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mSpray: A mobile phone technology to improve malaria control efforts and monitor human exposure to malaria control pesticides in Limpopo, South Africa

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ABSTRACT

Recent estimates indicate that malaria has led to over half a million deaths worldwide, mostly to African children. Indoor residual spraying (IRS) of insecticides is one of the primary vector control interventions. However, current reporting systems do not obtain precise location of IRS events in relation to malaria cases, which poses challenges for effective and efficient malaria control. This information is also critical to avoid unnecessary human exposure to IRS insecticides. We developed and piloted a mobile-based application (mSpray) to collect comprehensive information on IRS spray events. We assessed the utility, acceptability and feasibility of using mSpray to gather improved homestead- and chemical-level IRS coverage data. We installed mSpray on 10 cell phones with data bundles, and pilot tested it with 13 users in Limpopo, South Africa. Users completed basic information (number of rooms/shelters sprayed; chemical used, etc.) on spray events. Upon submission, this information as well as geographic positioning system coordinates and time/date stamp were uploaded to a Google Drive Spreadsheet to be viewed in real time. We administered questionnaires, conducted focus groups, and interviewed key informants to evaluate the utility of the app. The low-cost, cell phone-based "mSpray" app was learned quickly by users, well accepted and preferred to the current paper-based method. We recorded 2865 entries (99.1% had a GPS accuracy of 20 m or less) and identified areas of improvement including increased battery life. We also identified a number of logistic and user problems (e.g., cost of cell phones and cellular bundles, battery life, obtaining accurate GPS measures, user errors, etc.) that would need to be overcome before full deployment. Use of cell phone technology could increase the efficiency of IRS malaria control efforts by mapping spray events in relation to malaria cases, resulting in more judicious use of chemicals that are potentially harmful to humans and the environment.

1. Introduction

In 2012, malaria resulted in an estimated 627,000 deaths, primarily to African children under the age of five (WHO, 2013a). Indoor residual spraying (IRS) is one of the primary vector control interventions in many malaria-endemic countries (WHO, 2006). IRS involves the application of insecticides, including DDT and pyrethroids, to the internal walls and ceilings of dwellings or structures where mosquito vectors alight (WHO, 2013b). IRS coverage in 2011 included 4.7 million structures across 13 African countries (PMI, 2013), and estimated 2010 costs of IRS chemicals for just 10 of these countries totaled 7 million US dollars (Sine et al., 2011). Although the benefits of IRS are clear, there may also be associated risks from residential and occupational exposure to IRS pesticides (deJager et al., 2009; Eskenazi et al., 2009; Horton et al., 2011).

In addition to rapid case identification and treatment, monitoring of IRS is important for malaria control efficiency and efficacy. For example, in South Africa, the Limpopo Province Malaria Control Programme (MCP) directs province-wide IRS spray operations and maintains a database of all diagnosed malaria cases as mandatorily reported by all health

Abbreviations: IRS, indoor residual spraying; MCP, Malaria Control Programme; GPS, Global Positioning System; PDAs, personal digital assistants.

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care providers. Though the computerized MCP database of malaria cases includes their exact residence (with geographic positioning system (GPS) coordinates), the current IRS documentation system is less comprehensive. Spray operators provide a paper record of the spray event to residents of a sprayed home, but this is frequently lost. They also maintain paper-and-pencil-based daily summaries (SP forms) of rooms and structures sprayed and the insecticides used (type and quantity). However, this information is only available at the village level rather than at the homestead level. Homestead level IRS spray information would allow public health government authorities to document with certainty whether homesteads where malaria patients reside have been sprayed and with which pesticide as it is possible that not all homesteads in a given village undergo IRS applications or that there is pesticide resistance. This level of information could potentially aid in planning future malaria control efforts. Herein, we describe and test a method to gather real-time homestead- and chemical-level IRS spray data through the use of simple, cell phone based technology in an effort to improve IRS monitoring.

2. Methods

2.1. Ethical review

In consultation with the University of California Center for Protection of Human Subjects, it was determined that the activities undertaken to develop, test, and improve the mSpray app did not constitute "Human Subjects Research" because: 1) the mSpray app testing and the group discussions were conducted within the Limpopo Malaria Control Programme for the purpose of quality improvement of its internal IRS operations, and 2) surveys completed by staff contained no personally identifying information. Additionally, no other personal or demographic information was obtained from the residents of the homesteads where information on IRS events was recorded.

2.2. Development of mSpray

Development of the mSpray app was an iterative process involving input from the UC Berkeley and University of Pretoria researchers, the Limpopo Malaria Control Programme (MCP), and spray foremen. Through meetings with the MCP staff, we determined the importance of geocoding spray information. UC Berkeley staff presented multiple geocoding options to MCP staff including GPS bar coding of structures, direct entry of sprayed homesteads on a map, using cameras with GPS capacity to document sprayings, etc. We considered the pros and cons of each option and weighed such factors as cost, carrying size, ease of data collection, storage capacity, battery life and charging of the device, ease of access to and use of the data afterwards, potential of device theft, the skill and literacy level of the user, and other user barriers to acceptance (cultural, language, etc.). We determined that cell phone technology would likely be the best option. We then compared the GPS accuracy of a smartphone relative to a hand-held research-grade Garmin unit (*Garmin eTrex®30 Handheld GPS*). Both devices produced comparable and acceptable accuracy (≤10 m) in a large town and in outlying rural areas in Limpopo, South Africa. We selected an Android-based smartphone (*Samsung Y GT-S5360 Android 2.3.6 Smartphone*; cost ~ US$300) based on its affordability, the ease with which new

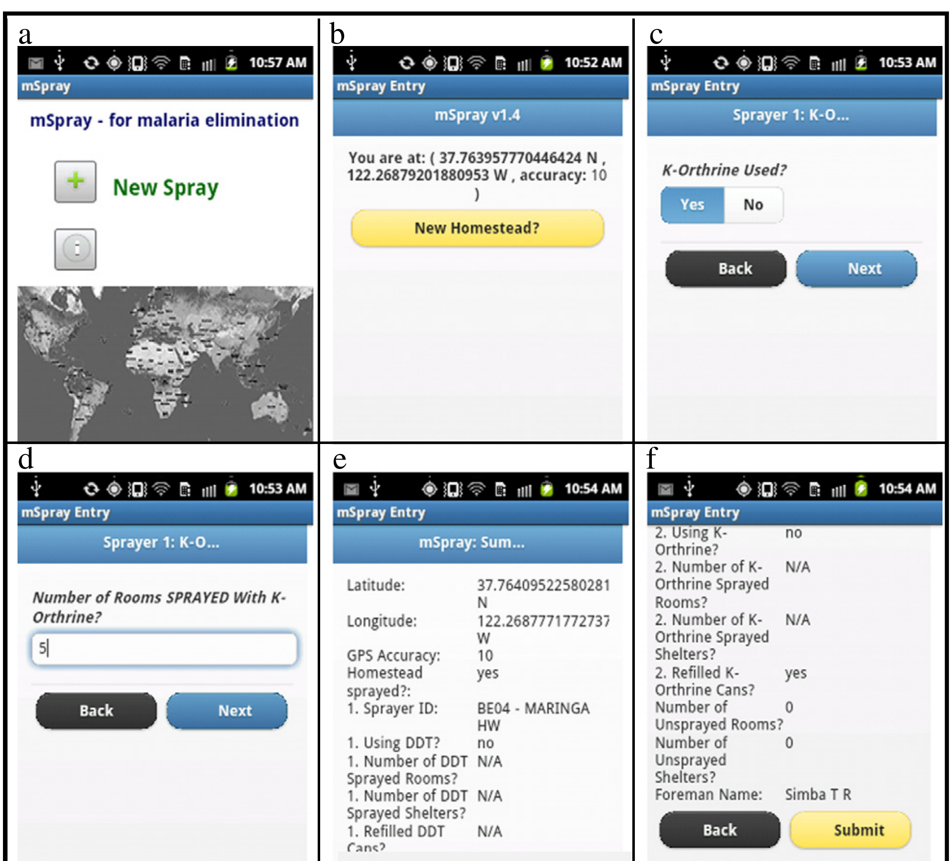

Fig. 1. Select screens on the mSpray app. a. Startup screen for mSpray. b. GPS coordinate reading at the site of the spray event. c. Insecticide applied by user (Sprayer 1). d. Number of rooms sprayed with the insecticide specified. e and f. Summary of spray event.

applications (or "apps") could be programmed and installed, and its ability to obtain GPS coordinates. Cell phones were acquired through donations.

In communication with MCP leadership staff, we identified critical IRS event information to be collected with the app. An app prototype was then developed by UC Berkeley programmers and it was beta tested with spray workers/foremen in Limpopo. Preliminary training occurred in October 2012, two weeks prior to the start of the spray season. Over the subsequent month, we received extensive feedback on the prototype's user interface and verified that the app was functioning properly. A number of problems were identified and, based on responses from the MCP collaborators and spray workers/foremen, the app was revised. A total of five mSpray versions were created before it was finally launched in the pilot study. Throughout the pre-testing and during the field study, researchers at UC Berkeley responsible for programming the app and summarizing the real-time data collected with mSpray continuously verified that information was being uploaded onto the Google spreadsheet properly.

The final mSpray app comprised 24 simple data entry screens and a summary screen (Fig. 1; see also Supplemental Fig. 1 for entire flow diagram) and it was installed on 10 data-enabled cell phones. Screens prompted the user to enter the name of the IRS supervisor (foreman) and the worker(s) conducting the spraying (spray worker), the number of rooms/shelters sprayed and unsprayed on a homestead, the insecticide(s) used, and whether insecticide compression sprayers were refilled, and to capture the GPS coordinates of the homestead. A date/time stamp was automatically applied to each entry. Once submitted, encrypted data were stored on the phone's memory card and automatically transferred via internet to a Google Drive Spreadsheet (http://developers.google.com) where it could be viewed in real time.

2.3. Pilot testing

We pilot tested mSpray in the Vhembe district of Limpopo province. Thirteen MCP staff (users included one team leader, 11 foremen, one spray worker) were assigned to record all sprayings for five spray teams consisting of 41 workers in total. Prior to initiating the pilot study, MCP staff provided a final two-hour, hands-on training to the mSpray users. The protocol specified that once a spraying had been completed at a homestead, the foreman who followed the spray team would complete the mSpray entry. To ensure accurate GPS readings, they were instructed to complete all data entry for a spray event while standing still outside the entryway of the main structure of the homestead with a clear view of the sky. A refresher training was given in December to answer any questions and to confirm protocols. Official mSpray pilot testing began November 20, 2012 and sprayings were documented until the spray season ended in March 2013. A summary of spray events was generated on a weekly basis to verify proper use and functioning of the app.

2.4. Evaluation

Evaluation of mSpray occurred at three levels. First, we overlaid GPS coordinates of mSpray events upon high-resolution satellite imagery (Spot 5 2009), using ArcGIS Version 10.0 (Redlands, CA, USA), and used the resulting maps to confirm that sprays were recorded at visually-identifiable village and homestead locations. Second, we compared mSpray data with SP record forms to electronically quantify the percentage of successfully captured homestead spray events. Third, we gathered evaluation data from mSpray users at two time points: midway through spray season (January 2013) and soon after spray

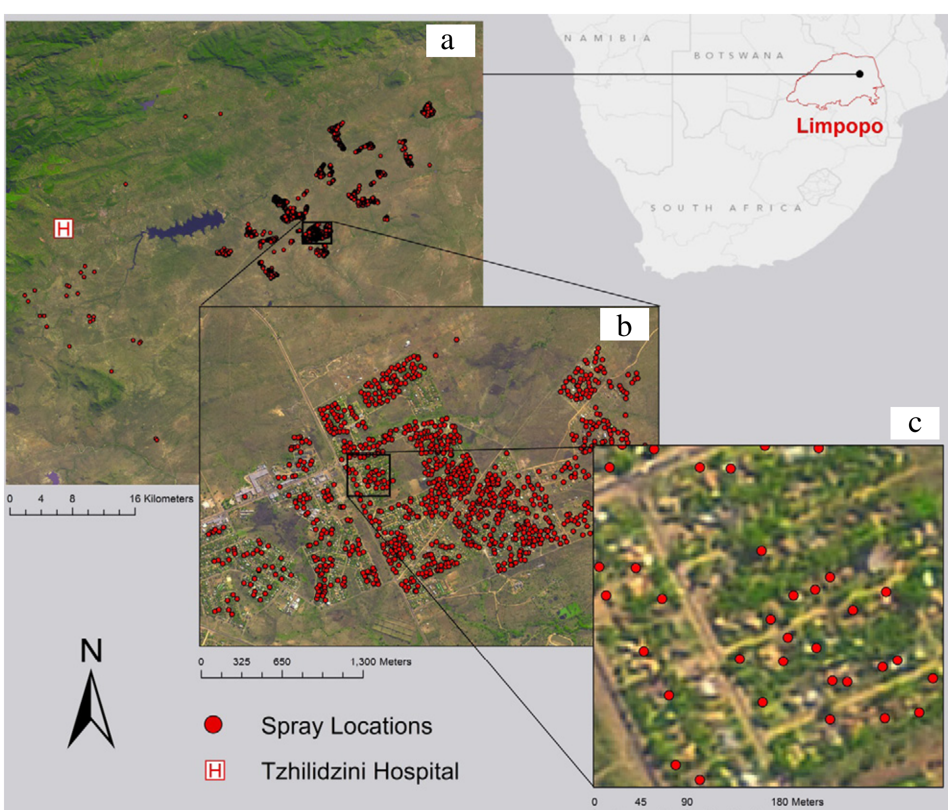

Fig. 2. Maps of IRS sprayings in Limpopo, South Africa as documented with mSpray. a. Vhembe district of Limpopo Province (upper left); b. Village-level sprayings (middle). c. Close-up of sprayings on a section of the village (SPOT-5 2009 (2.5 m) satellite multi-spectrum imagery).c. SPOT-5 2009 (5 m) satellite multi-spectrum imagery.

season (April 2013). Respondents answered multiple-choice and open-ended survey questions anonymously and then participated in group discussions. Survey data were described using STATA v11 (StataCorp, College Station, TX).

3. Results

3.1. Spray events

The map in Fig. 2 displays the location of spray events captured with mSpray, and includes a close-up of spray locations in one village. In most cases, the data entry appeared to occur in the center of the homestead. Our map suggests that villages may have been incompletely sprayed. Though this may be due to missed households and refusals to spray from residents, it likely also reflects incomplete use of mSpray, for reasons we describe below. Fig. 3 presents the numbers of structures sprayed by date, as captured by mSpray and by SP form records. A total of 2865 spray events were recorded on mSpray, comprising 22,301 rooms and 2904 shelters. These constituted 19% of rooms/shelters logged in SP form records (n = 134,901) during the study period. For a given date and spray worker, SP forms had an average of 35.6 (95% Confidence Interval = 32.6, 38.7) more rooms/structures. By the end of spray season, 82% of users had recorded 200 spray events or more on mSpray, though only one reported having recorded information for all spray events (Table 1). The cost for data bundles per phone for the season was approximately US$28.

3.2. Logistical and technical challenges

According to the 13 mSpray users who participated in evaluation sessions, logistical and technical challenges were to blame for the majority of missed mSpray entries. A main challenge was that too few workers were equipped with phones. Our intention was that a foreman with a phone would follow a spray crew and record spray events. Spray crews typically spread out to cover different streets; however, foremen expressed difficulty keeping up. In group discussions, foremen stated that they sometimes guessed how many rooms were in a house because the spray operators had moved on. The foremen also resorted to using SP record forms completed by the spray workers to enter the data in mSpray, sometimes combining data from multiple homesteads when they fell behind. These practices resulted in large single entries (e.g., >10 shelters/rooms) with one GPS coordinate. Approximately 18% of entries had >10 and 3.7% had >20 rooms and/or shelters entered on a single occasion. Almost all the users reported that they had done this at least some of the time (Table 1). As a solution, users suggested increasing the number of phones, though it was unclear who should carry the phones. Users expressed concerns over how spray workers could manage both phones and heavy compression sprayers or how foremen could input all data while performing other essential functions. It was suggested that if foremen continued to carry the phones, they would need to follow fewer sprayers, but this would require additional foremen.

Technical problems were another source of omissions in mSpray entries. Though we had no reported problems of poor cellular coverage or upload speeds, we encountered issues with uncharged cell phones, cell phone failure (one never linked to satellites and was decommissioned), and exhausted data bundles. Users reported that not having a charged phone was the leading reason for not using mSpray, and that cell phone failure was the second leading cause. Charging issues were traceable to short battery life of the cell phones (possibly exacerbated by heat and continued search functions), inability to charge phones in the field, and failures to charge overnight. Cell phone malfunctions included freezing and network problems. In late November, all phones ran out of data bundles but researchers discovered the problem immediately when there were no entries on the server. Though data collected during this period were stored on the memory of the cell phone and later downloaded, users may have stopped recording when their data bundles were exhausted if they were unaware that the phone could still store entries.

Some technical problems were exacerbated by logistical challenges. Because MCP staff who could troubleshoot technical problems were at a distance from the field, users could not readily access help when problems arose. Users who were unaware of the free “call me” function (i.e., a function which allows users to send a free text message asking

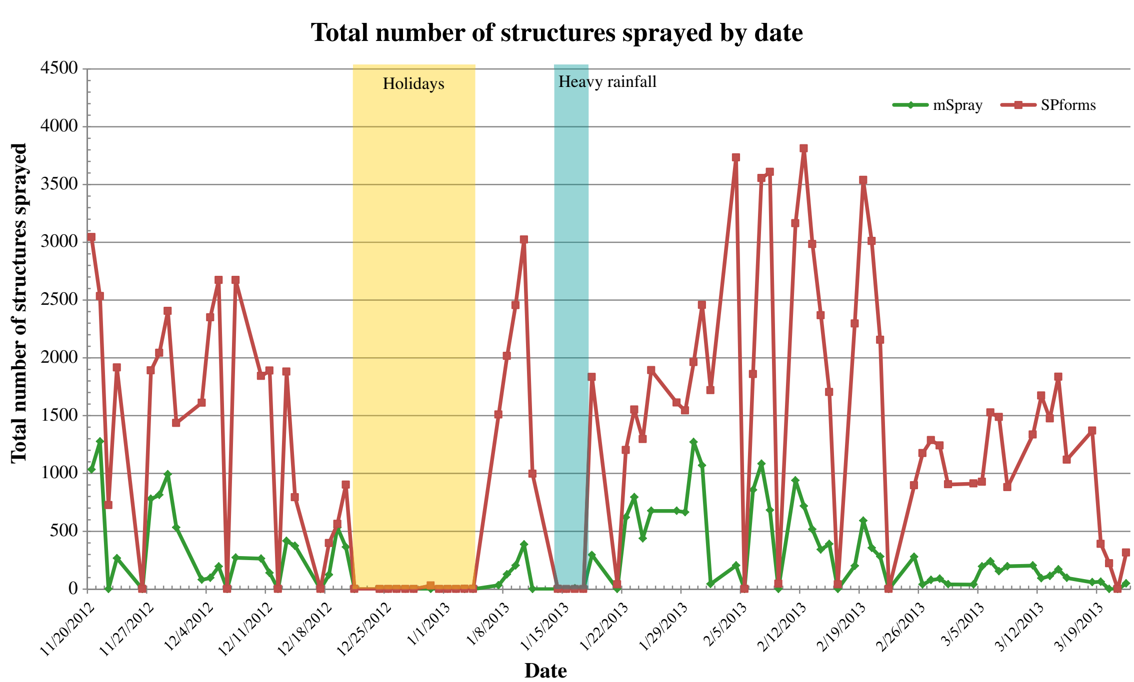

Fig. 3. Total number of structures (rooms + shelters) sprayed by date according to mSpray and SP form records. No sprayings were conducted in the field on certain dates: 2012—November 26, December 6 and 12, and on 2013—February 25 and March 21.

Table 1
Responses from users about mSpray, Limpopo, South Africa, 2013.[a]

	Survey 1 (n = 13)		Survey 2 (n = 11)	
	n	(%)	n	(%)
Prior experience using smartphone devices				
A lot	1	(7.7)	6	(54.5)
Some	8	(61.5)	5	(45.5)
Very little	2	(15.4)	0	(0.0)
None at all	2	(15.4)	0	(0.0)
Time it took to become comfortable with mSpray				
One day	5	(38.5)	3	(27.3)
A few days (<1 week)	7	(53.9)	4	(36.4)
A few weeks (<1 month)	1	(7.7)	3	(27.3)
>1 month	0	(0.0)	0	(0.0)
Still not comfortable	0	(0.0)	1	(9.1)
Number of events recorded on mSpray				
<20	1	(7.7)	0	(0.0)
20–50	5	(38.5)	1	(9.1)
50–100	0	(0.0)	1	(9.1)
100–150	0	(0.0)	0	(0.0)
150–200	1	(7.7)	0	(0.0)
200–250	0	(0.0)	2	(18.2)
250–300	0	(0.0)	2	(18.2)
More than 300	4	(30.8)	3	(27.3)
Don't know	2	(15.4)	2	(18.2)
Average length of time to record spray information				
1–2 min	3	(23.1)	4	(36.4)
3–5 min	10	(76.9)	6	(54.5)
Don't know	0	(0.0)	1	(9.1)
Behaviors				
During the time that user had mSpray, information was collected for…				
All of the homes	2	(15.4)	1	(9.1)
Most of the homes, but not all of them	9	(69.2)	6	(54.6)
Some of the homes (<1/2 of the homes sprayed)	2	(15.4)	4	(36.4)
Reason for not using mSpray[b]				
Forgot the phone	2	(9.5)	3	(13.0)
Did not have time	5	(23.8)	2	(8.7)
Made job harder	0	(0.0)	2	(8.7)
Phone was not Charged or battery died	10	(47.6)	8	(34.8)
Phone not working properly	4	(19.0)	5	(21.7)
Did not get a phone	0	(0.0)	3	(13.0)
User combined information for multiple homes (rather than one entry per homestead)				
Did not record any information on mSpray	0	(0.0)	1	(9.1)
Never	5	(38.5)	1	(9.1)
Some of the time (<1/2 of the time, but more than 1/4 of the time)	4	(30.8)	6	(54.6)
Most of the time (>1/2 of the time)	3	(23.1)	3	(27.3)
All of the time	1	(7.7)	0	(0.0)
Collected GPS data at the main entrance of homestead				
Never	0	(0.0)	2	(18.2)
Some of the time	1	(7.7)	4	(36.4)
Most of the time	6	(46.2)	3	(27.3)
All of the time	6	(46.2)	2	(18.2)
User knew exact number of rooms sprayed every time				
Strongly agree	4	(30.8)	2	(18.2)
Agree	5	(38.5)	6	(54.5)
Undecided	1	(7.7)	3	(27.3)
Disagree	2	(15.4)	0	(0.0)
Strongly disagree	1	(7.7)	0	(0.0)
Opinions of mSpray				
Could monitor sprayer's work				
Strongly agree	3	(23.1)	5	(45.5)
Agree	6	(46.2)	5	(45.5)
Undecided	1	(7.7)	1	(9.1)
Disagree	2	(15.4)	0	(0.0)
Strongly disagree	1	(7.7)	0	(0.0)
mSpray provides accurate data on spray events				
Strongly agree	–	–	3	(27.3)
Agree	–	–	7	(63.6)
Undecided	–	–	0	(0.0)
Disagree	–	–	1	(9.1)
Strongly disagree	–	–	0	(0.0)
mSpray interfered with normal work				
Strongly agree	0	(0.0)	1	(9.1)
Agree	5	(38.5)	6	(54.5)
Undecided	0	(0.0)	1	(9.1)

(continued on next page)

Table 1 (*continued*)

	Survey 1 (n = 13)		Survey 2 (n = 11)	
	n	(%)	n	(%)
mSpray interfered with normal work				
Disagree	3	(23.1)	2	(18.2)
Strongly disagree	5	(38.5)	1	(9.1)
mSpray adds work				
Strongly agree	4	(30.8)	3	(27.3)
Agree	8	(61.5)	4	(36.4)
Undecided	0	(0.0)	0	(0.0)
Disagree	0	(0.0)	2	(18.2)
Strongly disagree	1	(7.7)	2	(18.2)
It takes too long to input data on mSpray				
Strongly agree	0	(0.0)	–	–
Agree	2	(15.4)	–	–
Undecided	2	(15.4)	–	–
Disagree	5	(38.5)	–	–
Strongly disagree	4	(30.8)	–	–
mSpray made it difficult to follow sprayers				
Strongly agree	2	(15.4)	1	(9.1)
Agree	3	(23.1)	3	(27.3)
Undecided	2	(15.4)	2	(18.2)
Disagree	3	(23.1)	4	(36.4)
Strongly disagree	3	(23.1)	1	(9.1)
mSpray was…		Mean $\pm$ SD		
Easy to use	–	–		7.8 $\pm$ 2.7
Fun to use	–	–		8.3 $\pm$ 3.0
User-friendly	–	–		8.0 $\pm$ 2.8
mSpray provides better data than SP forms				
Strongly agree	5	(38.5)	–	–
Agree	5	(38.5)	–	–
Undecided	0	(0.0)	–	–
Disagree	3	(23.1)	–	–
Strongly disagree	0	(0.0)	–	–
mSpray is easier to use than SP forms				
Strongly agree	7	(53.9)	–	–
Agree	4	(30.8)	–	–
Undecided	1	(7.7)	–	–
Disagree	1	(7.7)	–	–
Strongly disagree	0	(0.0)	–	–
mSpray is better than SP forms				
Strongly agree	7	(53.9)	–	–
Agree	6	(46.2)	–	–
Undecided	0	(0.0)	–	–
Disagree	0	(0.0)	–	–
Strongly disagree	0	(0.0)	–	–
mSpray takes more time to complete than SP forms				
Strongly agree	0	(0.0)	–	–
Agree	4	(30.8)	–	–
Undecided	0	(0.0)	–	–
Disagree	3	(23.1)	–	–
Strongly disagree	6	(46.2)	–	–
Overall satisfied with mSpray				
Strongly agree	10	(76.9)	2	(18.2)
Agree	3	(23.1)	8	(72.7)
Undecided	0	(0.0)	0	(0.0)
Disagree	0	(0.0)	1	(9.1)
Strongly disagree	0	(0.0)	0	(0.0)
User would recommend use of mSpray				
Yes	–	–	11	(100.0)
No	–	–	0	(0.0)
Preferred method to record spray events				
mSpray	–	–	4	(36.4)
SP forms (paper-based forms)	–	–	3	(27.3)
Either	–	–	4	(36.4)
Desired changes in future revisions[b]				
Colorful background	–	–	2	(6.1)
Font that is easier to read	–	–	3	(9.1)
Nicer font	–	–	2	(6.1)
Colorful buttons on the screen	–	–	2 s	(6.1)
Automated SP forms	–	–	3	(9.1)
Longer battery life	–	–	10	(30.3)
Better GPS	–	–	4	(12.1)
Better way to input IDs (i.e., no drop down menu)	–	–	7	(21.2)

[a] Responses are from surveys conducted midway and at the end of the spray season.

[b] Question allowed for multiple responses; thus, values reported were calculated by using the number of positive responses (yes) for each specific question divided by the total number of positive responses for all options and then multiplied by 100 to get a percent. The n's reported are number of respondents that selected a given item. For example, at the first survey, two respondents indicated that a missed event was attributable to a forgotten phone; this was two out of 21 total attributions or 9.5%.

for a callback) on the mSpray phone and who either did not have a cell phone with airtime or did not want to pay for a call expressed frustration with this. Each round of program updates also resulted in missed data entry days, since it required a round-up of phones to MCP headquarters for installation of the updated app.

Finally, some users expressed concerns about use of the cell phones themselves, including that the keys on the phones were too small to use easily, and that they had difficulty seeing the phone screen or reading the text due to small font size and glare from sunlight.

3.3. Human error

We also identified cases of human error. Despite the fact that DDT was not used in the region during the pilot period, three foremen recorded a total of 12 DDT sprayings; in later discussions it was confirmed that these were mistakes. The sprayer IDs in SP forms and mSpray were occasionally discordant. These were likely data entry errors attributable to a long drop-down list with similar last names. Human error was likely to blame for 26 cases (0.9% of all readings) of inadequate GPS accuracy (>20 m); 15 of these inadequate readings were made by a single user. Finally, prior to our December refresher training, some users were not aware that they needed to remain in one place for the entire entry; some may have moved around while they entered the data, including in vehicles.

3.4. Overall user experience with mSpray

Most users (69%) had experienced using smartphone devices prior to mSpray and were not afraid of the new technology. Users' responses to survey questions (Table 1) indicated that almost all felt comfortable using mSpray within a week of using the app and none found it difficult to use. Responses also indicated that recording events with mSpray was relatively quick: almost all users reported taking 5 min or less to record spray events and by survey 2, 36% took only 1 to 2 min. All users agreed that keeping track of IRS operations is a good idea and by the second survey, almost all felt mSpray allowed them to monitor their team's work and provided accurate data on spray events. Though by the second survey, a little over a third of users reported that mSpray made it difficult to follow the sprayers and more than half reported that mSpray interfered with their normal work, almost all felt mSpray was easy and fun to use and were satisfied with the app. In addition, all would recommend mSpray to other spray teams and only 27% preferred the paper forms to mSpray for IRS event documentation.

3.5. Overall MCP experience with mSpray

MCP officials had some concerns about mSpray, including about the time it took to get accurate GPS readings and potential resistance by workers with set work routines and little familiarity with technology. MCP was also concerned that use of mSpray prevented foremen from performing other essential duties, such as assisting their crews in moving furniture from homes prior to spraying.

In considering revisions to mSpray, MCP officials emphasized the importance of knowing not only the GPS coordinates of the sprayings but the names of the villages since this will help them in mop-up (going back to homesteads not initially sprayed). (However, we note that village names can be generated readily and accurately from the GPS coordinates.) MCP also wanted mSpray to record unsprayed as well as sprayed homesteads and to record the reason why unsprayed homesteads were not sprayed.

MCP officials did, however, identify some clear advantages of mSpray over the current system. For one, they appreciated the ability to produce maps using GPS coordinates gathered by mSpray, which helped them to visualize where sprayings had occurred and could be compared with residential information on malaria cases. In addition, they appreciated that mSpray records were available in real time, whereas the current system entails an approximate 4-week delay to access paper records. This usual lag prevents timely mop-up activities. Lastly, they recognized that mSpray has the potential to track sprayer's paths and could thus be used to increase efficiency of IRS operations.

4. Discussion

Mobile telephony subscription in South Africa has increased fivefold over the past decade and dramatically surpasses that of fixed landlines. By 2012, mobile telephone subscriptions were estimated to reach 68, 394,000 (138.4 per 100 inhabitants) (ITU World Telecommunication, 2013). In this project in Limpopo, South Africa, we harnessed this growing technology to increase the utility of data gathered by indoor residual spray (IRS) workers who apply insecticides for malaria control purposes. We found that the low-cost, cell phone-based “mSpray” app was learned quickly by spray teams, well accepted, and preferred to the current paper-based method, although we also identified some logistic and user problems that would need to be overcome before full deployment.

To our knowledge, technology has only been used to support IRS activities in one other setting. In Zambia, hand-held personal digital assistants (PDAs) were used in a pilot study to enumerate and geocode IRS target structures. The purpose was to estimate the volume of pesticides required and to inform distribution of spray workers based on density of dwellings; the PDAs were not used in the monitoring of the spray applications (National Malaria Control Centre Zambia Ministry of Health, 2007). Thus, mSpray is likely the first cell phone technology developed to document spray applications. However, cell phone technology has been used in a variety of public health activities in developing countries. For example, mobile phones have been used to track chlorine usage in drinking water in Haitian homes (Kaye et al., 2012); to record adverse events among patients undergoing tuberculosis therapy in KwaZulu Natal, South Africa (Chaiyachati et al., 2013); for the tracking and care of patients in Pakistan (Marcus et al., 2009) and along the Thai–Myanmar border (Meankaew et al., 2010); for the tracking and reporting of real-time disease worldwide (Outbreaks Near Me) (Freifeld et al., 2010); and to target emergency care with phone messaging by pregnant women in Iraq (Ismaeel and Jabar, 2013).

The mSpray application has numerous advantages over the current paper-based documentation system used in South Africa and elsewhere, the most important of which is the accurate monitoring of spray events at the homestead level (GPS coordinates). This has the potential of allowing map overlays of malaria cases, entomological data, and IRS use, increasing possibilities for more targeted vector control by location. In addition, data is recorded with a time/date stamp and can be provided to MCP and other data users in real time (Table 2). These features allow for a spatial and temporal merging of both spray events and malaria cases. In addition, these data could be used to target unsprayed homesteads for end-of-season “mop-up” spray operations. Thus, this method has the potential to increase efficiency in the use of expensive pesticides and reduce human exposure to these potentially hazardous agents. It can furthermore be a powerful tool in the management of vector resistance, by planning the use of different insecticide groups at the local level. Another advantage is that the routes of spray workers could be monitored. Although the spray workers might not welcome this close oversight, it may lead to greater efficiency in work practices. Providing maps to workers could be a motivator and a learning tool. Although we did not use this in the current application, smartphones are also equipped with cameras, so photographs could be taken to document the appropriate use of personal protective equipment and/or unusual observations and these could be readily linked to the date and location of the spray event.

However, our project also identified limitations of mSpray, key among these being the need for intensive, ongoing and on-site technical support for spray teams using the technology and the need to develop site-specific mSpray use protocols that take into account the work

Table 2
Strengths and limitations of a cell phone-based technology, mSpray, for documenting IRS applications, Limpopo, South Africa.

Strengths	Limitations
• Readily available technology	• Targeted theft item
• Good coverage in most places	• Needs activated Sim Card to work.
• Easy to use	• Not human error-proof
• Gets GPS coordinates to generate maps	• Current phones will become obsolete
• Has a time-date stamp	• Must record GPS outdoors and away from structures
• Allows for tracking routes of workers	• Tech savvy person needed to merge data onto Google spreadsheet and to map
• Can overlay malaria cases	• Needs to be customized for setting
• Can use phone camera to document	
• Data stored locally on phone and free on Google secure server	
• Gives real-time spray information	
• Stored GPS data is encrypted on the phone	

roles and competing personnel responsibilities. In our case, we learned that the foremen to whom we had assigned the task of entering data in mSpray often lagged behind the actual spray team and therefore did not know information about specific homesteads that was necessary for accurate data entry. While distributing mSpray phones to individual sprayers could help solve this problem, workers pointed out that it would be difficult for them to carry both their phones and their spray compression sprayers. Certain limitations we encountered (e.g., short battery life, poor visibility of cell phone screens, occasional poor GPS accuracy) could easily be improved with better programming of the app, a slightly larger cell phone screen, setting adjustments on phones, and improved training. Human error issues we encountered are not specific to mSpray. While cell phones have a limited lifespan and additional costs will be incurred with the purchase of newer models, the cost of data bundles may continue to decrease. Although the cost of phones and data bundles should be considered, these costs might be outweighed by increased efficiencies.

Efforts are currently underway to revise mSpray for future use, incorporating the feedback of the users and end-users. With our next generation of mSpray, we hope to improve the efficiency and utility of the app so that its overarching aims may be achieved: allowing the monitoring of IRS in relation to malaria cases, increasing the effectiveness and efficiency of malaria control operations and through this increased efficiency, ensuring the judicious use of insecticides as part of an integrated vector management strategy. However, the full deployment of mSpray would require the commitment of malaria control agencies to invest in the cost of cell phones, cellular bundles, training and oversight.

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Competing interests

The authors declare that they have no competing interests.

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