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ORIGINAL RESEARCH

Impact of Mobile Health (mHealth) Use by Community Health Workers on the Utilization of Maternity Care in Rural Malawi: A Time Series Analysis

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Purpose: Maternal mortality in Malawi is high, with low coverage of maternity care being a contributing factor. To improve maternal health coverage, an Android-based, integrated mobile health (mHealth) app called YendaNafe was introduced to community health workers (CHWs) in the Neno district, rural Malawi. This study evaluates the impact of this app on the uptake of antenatal care (ANC), facility-based births, and postnatal care (PNC), compared to a reference period where CHWs provided the same services without mHealth, using the interrupted time series analysis.

Patients and Methods: Using aggregated monthly data and segmented quasi-Poisson regression models, we compared the effects of mHealth on selected maternal health outcomes. The models were adjusted for the COVID-19 pandemic, the occurrence of cyclones, and a cholera epidemic. We analyzed data from six eligible health facilities and their respective catchment areas in which CHWs were using YendaNafe, and compared 12 months before and 12 months after its introduction.

Results: The use of YendaNafe was associated with a 22% immediate increase in facility-based births (aIRR 1.22, 95% CI 1.12–1.33, p<0.001) but not an immediate increase in new ANC visits (aIRR 1.02,95% CI 0.90–1.14, p=0.77), ANC in the first trimester (aIRR 1.17, 95% CI 0.95–1.45 p=0.13), or PNC visits (aIRR 1.03, 95% CI 0.79–1.36, p=0.81). For long-term effect, YendaNafe was associated with an increase in new ANC visits (aIRR 1.04, 95% CI 1.01–1.07, p <0.01) and ANC in the first trimester (aIRR 1.03,95% CI 1.00–1.07 p=0.046), but not facility-based births (aIRR 1.01, 95% CI 0.99–1.03, p=0.46) or PNC (aIRR 0.97 95% CI 0.93–1.01, p=0.14).

Conclusion: mHealth shows potential of increasing utilization of new ANC visits, ANC in the first trimester and facility-based births. Further research is needed to understand why mHealth did not have an effect on PNC.

Keywords: antenatal care, facility-based births, postnatal care, maternity care

Introduction

Effective interventions to reduce maternal mortality must be urgently implemented to meet the Sustainable Development Goal targets by 2030.[1] These interventions are most needed in sub-Saharan Africa, the region with the highest maternal mortality in the world. Priority interventions include improving the coverage of antenatal care (ANC), facility-based births by skilled attendants, and postnatal care (PNC).[2] Providing timely and high-quality ANC and PNC ensures health education, timely prenatal and postnatal screening, receipt of preventive services, and diagnosis and management of conditions arising in these two critical periods.[3,4] Giving birth in health facilities allows the provision of life-saving and essential obstetric and newborn care to prevent or

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treat complications. Therefore, improving attendance and quality of ANC, facility births, and PNC ensures that women receive life-saving care, which would reduce the risk of maternal and neonatal mortality.[5,6]

Improving coverage of maternal health services requires new and innovative ways of delivering health care. Community health workers (CHWs) have been used for decades to improve access to maternal health services, especially in limited-resource settings and in hard-to-reach areas.[7] The effectiveness of CHWs in improving maternal health outcomes depends on how they are organized to respond to needs in specific contexts. A recent review on optimizing CHW programs found gaps in evidence-based CHW workflows that can improve their effectiveness.[8] One promising intervention to improve CHW workflow is the use of mobile health (mHealth).[9] mHealth is defined as the use of mobile devices to support health care delivery.[10] When provided to well-trained and supported CHWs, mHealth can improve retention, satisfaction, and performance.[11–13] Despite the recent increase in CHWs using mHealth, there is a paucity of information about their impact on maternal health outcomes, and recent reviews have commented on the need to evaluate these outcomes.[14,15]

Malawi, a limited resource country in sub-Saharan Africa, has one of the highest maternal mortality ratios, estimated at 381 deaths per 100,000 live births.[16] While currently 96% of births are conducted by skilled attendants, Malawi lags when it comes to ANC and PNC uptake.[17] Only 51% of pregnant women have four or more ANC contacts, and 42% of postpartum women have a PNC visit within two days.[18,19] To reduce maternal deaths and improve uptake of maternal health services, Malawi is now advocating for increased use of mHealth-enabled CHWs.[17]

Partners In Health (PIH) Malawi, a local non-governmental organization, has worked in Malawi since 2007. PIH supports the Ministry of Health with health care delivery, infrastructure support, medications and medical supplies, and other health system strengthening activities.[20] The organization has supported a cadre of CHWs to improve the outcomes of health conditions in Neno district, one of the rural districts in Malawi, home to about 150,000 people.[21] Since 2007, CHWs in Neno have routinely followed clients through home visits using paper-based workflows. To improve the uptake of ANC, facility-based births, and PNC, PIH, in collaboration with the Ministry of Health and Medic (https://medic.org/), introduced a mHealth application called YendaNafe to CHWs in Neno in 2019.

YendaNafe is an integrated Android smartphone-based app developed in the community health toolkit (CHT) platform.[22] Designed specifically for CHWs in Neno and used during CHW home visits, YendaNafe supported CHWs with decision support and other functions, including reminders and scheduling of tasks, data collection and storage, and monitoring and mentorship by CHW supervisors. For pragmatic reasons, the rollout of YendaNafe was not randomized and was implemented in phases. By 2022, YendaNafe had been implemented in seven out of 14 health facility catchment areas of Neno. Further details of YendaNafe have been described elsewhere.[23] Since the app's introduction, we have not yet evaluated its impact on clinical outcomes. This study aims to evaluate the impact of implementing YendaNafe on the uptake of ANC, facility-based births, and PNC services as compared to a reference period where CHWs provided the same services without mHealth.

Material and Methods

Study Design

This study is a quasi-experimental study using a time series analysis.

The Setting, YendaNafe Design, and Rollout

Before the introduction of YendaNafe, CHWs in Neno already conducted home visits and followed up on various health conditions, including women requiring maternal health services, using a household-based approach. In the household-based approach, CHWs were assigned to households and followed all individuals living in those households. This approach led to significant improvements in many health outcomes in the district. For example, the rate of ANC visits in the first trimester and the number of women attending four or more ANC visits increased by 30% between 2016 and 2018. Details of the household-based CHW program before the YendaNafe introduction have been previously described.[24,25]

Although the household-based program improved some clinical outcomes, the workload of CHWs increased significantly due to follow-up of various health conditions. As a result, the YendaNafe app was introduced to improve the efficiency of CHW tasks. Additionally, the app was introduced to improve clinical outcomes further. The app was

intended to be used by CHWs during home visits and CHW supervisors during supervision and mentorship visits. We recently completed a qualitative evaluation of YendaNafe, where the app is described.[23] In Table 1, we elaborate on how the app may have supported the uptake of ANC, facility-based births, and PNC services.

YendaNafe was implemented in phases between 2019 and 2022 (Figure 1) in seven (Neno District Hospital, Dambe, Chifunga, Matope, Magaleta, Luwani and Ligowe) out of 14 catchment areas in the Neno district. Among the seven facilities, one was a referral facility (Neno District Hospital), and the remaining six were primary health facilities. Matope Health Centre was owned by a faith-based organization, and the rest of the facilities were owned by the Ministry of Health. Following the initial 5-day training, CHWs used the first 2–3 months to practice using the app, register all households within their catchment areas, and receive intensive mentorship and other support from their supervisors. During the transition period, CHWs used both the paper-based system and YendaNafe until all households were registered in

Table 1 YendaNafe Proposed Impact on Outcomes of Interests

YendaNafe Technical Feature	Mechanism of Change
• Mandatory pregnancy screening questions to eligible women of reproductive age group (automatically calculated from date of birth) to be completed by CHWs at each monthly visit. • Instructions to refer suspected pregnant women for pregnancy confirmation and start of ANC based on pregnancy screening questions. • Generation of pregnancy referral and follow-up tasks. This task must be completed within 72 hours, with automated reminders to mark the task as complete when the women visit the health facility.	• Automated age calculation and creation of a pregnancy screening task ensures that all women of reproductive age are screened for pregnancy regularly. Aimed to improve detection of new pregnancies. • Completing follow-up tasks ensures that pregnancies are confirmed and ANC is started early. Aimed to increase early start of ANC visits.
• The app creates follow-up tasks, which persist until 42 weeks of gestation age, according to the woman's scheduled ANC visits. • At monthly home visits, CHWs enter ANC information in the app, especially past ANC visit dates, which create additional follow-up tasks to schedule and attend future ANC visits at regular intervals. Reminders are set until tasks are marked completed. • YendaNafe guides CHWs to systematically screen for pregnancy-related danger signs. If one or more danger signs are present, the app instructs CHWs to refer the women to a health facility and record referral information in the app. The referral information creates a follow-up task immediately. Reminders are sent repeatedly until the task is completed within 72 hours.	• Automated pregnancy status ensures pregnant women receive CHW regular home visits and ensures CHWs consistently remind the women to attend ANC regularly. Aimed to increase overall number and frequency of ANC visits. • Regular prompts to screen for danger signs and follow-up tasks on completing referrals if danger signs are present. Aimed to improve detection of danger signs and timely seeking of healthcare to reduce pregnancy complications.
• Based on the information entered during ANC, a task is created for 38 weeks of pregnancy to ensure the CHW visits the woman to check if she has given birth and record information on the delivery. If the woman has not given birth, CHW reminds her to give birth at a health facility. • If a woman gives birth in a health facility, health facility-based CHW sends an in-app message confirming the birth.	• Reminders to women to give birth in health facilities and timely follow-up on birth-related information. Aimed to encourage facility births and timely recording of delivery information for subsequent follow-up such as postnatal care (PNC).
• A birth report is created upon receiving the in-app message about the delivery, resulting in creating a task for a PNC home visit by CHW on days 3 and 5. Task creation results in the generation of reminders which persist until women attend all required PNC visits in the health facility (at 1 and 6 weeks). • During PNC home visits, the app guides CHWs to conduct danger sign screening. If danger signs are present, the app instructs CHWs to refer the woman to a health facility. Referral results in reminder tasks that persist until marked completed.	• Timely recording of birth information ensures that women start PNC visits as early as possible and complete all required facility-based visits at predefined intervals. Aimed to ensure PNC follow-up according to national schedule. • Clinical decision support on PNC danger sign screening ensures women attend PNC as soon as danger signs are present. Aimed to increase detection of danger signs and timely seeking of healthcare to avoid complications.

Abbreviations: CHWs, community health workers; ANC, antenatal care; PNC, postnatal care.

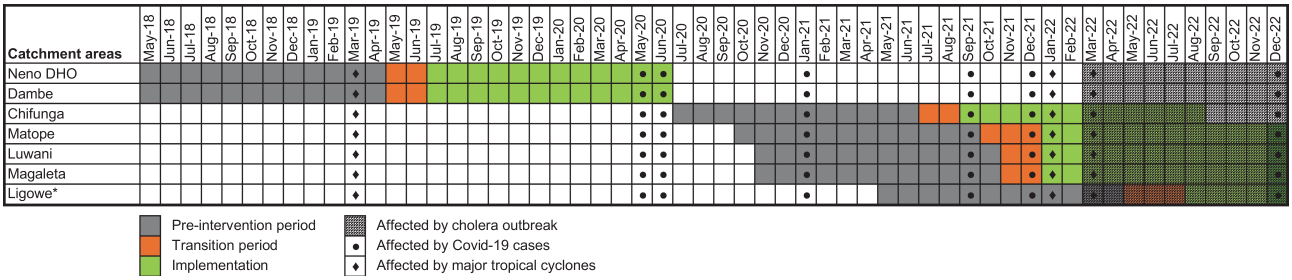

Figure 1 Timeline of each of the facilities.
Notes: * excluded from final analysis due to inadequate number of observations.
Abbreviation: DHO, District health office.

YendaNafe. At the time, the provision of ANC, intrapartum care, and PNC was provided without any user fees in the Neno district.

Data Sources, Data Collection, and Outcome of Interest

We included data from six facilities that offered ANC, intrapartum care, and PNC (Neno District Hospital, Dambe, Chifunga, Matope, Magaleta, and Luwani) (Figure 1). One facility (Ligowe Health Center) was excluded due to an inadequate number of monthly observations. We retrospectively collected data from nationally validated ANC, maternity, and PNC registers. These registers were mainly completed by nurses in health facilities during care provision. Based on our experience and the selected outcomes, there were no significant changes in the data collection tools or data recording practices over the course of the analysis period. We designed the tools to extract data from the registers in CommCare and recruited and trained four enumerators who extracted the data.

Along the maternal health continuum of care, we considered outcomes that would be impacted by YendaNafe and occurred within a specific month. Four outcomes were included in the analyses:

1) Number of new ANC visits
2) Number of pregnant women starting ANC in the first trimester.
3) Number of facility-based births
4) Number of new PNC visits

For all outcomes, individual data were obtained from the registers and aggregated monthly. For new ANC visits, facility-based births, and new PNC visits, we calculated visits per capita based on the facilities' monthly population to account for population changes over time. The facilities' monthly population was estimated from the Malawi population census.[21] For ANC in the first trimester, we calculated the percentage of women starting ANC in the first trimester by dividing the number of women who started ANC in the first trimester by the total number of new women who started ANC in that specific month.

We considered factors that might have influenced the utilization of ANC, facility-based births, and PNC, in addition to the use of the YendaNafe app by CHWs. We identified three factors: COVID-19, tropical cyclones, and a cholera outbreak. Studies in sub-Saharan Africa, including Malawi, have shown declines in ANC, facility-based births, and PNC due to the COVID-19 pandemic.[26–28] Similarly, the occurrence of major tropical storms in Malawi has led to disruptions to health services. The tropical storms have also been associated with Malawi's worst cholera outbreak, which started in 2022, immediately after one of the tropical cyclones.[29] Neno district was impacted by these factors (Figure 1).

Additionally, we extracted aggregated operational data from the YendaNafe database to demonstrate the coverage of the intervention throughout the analysis period. CHWs routinely collected these data during home visits. The data extracted included households registered and visited monthly, total ANC and PNC home visits, and total births registered during the study period. Unfortunately, these data were not available for the pre-intervention period.

Data Management and Statistical Analysis

We used an interrupted time series (ITS) analysis, one of the most robust quasi-experimental designs,[30] to compare the trends in outcomes before and after the introduction of YendaNafe. ITS accounts for pre-existing trends in the outcome by measuring the effect of an intervention beyond the expected secular trend.[31] We used ITS to measure the impact of YendaNafe because:

1. YendaNafe applied to and affected all eligible women in the intervention health facilities' catchment areas. This allowed the aggregation of all data from all eligible facilities into one cluster, allowing the assessment of the combined impact of the intervention. Aggregating the facilities' data into one cluster also improved the robustness of the findings, as some individual facilities had relatively small sample sizes, and applying ITS modeling to individual facilities would have reduced the reliability of the findings.
2. YendaNafe implementation had a specific start date.
3. We had more than eight monthly observations before and after the intervention was implemented, which was adequate for ITS analysis.[32]
4. For pragmatic reasons, we could not randomize the YendaNafe intervention. The study design had to follow the implementation plan in the seven catchment areas.

We conducted an ITS analysis using "study time". The study time, the number of months relative to the start of YendaNafe in each facility, included 12 months before the introduction of YendaNafe and 12 months during the full implementation of YendaNafe, excluding the transition period (Figure 1).

For the outcomes used in the ITS analysis, we encountered months of missing outcomes due to lost records (see Supplementary Table 1). We replaced the aggregated outcomes for these months with an outcome reported in the national Health Management Information System (HMIS). HMIS is a national data system used to report aggregated data on various health services. The source of the aggregated data is the same patient-level registers that we consulted during our data collection. The quality of maternal health HMIS data is high in Malawi, and previous studies have used HMIS data.[33–35] We conducted a sensitivity analysis using the original data and presented the results in Supplementary Table 2.

Since all the outcomes were count data and the variances were higher than the mean, we conducted the segmented regression analysis using the quasi-Poisson regression model with log link, one of the generalized linear models (Equation 1 as an example).

$$\log(\text{newANC}_t) = \beta_0 + \beta_1 \text{time}_t + \beta_2 \text{yendanafe}_t + \beta_3 \text{time after implementation}_t + \beta_4 \text{COVID} - 19_t + \beta_5 \text{cholera}_t + \beta_6 \text{cyclone}_t + \beta_7 \log(\text{population}_t) + \varepsilon_t \quad (1)$$

Where time was the number of implementation months, YendaNafe defined whether YendaNafe was used or not, time after implementation was the time after implementation of YendaNafe, and log population was the log link. We also adjusted for COVID-19, the cholera outbreak, and the major tropical storms; these variables were binary (yes/no) for the given month.

Two regression estimates evaluated the effect of using YendaNafe: 1) level term ($ß_2$) signifying immediate change after implementing YendaNafe and 2) slope term ($ß_3$) signifying long-term change after implementing YendaNafe.

After the initial quasi-Poisson model, we checked for homoscedasticity and autocorrelation using residual plots, probability plots, autocorrelation function plots, and partial autocorrelation function plots. Where there was evidence of heteroscedasticity and autocorrelation, we used the quasi-Poisson regression model with Newey-West standard errors and assumed the autocorrelation was first-order autocorrelation.[36] We used first-order autocorrelation, as previous studies have shown that first-order autocorrelation is common in these outcomes.[37]

We report the results of the quasi-Poisson regression models as incidence rate ratios (IRR) with 95% confidence intervals (CI) for the pre-intervention slope, immediate, and gradual effects. A p-value of less than 0.05 was used as the cut-off for statistical significance. STATA (version 17) was used to perform all analyses.

Ethical Review

The study was approved by the Neno District Research and Ethics Committee and the Malawi National Health Sciences Research Committee. As we used routinely collected health data, we did not obtain informed consent. At the point of

data collection, only de-identified data was collected. Access to de-identified data was restricted to study investigators and data was kept in password protected files and computers.

Results

Descriptive Statistics

During the implementation of YendaNafe, 14,564 households were registered, 87% of which were visited monthly by CHWs on average. Overall, CHWs made 11,656 and 4022 pregnancy-related home visits and postnatal care-related home visits, respectively, and registered 1522 births.

During the 24 months of the study in six health facilities, 5186 women attended ANC (2462 in the pre-intervention period and 2724 in the intervention period), 5537 women gave birth in facilities (2582 in the pre-intervention period and 2955 in the intervention period), and 6300 received PNC (2832 in the pre-intervention period and 3468 in the intervention period) (Table 2). Compared to the 12 months before YendaNafe implementation, new ANC visits, ANC visits in the first trimester, facility-based births, and PNC visits increased, although the increase was only statistically significant for facility-based births and PNC (Table 2). Facility-based births and new PNC visits increased from 215 to 246 per month ($p<0.01$) and 236 to 289 per month ($p<0.01$), respectively (Table 2).

Effect on ANC, Facility-Based Birth and PNC

With the introduction of YendaNafe, the rate of new ANC visits increased from 2.9 to 3.1 per 1000 population (Table 2). There was no immediate change in the rate of new ANC visits after introducing YendaNafe (aIRR 1.02,95% CI 0.90–1.14, p=0.77). However, there was a gradual 4% month-to-month increase in new ANC visits (aIRR 1.04, 95% CI 1.01–1.07, $p <0.01$) (Table 3 and Figure 2). The percentage of pregnant women starting ANC in the first trimester was

Table 2 Descriptive Statistics

Variables	Before YendaNafe	After YendaNafe	p-Value[#]
Antenatal care (ANC) visits			
Total new ANC visits-n, %	2462 (47)	2724 (53)	
Monthly new ANC visits-mean, sd	205 (25)	227 (30)	0.07
Rate of new ANC visits/1000 population-mean, sd	2.9 (0.4)	3.1(0.4)	0.16
ANC Visit in the first trimester			
Total visits-n, %	766 (47)	864 (53)	
Visits in the first trimester/month-mean, sd	64 (15)	72(10)	0.12
Percentage of ANC in first trimester-mean, sd	30.9 (4.2)	31.8 (2.6)	0.51
Facility-based births			
Total facility births-n, %	2582 (47)	2955 (53)	
Monthly facility-births-mean,sd	215 (24)	246 (20)	**<0.01**
Facility births/1000 population-mean, sd	3.0 (0.3)	3.4(0.3)	**<0.01**
Postnatal care (PNC)			
Total-n, %	2832 (45)	3468 (55)	
New PNC visit per month-mean, sd	236 (47)	289 (18)	**<0.01**
New PNC visit per 1000 population-mean, sd	3.3 (0.6)	4.0 (0.3)	**<0.01**

Notes: # Bold values indicate p-values less than 0.05.
Abbreviations: ANC, antenatal care; PNC, postnatal care; sd, standard deviation; n, number; %, percentage.

Table 3 Results From Segmented Regression Analysis

Outcome		IRR (95% CI)*	P-Value#	Adjusted IRR (95% CI)*	P-Value#
Antenatal care (ANC)					
New ANC visits	Secular trend	0.99 (0.97–1.00)	0.09	0.98 (0.97–1.00)	0.07
	Immediate effect	1.13 (0.97–1.31)	0.11	1.02(0.90–1.14)	0.77
	Gradual effect	1.02 (1.00–1.04)	0.05	**1.04 (1.01–1.07)**	**<0.01**
ANC in the first trimester	Secular trend	0.98(0.96–0.99)	<0.01	0.98 (0.96–0.99)	0.01
	Immediate effect	1.14 (0.97–1.34)	0.11	1.17(0.95–1.45)	0.13
	Gradual effect	**1.04(1.01–1.06)**	**<0.01**	**1.03(1.00–1.07)**	**0.046**
Facility-based births					
Facility births	Secular trend	0.99(0.98–1.01)	0.29	0.99(0.98–1.00)	0.23
	Immediate effect	**1.23 (1.10–1.37)**	**<0.001**	**1.22 (1.12–1.33)**	**<0.001**
	Gradual effect	1.00 (0.98–1.01)	0.82	1.01 (0.99–1.03)	0.46
Postnatal care (PNC)					
New PNC visits	Secular trend	1.03 (1.01–1.05)	0.02	1.03 (1.00–1.05)	0.05
	Immediate effect	1.02 (0.82–1.26)	0.86	1.03 (0.79–1.36)	0.81
	Gradual effect	0.97 (0.94–1.00)	0.05	0.97 (0.93–1.01)	0.14

Notes: # Bold values indicate p-values less than 0.05 * Bold values indicate statistically significant results.
Abbreviations: IRR, incident rate ratios; CI, confidence interval; ANC, antenatal care; PNC, postnatal care; %, percentage.

30.9% before YendaNafe and increased to 31.8% during YendaNafe (Table 2). There was no immediate change after introducing YendaNafe (aIRR 1.17, 95% CI 0.95–1.45, p=0.13) and a marginal 3% month-to-month increase (aIRR 1.03,95% CI 1.00–1.07 p=0.046) (Table 3 and Figure 3).

Rates of facility-based births increased from 3.0 to 3.4 per 1000 after introducing YendaNafe (Table 2). We found a 22% immediate increase in facility-based births (aIRR 1.22, 95% CI 1.12–1.33, p<0.001), but no subsequent gradual change (aIRR 1.01, 95% CI 0.99–1.03, p=0.46) (Table 3 and Figure 4).

Rates of PNC increased from 3.3 to 4.0 per 1000 population (Table 2). We found no statistically significant immediate or gradual effect of YendaNafe on number of new PNC visits (Immediate effect: aIRR 1.03, 95% CI 0.79–1.36, p=0.81, gradual effect: aIRR 0.97 95% CI 0.93–1.01, p=0.14) (Table 3 and Figure 5).

After performing the analyses using the original data, adjusted estimates of the immediate and gradual effect of new ANC visits, facility-based births, and PNC visits did not differ from the results where we replaced selected months with missing records with HMIS data (Supplementary Materials). The only difference was the ANC in the first trimester, which was not significant in the original data but was marginally significant in the data presented in the main results.

Discussion

There have been increasing calls to evaluate the impact of mHealth due to the paucity of data on outcomes.[38] This study fills this gap by providing the first quantitative evaluation of the impact of YendaNafe use by CHWs. By examining the performance of YendaNafe use by CHWs in a rural district of Malawi, this study contributes evidence to mHealth literature in limited resource settings. This study found an impact of the YendaNafe mHealth app for CHWs on selected outcomes along the maternal health continuum of care. Although YendaNafe did not show an immediate effect on new

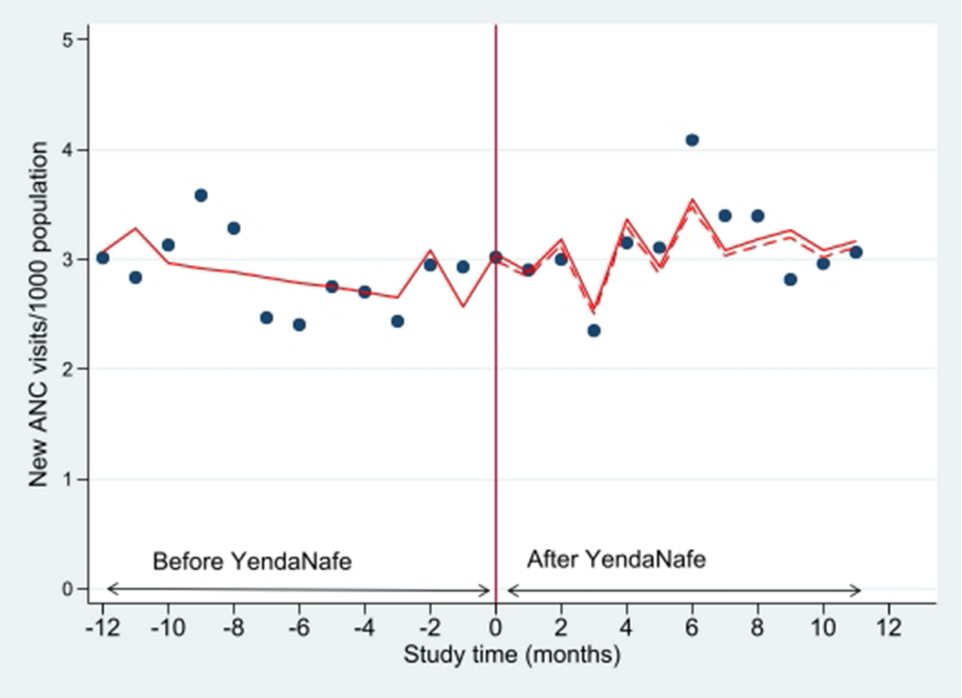

Figure 2 Interrupted time series analysis of new antenatal care visits.
Abbreviation: ANC, antenatal care.

ANC visits and ANC in the first trimester, it demonstrated a gradual effect on these two outcomes. YendaNafe had an immediate effect on facility-based births but did not have a long-term effect. Finally, YendaNafe did not have any immediate or gradual effect on PNC.

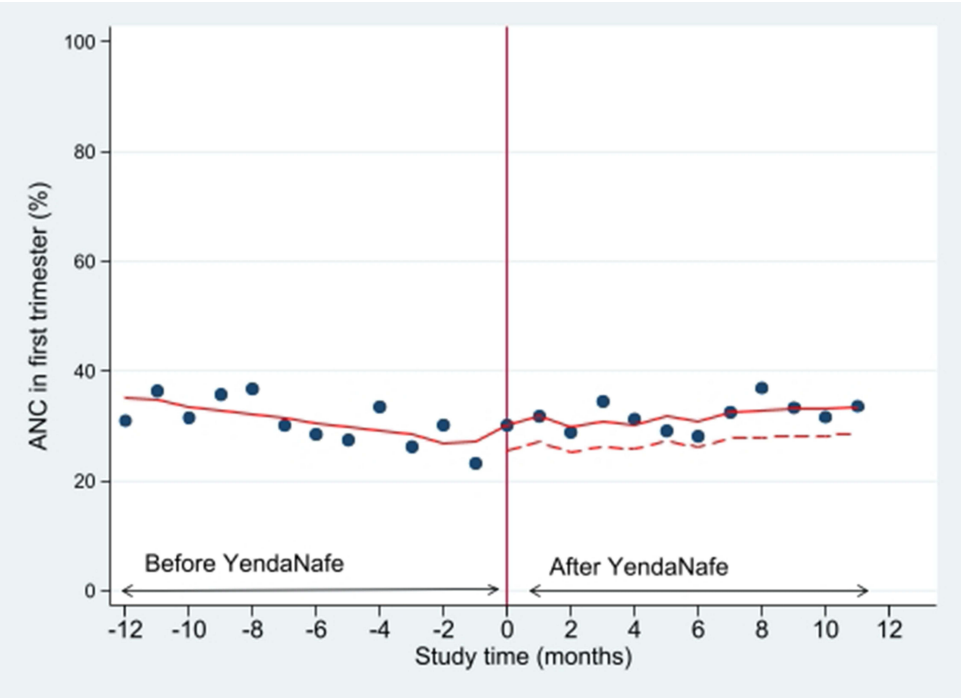

Figure 3 Interrupted time series analysis of ANC in the first trimester.
Abbreviations: ANC, antenatal care; %, percentage.

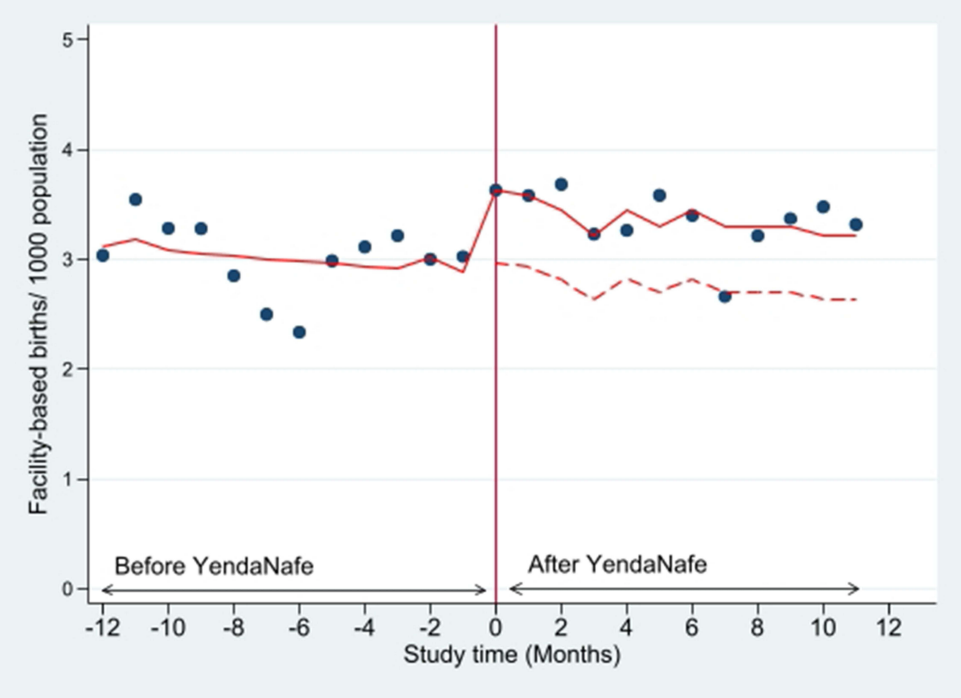

Figure 4 Interrupted time series analysis of facility-based births.

Interpreting these findings requires a contextual understanding of maternal health uptake in Malawi and the CHW program in Neno. In general, recent estimates show high maternal health coverage in Malawi.[18] Furthermore, YendaNafe was implemented in a well-established CHW program that had already reached full coverage in Neno district before the

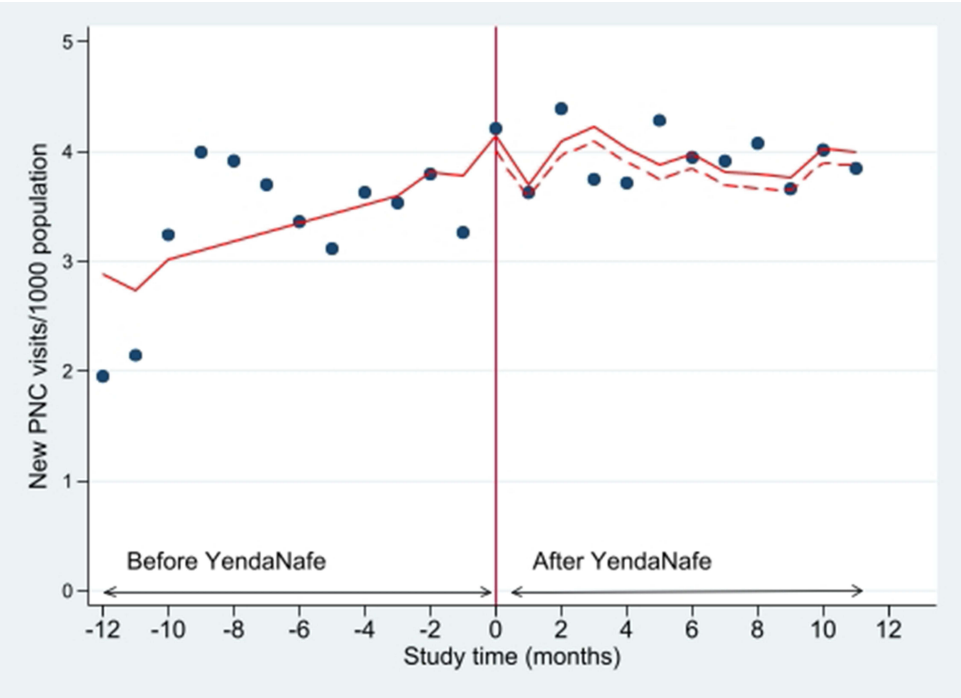

Figure 5 Interrupted time series analysis of postnatal care visits.
Abbreviation: PNC, postnatal care.

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introduction of YendaNafe. Evaluation of this well-established non-mHealth enabled program showed increased uptake of some of these outcomes already before the mHealth tool was introduced.[25]

ANC coverage in Malawi is high, estimated at 97%.[18] Implementing programs to increase this outcome further may yield small increases due to this high coverage. For example, a previous mHealth study in Rwanda found no effect of mHealth on the first ANC visit, attributed to the already high coverage of ANC.[39] The high coverage of ANC may explain the marginal 4% month-to-month increase in new ANC visits in this study. YendaNafe may have improved new ANC visits due to clinical decision support when screening for pregnancies, improving adherence to referrals after identifying a possible pregnancy or women who are already pregnant, and tasks and reminders to ensure CHWs follow up on the referred suspected or confirmed pregnant women.

The baseline rate of ANC in the first trimester was 31%. We found no immediate change and only a marginal 3% month-to-month increase. The mechanism by which YendaNafe increased ANC should also have increased ANC attendance in the first trimester. A previous study in Rwanda found no immediate or long-term change in this outcome.[40] Our previous study found that mHealth studies rarely evaluate this outcome despite its essential role in enhancing ANC coverage.[41] Typically, women who start ANC in the first trimester are more likely to attend more visits, including four or more or even eight or more ANC visits. This study shows the potential to increase the uptake of ANC in the first trimester, but we suspect that barriers outside the mHealth must have impeded the app's ability to increase attendance in the first trimester. Previous studies in Malawi have shown hesitancy in disclosing pregnancies in the first trimester due to fear of witchcraft and embarrassment in case of a miscarriage.[42] Additionally, we have evidence from the qualitative evaluation of YendaNafe on pregnancy disclosure. In this evaluation, most CHWs commented that it was highly challenging for women to disclose their reproductive history to CHWs.[23] As such, CHWs often learn about pregnancies after the first trimester. Further studies must be conducted to understand how to encourage early disclosure of pregnancies and evaluate ways to motivate women to start ANC early. Interventions encouraging women to start ANC early can then be integrated with mHealth to improve this outcome.

The study found that YendaNafe use immediately increased facility-based births, but the gradual effect was not significant. In general, many studies in sub-Saharan Africa provide evidence of the positive impact of mHealth on increasing facility-based births.[43,44] Studies in Ethiopia and Tanzania found that mHealth increases the utilization of facility-based births.[44,45] For example, Webber et al[46] found that mHealth resulted in a 50% immediate increase but a slight month-to-month increase (3%) in facility-based births.Due to YendaNafe's reminders when women were due to give birth, CHWs were able to visit the women and encourage them to give birth in health facilities. The effect of the intervention was seen immediately but not overtime because once the coverage was already high, there was minimal room for further improvement. In Malawi, facility-based births are as high as 96%.[17] In settings where coverage of facility-based births is high, mHealth has had limited opportunity for impact.[40]

We found no impact of YendaNafe on PNC despite Malawi's lower PNC coverage and the app's design to increase PNC. Few studies have evaluated the impact of mHealth on PNC in sub-Saharan Africa, and the results have been mixed.[41] A study conducted in Rwanda by Ruton et al[39] found a gradual increase in PNC in facilities that implemented mHealth and received additional health system strengthening; facilities without additional health system strengthening did not have this effect from mHealth. In a mHealth study in Tanzania, the implementation of mHealth did not have any immediate or gradual effect on PNC.[46] These results show a complex relationship between mHealth and PNC, and contextual factors may explain the lack of impact (or any improvement). During a qualitative study exploring the experiences of CHWs on using YendaNafe,[23] many CHWs and program staff reported challenges with PNC workflow and PNC in general. Due to the time-bound nature of PNC visits by CHWs in the app (at three and five days post-birth), many CHWs thought this was impossible and requested revisions of the PNC workflows. Challenges reported included PNC women moving to other locations apart from their villages after giving birth, facility staff not sending a report of birth immediately to a CHW, postnatal women staying at the hospital for a long time before discharge, and postnatal women not disclosing the birth to CHWs until the next routine CHW visit. The CHW program supervisors also reported that the poor performance of CHWs themselves was a challenge in PNC. Although this study was not designed to assess these issues, and hence, the results were not reported in the published paper, these results may have explained the lack of changes in PNC. Further work is being done to revise and modify the PNC protocol and workflows to improve the PNC outcomes. Future evaluations can also

focus on understanding how the reasons explored in the qualitative study affect PNC use and if modifying PNC protocols in the app is one of the solutions to address the lack of impact of the app on PNC.

While this study finds the long-term impact of YendaNafe on ANC visits and the immediate impact of YendaNafe on facility-based births in rural areas of Malawi, the generalizability of the findings may be limited to the contextual factors of this study. Whereas the study may be generalizable to all other facilities in the Neno district and similar districts in Malawi due to similar contextual backgrounds, generalizability in other settings may be limited. The study was conducted in a resource-limited and rural setting in a country with relatively high maternal mortality. This may limit generalizability to high-income countries and urban settings. YendaNafe was also implemented in a context affected by a cholera epidemic and tropical cyclones. This could limit generalizability in contexts not affected by these contextual factors. More importantly, YendaNafe was adapted to a specifically designed CHW program, and hence, YendaNafe needs to be adapted if it is used in different CHW programs and health systems. Further research is needed to understand how YendaNafe may perform in a context different from this study's context.

The main strength of this evaluation was the use of ITS, which presents a robust evaluation of YendaNafe. However, results need to be interpreted with caution. We included 12 months of pre-intervention and 12 months of intervention in six facilities, which was adequate for this evaluation. Conducting another assessment after a longer period of YendaNafe use can help determine if the intervention effect is sustained over time. Evaluating over extended periods also allows the inclusion of outcomes that span multiple months. For example, it may be beneficial to assess the impact of YendaNafe on four or more and eight or more ANC contacts over the course of a pregnancy. Future evaluations of YendaNafe can also focus on impact of YendaNafe on separate facilities, contextualizing impact of YendaNafe on location and type of facilities. Additionally, future evaluation of YendaNafe can focus on evaluating the impact of YendaNafe on maternal mortality. As a rare event and with the relatively short evaluation period and only six included facilities, measuring changes in maternal mortality was not possible in this evaluation. As such, we measured outcomes in the maternal health continuum, which reflect improvement in access to care and act as the pathway toward reduction in maternal mortality. We treated all the intervention health facilities as one cluster, assuming no referrals to these facilities or outside of this cluster for care. However, it is possible that some women from outside the cluster may have accessed the service in the intervention cluster, and women within the cluster may have accessed care outside the cluster. This could have impacted the results, but we expect minimally. Finally, we used routinely collected data, which may have been of sub-standard quality. However, this would be the case during both pre-intervention and intervention periods. We trained data collectors to collect primary data and supplemented missing data from HMIS to improve validity.

Conclusion

We found that implementing a mHealth application, YendaNafe, in rural Malawi was associated with a long-term increase in the rate of new ANC visits and ANC visits in the first trimester. For facility-based birth, mHealth was associated with immediate but not long-term impact. However, mHealth did not have any immediate or long-term effect on PNC. Future considerations for YendaNafe include another evaluation over a longer period to assess its impact on outcomes that span multiple months (eg, four or more ANC visits) and exploring why YendaNafe could not improve PNC outcomes. YendaNafe shows promise in improving maternal health outcomes and can be considered for further scale-up.

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Disclosure

This manuscript forms part of the first author's upcoming PhD thesis, which is still in progress. As the PhD thesis has yet to be completed, it is not currently publicly available. The author(s) report no conflicts of interest in this work.

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