ARIZONA STATE UNIVERSITY College of Health Solutions

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BMI 593 Applied Project

Digital Health in Africa: A Systematic Review of the Impact of Digital Health Technology on Communicable Disease Outcomes

Submitted by:

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ABSTRACT

Background: Despite the efforts of policymakers and stakeholders, major communicable diseases such as HIV, malaria, lower respiratory infections (LRTIs) and diarrheal illnesses still contribute significantly to mortality rates in African. HIV resulted in 435,000 deaths and is more prevalent in the southern region of Africa. Malaria resulted in 388,000 deaths and was more prevalent in Nigeria and Democratic Republic of Congo. LRTIs resulted in 774,000 deaths and were more prevalent in Central African Republic and Somalia. Finally, diarrheal illnesses resulted in 496,000 deaths and were more prevalent in western region of Africa.

Objective: The purpose of this systematic literature review is to identify quantitative studies on the impact of digital health technologies on the health outcomes of HIV, malaria, lower respiratory tract infections (LRTIs) and diarrheal diseases in African countries.

Methods: A systematic literature review was conducted by extracting data from the following databases: CINAHL, Scopus, PubMed, Pan-African Clinical Trials registry and African Medical Indicus. The keywords used for research in this review were malaria, HIV, diarrhea, LRTIs, telemedicine, mHealth, eHealth and Africa. The search terms used were slightly different for each database. Titles, abstracts, and full texts of the studies were screened along with a quality assessment of the articles. A narrative analysis was then used to synthesize the information into developing themes.

Results: The research gave 1051 hits, and 23 studies were identified based on the inclusion and exclusion criteria. SMS messages were the most common form of digital health technology while most of the studies in this review were conducted in Kenya. For impact of digital health technology, ten studies identified impact on HIV, ten studies identified impact on LRTIs, five studies identified on malaria while four studies identified impact on diarrhea.

Discussion: For HIV, digital health technology improved treatment and testing outcomes, but had a mixed impact on follow-up care. For LRTIs, digital health interventions had mixed impact on treatment outcomes but improved follow-up care outcomes. For malaria, digital health interventions mainly improved test results, but had a mixed impact on treatment outcomes. For diarrheal diseases, digital health interventions improved monitoring and tracking of diarrheal diseases.

Conclusions: This review shows that digital health technology have a mixed impact on the health outcomes of HIV, malaria, LRTIs and diarrheal diseases in Africa. It also shows that SMS messages were the most common form of digital health technology, and that digital health technology was mostly implemented in Sub-Saharan countries like Kenya and South Africa.

Keywords: *Africa, HIV, malaria, LRTI, diarrhea, telemedicine, digital health technology*

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DIGITAL HEALTH IN AFRICA

1. INTRODUCTION

Communicable diseases are estimated to be responsible for more than 25% of all deaths globally, with a staggering 10 million deaths per year [1]. These diseases take a huge toll on public health infrastructure, are often associated with poor socioeconomic conditions, and are the biggest contributors to mortality rate in low income and lower-middle income countries [1].

The World Health Organization (WHO) defines communicable diseases as illnesses caused by the transfer of bacteria, viruses, parasites or fungi from people, insect bites or contaminated food and water [2]. Communicable diseases are usually more prevalent in low-income countries and lower-middle income countries due to poor climate conditions, lack of economic progress, extreme poverty levels, inadequate health policies and inter-tribal conflicts [1]. And according to a 2020 World Bank report, Africa has the highest distribution of low-income and lower-middle income countries with GDPs of less than $1045 to $4095 (see Figures 1 & Table 1) [3]. Thus, it is necessary to analyze the prevalence of communicable diseases in African countries.

Figure 1. Map showing the distribution of income groups across the globe in the year 2020. Highlighted region in red represents Africa which has more low-income and lower-middle countries than other regions [3].

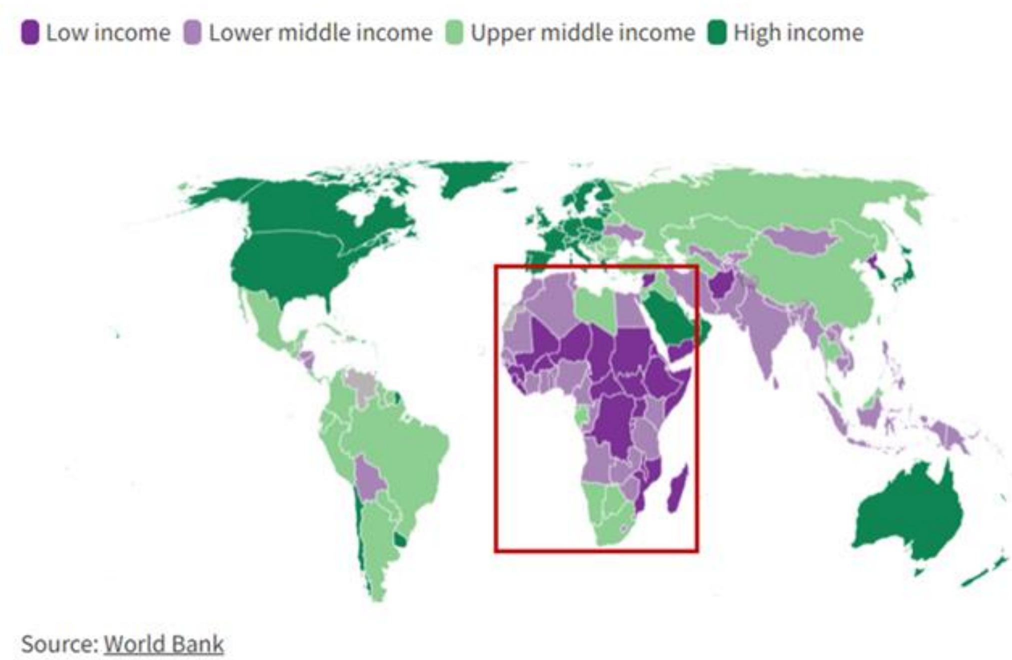


Table 1. Table showing the percentage distribution of income groups in Africa compared to other regions in the world [4].

Geographical locations	Low-income countries	Lower-middle income countries
Africa North	N/A	7.3%
Africa South	88.9%	32.7%
East Asia	3.7%	10.9%
Middle East, West Asia	7.4%	10.9%
Indian sub-continent	N/A	12.7%
Pacific states	N/A	14.6%
South America and Caribbean	N/A	10.9%

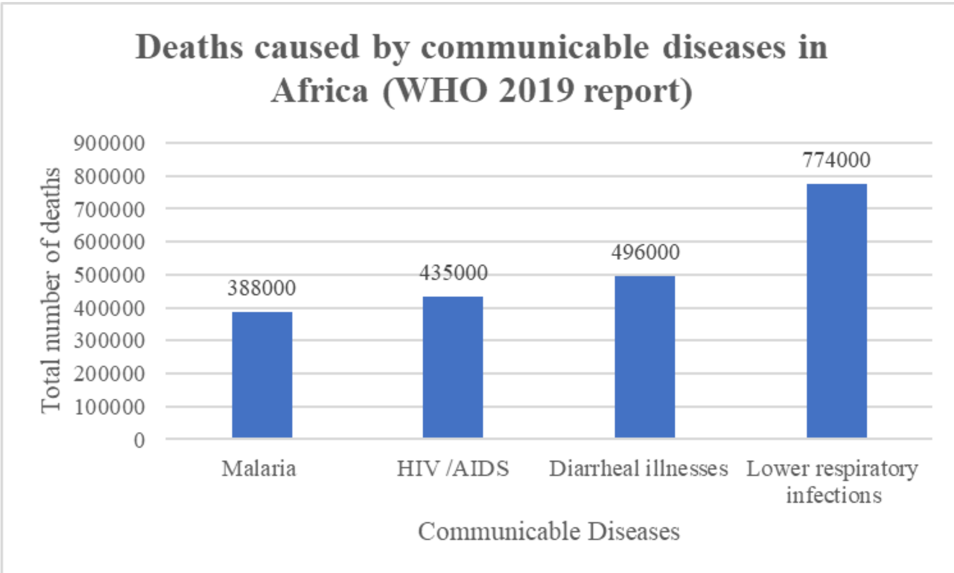
1.1 *Communicable Diseases in Africa*

According to a report by the World Health Organization (WHO), Africa has the highest mortality rates in the world, and communicable diseases are responsible for over 67% of deaths in this region [5]. Data from this report also shows that the major communicable diseases in Africa are HIV, malaria, lower respiratory infections, and diarrheal illnesses [5].

HIV: The human immunodeficiency virus (HIV) is a disease condition that limits the ability of the body to protect itself from various infections by destroying the white blood cells [6]. This virus is transmitted through contact with bodily fluids such as semen and blood via unprotected sex or contaminated needles and syringes [6]. The WHO reported that in 2019, HIV accounted for 435,000 deaths in Africa (see Figure 2) and was more prevalent in Southern African countries like Botswana, Lesotho, South Africa, Eswatini and Zimbabwe [5, 7].

Malaria: Malaria is a disease condition caused by the *Plasmodium* parasite and transmitted by mosquitos to humans through bites [8]. The symptoms of this disease include fevers and headaches which are notoriously hard to diagnose or predict by physicians and can lead to death if left untreated [8]. The WHO reported that in 2019, malaria accounted for 388,000 deaths (see Figure 2) and was more prevalent in Nigeria, Democratic Republic of Congo, Tanzania, and Mozambique [5, 8].

Figure 2. Graph illustrating the number of deaths caused by HIV, malaria, lower respiratory tract infections and diarrheal illnesses in Africa in 2019 [5].



Lower respiratory tract infections (LRTIs): Lower respiratory tract infections or LRTIs are defined as a group of diseases that affect the lower portion of the respiratory system [9]. They include bronchitis, pneumonia, and tuberculosis [9]. This subset of diseases also disproportionately affects children who are under five years old and elderly adults between 65 and 79 years old [9]. The WHO reported that LRTIs accounted for 774,000 deaths in Africa (see Figure 2) [5]. It is also reportedly more prevalent in Central Republic of Africa, Somalia, and Eritrea [10].

Diarrheal Illnesses: This is a disease condition that is characterized by frequent passage of liquid stools and is caused by contact with water, food or people that have been infected by viruses, bacteria, or other parasites [11]. Children under 5 years old are usually more susceptible to diarrheal illnesses and it can lead to dehydration and in certain cases, death [11]. The WHO reported that diarrheal illnesses accounted for 496,000 deaths in Africa (see Figure 2) [5]. Diarrheal illnesses are also more prevalent in Nigeria, Chad, and Niger [10].

Given the prevalence and severity of the infectious diseases, the United Nations organization provides a framework to improve health outcomes in Africa and the rest of the world by implementing its Sustainable Development Goals (SDGs) [12]. These goals are based on the 2030 Agenda for Sustainable Development and the Paris Agreement and there are about seventeen of them [12]. However, only the third sustainable development goal (UN-SDG 3) aims to eradicate the epidemics of HIV/AIDS, tuberculosis, malaria, and other communicable diseases by achieving two main targets [12]. The first target is to eradicate communicable diseases by improving health outcomes in Africa and other parts of the world by the year 2030 (Target 3.3), and the second target is to guarantee unfettered access to vital health services and medicines for everyone by 2030, regardless of socioeconomic status (Target 3.8) [12]. This poses the question:

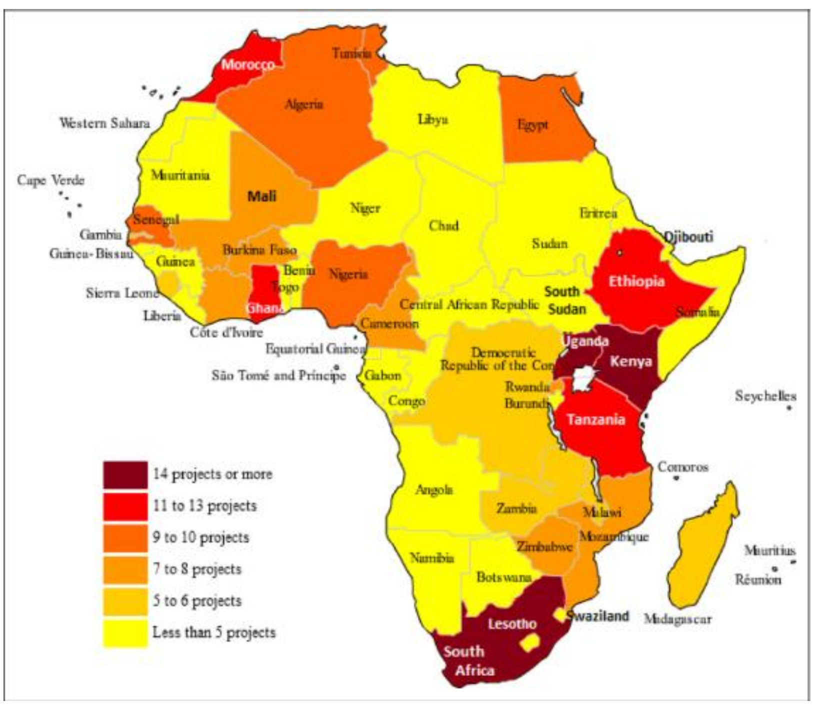
how can we improve health outcomes for communicable diseases and provide unfettered access to healthcare in Africa?

1.2 *Digital Health Technology, the Solution to Communicable Diseases?*

A solution to communicable diseases in Africa is the implementation of digital health technology. Digital health technology can be defined as the use of radios, computers, cell phones, laptops, internet applications and databases to deliver healthcare services and improve population health outcomes [13]. Digital health technology can be sub-categorized based on its healthcare functions: 1) electronic health records (EHRs) for the management of patient and public health information, 2) telemedicine or telehealth used to deliver healthcare services from a distance and, 3) mobile health (mHealth) which is the delivery of health information and care using mobile devices [13].

Despite the potential benefits of digital health technology, only a handful of countries have access to these technologies. From Figure 3, countries like South Africa, Kenya, Lesotho, and Uganda reportedly have the highest access to digital health technology while countries like Morocco, Ethiopia, Tanzania and Ghana continue to make significant progress in implementing digital health technology projects [14]. Other countries still have a long way to go before achieving adequate penetration of digital health technology and so would benefit more from this research [14]. Ola et al. suggest that mobile devices and internet broadband services can improve access to digital health technology, and subsequently improve health outcomes of communicable diseases in Africa [13].

Figure 3. Map showing distribution of digital health technology projects across Africa [14].



1.3 *Research Aim*

The main objective of this review is to examine the implementation of digital health technologies and their impact on the health outcomes of HIV, malaria, lower respiratory tract infections and diarrheal diseases. This objective can be summed up in the following questions: What is the impact of digital technologies on communicable disease outcomes? What digital health technologies are commonly used to combat communicable diseases in Africa?

2. METHODS

2.1 *Databases*

This systematic literature review was performed to aggregate studies that identify the effect of digital health technologies on communicable disease outcomes in Africa. Five bibliographic databases: Scopus, CINAHL, PubMed, Pan African Clinical Trials registry and African Medical Indicus were searched for studies according to a pre-defined inclusion and exclusion criteria.

2.2 *Inclusion & Exclusion Criteria*

Inclusion criteria were randomized controlled studies and studies on digital health technology used in Africa. Exclusion criteria were studies not written in English, studies not covering the use of digital health technology on HIV, malaria, LRTI or diarrhea and studies published before 2010.

2.3 *Search Strategy*

The search strategy was developed based on three search concepts: (i) infectious diseases; (ii) digital health interventions; (iii) Africa. The keywords and database search terms were combined with each other using Boolean operators such as “AND” or “OR” as well truncation, wildcards, and quotations where necessary. The keywords used to formulate search strings in this review were malaria, HIV, diarrhea, LRTIs, telemedicine, mHealth, eHealth and Africa. However, the search terms used were slightly different for each disease and database due to differences in indexing.

An example of the search string used for identifying malaria related studies in the PubMed database is shown below:

(telemedicine [MeSH Terms]) OR (telemedicine [Title/Abstract] OR ehealth [Title/Abstract] OR mhealth [Title/Abstract] OR telehealth [Title/Abstract])) AND ((malaria [MeSH Terms]) OR (malaria [Title/Abstract])

2.4 *Data Extraction & Synthesis*

Search results were exported to Mendeley, and the Mendeley deduplication tool was used to remove any duplicates. Full-text articles were also independently screened for inclusion and review by a single author of the project. The search results are presented in flowchart form

(Figure 4), and the characteristics of the included studies were summarized and presented in Tables 2-4.

The data extracted from the included studies were grouped according to disease conditions and they included: the author's name and year, study location and sample size, interventions and outcomes measured. A summary of the findings and results of the study were grouped according to disease conditions and presented in Tables 5 to 8.

2.5 *Risk of Bias & Quality Assessment*

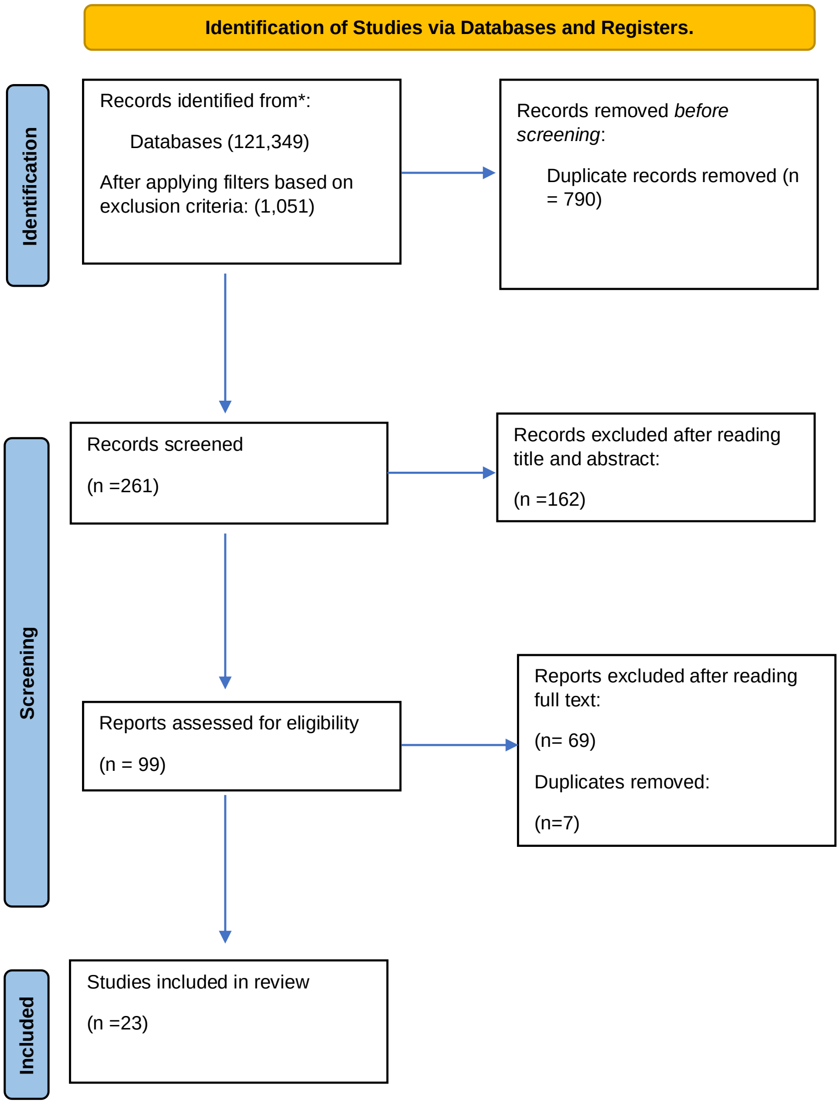
The Critical Assessment Skills Program (CASP) checklist was used to determine the quality and bias of the RCTs included in this study [15]. The following scores: 2 for 'Yes', 1 for 'Can't tell' and 0 for 'No' were used to rate each study. A scale of 0 to 12 is for low-quality research, 13 to 19 for medium-quality research, and 20 to 26 for high-quality research. All final decisions regarding the quality and validity of each study were made by a single author. Results of the quality assessment are depicted in Table S11 under Appendix.

3. RESULTS

3.1 *Study Identification & Selection*

The initial search was based on disease status: HIV/AIDS, malaria, tuberculosis and LRTI, and diarrheal diseases, which resulted in a total of 121,349 hits. Filtering for RCTs, English studies and studies conducted in African settings gave 1,051 citations. After removing duplicates, 261 articles were left for title and abstract screening of which a final total of 23 studies were included in this review (see Figure 4).

Figure 4. Flow diagram illustrating summary of results from database search



3.2 *Study Characteristics*

The characteristics of the studies were summarized and included in Tables 2-4. Table 2 organized the countries and locations of the studies in this review. Kenya was the country with the highest number of studies while Malawi and Niger had the lowest number of studies. Table 3 organized the diseases studied which are listed in order of frequency. HIV and LRTIs were the most studied diseases while diarrhea illnesses were the least studied. Finally, Table 4 organized the digital technologies used. SMS messages were the most frequently implemented digital health technology while web-based applications were the least implemented.

Table 2. Table showing locations of studies analyzed in this review.

Countries	Number of studies	References
Kenya	6	[18, 20, 22, 24, 25, 29]
South Africa	5	[17, 31, 35-37]
Uganda	3	[21, 33, 34]
Cameroon	3	[16, 23, 32]
Tanzania	2	[19, 38]
Zambia	2	[26, 27]
Malawi	1	[28]
Niger	1	[30]

Table 3. Table showing frequency of diseases analyzed in this review.

Diseases	Number of studies	References
HIV	10	[16-25]
LRTIs	10	[26-28, 31-37]
Malaria	5	[26-30]
Diarrhea illnesses	4	[26-28, 38]

Table 4. Table showing frequency of digital technologies analyzed in this review.

Interventions	Number of studies	References
SMS	20	[16-21, 23-29, 31, 32, 34-38]
Mobile applications	4	[26, 27, 30, 33]
Web-based applications	2	[18, 22]

Effectiveness of Digital Health Intervention on HIV

The results from the studies on HIV were summarized and presented in Table 5 according to author, year, themes, outcomes, technology used and its impact on HIV outcomes. The most common themes were classified as follows: five explored HIV treatment [16, 20, 22-24], three explored HIV testing [17, 18, 24], five explored HIV follow-up care [19-21, 23, 25], and one explored financial cost [16]. Some studies reported improvements in HIV outcomes while others reported negative HIV outcomes or no outcomes.

Table 5. Table showing summary of findings from studies on HIV.

Author/Year	Country	Digital Intervention	Themes	Outcomes	Impact
Bigna et al, 2014 [16]	Cameroon	SMS, Phone calls	Treatment, Financial Cost	Attendance, Cost effectiveness	Improved cost and attendance
De Tolly et al, 2017 [17]	South Africa	SMS	Testing	Health counselling and testing	Improved counselling and testing
Finocarrhio-Kessler et al, 2018 [18]	Tanzania	Internet-based tracking system	Testing	HIV testing in infants	Improved HIV testing in infants
Hyuha et al, 2021 [19]	Tanzania	SMS messages	Follow-up care	Follow-up to HIV care	Improved follow up to HIV care
Kinuthia et al, 2021 [20]	Kenya	SMS messages	Treatment, Follow-up care	Adherence, Attendance, Clinical follow-up	No impact on adherence, clinical attendance and follow-up care
Kiwanuka et al, 2018 [21]	Kenya	SMS, Phone calls	Follow up-care	Follow-up visits	Reduced follow up visits
Kurth et al, 2019 [22]	Kenya	Internet-based counselling program	Treatment	Adherence	No impact on adherence
Mbuagbaw et al, 2012 [23]	Cameroon	SMS messages	Treatment, Follow-up care	Adherence, Follow-up visits	Improved adherence, Reduced follow-up visits
Odeny et al, 2014 [24]	Kenya	SMS messages, Phone calls	Treatment, Testing	Attendance, Testing in infants	Improved attendance and HIV testing in infants
Van der Kop et al, 2018 [25]	Kenya	SMS messages, Phone calls	Follow-up care	Follow-up visits	Reduced follow-up visits

<u>HIV Treatment</u>: Two studies reported that digital health technology improved clinical attendance by HIV patients. Bigna et al. reported that a combination of phone calls and SMS messages improved clinical attendance from 51% up to 89% [16] while Odeny et al. reported that SMS messages improved clinical appointments from 11.8% to 19.6% [24]. Alternatively, Kinuthia et al. reported that SMS messages had no impact on clinical attendance (88.2% vs 88.6% and 88.8%) [20]. Only one study reported that digital technologies improved adherence in HIV. Mbuagbaw et al. reported that SMS messages improved ART adherence from 66.7% to 71.3% after six months [23]. By comparison, both Kinuthia et al. and Kurth et al. reported that ART adherence was not impacted by either SMS messages or an internet-based program respectively [20, 22].

<u>HIV Testing</u>: All three studies reported that various digital technologies improved HIV testing outcomes. De Tolly et al. reported that motivational SMS messages were greatly improved HIV counseling and testing (HCT) than other types of SMS messages [17]. This is similar to the findings of Odeny et al. who also reported that SMS improved early infant testing compared to the control group (92.0% vs 85.1%, $p = 0.04$) [24]. Finocarrhio-Kessler et al. reported that an internet-based tracking system also improved testing from 54% to 70% of infants [18].

<u>Follow-up care</u>: Only one study reported that digital health interventions improved HIV follow-up care. Hyuha et al. reported that SMS messages improved follow up care from 23% to 77% [19]. Alternatively, Kiwanuka et al. reported that SMS messages reduced follow up visits from 82.8% to 75.4% [21]. Similarly, Van der Kop et al. also reported that SMS messages reduced HIV follow-up visits from 81% to 79% [25]. Mbuagbaw et al. also reported that SMS messages reduced HIV follow-up from 83.8% to 79.2% [23]. On the other hand, Kinuthia et al. reported that SMS messages had no impact on follow up care (12.9% vs 13.8% and 14.4%) [20].

<u>Financial Cost</u>: Bigna et al. reported that SMS messages were reported to be more cost efficient (1.8) than SMS plus call (0.3) and call (1.5) [16].

Effects of Digital Health Intervention on Malaria

This results from the studies on HIV were summarized and presented in Table 6 according to author, year, themes, outcomes, technology used and its impact on malaria outcomes. Four studies explored malaria treatment themes [27-30], while one study each explored financial cost [26] and malaria follow-up care [29]. Some studies reported improvements while other studies demonstrated negative impact on malaria outcomes.

Table 6. Table showing summary of findings from studies on malaria.

Author/Year	Country	Digital Intervention	Themes	Outcomes	Impact
Biemba et al, 2019 [26]	Health facilities in Zambia	Mobile application, SMS messages	Financial cost	Cost efficiency	Reduced cost efficiency
Biemba et al, 2020 [27]	Health facilities in Zambia	Mobile application, SMS messages	Treatment	Supervision	Reduced in supervision of malaria
Steinhardt et al, 2019 [28]	Health facilities in Zambia	SMS messages	Treatment	Quality of care or malaria management	No impact on management for malaria
Talisuna et al, 2017 [29]	Hospitals in Kenya	SMS messages	Treatment, Follow-up care	Adherence, Follow-up care	Reduced medication adherence, Improvement in follow-up visits
Zakus et al, 2019 [30]	Community health centers in Niger	Mobile application	Treatment	Quality of care	Improved quality of care for malaria

Malaria Treatment: Only one study showed that digital health technology improved malaria treatment outcomes. Zakus et al. reported that a mobile application improved the quality of care for malaria from 67.2% to 83.3% [30]. However, other studies reported that digital health technology negatively impacted malaria treatment outcomes. Biemba et al. reported that a hybrid of mobile applications and SMS messages reduced supportive supervision of malaria from 87.7% to 85.7% [27]. Talisuna et al. reported that SMS messages reduced medication adherence from 72.3% to 69.2% [29]. Finally, Steinhardt et al. reported that SMS messages decreased malaria case management for malaria from 16.8% to 12.1% [28].

Follow-up Care: Talisuna et al. reported that SMS messages improved follow-up care from 74.0% to 81.4% on day 3 and improved from 52.5% to 63.4% on day 28 [29].

Financial Cost: Biemba et al. reported that a mobile application/SMS hybrid reduced cost efficiency by increasing the cost of malaria care from USD 6.71 to USD 19.53 [26].

Effects of Digital Health Intervention on Lower Respiratory Tract Infections

The results from the studies on LRTIs were summarized and presented in Table 7 according to author, year, themes, outcomes, technology used and its impact on LRTI outcomes. Seven studies explored the treatment of LRTIs [27, 28, 31-33, 35, 36], two studies reported follow-up care of LRTIs [33, 37], and one study each reported on financial [26)] and behavioral outcomes [35].

LRTI Treatment: Two studies showed that different types of digital health technology had different impact on tuberculosis (TB) treatment success. Cattamanchi et al. reported that a mobile application improved tuberculosis treatment success from 70.9% to 72.7% [33]. Alternatively, Louwagie et al. reported that SMS messages decreased treatment success from 70.1% to 67.8% [35]. Different types of digital health technology also had different impacts on TB treatment completion. Cattamanchi et al. reported that a mobile application improved TB treatment completion from 78.9% to 81.0% [33]. By comparison, Basset et al. reported that SMS messages reduced TB treatment completion rates from 44% to 41% [31]. For medication adherence, two studies reported that digital technologies had no impact. Bediang et al. reported that SMS messages had no impact on medication adherence (99.3% vs 98.5%) [32]. Similarly, Louwagie et al. also reported that SMS messages had no impact (89.7% vs 90.8%) [35]. For pneumonia, studies showed that different technology had different impact on its treatment outcomes. Biemba et al. reported that a mobile application/SMS hybrid intervention improved appropriate treatment methods for pneumonia from 48.9% to 52.3% [27]. Contrastingly, Steinhardt et al. reported that SMS messages reduced accuracy of pneumonia prescriptions from 14% to 10% [28]. Finally, Mwansa-Kwambafwile et al. reported that SMS messages improved TB initiation from 72% and 73% to 87%. [36]. They also reported that SMS messages improved initiation by reducing treatment delay from 13 days and 8 days to 4 days [36].

LRTI Testing: Only one study reported on the impact of digital technologies on LRTI testing. Davis et al. reported that SMS messages had no impact on TB evaluation (14% vs 15%) or TB diagnosis (1.5% vs 1.1%) [34].

Follow-up Care: Studies showed that different digital health technology had different impacts on TB follow-up care. Wagstaff et al. reported that SMS messages improved TB follow-up care from 51.5% to 62% [37]. They also reported that SMS messages reduced follow-up delays from 12.9 days to 9.7 or 11.5 days [37]. Alternatively, Cattamanchi et al. reported that the use of a mobile application had no impact on TB follow-up care (87.3% vs 87.5%) [33].

Financial Cost: Biemba et al. reported that a mobile application/SMS hybrid intervention negatively impacted cost efficiency by increasing the cost of pneumonia care from USD 6.60 to USD 16.97 [26].

Behavior: Studies showed that SMS messages had a mixed impact on promoting healthy behaviors in TB patients. Louwagie et al. reported that SMS messages reduced alcohol abuse in TB patients by reducing AUDIT scores from 13.12 to 8.70 [35]. Alternatively, Louwagie et al. also reported that SMS messages had no impact on smoking tendencies for adults with TB (92.8% vs 94.4%) [35].

Table 7. Table showing summary of findings from studies on LRTIs.

Author & Year	Country	Digital Intervention	Themes	Outcomes	Impact
Bassett et al, 2016 [31]	South Africa	SMS messages, Phone calls	Treatment	TB treatment completion	Reduced TB treatment completion
Bediang et al, 2018 [32]	Cameroon	SMS messages	Treatment	TB treatment success, TB medication adherence	Improved TB treatment success rates, No impact on TB medication adherence
Biemba et al, 2019 [26]	Zambia	Mobile application, SMS messages	Financial cost	Financial cost	Increased costs of pneumonia treatment
Biemba et al, 2020 [27]	Zambia	Mobile application, SMS messages	Treatment	Supportive supervision of pneumonia	Improved supervision of pneumonia
Cattamanchi et al, 2021 [33]	Uganda	Mobile application	Treatment, Follow-up care	TB treatment success, TB treatment completion, TB follow	Improved TB treatment success, No effect on TB follow-up care
Davis et al, 2019 [34]	Uganda	SMS messages	Testing	TB diagnosis, TB evaluation	No impact on TB evaluation or diagnosis
Louwagie et al, 2022 [35]	South Africa	SMS messages	Treatment, Behavior	TB treatment success, TB medication adherence, Behavior	No impact on TB medication adherence, Reduced TB treatment success rate, Reduced alcohol abuse, No impact on smoking habits

Effects of Digital Health Intervention on Diarrheal Illnesses

The results from the studies on diarrheal illnesses were summarized and presented in Table 8 according to author, year, themes, outcomes, technology used and its impact on outcomes of diarrheal illness. Two studies have investigated the treatment of diarrheal diseases [27, 28]. One study looked at financial costs [26] and behavior outcomes [38] separately. Some studies reported a mixed impact in diarrheal disease outcomes, others reported improvements or demonstrated a negative impact on diarrheal disease outcomes.

Treatment: Studies showed that SMS messages negatively impact treatment outcome for diarrheal illnesses. Biemba et al. reported that SMS messages reduced supervision for diarrheal illnesses from 70.3% to 63.8% [27]. Steinhardt et al. reported that SMS messages reduced accuracy of prescription for diarrheal illnesses reduced by 17.1% compared to 2.9% [28].

Financial Cost: Biemba et al. reported a negative impact by digital health intervention on cost efficiency of diarrheal illness. They reported that a mobile application/SMS hybrid intervention increased the cost of care for diarrheal illnesses from USD 9.08 to USD 18.66 [26].

Surveillance & Tracking: Studies showed that some types of SMS messages were more impactful on diarrhea surveillance outcomes compared to other types of SMS messages. Rego et al. reported that a 1-question SMS survey was more effective in provoking responses than a 3-question SMS survey (51.0% vs 43.8%). They also reported that SMS messages with financial incentives had more responses than unincentivized SMS messages (50.6% vs 44.0%) [38]. For reported cases of diarrhea, they reported that daily SMS messages were more effective than weekly SMS messages (51.2% vs 21.9, and finally, incentivized SMS messages were more effective than unincentivized SMS messages (38.7% vs 33.6%) [38]. Alternatively, Rego et al. also reported that neither daily nor weekly SMS messages had an impact on the number of reported diarrhea cases (46.6% vs 48%), %) [38]. Rego et al. also reported that neither 1 question and 3 question SMS messages had any impact on number of diarrhea cases (36.4% vs 36.3%) [38].

Table 8. Table showing summary of findings from studies on diarrheal illnesses.

Author/ Year	Country	Digital Intervention	Themes		Outcomes	Impact
Biemba et al, 2019 [26]	Zambia	Mobile application, SMS messages	Financial cost		Financial cost	Increased costs of diarrhea treatment
Biemba et al, 2020 [27]	Zambia	Mobile application, SMS messages	Treatment		Supportive supervision	Reduced supervision of diarrhea in patients
Rego et al, 2020 [38]	Tanzania	SMS messages	Surveillance & Tracking		Diarrhea surveillance (response rates and reported cases)	1-question & incentivized surveys increased diarrhea response rates, daily surveys increased reported cases of diarrhea, No impact on response rates for daily or weekly reminders, No impact on reported cases for 1 or 3 question survey

4. DISCUSSION

4.1 *Main Findings*

In this review of studies set in Africa, 23 randomized controlled trials were identified and included based on the preset inclusion criteria. The studies in this review were mostly implemented in Kenya (n = 6/23), and the most studied digital health interventions were SMS messages (n = 19/23). Most of the trials in this review reported on the effect of digital health interventions on treatment outcomes of communicable diseases (n = 14), with HIV and LRTIs as the most prevalent disease conditions (n = 10). Overall, the descriptive analysis of this study showed that digital health interventions mostly improved treatment and follow-up care outcomes but had negative or no impact on others.

4.2 *Comparison of Findings*

Most of the studies in this review came from Kenya and South-Africa which are situated in the Eastern and Southern parts of Africa. One reason for this could be that these countries or regions are historically more receptive to technology than other African countries. Jahangirian et al. reported that Kenya and South Africa are more receptive to digital health technology due to the implementation of long-term initiatives and policies [14]. They state that the growth and acceptance of digital health technologies in Kenya can be attributed to their participation in the SHARE (Satellites for Health and Rural Education) initiative in 1985 while South Africa was reported to be one of the pioneers and adopters of telemedicine in Africa from as far back as 1998 [14]. Jahangirian et al. also reported that African countries generally adopted Internet technology rather than mobile technology [14]. This is contrary to findings in this review where SMS or mobile based projects make up a significant portion of digital health interventions assessed.

Findings on HIV in this review suggest that digital health technology can improve HIV treatment and testing outcomes, but negatively impact follow-up care. The most prevalent HIV treatment outcome in this review was clinical attendance. Consequently, it has been reported that parents of children with HIV who use phone calls or text messages have significantly improved clinical attendance [16, 24]. This indicates that both were good enough to improve HIV clinical attendance in the African context due to their capacities as reminders. A different review by Robotham et al. which investigated the effects of digital health on clinical attendance found similar results, albeit to varying degrees [39]. However, this review was conducted across different settings in multiple continents, and so comparisons between the effect of digital health interventions on clinic attendance in various income settings might be needed. Only two trials in this review reported a positive effect on for infant HIV testing, and they both utilized an SMS notification or reminder system [18, 24]. These findings are similar to those presented in a review by Colaci et al. which investigated the use of digital health interventions to improve maternal health outcomes in low-income countries [40]. Osei & Mashamba-Thompson also provide an overview of the utilization of mhealth in treatment support and HIV screening in LICs and LMICs [41]. One conclusion of this study showed that mHealth interventions improved knowledge of modern diagnostic and screening techniques in healthcare workers [41]. Another conclusion of the study showed that mHealth improved disease surveillance and treatment adherence in HIV patients [41]. One con of this study is that mHealth interventions can lead to non-adherence and non-compliance due to alert fatigue [41]. The results of this review also showed that SMS messages reduced the number of follow-up visits in Kenyan HIV-negative adults [22]. This is in contrast to the results of another trial that reported that SMS messages significantly improved follow-up in HIV-positive Tanzanian adults [19]. It is plausible that differences in these findings may be due to differences in study populations (HIV-negative versus HIV-positive adults). It could also be due to cultural differences as some cultures might prefer physical interaction or in-person reminders to digital reminders.

Findings on malaria from this review suggest that digital health technology improved follow-up care but had a mixed impact on treatment outcomes [29, 30]. No relevant reviews were identified on the topic of quality of care or follow-up care for malaria. However, findings on the positive impact of digital health interventions on malaria are not uncommon. A review by Hall et al. maintains that malaria prevention and control can be implemented through the use of mobile phones and SMS reminders in LMICs like Thailand, Myanmar and Brazil [42]. Thus, the findings reported in this review can be assumed to be valid. Alternatively, other findings in this review also suggest that digital health interventions negatively impact malaria treatment outcomes especially medication adherence [29]. These findings are contradicted by Saint-Geron et al. which state that a hybrid SMS/mobile app intervention improved malaria compliance in Brazilian health centers [43]. However, these findings might be different due to the difference in interventions so it might be important to investigate the impact of a mobile application and SMS hybrid on malaria adherence. Additionally, Brinkel et al. reported a significant improvement in the surveillance of malaria, but was results were significantly biased due to a selective reporting of results caused by lack of published literature on applications of mHealth in Africa [44].

The findings on LRTIs in this review suggest that digital health interventions have mixed results on tuberculosis treatment outcomes. Digital health interventions have been reported to have both positive and negative effects on tuberculosis treatment success and completion rates. However, the mixed results of these treatment outcomes may be due to the type of intervention used in each trial. Trials that reported a positive impact on tuberculosis treatment success and completion used mobile (mHealth) or apps, while those reporting negative results used SMS messaging [31, 33, 35]. Similarly, Ridho et al. reported that SMS messages can either improve or have no effect on medication and concluded that there any plans to implement any SMS interventions for medication adherence should be carefully considered [45].

Finally, the findings on diarrheal diseases in this review suggest that the impact of digital health interventions depends on the type of intervention employed. For diarrhea surveillance, financially incentivized SMS messages have been reported to increase the frequency of reported cases and response rates [38]. Although no other relevant reviews reported on the use of financial incentives and SMS messages for diarrheal outcomes, another study by Gibson et al. reported that financial incentives and SMS messages improved polio immunization rates amongst Kenyan children [46]. This finding emphasizes the importance of additional motivators in improving patient health through digital health technology.

4.3 *Strengths & Limitations*

This review seeks to investigate the impact of digital health interventions on major infectious diseases in the African setting. The findings in this study suggest that the effect of digital health interventions may vary depending on the disease, clinical areas, type of intervention and the outcomes assessed. A strength of this review is that it provides an in-depth insight into the implementation of digital health interventions in a region that is often ignored or under-represented in informatics or scientific research. However, this review also has several limitations. This review was a systematic review, but the literature search was limited to five databases PubMed, CINAHL, Scopus, Pan African Clinical Trials and African Medical Indicus. There was no search of grey literature or author consultations and thus, key information might be missed. A second limitation of this review is that it only included trials from 8 out of 54 countries in Africa, of which the majority of the trials were set in Kenya (6/23). This affects how generalizable and applicable the results of this review are to Africa as a whole. A possible reason for this is that the inclusion criteria only involved articles written in English and so could have excluded evidence from certain countries.

Another limitation of this review is that the term: 'digital health intervention' is very broad and consists of very different interventions and thus, it may be counter-productive to pool them together. It is entirely possible that different types of interventions may have completely different effects on communicable disease outcomes. Finally, most of the studies in this review were rated as moderate quality or low quality either due to poor reporting or poor study design. This could be attributed to factors such as lack of funding, privacy and ethical issues, poor infrastructure and an inadequate workforce [7].

4.4 *Recommendations for Future Research*

One major gap in the research for this review was that only a few studies reported on financial or behavioral outcomes for communicable diseases [16, 26, 35]. Although most of the findings for these outcomes were negative, it was not ideal to draw conclusions from such limited evidence. Therefore, future researchers are advised to conduct more randomized controlled trials of the impact of digital health interventions on improving financial and behavioral outcomes of infectious diseases in Africa.

Another major gap in the research for this review was that all the studies in this review focused on the Sub-Saharan region especially in Southern and Eastern Africa. Digital health interventions are implemented all over the African continent and so more research should be done on the application of digital health interventions in often overlooked African countries [39]. Researchers are advised to consider differences in culture, language, health care policy and income status in order to better understand how digital health interventions may benefit the most people and provide a bigger picture for future stakeholders. There should also be more qualitative research into the feasibility of these digital interventions.

Finally, affiliations and collaborations between African countries and interested organizations such as the World Health Organization and United Nations should be encouraged to improve the quality and quantity of future trials. However, any funding or contributions should be acknowledged and reported to avoid any bias.

5. CONCLUSIONS

This review suggests that overall, digital health technology had a mixed impact on health outcomes for HIV, malaria, LRTIs and diarrheal illnesses. SMS messages were the most implemented form of technology and had mixed impact on HIV treatment outcomes but improved surveillance of diarrheal illnesses. SMS messages also improved HIV testing outcomes as well as follow-up care in malaria. Alternatively, SMS messages negatively impacted treatment outcomes for malaria and LRTIs and negatively impacted HIV follow-up care. Under-reported technology such as mobile applications improved treatment outcomes for malaria and LRTIs while evidence on financial and behavioral outcomes were not enough to draw valid conclusions. Most studies in this review were concentrated in the Southern and Eastern regions of Africa and thus, more trials should be implemented to provide future stakeholders and researchers an insight on the effectiveness and feasibility of implementing digital health interventions in different African countries. Future collaborations are also needed to improve the quality of future trials.

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APPENDIX

Table S1. List of African countries used in search strings.

Lesotho, Swaziland, Botswana, Namibia, South Africa, Angola, Cameroon, Equatorial Guinea, Gabon, Congo, Chad, Central African Republic, Congo, the Democratic Republic, Sao Tome and Principe, Burundi, Eritrea, Madagascar, Reunion, Somalia, Comoros, Ethiopia, Rwanda, Djibouti, Kenya, Mayotte, Seychelles, Uganda, Mozambique, Zambia, Malawi, Tanzania, Zimbabwe, Benin, Liberia, Saint Helena, Burkina Faso, Gambia, Mali, Ghana, Mauritania, Senegal, Cape Verde, Cote D'ivoire, Guinea, Niger, Sierra Leone, Guinea-Bissau, Nigeria, Togo, Algeria, Egypt, Libyan Arab Jamahiriya, Morocco, Tunisia, Western Sahara and Sudan.

Table S2. Example of filtered PubMed search terms for Tuberculosis.

(((telemedicine[MeSH Terms]) OR ('telemedicine'[Title/Abstract] OR 'ehealth'[Title/Abstract] OR 'health'[Title/Abstract] OR 'telehealth'[Title/Abstract])) AND ((tuberculosis[MeSH Terms]) OR (tuberculosis[Title/Abstract] OR 'Koch diseases'[Title/Abstract]))) AND (((("africa"[MeSH Terms] OR ((("africa"[Title/Abstract] OR "african"[Title/Abstract] OR "nigeria"[Title/Abstract] OR "ethiopia"[Title/Abstract] OR "egypt"[Title/Abstract] OR "dr congo"[Title/Abstract] OR "Tanzania"[Title/Abstract] OR "south africa"[Title/Abstract] OR "Kenya"[Title/Abstract] OR "Uganda"[Title/Abstract] OR "Algeria"[Title/Abstract] OR "Sudan"[Title/Abstract] OR "Morocco"[Title/Abstract] OR "Angola"[Title/Abstract] OR "mozambique"[Title/Abstract] OR "Ghana"[Title/Abstract] OR "madagascar"[Title/Abstract] OR "cameroon"[Title/Abstract] OR "ivory coast"[Title/Abstract] OR "niger"[Title/Abstract] OR "burkina faso"[Title/Abstract] OR "mali"[Title/Abstract] OR "malawi"[Title/Abstract] OR "zambia"[Title/Abstract] OR "senegal"[Title/Abstract] OR "chad"[Title/Abstract] OR "somalia"[Title/Abstract] OR "zimbabwe"[Title/Abstract] OR "guinea"[Title/Abstract] OR "rwanda"[Title/Abstract] OR "benin"[Title/Abstract] OR "burundi"[Title/Abstract] OR "tunisia"[Title/Abstract] OR "south sudan"[Title/Abstract] OR "togo"[Title/Abstract] OR "sierra leone"[Title/Abstract] OR "libya"[Title/Abstract] OR "Congo"[Title/Abstract] OR "liberia"[Title/Abstract] OR "central african republic"[Title/Abstract] OR "mauritania"[Title/Abstract] OR "eritrea"[Title/Abstract] OR "namibia"[Title/Abstract] OR "gambia"[Title/Abstract] OR "botswana"[Title/Abstract] OR "gabon"[Title/Abstract] OR "lesotho"[Title/Abstract] OR "guinea bissau"[Title/Abstract] OR "guinea bissau"[Title/Abstract] OR "equatorial guinea"[Title/Abstract] OR "mauritius"[Title/Abstract] OR "eswatini"[Title/Abstract] OR "djibouti"[Title/Abstract] OR ("sao"[All Fields] AND "tome"[All Fields])) AND "principe"[Title/Abstract]) OR "seychelles"[Title/Abstract] OR "reunion"[Title/Abstract]

OR "western sahara"[Title/Abstract] OR "mayotte"[Title/Abstract] OR "saint helena"[Title/Abstract])) NOT "african american"[Title/Abstract]))) AND ((clinicaltrial[Filter] OR randomizedcontrolledtrial[Filter]) AND (english[Filter]))

Table S3. List of initial search terms used in the PubMed database and numbers of studies found

Concept	Initial Search terms	Results after filters applied: Clinical or RCTs, African studies, English
Tuberculosis	((telemedicine [MeSH Terms]) OR ('telemedicine'[Title/Abstract] OR 'ehealth'[Title/Abstract] OR 'health'[Title/Abstract] OR 'telehealth'[Title/Abstract])) AND ((tuberculosis [MeSH Terms]) OR (tuberculosis [Title/Abstract] OR 'Koch diseases'[Title/Abstract]))	160
Malaria	(telemedicine [MeSH Terms]) OR (telemedicine [Title/Abstract] OR ehealth [Title/Abstract] OR mhealth [Title/Abstract] OR telehealth [Title/Abstract])) AND ((malaria [MeSH Terms]) OR (malaria [Title/Abstract])	4
HIV	((telemedicine [MeSH Terms]) OR (telemedicine [Title/Abstract] OR ehealth [Title/Abstract] OR mhealth [Title/Abstract] OR telehealth [Title/Abstract])) AND (((HIV [MeSH Terms]) OR (AIDS[Title/Abstract] OR 'AIDS Virus'[Title/Abstract] OR 'human immunodeficiency virus'[Title/Abstract] OR 'human immune deficiency virus'[Title/Abstract]))	10
Diarrheal Diseases e.g., diarrhea, cholera, dysentery	((telemedicine [MeSH Terms]) OR ('telemedicine'[Title/Abstract] OR 'ehealth'[Title/Abstract] OR 'mhealth'[Title/Abstract] OR 'telehealth'[Title/Abstract])) AND (diarrhea [Title/Abstract] OR cholera [Title/Abstract] OR dysentery [Title/Abstract])	2
Lower respiratory infections e.g., bronchitis,	((telemedicine [MeSH Terms]) OR ('telemedicine'[Title/Abstract] OR 'ehealth'[Title/Abstract] OR 'mhealth'[Title/Abstract] OR 'telehealth'[Title/Abstract])) AND (pneumonia [Title/Abstract] OR bronchitis [Title/Abstract] OR bronchiolitis [Title/Abstract])	5

bronchiolitis and pneumonia		

Table S4. List of search terms used in the CINAHL database and numbers of studies found.

Concept	Search Terms	Results after filtering for English Language; Randomized Controlled Trials; Geographic Subset: Africa Expanders - Apply equivalent subjects Search modes - Boolean/Phrase
Tuberculosis	AB (telemedicine or telehealth or ehealth or e-health or mhealth or m-health) AND AB (tuberculosis or mycobacterium tuberculosis or tb)	66
Malaria	AB (telemedicine or telehealth or ehealth or e-health or mhealth or m-health) AND AB malaria	32
HIV	AB (telemedicine or telehealth or ehealth or e-health or mhealth or m-health) AND AB (hiv or aids or acquired human immunodeficiency syndrome or human immunodeficiency virus)	366
Diarrheal Diseases e.g., diarrhea, cholera, dysentery	AB (telemedicine or telehealth or ehealth or e-health or mhealth or m-health) AND AB diarrhea	28
	AB (telemedicine or telehealth or ehealth or e-health or mhealth or m-health) AND AB cholera	5
Neonatal Diseases e.g., sepsis and meningitis	AB (telemedicine or telehealth or ehealth or e-health or mhealth or m-health) AND AB neonatal sepsis	2

	AB (telemedicine or telehealth or ehealth or e-health or mhealth or m-health) AND AB meningitis	4
Lower respiratory infections e.g., bronchitis, bronchiolitis and pneumonia	AB (telemedicine or telehealth or ehealth or e-health or mhealth or m-health) AND AB bronchitis	4
	AB (telemedicine or telehealth or ehealth or e-health or mhealth or m-health) AND AB bronchiolitis	3
	AB (telemedicine or telehealth or ehealth or e-health or mhealth or m-health) AND AB pneumonia	39

Table S5. List of search terms used in the Scopus database and numbers of studies found.

Concept	Search Terms	After filtering for Clinical or RCTs, African studies, English
Tuberculosis	('telemedicine' OR 'ehealth' OR 'mhealth' OR 'telehealth') AND ('tuberculosis' OR 'koch's AND diseases')	29
Malaria	('telemedicine' OR 'ehealth' OR 'mhealth' OR 'telehealth') AND ('malaria')	49
HIV	("telemedicine" OR "ehealth" OR "mhealth" OR "telehealth") AND ('aids' OR 'aids AND virus' OR 'hiv' OR 'human AND immunodeficiency AND virus')	39
Diarrheal Diseases e.g., diarrhea, cholera, dysentery	('telemedicine' OR 'ehealth' OR 'mhealth' OR 'telehealth') AND ('diarrhea' OR 'cholera' OR 'dysentery')	20
Lower respiratory infections e.g., bronchitis, bronchiolitis and pneumonia	('telemedicine' OR 'ehealth' OR 'mhealth' OR 'telehealth') AND ('pneumonia' OR 'bronchitis' OR 'bronchiolitis')	45

Table S6. List of search terms used in secondary databases.

Database	Search Terms	After filtering for Clinical or RCTs, African studies, English
Pan African clinical trials	SMS OR MHEALTH	144
African Medical Indicus	(tw:(telemedicine)) OR (tw:(ehealth)) OR (tw:(telehealth)) OR (tw:(mhealth)) OR (tw:(SMS)) OR (tw:(text messages))	1

Table S7. Characteristics of studies showing the effect of digital health interventions on HIV.

Author & Year	Study Design/Setting	Intervention Type	Length of study	Participant Age (Years)	Sample Characteristics	Outcomes Measured	Major Finding	Major Themes
Bigna et al, 2014 [16]	Hospitals in Cameroon	SMS plus call, call, SMS	4 months	Adult carers (>=18), children (<18)	242 carers of children with HIV	Attendance rate, Cost effective reminder	Text plus call most effective in improving clinical attendance, text message most cost effective	Treatment & Financial cost
De Tolly et al, 2012 [17]	Mobile phone database of South Africans	SMS message (information al and motivational)	Not specified	Not specified	2,553 adult mobile phone users	Uptake of health counselling and testing (HCT)	Increased uptake for HCT than informational SMS	Testing

Finocarrhio et al, 2018 [18]	Hospitals in Tanzania	Internet-based tracking system	4 years	>=18 mothers, <24 weeks	558 HIV positive mothers-pairs	Likelihood of HIV testing in infants	Increased HIV testing in infants	Testing
Hyuha et al, 2021 [19]	Hospitals in Tanzania	SMS	6 months	>=18	255 adult trauma patients	Follow-up to HIV care	Increased likelihood to follow up to HIV care	Follow-up care
Kinuthia et al, 2021 [20]	Clinics in Kenya	SMS (interactive text messages, 1-way text messages)	5 years, follow up two years after delivery	>=14	824 pregnant women living with HIV	Adherence, clinical attendance, clinical follow-up	No effect on adherence (viral load), clinical attendance and follow-up care	Treatment & Follow-up care
Kiwanuka et al, 2018 [21]	Kenyan Communities	SMS with phone call	2 years	15 to 49	662 HIV negative adults	Follow-up visits	Decreased likelihood in follow up visits	Follow up-care
Kurth et al, 2019 [22]	Clinics in Kenya	30 to 60 mins internet-based counselling program	1 year	>=18	236 at risk individuals	HIV treatment adherence	No effect on HIV treatment adherence	Treatment

Mbuagbaw et al, 2012 [23]	Hospitals in Cameroon	Motivational SMS with weekly reminder	6 months	>=21	200 HIV positive adults	HIV treatment adherence, HIV follow-up visits	No in ART adherence, Reduced follow-up visits	Treatment & Follow-up care
Odeny et al, 2014 [24]	Clinics in Kenya	SMS (interactive) and phone calls	not defined	>=18	388 HIV positive pregnant women	Clinic attendance, Early infant HIV testing	Improvement in attendance and early infant HIV testing	Treatment & Testing
Van der Kop et al, 2018 [25]	Clinics in Kenya	SMS (interactive) and phone calls	>1 year	>=18	700 HIV positive adults	HIV follow-up visits	Reduction in HIV follow-up visits	Follow-up care

Table S8. Characteristics of studies showing the effect of digital health interventions on malaria.

Author & Year	Study Setting	Intervention Type	Length of Study	Participant Age (Years)	Sample Characteristics	Outcomes Measured	Major Findings	Themes
Biemba et al, 2019 [26]	Health facilities in Zambia	Mobile application/ SMS hybrid	not specified	>=18	124 health care workers and clinical management staff	Financial cost	Increased costs in treating malaria	Financial cost

Biemba et al, 2020 [27]	Health facilities in Zambia	Mobile application/SMS hybrid	5 months	2-59 months	3690 children with malaria, pneumonia or diarrhea, 69 clinical health workers	Supportive supervision	Decrease in supportive supervision of malaria	Treatment
Steinhardt et al, 2019 [28]	Health facilities in Zambia	SMS	12 months	<5	2360 with either malaria, pneumonia or diarrhea	Quality of care for malaria mgmt.	No improvement in treatment and management for malaria	Treatment
Talisuna et al, 2017 [29]	Hospitals in Kenya	SMS reminders	not specified	Children < 5 and their caregivers	1677 children with malaria	Medication adherence, Follow-up care	Reduced medication adherence, Improvement in follow-up visits	Treatment & Follow-up care
Zakus et al, 2019 [30]	Community health centers in Niger	Mobile application	8 months	children (<5), clinical health workers (=<18)	252 children with malaria, pneumonia or diarrhea, 31 clinical health workers	Quality of care	Improvement in quality of care for malaria	Treatment

Table S9. Characteristics of studies showing the effect of digital health interventions on LRTIs.

Author & Year	Study Setting	Intervention Type	Study Length	Participant Age (Years)	Sample Characteristics	Outcomes Measured	Major Findings	Themes
Bassett et al, 2016 [31]	Hospitals and Clinics in South Africa	SMS, phone calls	36 months	>=18	4903 adults with HIV/TB	TB treatment completion	Decrease in TB treatment completion	Treatment
Bediang et al, 2018 [32]	Treatment and Diagnostic centers in Cameroon	SMS reminder	14 months	>=18	279 patients with tuberculosis	TB treatment success, TB medication adherence	Improvement in TB treatment success rates, No effect on TB medication adherence	Treatment
Biemba et al, 2019 [26]	Health facilities in Zambia	Mobile application/ SMS hybrid	not specified	>=18	124 health care workers and clinical management staff	Financial cost	Increased costs of pneumonia treatment	Financial cost
Biemba et al, 2020 [27]	Health facilities in Zambia	Mobile application/ SMS hybrid	5 months	<5	3690 children with malaria, pneumonia or diarrhea, 69 clinical health workers	Supportive supervision of pneumonia	Improvement in supervision of pneumonia	Treatment
Cattamanchi et al, 2021 [33]	Health facilities in Uganda	Mobile application	8 months	>=18	1913 patients with tuberculosis	TB treatment success, TB treatment	Improvement in TB treatment success, No effect on TB	Treatment & Follow-up care

						completion, TB follow	follow-up care	
Davis et al, 2019 [34]	Communities in Uganda	SMS	12 months	Children from <5 to 14, adults >15	387 household contacts	TB diagnosis, TB evaluation	No improvement on TB evaluation or diagnosis	Testing
Louwagie et al, 2022 [35]	Clinics in South Africa	SMS	14 months	>=18	574 patients with tuberculosis	TB treatment success, TB medication adherence, healthy behavior	No effect on TB medication adherence, Decrease in TB treatment success rate or healthy behavior, Improvement in alcohol abuse, No effect on smoking habits	Treatment & Behavior
Mwansa-Kwambafwile et al, 2021 [36]	Clinics in South Africa	SMS	19 months	>=18	314 TB positive patients	TB treatment initiation	Increased frequency and likelihood of treatment initiation	Treatment

Steinhardt et al, 2019 28	Health facilities in Malawi	SMS	12 months	<5	2360 with either malaria, pneumonia or diarrhea	Quality of care	Decrease in pneumonia prescription	Treatment
Wagstaff et al, 2019 [37]	Clinics in South Africa	SMS (motivational reminder vs generic reminder)	not specified	>18	649 TB positive patients	TB Follow-up care	Improvement in TB follow-up care	Follow-up care

Table S10. Characteristics of studies showing the effect of digital health interventions on diarrheal illnesses.

Author/ Year	Study Setting	Intervention Type	Study Length (Months)	Participant Age (Years)	Sample Characteristics	Outcomes Measured	Major Findings	Themes
Biemba et al, 2019 [26]	Health facilities in Zambia	Mobile application, SMS	not specified	>=18	124 health care workers and clinical management staff	Financial cost	Increased costs of diarrhea treatment	Financial cost
Biemba et al, 2020 [27]	Health facilities in Zambia	Mobile application, SMS	5 months	<5	3690 children with malaria, pneumonia or diarrhea, 69 clinical health workers	Supportive supervision	Reduced supervision of diarrhea in patients	Treatment

Rego et al, 2020 [38]	Communities in Tanzania	SMS surveys (daily vs weekly, incentivized vs non-incentivized, 1-question vs 3-question)	6 months	Guardians (>=18) of children (6 months to 5 years) with diarrhea	141	Diarrhea surveillance (response rates and reported cases)	1-question & incentivized surveys increased diarrhea response rates, daily surveys increased reported cases of diarrhea, No effect on response rates for daily or weekly reminders, No effect on reported cases for 1 or 3 question survey	Surveillance & Tracking
Steinhardt et al, 2019 [28]	Health facilities in Malawi	SMS	12 months	<5	2360 with either malaria, pneumonia or diarrhea	Prescription	Decrease in prescription for diarrheal illness	Treatment

Table S11. CASP Quality Ratings for Included Studies.

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Score
Basset et al, 2016	**Y**	**Y**	**N**	**NYN**	**Y**	**Y**	**N**	**Y**	**N**	**N**	**Y**	**14**
Bediang et al, 2018	**Y**	**Y**	**N**	**NYN**	**Y**	**Y**	**Y**	**Y**	**?**	**N**	**Y**	**17**
Biemba et al, 2020	**Y**	**Y**	**Y**	**NNN**	**Y**	**?**	**N**	**Y**	**N**	**Y**	**Y**	**15**
Bigna et al, 2014	**Y**	**Y**	**Y**	**?YY**	**Y**	**Y**	**Y**	**Y**	**?**	**Y**	**Y**	**23**
Cattamanchi et al, 2021	**Y**	**Y**	**Y**	**NYY**	**Y**	**Y**	**Y**	**Y**	**?**	**Y**	**Y**	**23**
Davis et al, 2019	**Y**	**Y**	**Y**	**?NN**	**N**	**Y**	**Y**	**Y**	**N**	**N**	**Y**	**15**
De Tolly et al, 2012	**Y**	**Y**	**N**	**NNN**	**N**	**N**	**?**	**Y**	**Y**	**N**	**Y**	**11**
Finocarrhio et al, 2018	**Y**	**Y**	**N**	**?YY**	**Y**	**Y**	**Y**	**Y**	**?**	**Y**	**Y**	**22**
Hyuha et al, 2021 Parallel	**Y**	**Y**	**Y**	**YYN**	**Y**	**N**	**N**	**Y**	**Y**	**Y**	**Y**	**20**
Kinuthia et al, 2021	**Y**	**Y**	**Y**	**NNY**	**Y**	**Y**	**Y**	**Y**	**?**	**Y**	**Y**	**21**
Kiwanuka et al, 2018	**Y**	**Y**	**Y**	**NNN**	**Y**	**?**	**Y**	**Y**	**?**	**Y**	**Y**	**18**
Kurth et al, 2019	**Y**	**Y**	**Y**	**NNN**	**Y**	**?**	**Y**	**N**	**?**	**Y**	**Y**	**16**
Louwagie et al, 2022	**Y**	**Y**	**Y**	**NYY**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**24**
Mbuagbaw et al, 2012	**Y**	**Y**	**Y**	**NYY**	**Y**	**Y**	**Y**	**Y**	**?**	**Y**	**Y**	**23**

Mwansa-Kwambafwile et al, 2022	**Y**	**Y**	**Y**	**NYY**	**Y**	**Y**	**Y**	**Y**	**?**	**Y**	**Y**	**23**
Odeny et al, 2014	**Y**	**Y**	**Y**	**NNN**	**Y**	**?**	**Y**	**Y**	**?**	**Y**	**Y**	**18**
Rego et al, 2020	**Y**	**Y**	**Y**	**YNN**	**Y**	**Y**	**N**	**Y**	**?**	**Y**	**Y**	**19**
Steinhardt et al, 2019	**Y**	**Y**	**Y**	**NNN**	**Y**	**Y**	**Y**	**Y**	**?**	**Y**	**Y**	**19**
Talisuna et al, 2017	**Y**	**Y**	**Y**	**NNY**	**Y**	**Y**	**Y**	**Y**	**?**	**?**	**Y**	**20**
Van der Kop, 2018	**Y**	**Y**	**Y**	**NNY**	**Y**	**Y**	**Y**	**Y**	**?**	**Y**	**Y**	**21**
Wagstaff et al, 2019	**Y**	**Y**	**Y**	**NYY**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**24**
Zakus et al, 2019	**Y**	**Y**	**Y**	**???**	**Y**	**?**	**Y**	**N**	**N**	**Y**	**Y**	**18**

Legend for Critical Appraisal Skills Program (CASP) questions scoring

Yes (Y) = 2; Can't Tell (?) = 1; No (N) = 0
Q1: Did the study address a clearly focused research question?
Q2: Was the assignment of participants to interventions randomized?
Q3: Were all participants who entered the study accounted for at its conclusion?
Q4: Were participants or investigators or analysts blinded? (6 points possible)
Q5: Were the groups similar at the beginning of the randomized controlled trial?
Q6: Did each group receive the same level of care apart from the intervention?
Q7: Were the effects of intervention reported comprehensively?
Q8: Was the precision of the treatment effect reported?
Q9: Do the benefits of the experimental intervention outweigh the harms and costs?
Q10: Can the results be applied to your local population/in your context?
Q11: Would the intervention provide greater value than existing interventions?