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Scaling up electronic village registers for measuring vital statistics in rural villages in Malawi

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Setting: Eighty-three villages without electricity in Mtema Traditional Authority, Lilongwe District, Malawi.
Objectives: To describe 1) the expansion of the electronic village register (EVR) to 83 villages in Mtema Traditional Authority, 2) the challenges encountered and changes made to render the system robust and user-friendly, 3) the value propositions developed to increase the system's desirability, and 4) the results of the village register.
Design: Descriptive study.
Results: After the deployment of the EVR in one village in 2013, the system was extended to 83 villages with modifications to render it more robust and user-friendly. These changes included modifications to the power, connectivity and work stations, better battery security and a single modular electronics panel. Value propositions of the EVR for the village headmen included daily postings of news/sports items and sockets for charging mobile phones and lanterns. Of the 47 559 residents registered, 48% were male, 14% were aged 0–4 years, 43% were aged 15–44 years and 4% were aged ⩾65 years. Between 1 April 2016 and 31 March 2017, 976 births and 177 deaths were recorded. The total equipment cost per village was US$2430.
Conclusion: An electronic village birth and death registration system can function in an area with no communication or electricity infrastructure.

In March 2013, an electronic village register (EVR) was installed in the village of Chalasa, an area without electricity and modern amenities in rural Malawi.[1] Several years before, the Government of Malawi had introduced a decentralised system using paper registers—the village register—through the National Registration Bureau to record the number of citizens and new births and deaths in a village, which was the start of a population register. A study in Zomba District showed that while the recording of births and deaths could be done, collation and analysis of data from villages on a timely basis was almost impossible due to poor infrastructure, limited human resources and inadequate transport.[2] A potential solution was to use an EVR to transmit data through cellular phone networks or wireless connections from village headmen to group village headmen to the Traditional Authority to the District Commissioner, which could then be shared with the health facilities.

To set up a functioning EVR required solutions to several important challenges, including the absence of electricity, accommodating the local language, low literacy levels among village headmen and lack of computer skills. A touchscreen computer was chosen to address the absence of computer skills, with software designed to provide registration functions in an easy-to-use stepwise approach.[3] Language is a common barrier in technology applications in most resource-constrained settings.[4] The user interface was therefore developed in the local language (Chichewa), and the entire system was powered using two deep-cycle batteries, charged using a solar panel mounted on the roof of the village headman's house. Installing solar power allowed for the addition of lighting through a single light bulb in the home, an innovation greatly valued by the village headman and his villagers. The selection of hardware for the EVR was guided by the need for low power consumption and robust design based on direct current.[5]

The EVR was successfully deployed in the homes of the headmen of two villages, Chalasa and Mtema, and at the Mtema Traditional Authority's office in 2013.[1] Each village member had their details entered into the EVR and each was issued with a nationally unique health ID number, based on a model for identifying patients in government hospitals launched in 2001. These details were then printed on an adhesive label and stuck on the front of the village member's health passport.[6] Births and deaths in the village were documented in quarterly reports.

Following this success, the EVR was extended to all 83 villages in the Traditional Authority to determine whether an electronic village birth and death registration system could be functional and interconnected in an area with no electricity. The present paper describes the 1) expansion of the EVR system, 2) challenges encountered and changes made to render the system more robust and user-friendly, 3) value propositions that were addressed to ensure the system is as valuable to the village headmen and villagers as possible, and 4) demographic characteristics of the village residents.

METHODS

Study design

This was a descriptive ecological study reporting on the expansion of and changes made to an existing EVR system.

Setting

General setting

Malawi, in Central Africa, has an estimated population of 17 million and a nominal per capita gross do-

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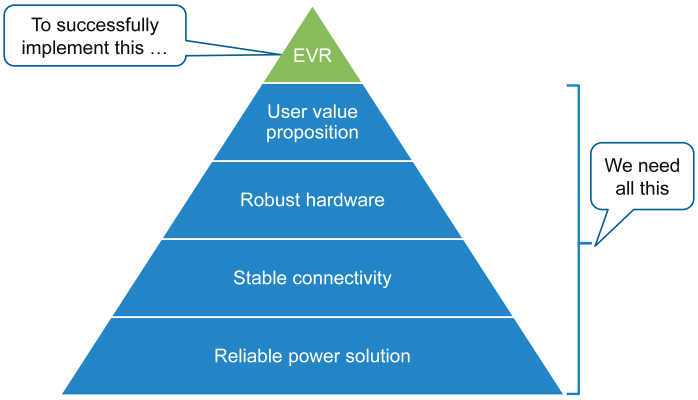

FIGURE 1 A successful EVR is predicated on a foundation of desirability for the user and feasibility of the solution. EVR = electronic village register.

mestic product of US$250.[7] The country is divided into five health zones and 28 districts. Lilongwe District, where the capital city is located, is divided into 18 Traditional Authorities, with 221 group village headmen and 2234 villages, each with a village headman.[8] Village headmen report to a group village headman, who in turn reports to the Traditional Authority. The Traditional Authority reports to the District Commissioner, the controlling officer in the local government.

Site setting

The Traditional Authority of Mtema has an estimated population of 48 000, with nine group village headmen and 83 villages.[8] Mtema Traditional Authority is poor and without electricity.

Study population

All current residents in 83 villages in the Mtema Traditional Authority.

Populating the village register

Data were collected door-to-door by registering villagers in the EVR if they already had a health passport, or issuing a health passport to those who did not have one, registering them in the EVR and issuing them with a national health ID and placing a barcode sticker on the health passport.

Training of village headmen and secretaries

Village headmen were designated to use and update the EVRs. All 83 village headmen and their secretaries (a total of 180 people) were informed of the importance of registration and were trained in registering births and deaths in the EVR, using the news application and in basic troubleshooting.

Data variables and analysis

Study data were obtained from the EVR, and included the number of males and females resident in the village stratified by age, and births and deaths that occurred between 1 April 2016 and 31 March 2017. Data for each village were analysed descriptively using percentages and frequencies.

Technological approach

For the EVR to be successful, we needed to address issues of both desirability by the village headmen and feasibility of the system. To address desirability, we developed a number of value propositions for the user. To address feasibility, we developed a robust technology stack. These dependencies are shown in Figure 1.

Ethics

Deployment of the EVR was agreed and authorised by the National Registration Bureau, Lilongwe, and study consent was obtained from the Malawi National Commission for Science and Technology, Lilongwe, Malawi. Clearance for publication was obtained from the Malawi National Health Science Research Committee, Lilongwe, Malawi, and a waiver for the need for patient-informed consent was obtained from the Ethics Advisory Group, International Union Against Tuberculosis and Lung Disease, Paris, France.

RESULTS

Expansion of EVR to all villages of the Mtema Traditional Authority, 2015–2017

Selecting villages for expansion

Six villages in the Mtema Traditional Authority were selected to pilot a mesh network that would be used to link the rest of the villages.[9,10] Following the success of the pilot in 2014, the mesh was expanded to all villages.

Support for electronic village register users

After the EVR workstations were installed in the villages, each user had a user name and password created. Daily support was provided through onsite and remote supervision. Onsite support was provided by mentoring the village headmen and their clerks on routine use of the system and providing first-line support for the hardware and network infrastructure at the village; any equipment problems were resolved during these visits. Remote support, initiated through observation of EVR activity using the mesh network, was provided through telephone calls.

Evolution of the electronic village register

Power and connectivity

Solar panels and wireless equipment were initially installed on the roof of the village headman's home (Figure 2A). This required modification to the physical

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Conflicts of interest: none declared.

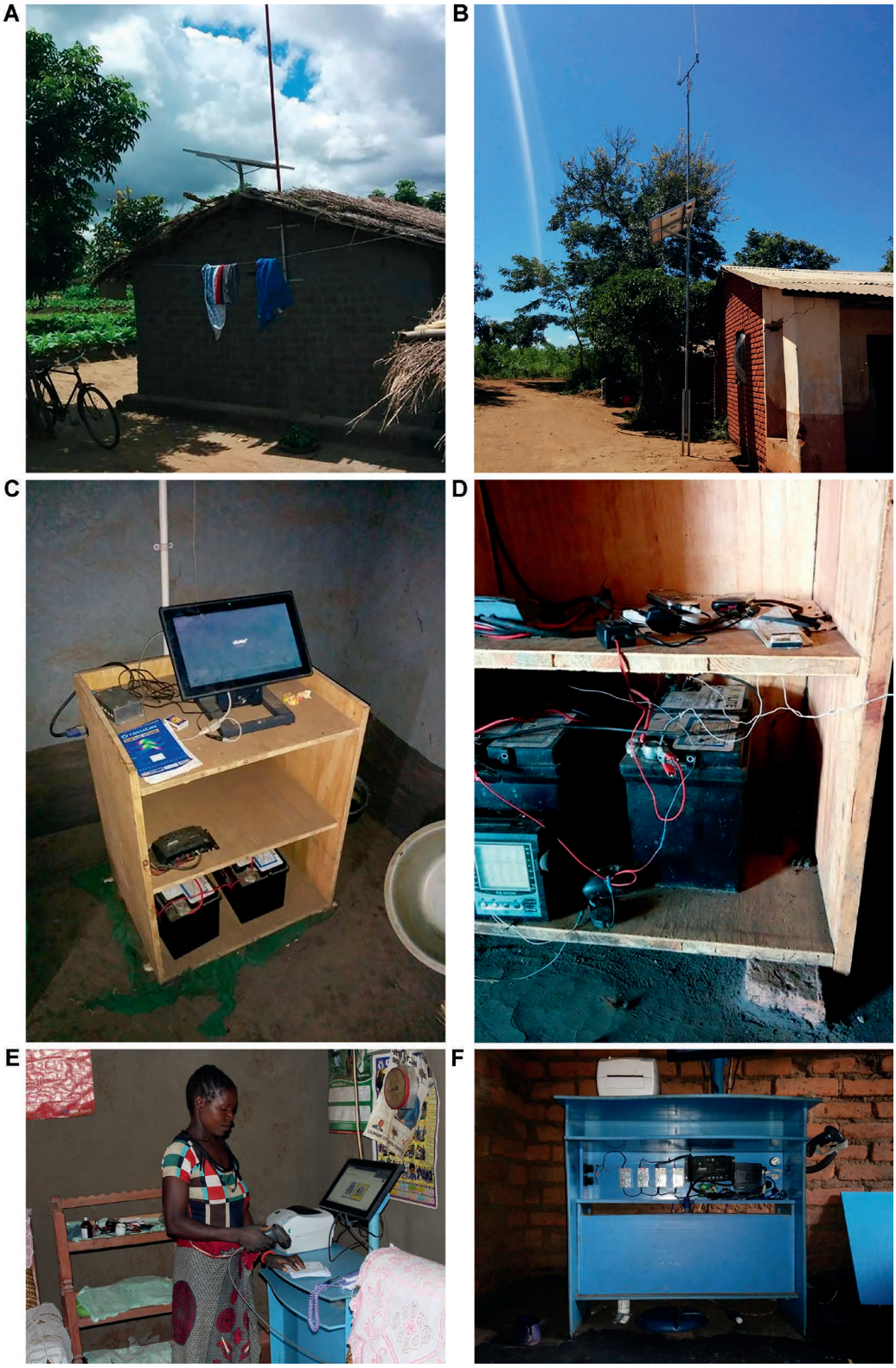

FIGURE 2 **A)** Solar panels and wireless equipment were initially installed on the roof of the village headman's home. **B)** Later versions placed the installations close to, but independent of, the home, with pivots at the base for ease of maintenance and an adjustable bracket on the solar panels for seasonal changes in the sun's angle. **C)** Initially, workstations did not cater for sitting, and were made from wood, which was subject to water and pest damage. There was also no security for the batteries. **D)** Open access to the batteries in the early workstation design meant that the batteries were often connected to other devices using makeshift wiring and, as a result, were frequently drained to such low levels that the solar charger could not recharge them, rendering the entire system inoperative. **E)** The workstation is now custom-constructed out of polyvinyl chloride, has a shelf for paperwork and an adjustable mounting bracket for easy viewing of the touchscreen while standing (as this village headwoman is doing) or sitting. **F)** The batteries are now enclosed behind a lockable panel that also houses and protects the electronics, which are installed on a single modular equipment panel for ease of installation and maintenance.

TABLE 1 Age and sex distribution of residents in 83 villages of the Mtema Traditional Authority, Lilongwe District, Malawi, as of 31 March 2017

	Age group, years					Total
Sex	0–4	5–14	15–44	45–64	⩾65	*n* (%)
Male	3 344	7 233	9 715	1 816	840	22 948 (48)
Female	3 469	7 064	10 857	2 073	1 148	24 611 (52)
Total	6 813	14 297	20 572	3 889	1 988	47 559

structure, as many homes are poorly constructed. The solar panels were mounted at a fixed angle on the roof of the house. Later versions placed the installations close to, but independent of, the home (Figure 2B), with pivots at the base for ease of equipment maintenance and an adjustable bracket on the solar panels for seasonal changes. Each village was initially connected to the main network using a point-to-point wireless link, which was dependent on precise positioning of the antenna, a time-consuming process of trial and error. Connectivity was later redesigned using mesh networking and omnidirectional antennas, with wireless equipment that 'self-discovers' a path back to the server using mesh nodes installed in neighbouring villages. Each village may associate with several neighbours, creating a spider web-like set of links that provides redundant pathways, adding fault-tolerance to the network. Implementing the mesh network proved more difficult than anticipated. Due to extreme distances between some of the village headmen's homes, tall trees close to some homes and mountainous terrain blocking the signal, some antennae had to be raised. Towers located at nearby health centres were used to mount additional wireless equipment to act as relay points between village clusters that did not have line-of-sight.

Developing robust hardware solutions

A design-reality gap analysis revealed several shortcomings in the early EVR system.[11] Wooden workstations were subject to damage from water and/or termites, and did not allow sitting. There was no security for the batteries, and significant abuse occurred, jeopardising the system's effectiveness (Figure 2C). The main abuse was from devices (e.g., radios, inverters, cell phones) being connected directly to the battery, and makeshift wires from the battery to lights in other rooms (Figure 2D). The batteries were sometimes removed for use elsewhere. Batteries were thus frequently drained to such low levels that the solar charger could not recharge them, rendering the entire system inoperative.

New solutions addressed these shortcomings. The workstation is now custom-constructed from durable, water-resistant polyvinyl chloride with a raised toe-kick (allowing seated use) and a shelf for paperwork. Instructions for manufacturing the desks have been posted on the Internet.[12] An adjustable mounting bracket allows easy viewing of the touchscreen while standing or sitting (Figure 2E). The batteries are enclosed in a lockable panel that also houses and protects the electronics. There are sockets for charging two cell phones, with a limit on the amount of power each socket can provide. All electronic devices for the EVR are on a single modular equipment panel to reduce installation and maintenance efforts in the field (Figure 2F).[13] The system has been redesigned to run 24 h a day, with a power reset button but no 'off' switch, to make the system always available to the user.

Value propositions for the village headman

Village headmen could use the system workstation to charge their devices (e.g., phones) and to have lighting in their homes. The low frequency of births and deaths meant that village headmen interacted with the system as little as once every 2 or 3 months, a barrier to the system's adoption, which usually results in under-reporting of births and deaths,[14] and additional functionality of the system was required. Discussions with the village headmen identified lack of information about current national and local events as an opportunity: a news application with daily summaries of news and sports from Malawian newspapers was therefore added to encourage daily use.

Demographics of village residents and citizens

The EVR shows the census of the 83 villages comprising the Mtema Traditional Authority to be 47 559 as of 31 March 2017. A summary of the village-specific demographics is given in Table 1, and shown in Figure 3. Approximately 48% (22 948) of the population was male, with 14% of the population aged <5 years, 43% aged <15 years and 4% aged ⩾65 years. Between 1 April 2016 and 31 March 2017, 976 births (51% male) and 177 deaths (63% male) were recorded in the EVR (Table 2).

Cost of deploying the EVR to the 83 villages of the Mtema Traditional Authority

The equipment costs associated with expanding the EVR to the 83 villages in the Mtema Traditional Authority are shown in Table 3. The total equipment cost per village was US$2430.

DISCUSSION

This article builds on our success in installing an EVR in a rural village in Malawi in 2013,[1] and describes the expansion of this EVR to all 83 villages within the Mtema Traditional Authority. The expansion required changes to make the system more robust, user-friendly and useful to the community leaders. We now have accurate, up-to-date information about the demographics of village residents and have recorded births and deaths that occurred between 1 April 2016 and 31 March 2017. Such vital statistics data will allow the government and other stakeholders to have an up-to-date census of village populations that can be used for planning and implementing grassroots development activities.

The demographic data collected showed a lower proportion of 0–4-year-olds in the Mtema Traditional Authority than expected. One reason for this reduction could be the documented reduction in fertility rate in Malawi from 5.7 to 4.4 between 2010 and 2015.[15] Our data also showed fewer deaths in females than in males over the 1-year period, similar to findings in Malawi's most recent demographic survey.[15]

Strengths and limitations

Our approach builds on two foundational components developed in previous years linking the community with the health facility. We use the same patient identifier to identify village individuals as we do to identify them as patients in a health facility, a unique national patient ID number currently issued to more than 4 million Malawians.[3] This is advantageous as a possible source of vali-

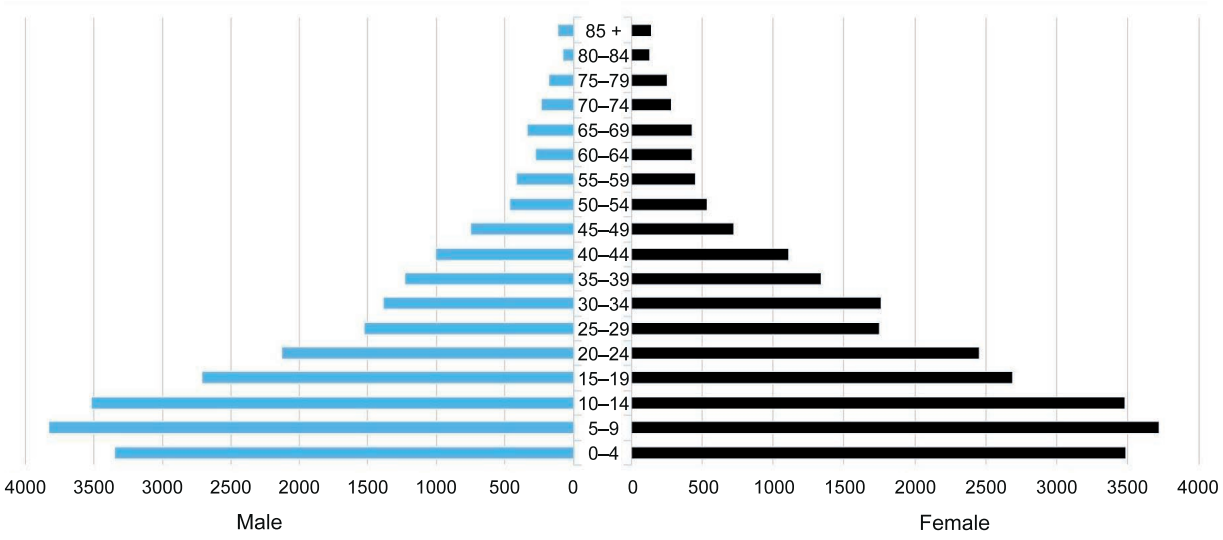

FIGURE 3 Tornado plot showing the demographics for 83 villages in the Mtema Traditional Authority.

dating registrations under the National Registration Bureau's recently launched National Registration Programme.[16] To provide electronic access to information within the village, we have also built upon an existing wireless network put in place in 2008 to connect health facilities serving this community.

The EVR is an expensive intervention at the village level, with a total equipment cost of US$2430 per village. We recognise that there are cheaper ways to implement the EVR. However, our approach is based on adding value rather than reducing costs, and we believe that a community-based information platform with many functions will allow costs to be amortised across many budget lines.[17] What might these additional functions be? First, the platform might be used to assist health programmes in tracing persons lost to follow-up from anti-tuberculosis or antiretroviral treatment, or to ensure timely infant immunisations. It might also be used for village-level information, such as access to prices and markets for agricultural commodities or resources for justice and peace, or to augment social programmes on cash transfer or welfare/protection of orphans and vulnerable children.

Second, our platform deals with social development: the introduction of news stories at the village level is an innovative first step forward.[18] Anecdotes, however, suggest that the news stories are viewed less frequently than anticipated; this could be due to the high level of illiteracy among users. We now plan to add pictures and short audio clips to make the application more attractive. We are beginning to understand that if we create a functional, appealing workspace for community leaders to conduct their functions, they will be more predisposed to use that workspace, thereby lowering the barriers to conducting their civic and social responsibilities.

Third, our platform could act as an early warning system for disease outbreaks: for example, a sudden increase in deaths could herald an outbreak of viral haemorrhagic fever, such as occurred recently in West Africa with Ebola.[19]

Finally, it could assist the growing interest of research institutions to identify and follow up cohorts of children from birth to adulthood and beyond.

TABLE 2 Births and deaths in 83 villages in the Mtema Traditional Authority, Lilongwe District, Malawi, between 1 April 2016 and 31 March 2017

	Male *n*	Female *n*	Total *n*
Births	497	479	976
Deaths	111	66	177

CONCLUSION AND NEXT STEPS

We have built on our success of introducing an EVR in Chalasa village, rural Lilongwe, to expand this technology to 83 villages in one of the Traditional Authorities in Malawi. We have adapted the system so that it is now more robust, user-friendly and valuable to community leaders. The shift from a paper system takes time, as with all behavioural change. The system remains heavily reliant on routine supervision visits to ensure all vital events are captured. However, we expect this dependency to diminish over time. Having shown the feasibility of extending the EVR to a full

TABLE 3 Equipment cost of deploying the electronic village register in the 83 villages of the Mtema Traditional Authority, Lilongwe District, Malawi

Equipment	$US
Touchscreen computer (J2-225; J2 Retail Systems, Manor Park, UK)	720
Thermal label printer (GC420T; Zebra Technologies, Lincolnshire, IL, USA)	345
Barcode scanner (LS-2208, Symbol, Zebra Technologies)	135
Solar panel (2 × 12 volt, 85 watts)	220
Deep-cycle battery (2 × 100AH, Raylite RR2; Solardome SA, Stellenbosch, South Africa)	400
DC/DC power converters (4 x TUSOTEK TS-IPS-V02; Hackaday)	40
Rechargeable lantern (Suaoki LED Camping Lantern; ShenZhen Global Egrow E-Commerce, Shenzhen, China)	15
Miscellaneous wiring	50
Polyvinyl chloride desk[12]	200
Connectivity equipment (Mikrotik Basebox 5 + 2.4 GHz wifi card + antennas; Mikrotik, Riga, Latvia)	250
Solar charge controller (Steca 1515; Steca Elektronik, Memmingen, Germany)	55
Total equipment costs	2430

Traditional Authority, we are beginning to explore additional functionalities to assist with various health care and social development activities, with the goal of increasing the viability of the system, as the EVR is expensive as a stand-alone system.

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Contexte : Quatre-vingt-trois villages sans électricité dans la zone d'autorité traditionnelle de Mtema, district de Lilongwe, Malawi.
Objectif : Décrire 1) l'expansion du registre électronique de village (EVR) aux 83 villages de la zone d'autorité traditionnelle Mtema, 2) les défis rencontrés et les modifications effectuées pour rendre le système robuste et convivial, 3) les propositions de valeur élaborées pour augmenter la désirabilité du système, et 4) les résultats du registre de village.
Schéma : Etude descriptive.
Résultats : Après le déploiement de l'EVR dans un village en 2013, le système a été étendu à 83 villages, avec des modifications visant à la rendre plus robuste et plus convivial. Ces changements ont inclus des modifications du courant, de la connectivité et des stations de travail, une meilleure sécurité au niveau des piles et un panneau électronique modulaire unique. Les propositions de valeur de l'EVR pour les autorités du village ont inclus des affichages quotidiens relatifs aux actualités/aux sports et des prises pour charger les téléphones mobiles et les lanternes. Sur les 47 559 résidents enregistrés, 48% étaient des hommes, 14% avaient de 0 à 4 ans, 43% avaient de 15 à 44 ans et 4%, ≥65 ans. Entre le 1er avril 2016 et le 31 mars 2017, 976 naissances et 177 décès ont été enregistrés. Le coût total de l'équipement a été de US$2430 par village.
Conclusion : Un système d'enregistrement électronique villageois des naissances et des décès peut fonctionner dans une zone dépourvue d'infrastructures de communication ou d'électricité.

Marco de referencia: Ochenta y tres aldeas que no cuentan con suministro eléctrico en la Autoridad Tradicional de Mtema de la provincia de Lilongwe, en Malawi.
Objetivos: Describir los siguientes aspectos: 1) la ampliación del registro de aldea electrónico (EVR) a 83 aldeas de la Autoridad Tradicional de Mtema; 2) las dificultades encontradas y las modificaciones introducidas con el objeto de lograr un sistema de mayor solidez y utilización más sencilla; 3) las propuestas de valor formuladas con miras a hacer más atractiva la utilización del sistema; y 4) los resultados del registro de aldea electrónico.
Métodos: Fue este un estudio descriptivo.
Resultados: Tras la introducción del EVR en una aldea en el 2013, se amplió el sistema a 83 aldeas con modificaciones que aportaban mayor solidez y facilidad de utilización. Los cambios abordaron la potencia de la alimentación, la conectividad y las estaciones de trabajo, una mayor seguridad de las baterías y un tablero modular electrónico único. Las propuestas de valor sobre el EVR dirigidas a los jefes de aldea fueron la publicación diaria de noticias y deportes y la alimentación de las tomas para cargar los teléfonos móviles y las linternas. De los 47 559 residentes registrados, 48% eran de sexo masculino, 14% tenían entre 0 y 4 años de edad, 43% entre 15 y 44 años y 4% ≥65 años. Del 1° de abril del 2016 al 31 de marzo del 2017 se registraron 976 nacimientos y 177 defunciones. El costo total del equipo por aldea fue de US$2430.
Conclusión: Un sistema electrónico de registro de los nacimientos y las defunciones puede funcionar en una zona que no cuenta con infraestructura de comunicaciones ni suministro eléctrico.

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