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Original Article/Research

Evaluating mobile health interventions for HIV patients in Nigeria: Healthcare policy implications from a simulation study

Eren Demir [a], Usame Yakutcan [a,*], Adekunle Olatayo Adeoti [b], Christian Isichei [c,d], Shola Adeyemi [e]

[a] Hertfordshire Business School, University of Hertfordshire, AL10 9AB Hatfield, United Kingdom
[b] Department of Medicine, Ekiti State University/Ekiti State University Teaching Hospital, Ado-Ekiti, Nigeria
[c] Executive Department, Faith Alive Foundation-Nigeria, Jos, Nigeria
[d] Department of Chemical Pathology, Jos University Teaching Hospital, University of Jos, Jos, Nigeria
[e] Research and Development Department, Bohemian Smartlytics Ltd., Haverhill, United Kingdom

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ABSTRACT

Objectives: People living with HIV/AIDS (PLWHA) benefit from mobile health (mHealth) technologies through self-managing and monitoring their disease with enhanced patient experience and health outcomes. However, the efficiency and cost-effectiveness of these interventions are yet to be studied. The study aims to assess the impact of mHealth on operational and cost metrics relevant to PLWHA and HIV service delivery.
Data Sources: Data were a mixture of primary and secondary data from the hospital setting, experts' opinions, reports, and the literature.
Method: Using a web-based simulation platform, SmartHIV Manager™, for the management of HIV services, we tested scenarios based on four possible reductions in the number of clinic visits and four groups of PLWHA who can be offered a mobile device free of charge (16 scenarios in total). The study was conducted in collaboration with Faith Alive Foundation Hospital (Nigeria) using a mHealth app (BSmart Chart).
Results: In the worst-case scenario, the hospital anticipates a 14 % decrease in the number of visits from stable patients, nine fewer doctors to operate their service, and a 3 % savings in total cost after accounting for mHealth intervention expenses and mobile phone acquisition. With the service currently running at 161 % doctor capacity, this intervention alleviates staff pressure and ensures quality care.
Conclusion: The study shows significant system efficiency gains, fewer visits, better health outcomes, economic benefits for stable patients, and increased capacity. These findings apply to most HIV services worldwide, especially in times of limited resources.
Public Interest Summary: Mobile health (mHealth) technologies support people living with HIV/AIDS by helping them manage their health and receive remote monitoring. This study examines the impact of mHealth apps on the costs and operations of HIV services. Conducted in a rural HIV setting in Nigeria, where many patients face financial challenges, the research used a simulation-based decision support tool (known as SmartHIV Manager) to test the scenario of providing free mobile devices and reducing clinic visits for stable patients. Results indicated that this approach could reduce patient visits and healthcare costs while easing the workload of overburdened doctors. Globally, introducing mHealth apps could be impactful, given the constraints of limited healthcare staff and budgets.

Introduction

Mobile Health (mHealth) technologies are seen by practitioners and policymakers as an opportunity to improve patient outcomes and increase the cost-effectiveness of health services [1,2]. The benefits have been reported by mHealth users with chronic diseases, including diabetes mellitus, bronchial asthma [3–5], and people living with HIV/AIDS (PLWHA) in self-managing and monitoring their disease.

* Corresponding author.
E-mail addresses: e.demir@herts.ac.uk (E. Demir), u.yakutcan@herts.ac.uk (U. Yakutcan), kadeoti2002@gmail.com (A.O. Adeoti), christian_isichei@yahoo.com (C. Isichei), s.adeyemi@bsmartlytics.com (S. Adeyemi).

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mHealth solutions for PLWHA integrate critical health and medical-related self-assessment reports with features to engage in care, social support, and evaluation methods to describe needs. Studies suggest that these features have advanced the patient experience, created better health outcomes, increased the patient's well-being, and improved treatment adherence through timely medication reminders [6–9].

As a result, we are now seeing health systems begin to leverage mHealth solutions for PLWHA [10], i.e., EmERGE [11], Epic [12], and PositiveLinks [13]. However, these mobile apps are restricted to patients at specific health systems, as they are commissioned and deployed for use within their patient population only and for a particular purpose. Effective mHealth solutions are not widely available on app store platforms for PLWHA and do not meet the needs of key stakeholders. The BSmart Chart app [14] was developed to meet the needs of stakeholders with a focus on PLWHA and has many desirable features and functionalities, including the ability to connect with healthcare professionals and family and friends (known as "Buddy") in real-time. The stakeholders are empowered with real-time patient information for discussion on a simplified data visualisation platform. Other existing mobile apps that provide HIV self-management services have been reviewed as low-quality and lacking functional features [15].

Background and objectives

mHealth provides real-time availability of data to service providers to monitor patients' status, provide timely intervention and coordinate care beyond the face-to-face clinical encounter. It can reduce routine clinical appointments and decrease the impact on HIV patients' lives and healthcare expenditure [15]. Over 70 % of PLWHA live in resource-poor settings, where many people live below US$ 1 per day [16]. Transportation barriers and costs for accessing HIV clinics are well-known phenomena [17-18],. Even when patients arrive, most are subjected to long waiting times due to the lack of resources, e.g., a shortage of doctors, nurses, and counsellors [19]. This waiting impedes a patient's ability to maximise the benefits from healthcare services and the dwindling economic support for the care of PLWHA. Similar challenges are experienced in developed nations, where funding cuts have forced HIV services to shift towards cost-saving measures, resulting in restricted access to care and support services and longer wait times [20]. According to the national guideline, stable PLWHA are seen on average 2–4 times per year (every 3–6 months) [21]. With the BSmart Chart app, the mHealth solution of interest in this study, stable HIV patients would need to see their physician face-to-face once a year while continuously monitoring laboratory results (blood tests), HIV health status, psychosocial support and routine interaction with healthcare professionals through the app as necessary. Swendeman et al. suggest that HIV population groups with behavioural challenges and comorbidities would benefit most from mHealth tools [9]. For stable patients, the laboratory tests remain routine check-ups as there are often limited differences in the results [15]. These patients are considered suitable for retrieving blood test results on a smartphone app. However, unstable patients' results fluctuate [22], and clinicians have expressed their concerns that retrieving results via the smartphone app may exacerbate patients' anxieties and make them struggle to interpret the results. Hence, a face-to-face consultation is more appropriate.

There is evidence in the literature that mHealth tools in HIV care have the potential to improve the quality of life by empowering PLWHA to take control and enhance patients' engagement and self-management of their disease [1–5]. Evidently, the benefits for patients are well established, whereas the impact on HIV service delivery is limited. The reduction in hospital visits will inevitably reduce the burden on clinics (due to overcrowding and inadequate resources); however, the implications on activity, human resource needs, waiting times, and its cost-effectiveness are unknown. Exploring the impact of mHealth interventions on service delivery for decision-making is crucial to improving health service delivery. However, there is a gap in the capacity and efficiency of the planned intervention(s) compared to the current practice. In the event of limited and dwindling resources, HIV services worldwide, particularly in Sub-Saharan Africa [16], the savings could pave the way for the cost of the intervention, including the acquisition of smartphones for those unable to afford a device (compatible with the mHealth app). Policies should be grounded in solid evidence of their effectiveness in improving performance before being implemented in real-life settings.

Therefore, a web-based interactive planning platform for managing HIV services (known as SmartHIV Manager), developed to support managers, public health programmes and policymakers at local, regional, and national levels, could address this challenge. It captures the realities of an HIV service in a virtual computer environment, capturing individual patients' movements from initial diagnosis to monitoring and antiretroviral therapy (ART) treatment. It includes most of the resources patients consume, such as doctors' and nurses' time, diagnostics, and counselling sessions. The platform, SmartHIV Manager, tests the impact of selected decision scenarios by comparing the current practice against possible changes, e.g., the adoption of mHealth tools. Hence, it is critical to evaluate the operational interventions and alterations to HIV care pathways using the BSmart Chart app and compare its efficiency with current clinical practice in HIV treatment facilities.

The main aims of this study are, therefore, 1) to generate evidence for policymakers for the policies that could be implemented to increase the use of mHealth interventions combined with the current face-to-face consultations and 2) to evaluate the impact of the implementation of mHealth as an intervention, including the purchase of affordable android smartphone devices, on several operational and cost performance metrics relevant to the delivery of HIV services, e.g., activity (new diagnosis and routine check-ups), resource utilisation, costing, and revenue. This should indicate the feasibility and scale of operational improvement and allow informed decisions on the best approaches to reconfiguring the delivery of HIV services.

Methods

The study was conducted in collaboration with Faith Alive Foundation (FAF), Jos, Nigeria, a non-governmental organisation (NGO) that provides care for about 7,500 PLWHA and operates small satellite clinics in remote areas of North-central Nigeria. However, PLWHA in those remote settlements often travel a great distance to access care at FAF's main facility, where they present for their routine appointments, ARV refills, laboratory investigations, and interpretation of results.

To evaluate the impact of interventions, we developed a discrete event simulation (DES) model for managing HIV services called SmartHIV Manager. The model, a web-based simulation platform, represents the entire pathway for PLWHA, covering diagnosis, treatment, monitoring, pharmacy, and counselling. The modelling framework represents the complexity of HIV services and the pathway of PLWHA within the system.

DES is a simulation technique used in healthcare to model and analyse healthcare systems, processes, and patient flow, including patient waiting times, resource consumption, and the impact of policy, procedure, and resource allocation changes [23]. Therefore, the DES technique was selected for the platform as it needs to represent the flow of patients, resources, and processes in the healthcare system through a series of discrete, time-stamped events, allowing healthcare managers to detect bottlenecks, analyse the impact of changes, and maximise resource use. For more than four decades, DES has been successfully utilised in healthcare contexts, such as demand and capacity planning, health service redesign, chronic disease management, and infectious diseases [24,25].

The model's purpose is to support key decision-makers in the optimal planning and management of HIV services, with a focus on ease of use rather than technical complexity. Therefore, the model is translated into a decision-support tool by integrating DES with a user-friendly interface (Fig. 1).

SmartHIV Manager was developed to support service managers and policymakers in the fight against HIV/AIDS without needing technical assistance. The front interface with control buttons is simple to use, and the input parameters can be customised so that the model is service-specific, irrespective of country, including demand, diagnosis, prevention, treatment, monitoring, costing, patient pathway, and human resources.

The simulation tool captures the HIV service to a sufficient level of detail, enabling key decision makers to evaluate an infinite number of "what if" scenarios and assess the impact of change, not just on one area of the system but also on its knock-on effect on other parts of the system (either directly or indirectly). For example, why limit the evaluation of mHealth as an intervention to activity and cost-effectiveness? How does mHealth affect service demand, utilisation of resources, staff requirements, budgeting, and financial planning? A myopic view of such challenges might lead to erroneous results and, as a result, a suboptimal solution.

SmartHIV Manager (see Fig. 1) was configured with two sets of input parameters: Current Practice (CP) and Scenario. Users can set their input parameters for CP (i.e., as is or status quo) against scenario(s) of interest (e.g., reduction in the number of visits due to mHealth intervention). This allows practitioners to stress test the system with an exhaustive set of easy-to-understand visualisations, forecasting over a 3-, 5- and 10-year period. The tool's dashboards cover all the key areas of concern in managing HIV, generating a wide range of outputs, such as prevention, UNAIDS 95–95–95 targets, budgeting, resource planning, and monitoring and evaluation.

The modelling approach

According to the World Health Organization (WHO) Consolidated guideline [22], globally, HIV services typically provide five stages of care and treatment: prevention, diagnosis, treatment, monitoring, and disease progression. At each stage of the patient pathway, resources are consumed in time, human and non-human resources. Through DES, resources are attached as patients flow into the system, a core feature of this modelling framework, e.g., a physician, nurse, rooms, blood tests, a counsellor, and pharmacy. As patients move through the system, their attributes are incorporated, e.g., age group, sex, ART class, pregnancy, and patient type (naïve or treatment-experienced). Furthermore, the number of times a patient is monitored per year, their comorbidities, whether a patient's HIV viral load is suppressed or not, if a patient adheres to treatment, viral load/CD4 count, and clinical outcomes are all modelled to depict a real-life patient's journey and HIV service provided within a simulation environment. Uncertainty and variation are captured through statistical distributions, including treatment times, waiting times, human resources, and costing. SmartHIV Manager is developed using Java Spring Boot, Spring Data, Spring Security, and Thymleaf. There is no available information in the literature as to the previous use of such web-based technology.

The animated front interface enables users to interact and communicate, allowing them to observe the behaviour of the HIV system (and patient pathway) under various conditions. The simulation model was developed in collaboration with key stakeholders, including HIV physicians, service managers, nurses, policymakers, programme implementers, and researchers across four different nations (Nigeria, South Africa, the United Kingdom, and Kenya). At each stage of model development, stakeholders' feedback was used to refine the model and repeated until they were satisfied. As a result, the pathway was captured in sufficient detail to be relevant to a wide range of HIV services worldwide.

Data sources and input parameters

Demand, pathway-related characteristics (e.g., mix of resources, treatment times, number of visits), treatment effectiveness (e.g., viral load failure rate), and costs are all inputs used to power SmartHIV Manager. All cost-related information was gathered in an international reserve currency (i.e., US dollars), including first- and second-line ART costs per person per year, laboratory costs per person per year, overhead and personnel expenditures per person per year, and mHealth-related costs, such as an annual subscription fee and the acquisition of mobile phones. Most of the input parameters were estimated via an in-depth examination of patient-level and national data. When no data was available, literature and expert opinion were employed. The list of input parameters can be found in Supplementary File 1: Table S1.

Validation and verification

We used black-box and white-box validation techniques to validate the simulation model, SmartHIV Manager. White-box validation involved HIV professionals verifying the HIV patient pathway and the simulation model. Moreover, the model is checked to ensure that the inputs are fit and represented accurately.

Black-box validation compared the results generated by SmartHIV Manager with data observed at two centres in Nigeria and one in Kenya. The results were within 5 % on either side of the expected outcome, suggesting that the model was deemed valid and ready for use in practice. The simulation tool was then tested for logical changes and extreme conditions.

Having developed, statistically validated, and ensured the tool's robustness, we evaluated the effect of implementing the mHealth

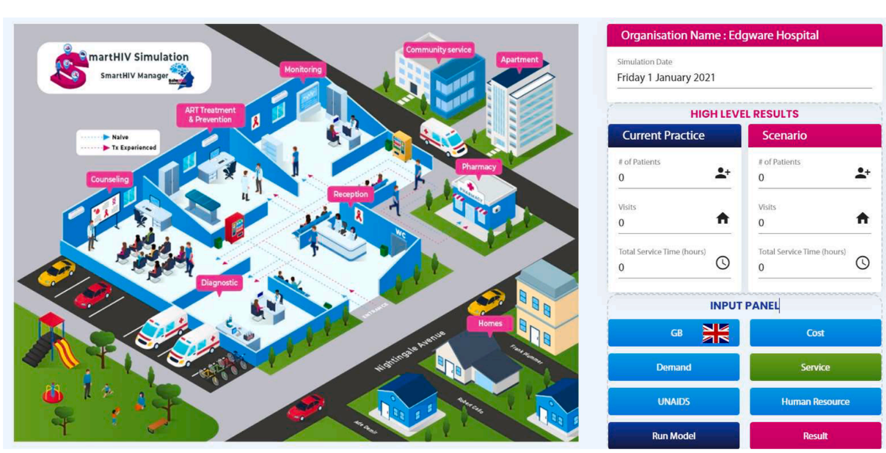

Fig. 1. Interface of the HIV patients' pathways DES model.

intervention (BSmart Chart app) on a number of operational and cost performance metrics, including the acquisition of mobile phones for a group of PLWHA who are unable to afford a device (at $40/device [26]).

BSmart chart app

Bohemian Smartlytics' Comprehensive HIV/AIDS Review and Treatment (BSmart Chart) app puts patients' interests at the centre of disease management [14]. The app supports PLWHA in most aspects of their disease management and connects with their healthcare professionals and buddies (e.g., family and friends) in real-time. This enables the sharing of encrypted data reports for discussion of therapy, where changes in health and well-being can be notified. Other key features include the ability to track adherence, nutrition, social, cognitive, emotional, satisfaction, and quality of life over time via easy-to-understand visualisation; risk of cardiovascular disease and metabolic syndrome estimated; appointment and medication reminders. Patients can manage their HIV and non-HIV medications, examine drug-drug interactions, and keep track of their medications and refills.

"Your Information Needs" feature enables users to access the desired information from legitimate sources on HIV-related issues and general health, ensuring the intended benefit with up-to-date information. The brain teaser feature is developed to enhance patients' knowledge and skills in HIV disease through interactive quizzes and exercises.

Nigeria, as a low- middle-income country (LMIC), faces significant socioeconomic challenges, with nearly 40 % of its population living below the poverty line. The digital divide is pronounced, particularly in rural areas where FAF operates. While smartphone penetration in Nigeria is around 50–60 %, access and affordability are major barriers for low-income populations, especially those in rural regions. Many patients at Faith Alive Foundation come from vulnerable backgrounds, dealing with chronic conditions like HIV/AIDS and tuberculosis. These patients often lack the resources to access healthcare, and their digital literacy is generally low.

The BSmart Chart app was successfully piloted at the FAF, assessing the perception, satisfaction, and benefits of PLWHA and healthcare workers (HCWs). The findings suggest that the BSmart Chart app is feasible, acceptable, and satisfactory among patients and HCWs [27]. According to the participants ($N = 50$), the highest performance capacity of the app was supporting HIV self-management through medication and appointment reminders (85.0 %) and regularly monitoring health outcomes (82.2 %).

Results

After extensive discussions and obtaining consent from HIV physicians and the management team at FAF, we identified four possible reductions in the number of clinic visits, i.e., low (↓30 %), medium (↓40 %), high (↓50 %), and very high (↓75 %). Also, four groups of PLWHA who can be offered an Android mobile device free of charge, i.e., low (20 %), medium (30 %), high (40 %), and very high (50 %) were identified. In all, 17 possible combinations of scenarios, including the baseline, were examined. For example, (↓30 %)(50 %) is a scenario based on the assumption that FAF will offer a (*low*) reduction in the number of visits amongst 30 % of the stable patient population (from an average of 4 visits to 2 visits per year), and 50 % of stable patients *(very high)* are provided with an affordable Android phone at no cost. The complete list of the scenarios illustrated as a 4 × 4 matrix is in Table 1.

As of February 2022, FAF provided care to 7,500 PLWHA with an annual HIV incidence rate of 5.9 % [28]. SmartHIV Manager is powered by 93 input parameters covering demand-related inputs, patient attributes, ART medications in use, prevention, treatment times, waiting times, monitoring visits, human resources, costing, and health outcomes. Approximately 75 % of patients are stable on ART with a viral load below 1000 copies per mL (5625 patients). The average cost of care per patient per year is as follows: first-line ART $113, second-line ART $250, laboratory $35, and staff costs and overheads $328 [29,30].

Table 1
Possible combination of scenarios.

		% of PLWHA offered a smartphone			
		Low (20 %)	Medium (30 %)	High (40 %)	Very high (50 %)
Reduction in the number of clinic visits	Low (↓30 %)	(↓30 %)(20 %)	(↓30 %)(30 %)	(↓30 %)(40 %)	(↓30 %)(50 %)
	Medium (↓40 %)	(↓40 %)(20 %)	(↓40 %)(30 %)	(↓40 %)(40 %)	(↓40 %)(50 %)
	High (↓50 %)	(↓50 %)(20 %)	(↓50 %)(30 %)	(↓50 %)(40 %)	(↓50 %)(50 %)
	Very high (↓75 %)	(↓75 %)(20 %)	(↓75 %)(30 %)	(↓75 %)(40 %)	(↓75 %)(50 %)

Notes: The value in the first brackets shows the percentage of the stable patient population offered a reduced number of clinical visits. The second represents the percentage of PLWHA offered a smartphone. Down arrow means a reduction.

With the implementation of the BSmart Chart as an mHealth intervention, we assume that stable HIV patients would see their physician face-to-face twice a year (from the current four visits), while continuously monitoring blood test results, HIV health status, and connecting with healthcare professionals within the app. The reduction in visits will not affect the ART and laboratory costs, whereas staff costs and overheads may decrease by up to 50 % (i.e., from $328/patient/year to $164/patient/year).

PLWHA in Nigeria, as in many sub-Saharan African countries, face significant socioeconomic vulnerabilities outside the routine HIV care, which is still subsidised by foreign aid. However, when these patients are subjected to various charges and fees at health facilities as the resources are dwindling, they may be discouraged from accessing treatment, which may result in fewer scheduled visits and non-adherence to medication, which may negatively impact patient treatment outcomes and public health [31].

According to the report by Dauda et al. [31], PLWHA in Nigeria spend on average 619 Nigerian Naira (NGN), which is $1.50, on transportation costs, 1,235 NGN ($2.99) on user fees (e.g., medical expenses). The value of time spent is around 573 NGN ($1.39) for each outpatient visit. The average burden on a patient, calculated as a percentage of daily income, stands at 187 %, indicating that out-of-pocket expenses to use services present a severe economic burden on patients, especially in Nigeria. Therefore, any reduction in the number of visits with the assistance of mHealth intervention can only be welcomed by patients and service providers, which would lead to improved health outcomes and economic benefits for patients while releasing capacity for HIV services, which are already struggling to cope with existing demand and new infections.

Service demand

We ran the simulation model for a period of five years (Jan 2022–Dec 2026) and generated results for each scenario shown in Table 1. Table 2 shows the outputs for the current practice (baseline outputs) with no intervention. The service demand is separated by patient type, i.e., naïve, those on treatment for <12 months from diagnosis, and those treatment-experienced (Tx) for >12 months. Based on the 5.9 % HIV incidence rate in Jos, Nigeria, by the year 2026, FAF should expect to care for 9,468 Tx experienced and 812 naïve patients, resulting in 41,938 and 7,179 visits to the clinic in 2026, respectively.

Fig. 2 shows the efficiency for all 16 scenarios over the five years. The line graph in the secondary y-axis illustrates the expected reduction in the number of visits, e.g., between January 2022 and December 2026,

Table 2
Operational and cost-related outputs for current practice.

SERVICE DEMAND	Current Practice (CP)					
No of Patients by Patient Type	2022	2023	2024	2025	2026	Total
Naïve	643	684	722	763	812	3,624
Tx Experienced	7,365	7,840	8,359	8,909	9,468	*N/A*
No of Visits by Patient Type						
Naïve	5,668	5,955	6,316	6,678	7,179	31,796
Tx Experienced	29,903	32,971	35,851	38,823	41,938	179,486
HUMAN RESOURCES - *Required No of Staff by Type*						
Doctor	49	54	58	63	68	*N/A*
Pharmacist	10	10	12	13	13	*N/A*
Medical Lab Scientist	15	17	18	19	20	*N/A*
HIV Specialist Nurse	12	13	14	15	17	*N/A*
General Nurse	9	10	12	12	13	*N/A*
BUDGETING - *Costs by Expense Type*						
First Line ART	$864,484	$919,312	$977,811	$1,038,606	$1,102,914	$4,903,127
Second Line ART	$54,400	$92,550	$131,750	$172,200	$214,525	$665,425
Laboratory Costs	$275,381	$297,704	$321,318	$345,821	$371,666	$1,611,890
Staff Costs and Overheads	$2,580,705	$2,789,902	$3,011,204	$3,240,837	$3,483,032	$15,105,680
Total cost of HIV care	$3,774,970	$4,099,468	$4,442,083	$4,797,464	$5,172,137	$22,286,122
Direct and Indirect costs for people seeking HIV services						
User fees for HIV Care per visit (1,235 NGN, $2.99/visit)	$106,357	$116,389	$126,079	$136,048	$146,860	$631,733
Transportation costs (619 NGN ~ $1.50/visit)	$53,357	$58,389	$63,251	$68,252	$73,676	$316,923
Value of time spent (573 NGN ~ $1.39/visit)	$49,444	$54,107	$58,612	$63,246	$68,273	$293,682
Total cost of direct/indirect cost to patients	$209,157	$228,885	$247,942	$267,546	$288,808	$1,242,338

based on the scenario (↓75 %, 50 %), 60,267 fewer clinic visits are expected by stable PLWHA at FAF (from the current practice of 179,486 visits down to 119,219 visits, i.e., 179,486–60,267). Note that scenarios with the same percentage of reductions in visits (e.g., ↓75 %) have a similar impact on service demand; hence, activity remains the same across all scenarios.

Table 3 illustrates five-year operational and cost-related efficiencies and the difference between current practice and mHealth intervention for scenarios (↓30 %, 50 %), i.e., the worst outcome out of the 16 scenarios for FAF. Based on this scenario, FAF would expect to reduce the number of visits for 30 % of its stable PLWHA and acquire mobile phone devices for 50 % of its stable patient population. A reduction of 25,772 visits is expected over the five years (by the end of 2026). The metrics for the scenario (↓30 %, 50 %) can be derived by taking the difference between the current practice (the figures in Table 2) and the efficiency outputs in Table 3, e.g., the expected number of visits in the year 2024 by Tx experienced patients is 30,702 (i.e., 35,851–5,149).

Human resource

The Workload Indicators of Staffing Need (WISN) [32] were implemented as part of the SmartHIV Manager's ability to establish human resource needs, a methodology developed by the WHO. The WISN is based on healthcare workers' workload, which establishes the required staff for a given healthcare facility and evaluates its workload pressure. According to Table 2, under no intervention, in 2022, FAF needs 49 doctors to ensure quality and timely care is provided for their patients, whereas 68 doctors will be needed by 2026 (due to an increase of 2,103 patients in 5 years).

Hospital resource use, as expressed in the number of hours required to treat HIV patients, should decrease. Under this scenario (↓30 %, 50 %), nine fewer doctors are needed in 2022 and 2023 (Table 3), releasing workload pressures to a certain degree (from 49 doctors to 40). A significant benefit is seen under scenario ↓75 % (Fig. 3), reducing the required number of doctors and nurses by 19 and 5 in 2022, respectively.

Therefore, the adoption of the BSmart Chart app could lead to improved efficiencies, free time, and a reduced workload for doctors and nurses. This will help FAF provide better, safer patient care and critical attention for non-stable patients. Additional efforts can be invested to support adherence to medication and retention in care.

Budgeting

Staff costs and overheads account for 68 % of expenses at FAF, followed by medication (24.5 %) and laboratory costs (7.5 %). Access to ART drugs in LMICs is usually covered by donor organisations, such as the Global Fund, the President's Emergency Plan for AIDS Relief (PEPFAR) and Bill and Melinda Gates Foundation [27,33]. FAF is an NGO, and any form of savings without compromising patient safety and quality of care will go a long way. mHealth intervention will not impact ART and laboratory costs; hence, savings can only be made from staff costs and overheads. The highest cost of mHealth intervention will be in the first year of implementation, i.e., the annual maintenance cost of the BSmart Chart app and the cost of mobile phone acquisition. Based on the scenario (↓30 %, 50 %), the first-year (2022) cost is expected to be $324,072 (see Table 3), where 50 % of stable patients are provided with a low-grade smartphone free of charge (at a cost of $40 each) with an annual maintenance fee of $27.05/patient to have full access to the app. Note that all patients (i.e., Tx experienced) at FAF and naive patients who started treatment each year are offered the app. Due to the reduction in the number of clinic visits, from 4 to 2 visits per year, 11 % savings is expected in staff costs and overheads in 2022 ($290,067) with a net saving of -$34,005 (i.e., $290,067 - $324,072). Accounting for direct and indirect costs for patients seeking HIV services in the form of user fees for HIV care per visit, transportation costs, and the value of time spent (i.e., $24,067), the total savings for the service and patients combined stand at -$9,938 for the year. Even in a worst-case scenario, FAF reaches the breakeven point at the end of year 1, with savings of more than $100,000 per year in subsequent years ($566,484 in 5 years).

As the percentage of stable patients using the mHealth app to reduce clinic visits rises, stark savings are noticed for patients and services. For example, a total savings of $1,783,353 under scenario (↓50 %, 50 %) over five years, between 2022 and 2026, of which $235,841 are direct/indirect cost savings to patients. Therefore, such investments are outweighed by cost reductions with better outcomes.

Discussion

This study investigated the impact of implementing mHealth intervention on HIV service delivery, assessed the operational and cost-related metrics, and demonstrated that adopting digital solutions (e.g., the BSmart Chart app) is feasible, cost-effective, and acceptable by

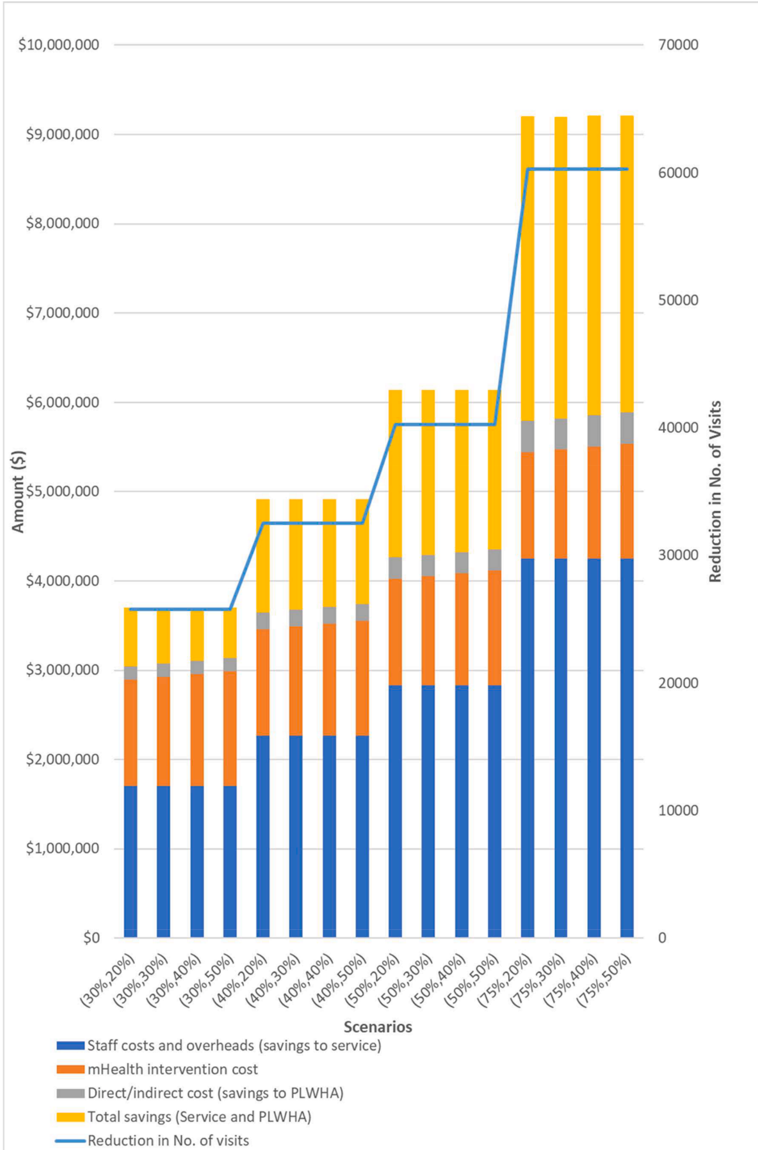

Fig. 2. Cost and operational efficiencies for all 16 scenarios over a five-year period (January 2022 – December 2026). mHealth: Mobile Health, PLWH: Patient living with HIV.

Table 3
Five-year operational and cost-related efficiencies (2022–2026). The difference between current practice and mHealth intervention for scenario (↓30 %, 50 %).

Efficiency (Current Practice-Scenario)	2022	2023	2024	2025	2026	Total
Service Demand						
Reduction in no of visits	4,093	4,676	5,149	5,658	6,196	25,772
Human Resources						
Reduction in no of Doctors	9	9	10	12	12	N/A
Reduction in no of Pharmacists	3	3	3	3	3	N/A
Reduction in no of Medical Lab Scientists	3	3	3	4	4	N/A
Reduction in no of HIV Specialist Nurses	3	3	3	3	3	N/A
Reduction in no of General Nurses	3	3	3	3	3	N/A
Budgeting						
Reduction in Staff Costs and Overheads	$290,067	$314,208	$338,676	$364,736	$392,222	$1,699,909
Cost of mHealth intervention	$324,072	$218,119	$232,097	$247,261	$263,416	$1,284,964
Surplus (savings)	**-$34,005**	**$96,089**	**$106,579**	**$117,475**	**$128,806**	**$414,945**
Reduction in direct/indirect cost (savings to patients)	$24,067	$27,495	$30,276	$33,269	$36,432	$151,539
Total savings (service & patients)	**-$9,938**	**$123,584**	**$136,855**	**$150,745**	**$165,239**	**$566,484**

PLWHA and service providers. Using SmartHIV Manager, we ran a combination of scenarios based on different adoption strategies to evaluate their feasibility and impact. Even the worst-case scenario resulted in significant efficiencies and cost savings due to a reduction in visits and fewer human resource requirements. The study site, FAF, currently operates with >100 % of available doctor capacity (i.e.,

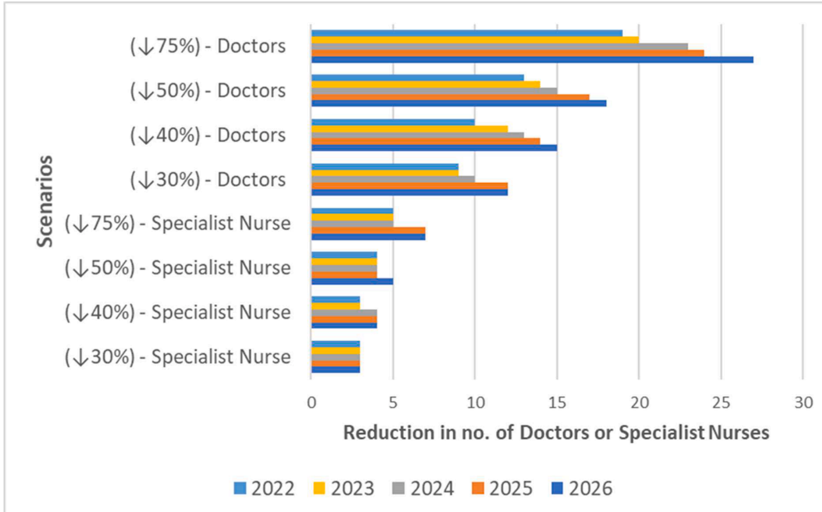

Fig. 3. Reduction in the number of doctor and nurse requirements under scenarios ↓30 %, ↓40 %, ↓50 % and ↓75 % between 2022 and 2026.

available doctors against required numbers); fewer doctor requirements would translate to a release of existing pressure on staff and the limited health facility, thus the opportunity to provide high-quality and the most needed compassionate care. Furthermore, it alleviates the problems of extremely crowded clinics and long waiting times. This scenario is highly feasible as it requires minimal changes to existing practices while still yielding benefits. It could be a practical starting point for FAF, given that many facilities may be hesitant to adopt major changes, especially if they lack the necessary staff to support the deployment and implementation of the BSmart Chart app.

For facilities with adequate staffing and prior experience in deploying digital solutions, the moderate scenario (↓40 %, 40 %) could be a feasible option. This scenario assumes a mid-range adoption of the BSmart Chart app, such as a 40 % reduction in clinical visits and 40 % of patients offered a smartphone. It has demonstrated balanced improvements in both efficiency (e.g., 32,500 fewer clinical visits over five years) and cost savings ($1.35 million). The moderate adoption rate allows for a gradual transition, making it practical for many healthcare settings that are ready for moderate process changes.

While the best-case scenario (i.e., ↓75 %, 50 %) demonstrated the most significant improvements in efficiency and cost-savings, it may be less feasible in the short term due to the high level of change required. However, it provides a valuable target for long-term planning and gradual implementation.

Factors such as available resources, staff training capabilities, patient readiness to adopt new technologies, and existing infrastructure influence the feasibility of each scenario. Healthcare facilities can choose the most appropriate scenario based on their specific circumstances and capacity for change.

The analysis also revealed potential savings from the high burden of out-of-pocket expenses, especially for comorbidities (direct and indirect fees), which are common impediments for PLWHA, who are more vulnerable socioeconomically, especially in LMICs. Such hospital service fees may negatively affect health outcomes, where patients could become less adherent to medication and attend fewer clinic visits [34]. mHealth would be an effective tool for reducing the potential disparities in health outcomes that are envisaged if international HIV donors eventually withdraw their funding of HIV programmes in LMICs. In recent years, the funding available to LMICs has dwindled, and the emphasis has been on high HIV-burden countries to finance their responses to HIV management using more efficient and cost-effective strategies.

The development of this digital tool, tailored to stakeholders' needs, would improve service delivery and prevent inequality in service access, especially in underserved communities and resource-limited settings, by ensuring timely interactions between patients and HCWs. Ultimately, this would minimise the wastage of scarce resources and enhance the judicious distribution of the limited HCW. Furthermore, HIV services in areas where the prevalence rate is high are already struggling to cope with existing and new demands. Even in the worst-case scenario, the model results show significant efficiency gains in terms of operational and financial outcomes. The reduction in the number of visits is beneficial for patients and services, via improved health outcomes and economic benefits for patients (transportation costs and user fees), as well as release of capacity and decrease in operational costs for services.

Further confirmatory studies are needed, including a clinical trial, to understand how the adopted scenarios would impact at a larger scale nationally in Nigeria, a country with about two million PLWHA [35]. As HIV treatment and prevention guidelines are updated periodically, these findings could inform future policies and management guidelines, offering policymakers insights about more effective ways of caring for PLWHA and the opportunity to face the upcoming challenges with greater confidence. Based on the simulation modelling approach adopted for this study and the distributional assumptions used to capture variability in the input parameters, the results are robust enough to be generalised to many HIV clinics in Nigeria and sub-Saharan Africa in general.

The overall operational cost is reduced significantly during the simulated five-year period, with minimal recurrent expenditure. A critical component of the capital cost is the training of HCWs, which is essential for successfully implementing mHealth interventions. This training is vital in ensuring that healthcare staff are adequately equipped to use the technology, as it introduces them to the mHealth platform, troubleshoot technical issues, and understanding workflows that integrate mHealth into clinical practice.

Training also covers key areas such as data management, patient interaction through digital platforms, and safeguarding patient privacy and confidentiality with encrypted information. Importantly, the system's design minimises the need for IT-savvy HCWs, as its basic interface requires minimal IT experience for full functionality. Therefore, despite the initial capital cost of training, it plays a pivotal role in the long-term efficacy and sustainability of mHealth interventions, contributing to reduced operational costs over time [36].

The provision of smartphones to clients at affordable or subsidised rates, along with training for PLWHA on using the app, is essential for the success of mHealth interventions, which depend on patient engagement and their ability to navigate the platform effectively. An initial training, which could include in-person sessions, instructional videos, or user-friendly manuals to ensure patients are comfortable with the technology, was adapted and found to be helpful [37].

Furthermore, continuous technical support tailored to the technological literacy of patients, such as through dedicated helplines or support staff, is crucial for maintaining long-term engagement. This ongoing assistance helps optimise the benefits of the intervention, ensuring the sustainability of mHealth solutions. Despite the need for initial support, the app's user-friendly interface requires minimal IT experience, allowing users to quickly become familiar with its functions, thus making the platform accessible to a broad range of individuals.

Our study demonstrates that mHealth tools developed to meet stakeholders' needs, such as the BSmart Chart app, offer a feasible, efficient, and cost-saving approach for PLWHA and HIV services. A large body of evidence suggests that mHealth is an effective digital solution providing efficient, cost-effective, and patient-centred care [38]. The medical advancements made in the field of HIV and the scaling of ART globally gave mHealth applications the potential to transform HIV care beyond suppression. This is an opportunity to support existing practices in many ways, such as managing comorbidities and timely intervention due to poor medication adherence, all for a better quality of life and improved health outcomes [33].

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CRediT authorship contribution statement

Eren Demir: Conceptualization, Data curation, Formal analysis, Methodology, Project administration, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Usame Yakutcan:** Conceptualization, Data curation, Formal analysis, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Adekunle Olatayo Adeoti:** Conceptualization, Data curation, Validation, Writing – original draft, Writing – review & editing. **Christian Isichei:** Conceptualization, Data curation, Validation, Writing – original draft, Writing – review & editing. **Shola Adeyemi:** Conceptualization, Data curation, Methodology, Project administration, Software, Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.hlpt.2024.100937.

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