, p < 0.001) and Data Collection & Health Information Management (Estimate = 0.402, p < 0.001), but a negative association with Logistics & Supply Chain Management (Estimate = -0.226, p < 0.001).

Information Sharing was negatively associated with Disease Surveillance & Response Systems (Estimate = -0.191, p < 0.001) but positively related to Data Collection & Health Information Management (Estimate = 0.196, p < 0.001), with no significant association observed for Logistics & Supply Chain Management (Estimate = -0.001, p = 0.877).

Finally, Technical Infrastructure was negatively associated with Disease Surveillance & Response Systems (Estimate = -0.229, p < 0.001) and Data Collection & Health Information Management (Estimate = -0.336, p < 0.001), but it was positively associated with Logistics & Supply Chain Management (Estimate = 0.351, p < 0.001).

These results emphasize the critical factors influencing the adoption and utilization of digital health tools across different domains. The significant positive associations for ease of use, data security, and staff IT experience suggest that these are essential drivers for successful implementation. However, infrastructure limitations and risk perceptions may serve as barriers, particularly in systems requiring high technical inputs.

Table 5. Association between users' Perceptions, Literacy, and Experiences In Implementing and Adopting the Digital Health Tools

Independent variables	Dependent variables Digital health tools in used	Estimate	p-value
Perceived Usefulness	Disease Surveillance & Response Systems	-.116	0.04
IT Knowledge	Disease Surveillance & Response Systems	.082	0.15
Education	Disease Surveillance & Response Systems	.017	0.77
Perceived Usefulness	Data Collection & Health Information Management	.183	<0.001
IT Knowledge	Data Collection & Health Information Management	-.205	<0.001
Education	Data Collection & Health Information Management	.155	0.004
Perceived Usefulness	Logistics & Supply Chain Management	-.002	0.96
IT Knowledge	Logistics & Supply Chain Management	.712	<0.001
Education	Logistics & Supply Chain Management	-.317	<0.001

Table 5 shows the associations between users' perceptions, IT knowledge, and education levels with the implementation of digital health tools. User perception of the usefulness of digital health tool was significantly associated with the use of tools for data collection and health information management (Estimate: 0.183, p-value: <0.001) but shows no significant effect in the area of Logistics and Supply Chain Management (Estimate: -0.002, p-value: 0.96). In addition, IT Knowledge demonstrates a positive association (Estimate: 0.082, p-value: 0.15) with Disease Surveillance & Response Systems tools, and a stronger association (Estimate: 0.712, p-value: <0.001) with Logistics & Supply Chain Management tools; however, this pattern does not apply to Education.

Table 6. Access Actual Users' Perceptions, Literacy, And Experiences In The Implementation And Critical Success Factors Archived In Adopting The Digital Health Tools

Independent variables	Dependent variables Digital health tools in used	Estimate	p-value
Perceived Usefulness	Disease Surveillance & Response Systems	-.116	0.04
IT Knowledge	Disease Surveillance & Response Systems	.082	0.15
Education	Disease Surveillance & Response Systems	.017	0.77
Perceived Usefulness	Data Collection & Health Information Management	.183	<0.001
IT Knowledge	Data Collection & Health Information Management	-.205	<0.001
Education	Data Collection & Health Information Management	.155	0.004
Perceived Usefulness	Logistics & Supply Chain Management	-.002	0.959
IT Knowledge	Logistics & Supply Chain Management	.712	<0.001
Education	Logistics & Supply Chain Management	-.317	<0.001
Disease Surveillance & Response Systems	Ease of use	.413	<0.001
Data Collection & Health Information Management	Ease of use	.697	<0.001
Logistics & Supply Chain Management	Ease of use	.697	<0.001
Ease of use	Critical Success	.720	<0.001

The findings in Table 6 showcases the relationships among the independent variables—perceived usefulness, IT knowledge, and education—and their influence on Paths to Ease of Use and Critical Success. The model shows that disease surveillance, data collection, and logistics & supply chain management are each strongly associated with ease of use (Estimates: 0.41, 0.70, and 0.70 respectively). This suggests that adoption in these areas positively contributes to the perceived ease of using digital health tools. Finally, ease of use has a direct and strong positive relationship with critical success (Estimate: 0.72).

This implies that the more user-friendly the digital health tools are, the more likely they are to achieve critical success in their implementation.

Table 7. The Association Of Infrastructure And The Adoption Of Digital Health Tool And How It Relates To The Critical Success Factors Archived

Independent variables	Dependent variables Digital health tools in used	Estimate	p-value
Perceived Usefulness	Disease Surveillance & Response Systems	-.158	0.005
Infrastructure	Disease Surveillance & Response Systems	.125	0.025
Technical Infrastructure	Disease Surveillance & Response Systems	.001	0.989
Perceived Usefulness	Data Collection & Health Information Management	-.190	<0.001
Infrastructure	Data Collection & Health Information Management	.329	<0.001
Technical Infrastructure	Data Collection & Health Information Management	-.026	0.616
Perceived Usefulness	Logistics & Supply Chain Management	.244	<0.001
Infrastructure	Logistics & Supply Chain Management	.547	<0.001

Technical Infrastructure	Logistics & Supply Chain Management	-.263	<0.001
Disease Surveillance & Response Systems	Ease of use	.349	<0.001
Data Collection & Health Information Management	Ease of use	.594	<0.001
Logistics & Supply Chain Management	Ease of use	.597	<0.001
Ease of use	Critical Success	.778	<0.001

The results from Table 7 present the association between Infrastructure and the implementation of digital health tools. Infrastructure was positively associated with adoption of disease surveillance & response systems ($\beta = 0.12$, $p = 0.025$), suggesting that improving infrastructure enhances the effectiveness of disease surveillance systems and data collection & health information management ($\beta = 0.33$, $p < 0.001$). Also, showed a strong positive association with adoption ($\beta = 0.55$, $p < 0.001$) of logistics & supply chain management tool**.** Furthermore, Ease of Use was associated with disease surveillance & response systems ($\beta = 0.35$, $p < 0.001$), data collection and health information management ($\beta = 0.59$, $p < 0.001$), and logistics and supply chain management ($\beta = 0.60$, $p < 0.001$). Similarly, Ease of use positively impacted critical success factors ($\beta = 0.78$, $p < 0.001$).

Discussion

A strategy to advance UHC involves enhancing health systems and promoting sustainable development, achievable through evidence-based decision-making utilizing innovative digital interventions, in alignment with Target 3.9d of SDG 3 [33], which aims to "Strengthen the capacity of all countries, particularly developing nations, for early warning, risk reduction, and management of national and global health risks" [34].

The use and adoption of digital health tools in low- and middle-income countries (LMICs) such as Nigeria offer considerable prospects and challenges. It is essential to guarantee that Nigeria's digital health systems are integrated, adaptable, sustainable, and supported by robust policies and leadership. There is insufficient knowledge concerning factors that affect the use and sustainable adoption of digital health tools in primary healthcare settings, where their use is intended by healthcare practitioners.

Descriptive Statistics of the Respondents' Characteristics

This study engaged a varied cadre of participants from multiple primary healthcare centers across three States in Northern Nigeria to ensure comprehensive insights.

The demographic characteristics of the respondents from various primary health facilities across three states in Northern Nigeria are notably significant.

The majority of participants, 105 (34.0%), were between the ages of 31 and 40. This finding is consistent with the research conducted by [35]. The age group of 31- 40 is particularly significant because it frequently represents a techno-savvy and professionally active segment of the population, which is essential for the sustainable adoption of digital health tools. Most of the health practitioners, 195 (63.1%), were male.

This finding is typical in other developing countries [36], [37], but it is not the case in developed countries, where people of both sexes have rights that are nearly equivalent to one another [38], [39].

An adequate, well-distributed and motivated health workforce is essential for achieving UHC and numerous SDGs, including health (SDG3), decent employment and economic

growth (SDG8), gender equality (SDG5), and migration (SDG10). Achieving SDG3 requires not just an augmentation of healthcare staff but also a targeted strategy and tailored policies that correspond with the distinctive characteristics and behaviors of the health workforce [40]. This requires improved accessibility, quality, analysis, and utilization of health workforce data to inform advocacy, planning, policy development, governance, and accountability at national, regional, and global levels.

The World Health Organization reports that 70% of the worldwide health workforce comprises females, a phenomenon referred to as the feminization of healthcare occupations. In Nigeria, women represent the predominant demographic among medical doctors and nursing and midwifery personnel, according to data from 2018 indicating that 65% of physicians and 87% of nursing staff were female [41]. Nonetheless, trained healthcare workers on the frontlines in Northern Nigeria are predominantly male because of insufficient educational attainment among girls. The gender imbalance among healthcare professionals in Northern Nigeria is a critical concern. The region encounters obstacles, including less educational achievement among girls, which constrains their prospects of becoming skilled healthcare professionals. Consequently, the majority of skilled healthcare professionals are male [42].

Conversely, a significant number of unskilled healthcare workers, including community health volunteers, are primarily female. This circumstance is shaped by cultural norms and the restricted presence of female healthcare practitioners [42].

Initiatives to rectify this discrepancy encompass enhancing educational possibilities for girls and fostering community involvement to endorse the acceptance of healthcare services provided by male frontline health workers [43].

In addition, a substantial proportion of participants were married, with 243 (78.6%) and 305 (98.7%) having completed at least tertiary educations. This indicates a well-educated and potentially stable demographic, which may positively influence the sustained use of these tools. The adoption and sustainable use of digital health instruments in primary healthcare centers in Nigeria can be influenced by a variety of factors, including the marital status of healthcare workers. Healthcare professionals who are married frequently balance their professional obligations with their family obligations. This dual role can have an impact on their capacity to engage with and implement new technologies, particularly if these tools necessitate additional training or time investment [44]. Furthermore, the tension associated with the adoption of new technologies may be mitigated by the fact that married individuals may have more robust support systems at home. This assistance may be provided by spouses or extended family members who assist in the management of domestic responsibilities.

Marriage can offer a sense of motivation and stability. Healthcare professionals may be more inclined to adopt digital health tools that can enhance their work efficiency and patient care when they feel supported at home [44]. It is interesting to note that the adoption of digital health instruments is contingent upon the availability of training and ongoing professional development. Healthcare professionals who are married may encounter difficulties in attending training sessions as a result of family obligations, which may impact their proficiency with these tools.

The success of the adoption of digital health tools is also contingent upon the policies and support supplied by healthcare institutions. Married healthcare professionals can more effectively engage with digital health initiatives and balance their responsibilities by utilizing flexible work schedules, on-site childcare, and other supportive measures.

In general, the key to sustainable adoption is the establishment of an environment that accommodates the diverse needs and

circumstances of healthcare workers, despite the fact that marital status can present both challenges and advantages.

In addition, 109 respondents (35.3%) exhibited a minimum level of IT knowledge. There is a similarity between this and a study that was carried out in one of the Northern States of Nigeria [36]. A number of factors have an impact on the minimum level of information technology proficiency of primary health workers in Northern Nigeria: The majority of primary health care institutions in Northern Nigeria are confronted with considerable resource limitations, such as insufficient financing for information technology infrastructure and training [45]. This makes it more difficult to provide health staff with the appropriate information technology skills and tools. It is common for there to be a dearth of all-encompassing training programs that are centered on information technology skills for those who work in the health care industry. It's possible that the training programs that are currently available don't effectively address the utilization of digital tools and technology that are necessary for the delivery of modern healthcare [45].

It is feasible that the region has limited access to dependable internet and energy, both of which are essential for the efficient utilization of information technology in the healthcare industry. In addition, the development and utilization of information technology solutions are both hampered by this infrastructure gap.

Although there are national standards and policies that are aimed at enhancing primary healthcare, the implementation of these policies and standards at the local level might be inconsistent.

It is necessary to develop targeted interventions in order to address these difficulties. These interventions should include greater financing, enhanced training programs, improved infrastructure, and effective policy implementation in order to strengthen the information technology capabilities of primary health workers in Northern Nigeria.

The majority of health centers, 168 (54.4%), were situated in rural areas and utilized at least one digital health tool. It is generally accepted that a sizeable percentage of PHCs in northern Nigeria are situated in villages and other rural areas. In comparison to metropolitan inhabitants, rural populations frequently encounter more obstacles while attempting to gain access to healthcare. The purpose of this distribution is to improve access to healthcare services for rural populations.

As part of broader efforts to improve health equity and guarantee that marginalized groups access vital health services [46], the focus on rural areas is a component of those general efforts. Nevertheless, the availability of services and the quality of such services might substantially fluctuate from one region and facility to another [47].

Descriptive Statistics of the Digital Health Tools

The digital health tool questionnaire was used to assess the perceived usefulness, ease of use, relative advantages, awareness of digital health tools, risk, data security, infrastructure, critical success factor, staff experience, information sharing, and technical infrastructure of digital health tool adoption among participants.

The subscale that evaluated the perceived usefulness of the digital health tool found that approximately 150 (48.5%) respondents agreed that these tools improved their ability to complete tasks. This result represents some concerns over the efficacy of digital health technologies intended for primary healthcare providers, which are understandable and should be accepted. However, many other studies illustrate the positive impacts that these technologies can have, despite the fact that there are obstacles of their own.

One recent study conducted by the WHO discovered that digital health technologies have

the potential to improve the mental health and performance of healthcare workers by enhancing the accuracy of decision-making, decreasing the amount of time required to complete tasks, and increasing productivity [48]. Not only can these tools increase communication among healthcare workers, but they also enable improved access to data that is updated every moment.

However, it is essential to keep in mind that the efficacy of these tools might vary depending on a number of circumstances, such as the particular setting in which they are utilized, the severity of the training that is offered, and the infrastructure that is already in place [49]. There are still gaps in the evaluation and impact of these technologies in many nations, particularly in LMICs. Furthermore, the relationship between training and perceived barriers to digital health access, current usage of digital tools, and beliefs regarding digital impact among a multi-country sample of community health workers (CHWs) was examined [44]. The analysis revealed no significant correlation between the frequency of training sessions and the current utilization of digital devices, indicating that an increase in training does not inherently influence a Community Health Worker's likelihood of employing digital devices in their professional activities.

In our study, a larger proportion 202 (65.4%) acknowledged that digital health tools facilitated their work processes or made their work easier. This is consistent with the findings from this research, where a variety of digital health tools that are utilized in primary care settings across Africa, including Nigeria, are studied and discussed. It sheds light on the difficulties encountered and the strategies that were successful, indicating that mobile health solutions have the potential to be useful provided that healthcare professionals receive sufficient training, and the applications are built to integrate with preexisting workflows [50] resulting in a well-integrated and effective delivery of primary health care services, according to a scoping review in LMICs [51].

Moreover, the digital health tools subscale indicated that 79 (25.6%) participants found digital health tools/systems to be generally frustrating, while 228 (73.8%) indicated that they find these tools/systems easy to use. It was not necessary to have a high level of technical expertise in order to use the user-centered platforms because they were meant to be as simple to comprehend as feasible. Individuals are less inclined to use a technology if they do not believe that it would significantly improve their job performance. This is because there is a relationship between the perceived ease of use and the adoption of technology. This is alignment with the research conducted in various settings in sub-Sahara Africa [50] and in Nigeria [52]. Generally speaking, the acceptability of digital health tools among healthcare personnel is high when the technologies are easy to use and can be easily integrated into the workflows that are already in place [53].

Most participants 214 (69.3%) reported having access to the digital health tools available, and 203 (65.7%) indicating that they comprehend the benefits of utilizing these tools. This scoping review study examined the implementation of digital health interventions aimed at strengthening health systems in sub-Saharan Africa over 10 years, revealing that a considerable proportion of participants reported access to digital health tools and comprehension of their benefits [12].

A significant number of participants, 88 (28.5%), reported a lack of consistent electricity, while 71 (23.0%) expressed disagreement regarding the quality of the network at their facility. In Nigeria, the inconsistent supply of electricity and inadequate internet services impede the effective use and adoption of digital health tools [54], [35]. The inadequate internet coverage is exacerbated by the unreliable electricity supply. Research evidence indicates that inadequate

electricity supply significantly hinders the adoption of digital health technology in the ECOWAS region. Frequent power outages are a prevailing issue in numerous areas across Nigeria, Burkina Faso, Niger, Liberia, and Mali [17], [55].

The subscale assessing critical success revealed that 244 individuals (79.0%) indicated that utilizing digital health tools enhances their control over their work, while 223 individuals (72.2%) reported that these tools improve the quality of their work. One of the main obstacles to the implementation of digital health technology in Sub-Saharan Africa, especially Nigeria, is inadequate electrical supplies [56], [50], [57].

In the information sharing subscale, 102 (33.0%) indicated that digital health tools/systems enhance information sharing within the health facility, while 154 (49.8) expressed that the digital health tools/systems enhance information sharing with other health facilities. [58], [50] consolidated information regarding the advancement of digital health technology to enhance primary healthcare during the COVID-19 pandemic. It discussed several digital health tools and their functions in improving decision-making and information exchange within and among healthcare facilities. In addition, the role of digital health tools in facilitating access to care for marginalized communities by improving information sharing within healthcare facilities was highlighted [59].

Majority, 192 (62.1%) concurred that an excessive focus on protecting patients' privacy impacts the utilization of digital health tools/systems. This research [50] examined diverse digital health tools utilized in primary care settings throughout Africa, emphasizing issues including inadequate network access and technological proficiency. It posits that although privacy concerns are significant, they may occasionally obstruct the proper use of digital health solutions if not harmonized with usability and accessibility. The implications of the development of digital health technologies during the COVID-19 pandemic are discussed along with the impact those technologies had on primary health care [58]. It highlights the importance of quality assurance and standards for digital health tools, pointing out that an excessive focus on privacy can make the acceptance and effective utilization of these technologies more difficult. An examination of the difficulties associated with protecting the privacy of patients while also providing effective health care coordination and delivery was presented by [60] This demonstrates that firm privacy rules can sometimes make it difficult to use digital health tools in a seamless manner, which can have an impact on the delivery of healthcare as a whole.

The technical infrastructure subscale indicated that 216 (69.9%) and 244 (79.0%) participants agreed that the IT budget of the health facility is sufficient to sustain and support the digital health tools/system; and that the health facility's existing infrastructure is enough to support the digital health tools/system, respectively. The study [57] examined the challenges and opportunities associated with digital health technologies in Africa, highlighting the necessity for integrated national infrastructures to facilitate sustainable outcomes; while [51] examined the potential of digital health solutions to improve primary healthcare delivery and attain universal health coverage, emphasizing the significance of digital literacy and appropriately allocated funding in LMICs, including Nigeria.

Available Digital Health Tools In Public Health Emergencies In Primary Healthcare Centres Across The Three States

A variety of digital health tools used in public health emergencies within the primary healthcare sector throughout the past five years. Within this period, about 11 digital health tools have been utilized. The predominant instrument utilized during this period was ODK 77 (24.9%), followed by OpenLMIS 70 (22.7%),

then Survey CTO 56 (18.1%), E-health card 34 (11.0%), NIPDS 29 (9.4%) and SORMAS 9 (2.9%) was also represented. RI SMS experienced the lowest use, representing merely 0.6%.

Several of these tools were captured as part of the digital health tools for pandemic preparedness in Nigeria, as reported in a national case study [61].

Socio-Demographic Factors That Influences The Adoption Of Digital Health Tools

The analysis revealed a highly significant relationship between age and adoption across all three domains ($\chi^2 = 203.64$, $p < 0.001$). Hence, our study suggests that the age of individuals in Nigeria can have a substantial impact on their adoption of digital health solutions. It is important to note that the largest group of participants fell within the age range of 31-40 years, comprising a total of 105 individuals, which accounts for 34.0% of the sample. Individuals working in the health care industry who are younger are more likely to utilize digital health solutions. Generally speaking, this age group have a greater familiarity with technology and are more willing to incorporate new digital solutions into their day-to-day activities. Other research discovered a statistically significant correlation between the age of the participants [62], [32]. This contrasts slightly with the findings by (Blondino C. K., 2024), who reported that older age was an indicator of digital device usage. When it comes to embracing digital health solutions, older health workers may experience more hurdles than younger peers. This may be the result of a lack of familiarity with digital technology, an aversion to change, or a preference for more conventional approaches. It is possible to help bridge the gap for elder health workers by providing them with proper training and support, which will make it simpler for them to embrace and use digital health solutions in an efficient manner.

In addition, this study also highlights the significant factors that influence the adoption of digital health instruments, such as sex, marital status, education level, IT expertise, profession, and geographic location. The results suggest that the adoption of digital health tools is substantially influenced by sex ($\chi^2 = 136.92$, $p < 0.001$), with individuals in marital relationships being the primary users across all systems.

Education level also emerged as a critical factor, with individuals who have completed tertiary education exhibiting virtually complete adoption in all areas, particularly in data collection and health information management and disease surveillance and response systems ($\chi^2 = 8.37$, $p = 0.007$).

The substantial impact of sex on the adoption of digital health tools is consistent with the World Health Organization's assessment of the role of digital health technologies in enhancing women's health and fostering gender equality [63]. The WHO report emphasizes that digital tools can improve access to healthcare services, particularly for women, by enabling them to manage their health independently and providing essential health information. In addition, there was a significant relationship between gender of the healthcare workers and their willingness to use digital health tools [32, 35].

Still, marital status also emerged as a significant factor, with individuals in marital relationships being the predominant users of all three systems. This may be due to the heightened health management responsibilities that are frequently associated with family life, which necessitate the use of digital health tools for the efficient delivery of healthcare.

The level of education emerged as a significant factor, with respondents holding higher education degrees demonstrating almost complete adoption in all domains. This aligns with findings from other research indicating that advanced educational attainment correlates with increased technology adoption, attributed

to enhanced digital literacy and improved access to resources. The complete adoption rate in disease surveillance and response systems, along with data collection, analytics, and visualization and logistics and supply management among respondents with higher education, highlights the significance of educational achievement in promoting the utilization of advanced health technologies. [57] examined the impact of digital health platforms on enhancing healthcare delivery in Africa, emphasizing the significance of education and training for the effective implementation of these technologies. The scoping review methodology delineated the use of digital health interventions and their influence on health systems, highlighting the significance of higher education in promoting the uptake and successful utilization of these tools [64]. This reported study analyzed diverse digital health applications and their implementation in many nations, including Nigeria, while emphasizing the need of education and training for healthcare professionals [50].

The influence of IT expertise on the adoption of logistics and supply chain management tools is notable, particularly with the highest adoption rates (83.8%) observed among individuals possessing advanced IT skills. This finding aligns with another research indicating that technical proficiency plays a crucial role in the effective use of digital health tools [20], [35]. The success of digital health in sub-Saharan Africa will hinge on the health workforce's proficiency in digital technologies [56]. On the other hand, individuals with minimal IT expertise primarily participated in disease surveillance and response, underscoring the necessity for specialized training initiatives to address this skills gap.

The role of profession played a crucial part in influencing the adoption of digital health tools ($\chi^2 = 151.55$, $p < 0.001$). The subsequent research also documented the utilization of digital tools by diverse categories of healthcare practitioners [20], [35], [62]. Our study indicated that the significance of profession was crucial, as record officers predominantly utilized logistics and supply chain management (87.5%), whereas disease surveillance and response systems were chiefly utilized by CHEW/DSNO professionals (78.0%). Healthcare professionals exhibited a notable inclination towards data collection and health information management, with a percentage of 43.1%. The observed patterns illustrate the unique requirements and duties linked to various professional positions within the healthcare system.

The geographical location significantly impacted adoption rates, as rural primary health centers excelled in the implementation of disease surveillance and response systems, achieving a remarkable 100.0% rate. ($\chi^2 = 212.79$; $p < 0.001$). The results slightly contrast the existing research suggesting that metropolitan regions typically possess superior infrastructure and resources to facilitate the implementation of advanced digital health technologies [65].

When examining these findings alongside other research, it becomes clear that the integration of digital health tools is complex, shaped by a variety of demographic, educational, professional, and geographical influences.

This research highlights the intricate relationships among multiple elements influencing the uptake of digital health technologies in Nigeria. It is essential to tackle these factors with specific interventions, including the enhancement of digital literacy, the improvement of IT training, and the assurance of equitable access across various regions, to fully realize the advantages of digital health technologies.

A significant relationship was observed between perceived usefulness and the adoption of digital health tools ($\chi^2 = 39.57$, $p < 0.001$). The findings we analyzed suggest that healthcare professionals in Nigeria agree that

the perceived usefulness of technology plays a crucial role in influencing the adoption of digital health tools.

Moreover, the relationship between perceived usefulness and the adoption of digital health tools indicates that users are more inclined to utilize these tools when they recognize their benefits. It highlights the significance of creating digital health solutions that prioritize user needs and provide tangible benefits to users. This relationship underscores the importance of ongoing user feedback and engagement in the development process to guarantee that these tools stay pertinent and efficient.

The results indicate a significant relationship between perceived usefulness and the adoption of digital health tools. This is consistent with earlier studies carried out in Northern Nigeria [20], and sub-Saharan Africa, highlighting the significance of perceived usefulness in the adoption of digital health interventions. For example, [35] discovered that the perceived usefulness significantly impacted the adoption of digital health tools in Nigeria, and by [66], in Ghana.

In a similar vein, a scoping review conducted by [64] emphasized the significant impact of perceived usefulness on the adoption of digital health interventions throughout sub-Saharan Africa. The results highlight the importance of creating digital health tools that prioritize the needs and preferences of users.

By ensuring that these tools are viewed as advantageous, healthcare providers can greatly increase their adoption rates, ultimately resulting in better healthcare outcomes. Moreover, ongoing user feedback and engagement in the development process are crucial for ensuring the tools remain relevant and effective.

As well, our findings indicate that the perception of usefulness plays a crucial role in the adoption of digital health tools. This aligns with the findings of [67] in their research on Bangladesh. This insight can inform future studies and development initiatives, guaranteeing that digital health solutions are both accessible and effective. Yet, the results indicating that perceived ease of use did not have a significant correlation with the adoption of digital health were corroborated by more research [68].

Also, awareness emerged as a significant factor ($\chi^2 = 102.29$, $p < 0.001$). The results indicate that awareness played a crucial role in the readiness to embrace digital health tools. This is consistent with earlier studies carried out in Northern Nigeria, highlighting the significance of awareness in the uptake of digital health interventions. [69] reported that the awareness of digital health technologies among healthcare workers in Nigeria had a significant impact on their readiness to embrace these tools during the COVID-19 pandemic. In addition, a scoping review conducted by [70] emphasized the essential importance of awareness in the utilization of digital health throughout Nigeria. The results highlight the importance of enhancing awareness campaigns and educational initiatives to encourage the use of digital health tools. By making sure that healthcare providers and the general public are thoroughly educated about the advantages and capabilities of these tools, we can greatly increase their adoption rates, which will ultimately result in better healthcare outcomes. This insight can inform future investigations and development initiatives, guaranteeing that digital health solutions are both accessible and effective.

In a similar vein, the perception of relative advantage strongly influenced adoption ($\chi^2 = 123.55$, $p < 0.001$). [20] demonstrated that the adoption of e-health technology in Nigerian hospitals was significantly affected by the perceived relative advantage of these tools. A scoping review by [70] emphasized the significant role of relative advantage in the utilization of digital health in Nigeria. The findings highlight the necessity for the design of digital health tools to consider user needs and

preferences. Ensuring that these tools present distinct advantages over traditional methods can significantly enhance their adoption rates among healthcare providers, thereby leading to improved healthcare outcomes.

Moreover, the significance of data security was evident, and hence, considered an important factor ($\chi^2 = 48.26$, $p < 0.001$). Data security was identified as a critical factor influencing the adoption of digital health tools in Northern Nigeria. This is consistent with prior studies in the region, highlighting the significance of data security in the implementation of digital health interventions. [71] reported that concerns regarding data security significantly influenced the adoption of digital health technologies in Nigeria. [70] emphasized the importance of data security in the utilization of digital health in Nigeria. The findings underscore the necessity of integrating robust data security measures into digital health tools. Ensuring the security of these tools can significantly enhance their adoption rates among healthcare providers, ultimately resulting in improved healthcare outcomes.

Our study analyzed the relationships among users' perceptions, IT knowledge, and educational attainment concerning the implementation of digital health tools in three areas: data collection and health information management, logistics and supply chain management, and disease surveillance and response systems.

User perception of the usefulness of digital health tools is significantly associated with their utilization for data collection and health information management (Estimate: 0.183, p-value: <0.001). This finding indicates that users who perceive digital health tools as beneficial are more inclined to adopt and effectively utilize them for health data management. In logistics and supply chain management, user perception of usefulness did not demonstrate a significant effect (Estimate: -0.002, p-value: 0.96), suggesting that alternative factors may be more influential in this field.

And IT knowledge exhibited a positive correlation with the adoption of digital health tools. IT knowledge exhibited a moderate positive correlation with the utilization of Disease Surveillance & Response Systems tools (Estimate: 0.082, p-value: 0.15); however, this correlation did not reach statistical significance. IT knowledge demonstrated a significant positive correlation with the utilization of Logistics and Supply Chain Management tools (Estimate: 0.712, p-value: <0.001). This pattern underscores the significance of IT proficiency in the efficient management of logistics and supply chain processes in the healthcare sector.

The anticipated pattern of associations was not observed in the Education domain, suggesting that education levels did not significantly influence the adoption and implementation of digital health tools in the examined areas. This indicates that although education is important, it may not be the foremost factor influencing the adoption of digital health tools, in contrast to other elements like user perception and IT proficiency.

This study highlights the significant impact of user perception of usefulness and IT knowledge on the adoption and implementation of digital health tools. The findings indicate that enhancing the adoption of digital health tools, especially in data collection, health information management, and logistics, requires efforts to improve user perceptions of the tools' usefulness and to enhance IT literacy among users. Our research examined the relationships between independent variables—perceived usefulness, IT knowledge, and education—and their effects on ease of use and critical success in the context of digital health tools. The model demonstrates that disease surveillance, data collection, and logistics and supply chain management are each significantly correlated with ease of use, with estimates of 0.41, 0.70, and 0.70, respectively. The adoption of digital health tools in these areas notably improves the perceived usability of these tools.

The significant relationship between ease of use and the previously mentioned areas highlights the necessity of user-friendly design and functionality in the adoption of digital health tools. The ease of use of these tools increases the likelihood of user adoption and integration into routine workflows, thereby enhancing their effectiveness in disease surveillance, data collection, and logistics and supply chain management.

In addition, ease of use demonstrated a direct and significant positive correlation with critical success, with an estimate of 0.72. This finding underscores that the user-friendly characteristics of digital health tools serve as both a facilitator of adoption and a critical determinant of their overall success. Ensuring that these tools are intuitive and accessible enhances user satisfaction and engagement, resulting in improved healthcare outcomes.

This study illustrates the significant impact of perceived usefulness, IT knowledge, and education on the usability and success of digital health tools. The identified associations in our model indicate that emphasizing user-centric design and ongoing education can markedly improve the adoption and effectiveness of these tools in healthcare environments.

Our study examines the relationship between infrastructure and the implementation of digital health tools, yielding significant insights. The adoption of disease surveillance and response systems was positively correlated with infrastructure ($\beta = 0.12$, $p = 0.025$), indicating that improvements in infrastructure may enhance the effectiveness of these systems. This finding demonstrates that strong infrastructure is vital for the effective deployment of disease surveillance tools, which are necessary for monitoring and addressing public health threats.

In addition, infrastructure demonstrated a significant positive correlation with data collection and health information management ($\beta = 0.33$, $p < 0.001$) and a robust positive correlation with the adoption of logistics and supply chain management tools ($\beta = 0.55$, $p < 0.001$).

Our results indicate that robust infrastructure is essential for the effective implementation of digital health tools in diverse areas, facilitating the efficient collection, management, and utilization of health data. In the context of this discussion, infrastructure refers to the availability of a supply of electricity, as well as the reliability and consistency of access to the internet and connectivity, the amount of broadband that is available, and the accessibility to computers. This is consistent with the findings obtained by [72] in the course of their inquiry of the state of electronic health in developing countries, including Nigeria.

The ease of use was identified as a significant factor influencing the implementation of digital health tools. The findings of our study indicate a positive association between ease of use and disease surveillance and response systems ($\beta = 0.35$, $p < 0.001$), data collection and health information management ($\beta = 0.59$, $p < 0.001$), as well as logistics and supply chain management ($\beta = 0.60$, $p < 0.001$). This indicates that user-friendly digital health tools enhance adoption rates, resulting in improved healthcare management and outcomes.

Similarly, ease of use significantly influenced critical success factors ($\beta = 0.78$, $p < 0.001$), highlighting its role in the overall success of digital health implementations. Prioritizing user-centric design and ensuring navigability of digital health tools can lead to increased adoption rates and enhanced efficiency within health systems.

Again, this study highlights the critical importance of infrastructure and perceived ease of use in the adoption and implementation of digital health tools. The associations identified in this research indicate that enhancing infrastructure and creating user-friendly tools are critical for the effective implementation of digital health solutions in healthcare environments.

Conclusion

The use and sustainable adoption of digital health solutions in low- and middle-income countries (LMICs) like Nigeria require a comprehensive strategy that includes infrastructure, stakeholder involvement, policy development, financial viability, and user-centered design. By concentrating on these domains, policymakers and practitioners can leverage digital health technologies to improve healthcare outcomes and attain greater equity in health services.

Our research has pinpointed multiple key areas essential for the effective expansion of digital health efforts in Nigeria. These encompass guaranteeing that programs have intrinsic attributes that deliver quantifiable benefits to address unmet needs and engaging end-users from the outset. The technical profile of the digital health tool should prioritize simplicity, interoperability, and adaptability. All stakeholders must be engaged, trained and motivated in order to effectively deploy and implement new projects.

Sustainable finance is essential for facilitating long-term growth, including adequate private sector investment. The policy framework governing digital healthcare efforts must be consistent with overarching healthcare policies. It is crucial to consider the extrinsic environment, which encompasses the provision of the necessary infrastructure to facilitate the implementation of digital initiatives on a large scale.

In the context of scaling and integrating digital health, collaborative endeavors to establish a less-siloed strategy may offer the necessary leadership to facilitate the deployment of new solutions in Nigeria. These practices may also influence the formulation and implementation of health programs in the years to come.

Our analysis revealed a number of contextual elements and interconnected pathways that likely mitigated the effects of digital health technologies in the context of primary health care. When assessing the role of digital solutions in primary health care settings, it is imperative to consider the technical functionality of the technology and the behavioural responses of the end-users. In addition, the larger health system's requirements and the digital ecosystem's readiness, which includes the capacity at the primary health care level to implement digital solutions, must be considered. Conceptual and/or methodological frameworks are necessary to enhance comprehension of the myriads of individual, organizational, technological, and system-level factors that influence the performance of digital health solutions, as well as to better understand, classify, and examine the associative mechanisms of digital health and PHC (or UHC-related) outcomes.

The deployment, utilization, and expansion of mobile health systems in Northern Nigeria are impeded by a greater number of obstacles and impediments. In addition to the impediments that obstruct progress, there are also enabling components that could be utilized to facilitate the design, implementation, and expansion of digital health tools. It is clear that the northern region of Nigeria may require contextualized strategies that are tailored to the unique challenges the region is currently experiencing.

A variety of factors, both facilitating and impeding, affect the digital health systems in Nigeria. Common barriers and enablers were identified by a variety of primary health care workers. In order to encourage use and sustainable adoption, all stakeholders must take an active role in overcoming the obstacles. In spite of the extant obstacles, this investigation indicates that digital health systems in Nigeria and sub-Saharan Africa are approaching a favourable future. This research revealed strategies and opportunities for the sustainable adoption and integration of digital health tools into the Nigerian health care systems.

In order to effectively and efficiently integrate digital health into public services in sub-Saharan Africa, particularly Nigeria, primary health care should improve its response capacity, increase the utilization of information and communication technologies, and address challenges through scientific evidence.

There should be a transition from donor-driven pilot initiatives to programs that are cost-effective, sustainable, robust, and managed by the Nigerian government. This is due to the substantial potential of digital health technologies to fortify Nigerian health systems in order to achieve UHC and the SDGs for health. To prevent the wastage of finite health resources, the duplication of efforts, and the wastage of time on unsuccessful interventions, this plan will employ a demand-driven, people-centered approach, as opposed to a supply-driven approach. It was determined that government ownership and leadership are essential for the long-term viability of digital health initiatives in Nigeria and their successful expansion.

Nevertheless, proof of concept alone is insufficient to propel digital technologies into widespread adoption for large-scale use. In order to successfully implement digital health tools, it is essential to establish a balance between a user who is receptive to the intervention, a high-quality digital instrument, and an appropriate framework at the policy and implementation levels. In order to accomplish this blend, the proposed tools must be user-friendly and possess an advantage over conventional service delivery methods. Furthermore, there should be no necessity for advanced training, or high-cost resource investment during their utilization.

Conflict of Interest

None declared.

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