Smartphones for community health in rural Cambodia: A feasibility study [version 1; referees: 2 approved with reservations]

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Abstract

Background: Village Malaria Workers (VMWs) are lay people trained to provide a valuable role in frontline testing and treatment of malaria in rural villages in Cambodia. Emergence of artemisinin-resistant malaria highlights the essential role of such VMWs in surveillance and early treatment of malaria. Smartphone technology offers huge potential to support VMWs in isolated and resource-poor settings.

Methods: We investigated the feasibility of issuing established VMWs with a smartphone, bespoke Android application and solar charger to support their role. 27 VMWs in Kampong Cham and Kratie provinces participated.

Results: 26/27 of the smartphones deployed were working well at study completion twelve months later. Interviews with VMWs using quantitative and qualitative methods revealed pride, ease of use and reports of faster communication with the smartphone. VMWs also expressed a strong wish to help people presenting with non-malarial fever, for which further potential supportive smartphone applications are increasingly available.

Conclusions: As a result of this pilot study, two smartphone based reporting systems for malaria have been developed at the Cambodian National Malaria Center, and the programme is now being extended nationwide. The full code for the smartphone application is made available to other researchers and healthcare providers with this article. Smartphones represent a feasible platform for developing the VMW role to include other health conditions, thus maintaining the relevance of these important community health workers.

Keywords

malaria, smartphone, technology, m-health, community
This article is included in the Mahidol Oxford Tropical Medicine Research Unit (MORU) gateway.

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**Competing interests:** No competing interests were disclosed.

**How to cite this article:** Ngor P, White LJ, Chalk J et al. Smartphones for community health in rural Cambodia: A feasibility study [version 1; referees: 2 approved with reservations] Wellcome Open Research 2018, 3:69 (doi: 10.12688/wellcomeopenres.13751.1)

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**Grant information:** The work was supported by the Wellcome Trust Major Overseas Programme in Southeast Asia [106698], the Wellcome Trust Intermediate Fellowship grant to SD [100174]; and the Bill and Melinda Gates Foundation (OPP1110500). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

**First published:** 12 Jun 2018, 3:69 (doi: 10.12688/wellcomeopenres.13751.1)
Introduction
More than 3 billion people, including 70% of the world’s poorest people, live in rural areas, where access to skilled medical care may be difficult, especially during the rainy season. Trained lay people in target communities can offer, via supported schemes, a valuable contribution to diagnosis and management of medical conditions such as malaria, childbirth and childhood diarrhoea. However, giving sufficient support to such community workers, including training updates, diagnostic support, stock control and data collection is challenging. Mobile phone technology provides the potential to improve the range and quality of services delivered by community health workers, but the majority of published literature on feasibility in developing countries is focussed on standard mobile phones (“feature phones”) rather than the next generation of smartphones.

The Cambodian National Malaria Center (CNM) has an established network of Village Malaria Workers (VMWs) across 19 provinces covering a population of approximately 1.5 million people. VMWs review villagers with fever, test them for malaria with a rapid test (SD Bioline Malaria Ag Pf/Pan; Standard Diagnostics Inc, Gyeonggi-do, Republic of Korea) and treat those with positive results with artemesinin-based antimalarial therapy. Rapid case reporting by coded text message (short message service; SMS) from feature phones has been established by CNM. We set out to evaluate the feasibility of replacing the feature phone part of this reporting system with smartphones and a bespoke Android-powered app (smartphone application).

Methods
A new smartphone application (“app”) was designed and built for Android phones using the Open Data Kit platform version 1.3. All instructions for installation, configuration, implementation and operation are explained in detail with examples on the Open Data Kit website. The minimum system requirements for the smartphone are Android devices 4.0 and above, and the phone should be connected to the Google App Engine hosting platform. Code is available. The app was designed to be simple to use, not require current network access to be operational, and allowed the VMW to enter case report data in an intuitive way using Khmer language. The information recorded by the app and sent to CNM was as shown in the screenshots in Figure 1, namely gender, age, malaria rapid test result, and residency status (permanent villager or mobile migrant). Experienced VMWs in Kampong Cham and Kratie provinces were called to a meeting and the proposed study explained by CNM staff. All VMWs gave verbal consent to participate in the study, and then VMWs received one smartphone (Acer Liquid Z3, Acer, Virginia, USA) and one solar power charger (model LG-FD12D10, TBS Solar Solution Center, Phnom Penh, Cambodia) each (total cost $175 per VMW), alongside a 3-hour training session delivered at the local Health Centre by CNM staff. A coded SMS was generated automatically and sent to CNM using 2G or 3G telecommunications networks, which have an estimated 99% coverage in Cambodia, including all the villages under study. The project ran for twelve months from September 2014.

Prior experience of smartphones for each VMW and their experiences in the role of VMW was established by in-person questionnaire at the outset of the study using closed questions (Pre-implementation questionnaire, Supplementary File 1). Survival of the smartphone at 12 months was determined by inspection by CNM staff, and quantitative and qualitative data on VMW’s experiences were collected by in-person questionnaire conducted by CNM health workers using open questions, translated from Khmer to English language and analysed for key emerging themes (Supplementary File 2). The information captured by the smartphone app and sent to CNM was available to the researchers. Outcome measures were 1) Survival of smartphones and chargers over twelve months and 2) Acceptability of smartphone use by VMWs using verbal questionnaires administered in-person by CNM staff.

Results
Twenty-seven experienced VMWs in Kampong Cham and Kratie provinces were trained to use the new smartphone system (Figure 3). VMWs in Kampong Cham province had previous experience with feature phones, while those in Kratie province had no experience of using phones in their work. Populations

Figure 1. Screenshots of bespoke app for data collection allowing data entry. Screenshots show gender (a), age (b), malaria rapid test result (c), residency status (permanent villager or mobile migrant) (d), and exit screen to send data including GPS signal (e).
Figure 2. Map of Cambodia showing location of research. Kampong Cham and Kratie provinces are shaded yellow (source: Cambodia National Malaria Center, adapted from http://www.un.org/Depts/Cartographic/map/profile/cambodia.pdf). The boundaries and names shown and the designations used on this map do not imply the expression of any opinion whatsoever on the part of the Ministry of Health of Cambodia concerning the legal status of any country, territory, city, or area or of its authorities, or concerning the delimitation of its frontiers or boundaries).

Figure 3. Village Malaria Workers (VMW) receive training. A group of VMWs in Kratie Province receiving training in the use of smartphones for the project at Sambo Health. All individuals gave their consent for the publication of this image.
were broadly similar in the two provinces in demographics and socio-economic factors. The average distance of each village to the nearest health centre was 7.53km (range 2.9–10.3 km) for Kampong Cham province, and 16.9km (range 4.57–39.1 km) for Kratie province. Road access to the health centre during the rainy season was typically considered impossible or extremely difficult.

The results of the pre-implementation in-person questionnaire at the outset of the study are shown in Table 1 and Dataset 2. 15/27 (56%) of the VMWs were female and the mean age was 39 years (range 20 – 62). 100% were literate (a requirement for being a VMW) with the highest level of education completed being primary school level only for 81%, and all had been in post for more than three years. 85% already owned a feature phone, but only three VMWs (11%) owned a smartphone and the majority (85%) had never used one. The baseline survey of expectations showed 78% were expecting the smartphones to make their work easier and 70% were excited/proud to be using them. Motivations for being a VMW were to help others (78%), stop malaria (63%),

| Table 1. Baseline demographics and views of Village Malaria Workers in the study. |
|------------------------------------------|-----------------|-----------------|-----------------|
| Demographics                            | Kampong Cham    | Kratie          | Total           |
| Total, n                                 | 14              | 13              | 27              |
| No. female, n (%)                        | 7 (50)          | 8 (62)          | 15 (56)         |
| Mean age in years (range)                | 38 (20 – 60)    | 40 (21 – 62)    | 39 (20 – 62)    |
| Education beyond primary, n (%)          | 1 (7)           | 4 (31)          | 5 (19)          |
| Prior phone use                          |                 |                 |                 |
| Already own feature phone, n (%)         | 13 (93)         | 10 (77)         | 23 (85)         |
| Have used feature phone before, n (%)    | 14 (100)        | 10 (77)         | 24 (88)         |
| Already own smartphone, n (%)            | 3 (21)          | 0 (0)           | 3 (11)          |
| Have used smartphone before, n (%)       | 4 (29)          | 0 (0)           | 4 (15)          |
| Expectations                             |                 |                 |                 |
| Thinks it will make VMW role easier, n (%)| 14 (100)        | 7 (54)          | 21 (78)         |
| Excited, n (%)                           | 8 (57)          | 1 (8)           | 9 (33)          |
| Proud, n (%)                             | 5 (36)          | 5 (38)          | 10 (37)         |
| Worried about losing it, n (%)           | 4 (29)          | 3 (23)          | 7 (26)          |
| Worried about difficulties charging it, n (%)| 0 (0)          | 1 (8)           | 1 (4)           |
| Worried about difficulties operating it, n (%)| 0 (0)          | 1 (8)           | 1 (4)           |
| Motivation for being a VMW               |                 |                 |                 |
| To help others, n (%)                     | 11 (79)         | 10 (77)         | 21 (78)         |
| To contribute to malaria control, n (%)  | 13 (93)         | 4 (31)          | 17 (63)         |
| To gain respect within their community, n (%)| 9 (64)         | 0 (0)           | 9 (33)          |
| To access free health care, n (%)        | 7 (50)          | 0 (0)           | 7 (26)          |
| Financial / other incentives, n (%)      | 7 (50)          | 2 (15)          | 9 (33)          |
| To attain new skills, n (%)              | 8 (57)          | 2 (15)          | 10 (37)         |
| Challenges faced as a VMW                |                 |                 |                 |
| Long distance to travel to a patient's home, n (%) | 1 (7)          | 5 (38)          | 6 (22)          |
| Lack of transport, n (%)                 | 2 (14)          | 4 (31)          | 6 (22)          |
| Not enough time, n (%)                   | 6 (43)          | 1 (8)           | 7 (26)          |
| Lack of incentives, n (%)                | 4 (29)          | 1 (8)           | 5 (19)          |
| Poor patient adherence / co-operation, n (%)| 8 (57)         | 1 (8)           | 9 (33)          |
| Misunderstanding about malaria, n (%)    | 3 (21)          | 1 (8)           | 4 (15)          |
| Too many other tasks                     | 3 (21)          | 1 (8)           | 4 (15)          |
| Not enough support from the Health Centre, n (%)| 5 (36)         | 1 (8)           | 6 (22)          |
attain new skills (37%), gain respect from their community (33%),
financial/other incentives, with payment of $20 USD per month
(33%), and to gain access to free health centre services (26%).
Problems faced by VMWs included poor adherence or cooperation
from patients (33%), not enough time (27%), long distance to the
patient’s home (22%), lack of transportation (22%), not enough
support from the Health Centre (22%), lack of incentives (19%),
too many other tasks (15%), and misunderstanding about malaria
in the village (15%).

At study completion 12 months later, a follow-up survey
(Dataset 3) showed 26/27 smartphones (96%) and 27/27 solar
chargers (100%) issued to VMWs were working well. One USB
connector on the smartphone was broken so it could not be
charged. In addition, one smartphone was stolen during the
training session prior to issue. CNM reported that training was
quicker and easier to conduct than for paper or feature phone data
collection methods. 20/27 (74%) VMWs reported cases using
smartphones - 14/14 (100%) VMWs from Kratie province (no
previous feature phone experience) and 6/13 (46%) from Kampong
Cham province (with previous feature phone experience) reported
data. For the 7 VMWs who did not report cases using smartphone,
2 recorded malaria cases by paper records, while for the remain-
ing 5 there were no malaria cases reported. Negative test results
were not routinely reported by SMS in accordance to CNM policy
due to funding limits on the number of SMSs allocated to the
scheme.

All 27 VMWs were interviewed by CNM health workers at the
end of the study using a semi-structured format with a topic guide,
to evaluate experience and attitudes (Supplementary Data 3).
Three main themes emerged: enjoyment and pride of owning the
smartphone, finding it easier to use than a feature phone for their
role (Kampong Cham province), and thinking that it allowed faster
communication. VMWs were asked about what people in their
village said about the smartphone and the key themes were
curiosity, envy, surprise and being aware of the phones attracting a
lot of attention in the village.

The pre-implementation questionnaire found evidence that in
villages with much reduced malaria incidence, many villagers who have fever are no longer consulting VMWs. 59% of VMWs
reported that only ‘some’ villagers would see them with a fever. In
a 3-month period (Sep-Nov 2014) the information captured by the
smartphone app showed tests on 89 febrile villagers were reported
in the 13 villages in Kampong Cham province (mean 7 per village,
range 3–10) including 19 malaria positive cases. In contrast,
in the same period in Kratie, 688 tests on febrile villagers were reported (mean 49 per village, range 25–75) including 371 malaria
positive cases. We also found evidence of frustration amongst
VMWs that they were unable to help those with non-malarial fever,
with 17/27 (63%) wanting to learn more about healthcare.

**Discussion**

This pilot study demonstrates the feasibility of using a smart-
phone with a bespoke app to support community health workers in
rural villages in low-income countries. VMWs reported pride and
enjoyment at having use of a smartphone for their role, and felt
it allowed faster communication. The smartphone raised the
profile of the VMW in their village.

A previous systematic review of 42 studies of using mobile
technology in developing countries has shown the feasibility and
some descriptive evidence of effectiveness of delivering health-
care using predominantly feature phones by professional front
line workers such as midwives, pharmacists, nurses, doctors and
some Community Health Workers (CHWs). Innovative studies are
emerging demonstrating the role of smartphone apps delivered
by professional healthcare workers in developing countries for
health such as hearing screening in South Africa and visual
acuity testing in Kenya. In addition, use of a smartphone-based
electronic decision support system by CHWs has shown promise for cardiovascular management in rural Tibet and India.
The current study expands the literature to demonstrate feasibility
and acceptability in an impoverished population of Cambodian
CHWs, to support malaria control strategies.

The emergence and spread of artemisinin resistant malaria in
Cambodia is a major threat to global health, thus control
of malaria in rural Cambodia is of the utmost importance. We
defined low numbers of malaria cases detected by the VMWs
in this study, with many VMWs feeling frustrated at being unable
to help those with non-malaria fever under the current scheme.
After a number of ‘negative’ tests people might not consult the
VMW with a fever anymore, thus the sentinel role of the VMW
scheme in surveillance for malaria is reduced. This undermines
malaria control programs because future outbreaks of malaria
could go unnoticed and then spread to surrounding regions.

Based on the evidence of this study and the national capacity built
in the relevant coding skills, the co-authors at the national control
program in Cambodia are now developing two smartphone based
reporting systems for malaria. At the VMW level, the application
developed in this study has been extended to record all the case
data recorded by VMW in paper records. This information is then
uploaded directly to the national malaria database after entry.
There is a plan to install this application on 3300 smartphones
for introduction in 14 districts, 22 districts, 9 districts in 2018,
2019, 2020, respectively, with a view to paperless reporting in
the future. An additional feature of an SMS alerting system has been
included in selected pilot areas, which immediately reports every
new case to every level of the surveillance system. This system
has been integrated into a reactive case detection intervention in
the piloted areas. At the health centre level, a similar application
has been developed which focuses on case reports and stock-out
alerts for treatments and diagnostics. This application has been
installed on tablets in 816 health centres covering the entire malaria
endemic area of Cambodia.

The limitations of this study are the small numbers of VMW
involved, the short duration of follow up and the restricted
amount of information collected on follow-up. These restrictions
are due to the project being conducted with no extra resources
available. In addition, the extension of the project by the CNM
due to excellent informal feedback meant longer follow up was no longer feasible or deemed necessary.

The VMW scheme in Cambodia urgently needs to be enhanced and extended to be the front line in monitoring for drug resistance and future epidemics. To achieve this, and to maintain its relevance to local communities, it should also become a service for other health problems, transforming VMWs into CHWs. These CHWs would treat or refer patients with other health concerns making them the first point of contact in a village. We have demonstrated smartphone technology to be a robust platform for delivery of these services in the local language, enabling use of voice calls, SMS, photography, video, audio and GPS location tracking. As telecommunication network coverage and mobile use expand globally, exploitation of smartphone applications hold growing promise to tackle the world’s greatest health issues. This highly successful pilot project of introducing smartphone-based reporting for malaria has allowed the CNM to develop the platform for implementation.

Data and software availability
Dataset 1: Baseline Demographics and Views VMW survey available on Figshare, https://doi.org/10.6084/m9.figshare.6326723

Dataset 2: Post Implementation Survey VMWs available on Figshare, https://doi.org/10.6084/m9.figshare.6327221

Data are available under the terms of the Creative Commons Zero “No rights reserved” data waiver (CC0 1.0 Public domain dedication).

Archived source code of Smartphone App at time of publication: https://doi.org/10.6084/m9.figshare.6353210

License: CC0

Consent
All Village Malaria Workers consented to participate in the questionnaires. This study was part of a service improvement project involving Village Malaria Workers working for the Cambodia National Malaria Center, and specific written consent to participate in the study was not deemed necessary.

Author contributions
PN, LJW, PC, JC, YL and SD conceived of the project and oversaw the design. PN and JC wrote and developed the code for the Smartphone app and trained the Village Malaria Workers (VMW) in its use. CN, PT, SS and NPD oversaw the conduct of the study. PC advised on community engagement. CF assisted with analysis of VMW questionnaires. PN, LJW, CF and SD analysed the data. PN, LJW, CF, JC, RM and SD prepared the manuscript. All authors read and approved the final manuscript.

Competing information
No competing interests were disclosed.

Grant information
The work was supported by the Wellcome Trust Major Overseas Programme in Southeast Asia [106698], the Wellcome Trust Intermediate Fellowship grant to SD [100174]; and the Bill and Melinda Gates Foundation (OPP1110500).

The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Acknowledgements
The authors wish to thank the Village Malaria Workers and communities who participated in this study, and the staff of the Cambodian National Malaria Center who assisted with training.

Supplementary material
Supplementary File 1: Pre-implementation survey: Baseline Demographics and Views.
Click here to access the data.

Supplementary File 2: Post-implementation survey: VMWs’ experience of using smartphones.
Click here to access the data.

References
Reference Source
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Current Referee Status:  ?  ?

Version 1

Referee Report 09 July 2018

doi:10.21956/wellcomeopenres.14942.r33291

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Overall, I felt the article was well-written and succinct, identifying a relevant improvement to support the work of an important niche health service provider (the VMW). Data collection for the study involved administration of a pre-study questionnaire, and in person questionnaire to collect qualitative and quantitative data on volunteers’ experiences. Outcome measures were (1) Survival of smart phones and chargers over 12 months post-study commencement (as determined by inspection of the equipment by CNM staff) and (2) acceptability of smart phone use by VMWs (emerging themes from the in-person questionnaires were collated).

The study made the assertion “the current study expands the literature to demonstrate feasibility and acceptability in an impoverished population of Cambodian CHWs, to support malaria control strategies.” In my view, however, the methods were not sufficient to capture some key feasibility and accessibility information. Furthermore, it appears that in some communities, the role of VMW is becoming obsolete in some areas “In the context of their current role in villages with reduced malaria, villagers presenting with fever are frequently not consulting VMWs.” The authors acknowledge the limitations posed by the small number of VMWs in the pilot study, the short duration of follow-up, and the restricted amount of information collected on follow-up, and also suggest the necessity to enlarge the role of VMWs to include more CHW responsibilities.

Recommendation: the authors might consider demonstrating how readily the VMW role could be expanded to a more general CHW role, which to me would ably make the case for feasibility. Most developing countries are plagued by a range of infectious diseases and finding broader public health use of technology would be more beneficial.

Assessing feasibility of the proposed implementation

The study was conducted in two health areas in communities that had different malaria profiles, with VMWs who had differing levels of prior exposure to smart phones, which makes the results feel more compelling. Literacy is a requirement for being a VMW, which may not be the case for community health workers in other settings.

Recommendation: the authors might consider discussing the ramifications of deploying the app more generally in the context of the literacy requirement.

Assessing technological and system capabilities/requirements
Implementation required provision of a smart phone, solar-powered smart phone charger and three hours of instruction.

This amount of training seemed to be adequate and effective, even in the cohort which had little prior exposure to smart phones, which suggests good feasibility in terms of skills transfer/capacity building. The study was carried out over a 12-month period, with the majority phones and chargers being found to be in good condition after that interval, further making the argument for feasibility. The authors acknowledged the short time frame (given the high cost, it would be expected that the lifetime of the phone would need to be significantly higher than one year). However, usage and storage conditions were not specifically addressed, and it was not clear to what extent smart phone durability was tested in real world conditions. If the expectation is that the phone systems are kept in a locked cabinet in the clinic the majority of the time, this may affect feasibility.

Recommendation: the authors might consider addressing how and when phones were accessible to the VMWs.

Advantages: The mobile app is simple to use, intuitive and does not require current network access to be operational. The software code open source and available online, making the study intervention accessible and replicable in that respect. The availability of 99% mobile data coverage in the study setting made it feasible for this study, but would perhaps be a concern for other remote health areas interested in trying this model.

Recommendation: the authors might consider discussing the practicalities of implementation in settings with less robust mobile data coverage (however, this may be considered to be outside of the scope of the study)

Concerns

1. The cost of USD175 per VMW seemed prohibitive to scaling. The article reports that “the numbers were limited by the cost of the phones” a challenge which lies at the heart of feasibility.

   Recommendation: the authors might consider addressing how this cost would be managed (the use of “supported schemes” is mentioned early in the text but not elaborated upon when referring to the plan for staged introduction of phones).

2. The authors chose to combine the findings of pride and excitement/proud to be using the phone. However, this concealed the fact that when disaggregated, the numbers for each category were actually quite low: My concern was that the study may not have adequately captured concerns relating to the use of the smart phone (given the closed nature of the questionnaire), and that problems might therefore be replicated. I would be interested to know why the 2 VMWs used paper records rather than the phones, and whether, if the other 5 VMWs had no cases to report, is introducing an expensive cellphone really feasible? I would further be interested in gaining more specific information about the uptake and use of the technology in the village with high numbers of reporting, and to what extent paper reports were generated in that setting, which is not elaborated in the text.

3. I felt that the study did not capture how the use of phones would/did make the work easier: I assume it would be related to data reporting, but this is not specified in the article. While the study
was able to record that VMWs felt the smart phones would allow faster communication, it is not specified if that was actually the case. The methods used did not capture this question, and it is not clear if that was assessed or determined in any way.

4. The authors make the assertion: “we have demonstrated smartphone technology to be a robust platform for delivery of these services in the local language, enabling use of voice calls, sms, photography, videos, audio and gps tracking.” Recommendation: the authors might consider disaggregating the data from the group which reported a large number of malaria cases using the smartphones to more strongly support this assertion.

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Not applicable

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Partly

**Competing Interests:** No competing interests were disclosed.

**Referee Expertise:** Field epidemiology, infectious disease and child vaccines

I have read this submission. I believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Referee Report 05 July 2018
doi:10.21956/wellcomeopenres.14942.r33292

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Overall, a very well written and useful paper delivering useful and practically-relevant evidence.
1. The need to shift from VMWs to CHWs is clearly spelled out in the final paragraph of the discussion, but needs to be more clearly and explicitly stated in the abstract.

Minor comments
1. The following sentence from the second paragraph of the results section is vague: “100% were literate (a requirement for being a VMW) with the highest level of education completed being primary school level only for 81%”. Does that mean that 81% had not completed primary school, yet were literate? Or that 81% had primary education and the remainder has secondary or above? I’m guessing the word “only may have been misplaced in this sentence.

2. Third paragraph of the results section: It is a little unclear whether the smart phone with the damaged USB port is the one counted as not working well. If so, I think it would be worthwhile to make it clear that all 27 were still in place.

3. The first sentence of the second paragraph of the discussion is too long. Please split in two and make it read easier.

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Referee Expertise: Malaria transmission and control

I have read this submission. I believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.