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RESEARCH ARTICLE

PesTrapp mobile app: A trap setting application for real-time entomological field and laboratory study

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ABSTRACT

Diseases such as malaria, dengue, Zika and chikungunya remain endemic in many countries. Setting and deploying traps to capture the host/vector species are fundamental to understand their density and distributions. Human effort to manage the trap data accurately and timely is an exhaustive endeavour when the study area expands and period prolongs. One stop mobile app to manage and monitor the process of targeted species trapping, from field to laboratory level is still scarce. Toward this end, we developed a new mobile app named "PesTrapp" to acquire the vector density index based on the mobile updates of ovitraps and species information in field and laboratory. This study aimed to highlight the mobile app's development and design, elucidate the practical user experiences of using the app and evaluate the preliminary user assessment of the mobile app. The mobile app was developed using mobile framework and database. User evaluation of the mobile app was based on the adjusted Mobile App Rating Scale and Standardized User Experience Percentile Rank Questionnaire. The process flows of system design and detailed screen layouts were described. The user experiences with and without the app in a project to study *Aedes* surveillance in six study sites in Selangor, Malaysia were elucidated. The overall mean user evaluation score of the mobile app was 4.0 out of 5 (SD=0.6), reflects its acceptability of the users. The PesTrapp, a one-stop solution, is anticipated to improve the entomological surveillance work processes. This new mobile app can contribute as a tool in the vector control countermeasure strategies.

Keywords: Dengue; mobile app; ovitrap index; *Aedes aegypti*; *Aedes albopictus.*

INTRODUCTION

Emerging and re-emerging diseases are significant issues in global health situation (Kilpatrick & Randolph, 2012). Dengue, an important vector-borne disease globally, is endemic in many tropical countries. The continued absence of effective vaccine and antivirals, hence chemical control, biological control, environmental management, health education and legislation are utilised to control the *Aedes* vectors and the diseases they carry (Chang *et al.*, 2011). Ovitrap, a device which consists of a 300-ml plastic container with straight and slightly tapered sides (Lee, 1999) is used to characterise the temporal and spatial distribution and abundance of *Aedes* mosquitoes in a locality by taking advantage of the preference of *Aedes* mosquitoes laying eggs in containers. Usually, a minimal number of ovitraps, i.e. 50 to 100 ovitraps, are deployed in one locality, indoor or/and outdoor, and recollected after 5 to 7 days to be used to estimate vector abundance in the targeted area (Mogi *et al.*, 1990). The ovitrap index, the entomological indicator, which quantifies the infestation frequency of vector mosquitoes, is the number of traps with study subjects (mosquito species) divided by the total recovered traps. The mean number of larvae per trap is used to estimate the adult mosquito abundance. These data are normally served to construct early warning prediction model to forestall dengue outbreaks and also recommend remedial actions to avoid and suppress the outbreak (Mogi *et al.*, 1990; Lee, 1992).

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Currently, the ovitrap deploying process is tedious and resource-hungry. The field team first deploys the ovitraps in a selected study site. While deploying in the study site, a distinct ovitrap code is assigned for each ovitrap and the house number, road and descriptions are recorded in a prescribed paper datasheet. To obtain the coordinates of the location, the same ovitrap code is inserted in the Global Positioning System (GPS) devices to capture the coordinates of the location. After five to seven days, the team search and collect the traps based on the recorded information. The status of the ovitraps, whether missing or found, is updated in the datasheet. Back in the laboratory, the datasheet is then transferred to a master Microsoft Excel file. The data from the GPS devices is exported to .csv or .dat file and updated in the master Excel file. Then, the species of the adult mosquitoes is identified and recorded in paper by the laboratory assistants if no computer is available in the laboratory. Subsequently, the species information will be matched and updated in the master Excel file. Finally, the ovitrap index and mean larva per trap are analysed and reported in graphs or charts. The common problems of these conventional manual activities are bulk data to compile, inconsistencies of recording method, errors while transcribing the information and misidentification of ovitraps. Different platforms of data recording and storage, from paper, GPS devices to Excel sheet, are not integrated. When the data grows large with many monitoring sites, without a database system, the data management and interpretation process with spreadsheets alone are exhaustive and error-prone.

Several mobile applications have been utilised to monitor animal trap by embedded sensor (Loughlin, 2013; Eiran & Earle, 2017), analyse the images of pests on glue board (Freudenberg *et al*., 2019) and monitor the capture-mark-recapture process (Bateman *et al.*, 2013). The US Centers for Disease Control and Prevention (CDC) developed a mobile app named "Epi Info Vector Surveillance Application" to track and enter mosquito surveillance data and insecticide resistance bioassay testing (Global Health, 2017). The commercialised outdoor GPS recording mobile app (e.g. Handy GPS, Geo Tracker, A-GPS Tracker) would be the alternatives to acquire coordinates of traps, but they are not integrated with the project database. As far as our knowledge can tell, mobile app to manage and monitor the process of animal trapping, from field to laboratory level, in particular for vector borne disease studies is scarce. Based on the requests from the medical entomologists, a one stop project-based mobile application (app) that integrate all processes to obtain *Aedes* index, from field to laboratory, is urgently needed. Therefore, we developed a mobile app named "PesTrapp" as a trap setting application for real-time field and laboratory study. This study aimed at three objectives, firstly, to describe the development and design of the mobile app; secondly, to elucidate the practical user experiences using the mobile app; thirdly, to evaluate the preliminary user assessment of the mobile app.

MATERIALS AND METHODS

Ethics approval and consent to participate

Ethical approval protocol from the Medical Research and Ethics Committee (MREC), Ministry of Health Malaysia was followed [reference number KKM/NIHSEC/P18-668(4)]. Written informed consent was obtained from users who consented to take part in the survey.

Development of the mobile app

The PesTrapp is developed from scratch using PHP (Bakken *et al*., 2000) and MySQL database storage (Oracle Corporation, 2020) on the Android operating system as Google's Android is open source Linux based (Alliance, 2010) and widely used (Chau *et al*., 2020). The user interface is developed using javascript code and html5. The final code are compiled and bundled using Apache Cordova (Foundation, 2020), open source Onsen javacsript library (Monaca Onsen UI Team, 2020) into wrapper and APK file. The services used by PesTrapp are Google Maps Application Programming Interface (API) for the mapping and Google Firebase API (Google Developers, 2020) for pushing notification.

Design of the mobile app

The functions of PesTrapp mobile are sequentially divided into several processes, namely preparation, deployment of ovitraps, collection of ovitraps, identification of species and reports. Upper part of Figure 1 showed the screen layout of preparation process. System administrator or project leader pre-register the PesTrapp users in the web dashboard. Subsequently, registered and login user able to register the study site in the mobile app by setting the site code, site name, type of site (landed houses or high-rise flats/apartments/condominiums), number of traps and code of traps. Lower part of Figure 1 depicted the deployment of ovitraps process. There are four main functions in the main menu of the app, namely, deployment of ovitraps, collection of ovitraps, identification of species and reports. User clicks the "Deployment of ovitraps" button and search or select the site from list. For landed houses, user inserts trap status (indoor/outdoor), house number, road, description of traps, records coordinate and takes photo of trap location. For high-rise flats/apartments/condominiums, user inserts trap status (indoor/outdoor), house number, level, block, description of traps and takes photo. The information is instantly saved in the database server. Capturing of coordinates per ovitrap is impossible in high-rise as GPS signal is often low. The ovitrap status screen is displayed for both deployment and collection of ovitrap using color coding. Green color indicates ovitraps that have been deployed, white color indicates ovitraps that have not yet been deployed.

The retrieved map and photo taken during deployment are served as reference during retrieving the trap as shown in upper part of Figure 2, user refers to the retrieved map and photo. The status of collected ovitrap that either recovered or not recovered is updated upon collection. If the trap is missing or broken, user updates as "Not recovered" option. The latest status of ovitrap being collected is constantly updated in ovitrap status page. Green colour indicates ovitraps that have been collected, white colour indicates ovitraps that have not yet been collected and red colour indicates not recovered trap. Lower part of Figure 2 showed the identification of species process and screen layouts. In the laboratory, user is required to insert the species identification details directly in the PesTrapp. The app displays overall, indoor and outdoor ovitrap index as well as overall, indoor and outdoor mean larvae per recovered ovitrap by species as shown in Figure 3. This app allows user to export the data to .csv format and print.

The preventive measures for the app's failure in case of app's crashes, with bugs and hacked include the daily backing up of the MySQL database system triggered automatically by cron job. The backup is synchronized to two different backup servers, namely one internal backup server in the centralized

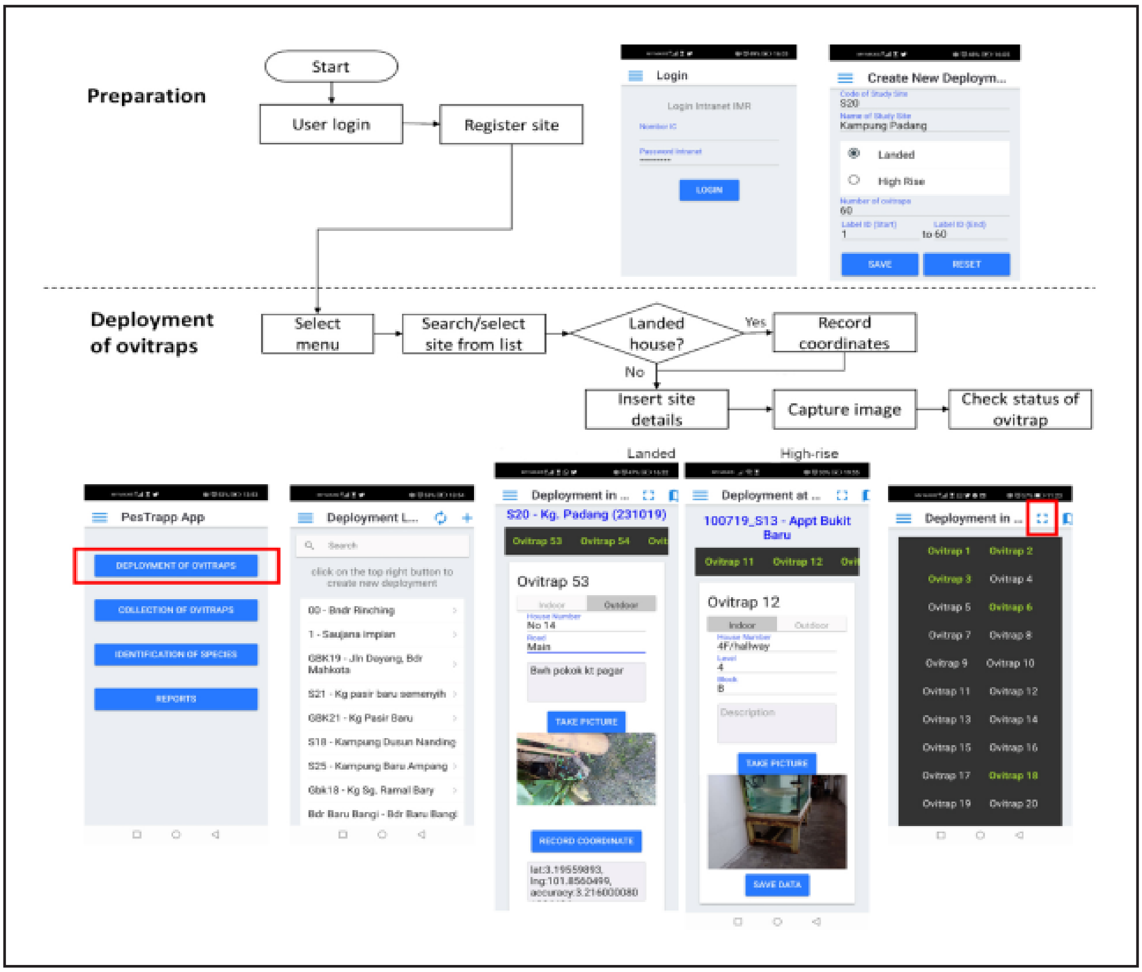

Figure 1. Screen layouts of the PesTrapp for preparation and deployment of ovitraps process.

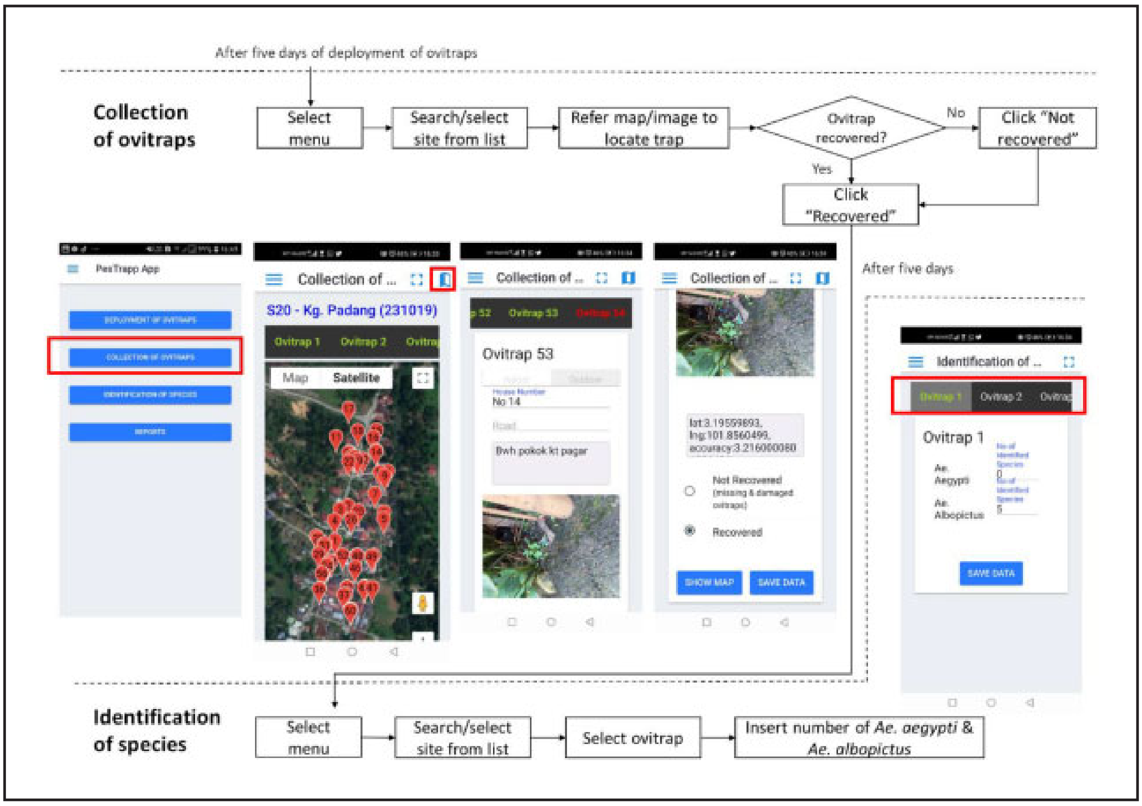

Figure 2. Screen layouts of the PesTrapp for collection of ovitraps and identification of species process.

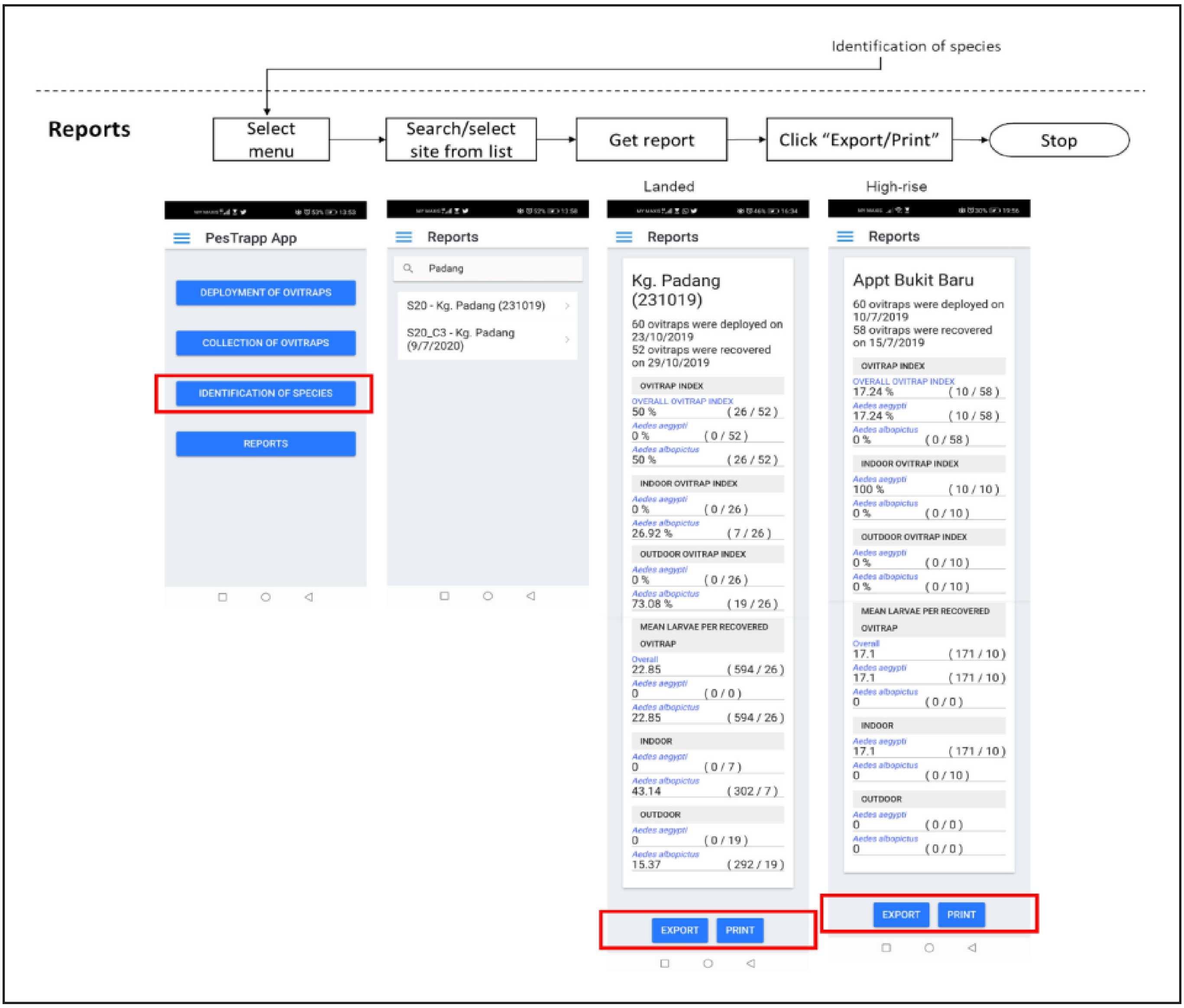

Figure 3. Screen layouts of the PesTrapp for reports process.

data center and one external backup server. The data is kept while no request to delete and sufficient backup capacity. The app is currently designed particularly in urban and sub-urban area with good internet connections. It is best practice for users to always pre-populate or pre-download the ovitrap data before going to the field to cater for the possibility of poor internet connection. In offline mode, input data can be saved in the mobile device using local storage mechanism. Subsequently, local data can be synchronized when go online again.

Practical user experiences of using the mobile app

The project members were divided into two teams, a team performed manual recording of ovitrap data placed and collected in field, while the other team used PesTrapp during sampling. Ovitraps deployment for *Aedes* sampling (60 ovitraps for each site) were carried out at six study sites in the district Gombak and Hulu Langat, Selangor. Five of the sites were landed houses (Kampung Sungai Chinchin, Kampung Baru Ampang, Kampung Padang, Kampung Jawa and Bandar Mahkota) and one was high-rise apartment (Apartment Bukit Baru). Practical user experiences of using the App in field and laboratory were described.

Preliminary user assessment of the mobile app

Preliminary user assessment of using the PesTrapp, including project leader and research assistants, was conducted. The evaluation form of 11 quantitative questions and three qualitative questions based on Mobile App Rating Scale (MARS) (Stoyanov *et al.*, 2015) and Standardized User Experience Percentile Rank Questionnaire (SUPR-Qm) (Sauro & Zarolia, 2017) were developed. MARS multidimensionally assess the quality of mobile applications (Sauro & Zarolia, 2017) and was applied to studies such as dengue reporting and mapping, health communication, and behavior modification mobile application (Karita *et al.*, 2020) and gamified pain management mobile application (Hoffmann *et al.*, 2020). SUPR-Qm was initially created to capture user experiences for website but was later adapted to measure user experiences for mobile application (Sauro & Zarolia, 2017).

The evaluation form of 11 quantitative questions measured the engagement [Question (Q) 1, target group: *"Is the app content information appropriate for you?"* and Q5, interactivity: *"Does it allow user input, contain prompts (notifications, etc.)?"*], functionality [Q2, ease of use: *"How easy is it to learn how to use the app?"*; Q3, performance: *"How* *accurately/fast do the app features (functions) and components (buttons/menus) work?*"; Q4, navigation: "*Is moving between screens appropriate uninterrupted; are all necessary screen links present?*" and Q9, integrability: "*Is the app integrates well with the other features (GPS, camera) of my mobile phone?*"], aesthetic [Q6, layout: "*Is arrangement and size of buttons, icons, menus and content on the screen appropriate or zoomable if needed?*"], information quality [Q7, goals: "*Does app have specific, measurable and achievable goals?*" and Q8, visual information: "*Is visual explanation of concepts – through images/ maps, etc. clear, logical, correct?*"] and acceptability [Q10, recommendation: "*Would you recommend this app to people who might benefit from it?*" and Q11, rating: "*What is your overall star rating of the app?*"] of the PesTrapp mobile app users.

Ten questions were adapted from MARS and one integrability question was extracted from SUPR-Qm. Each item adhered to 5-point scale (1-inadequate, 2-Poor, 3-Acceptable, 4-Good, 5-Excellent). Data were summarized as mean and standard deviation for each item and category that were then described accordingly. The evaluation form of three qualitative questions assessed the appreciation of app, usage of features and suggestions to improve the app.

RESULTS

Practical user experiences of using the mobile app

The use of PestTrapp mobile application in the field and laboratory entomological works created new experiences for the users who have already acclimated to manual practices. During deployment of ovitraps, users adjusted and adapted to the new way of recording information using mobile app instead of pen and paper. User experienced low in mobile phone's battery during deployment of ovitraps. Ensuring fully-charged battery and sufficient power bank with cable are vital if mobile app is used in field. Good internet connection was available throughout the studies.

During field collection of ovitraps, the capability of the image capturing and coordinates mapping had greatly sped up the process of collecting ovitraps and benefited the team members. The application was time-saving in term of recording of the location of ovitrap compared to manually recording using paper. How much time saved was not recorded in this study which focused on the functionality and user acceptance of mobile app. Despites of reducing paper consumption, recalling errors when collecting ovitraps after returning to the field five days after deployment were minimized. In manual way, the description of ovitrap locations were recorded in detail with the description such as "behind the vase, under the front desk, behind the banana tree". The general description often led to vague search scope and uneasy to locate the ovitraps.

In the laboratory, the use of PesTrapp during larval identification process took over the task that require Entomologist to enter the data manually into the Excel software. This function has greatly improved the process of bulk data entry which is generally time consuming and prone to human errors. The process of key in data involving the number of Aedes larvae found and its' species of each trap, were analysed instantly by the apps to obtain the ovitrap index and Aedes species index.

Collected mosquito larvae of L3 stage were identified using compound microscope after five days of collection. Identification listing based on study sites were automatically generated in the PesTrapp by clicking the "Identification of Species" button. The identified larvae were pooled according to their species of either *Aedes aegypti* or *Aedes albopictus* and the number of collected larvae were recorded in the PesTrapp. The total number of recovered ovitraps, ovitrap index and mean larvae per recovered ovitrap for both indoor and outdoor by species were automatically generated in the "Report" section in the PesTrapp.

Preliminary user evaluation of the app

Seven project users who used the PesTrapp mobile app in the process of deployment, collection and identification evaluated the mobile app on 21 July 2020 after using the app for at least one month. Table 1 showed the profiles of users as seven young adults (four female, three male) from age 24 to 36, with a mean age of 27.3 years (SD=4.1 years) and one of them was the project principal investigator. Most users used project phone to run the app one or more times per week (71%) and worked in both field and laboratory work (86%). The months of experience in project were mixed with the mean of 24.3 months (SD=16.2).

Table 2 shows the mean evaluation score of 4.0 (SD=0.6) and ranged from 3.4 to 4.6 out of 5.0. The 2-item "engagement" subscale with the mean of 3.8 (SD=1), target group scored way higher than the interactivity, with the mean of 4.1 (SD=0.9) and mean of 3.4 (SD=1.1) respectively. The 4-item "functionality" subscale, with similar score to engagement, users evaluated higher for ease of use, with the mean of 4.1 (SD=0.9) than the performance of with the mean of 3.7 (SD=1), navigation with the mean of 3.6 (SD=1.3) and integrability with the mean of 3.7 (SD=0.8). Next, the "aesthetic" subscale assesses the layout of mobile app obtained the mean of 3.9 (SD=0.7). The 2-item "information quality" subscale assesses the achievable goals and visual explanation of concepts through images and maps, scored the highest with a mean of 4.4 (SD=0.6). The 2-item "acceptability" subscale scored a mean of 4.2 (SD=0.8). All users would recommend this app to people who might benefit from it. Most of the users (4/7) rated the app four stars and above, while some users (3/7) rated the app three stars.

The qualitative evaluation of users on the appreciation of the app were positive. Most users praised the app for its efficiency in ovitrap monitoring especially the features of image capturing and coordinates. The comments include "*Effective and time saving. Very useful to trace back the ovitraps based on photos taken in field and recorded coordinates*",

Table 1. Sample Characteristics

Variable	Frequency	Percent
Gender		
Female	4	57%
Male	3	43%
Project role		
Principal investigator	1	14%
Co-investigator	0	0%
Research assistant	6	86%
Use app on		
Own phone	2	29%
Project phone	5	71%
Work scope		
Field work	1	14%
Laboratory work	0	0%
Both field and laboratory work	6	86%
	Mean	SD
Age	27.3	4.1
Months in project	24.3	16.2

Table 2. Evaluation of item scores for PesTrapp application (n=7)

Subscale	Score Mean (SD)
Engagement	**3.8 (1)**
Target group	4.1 (0.9)
Interactivity	3.4 (1.1)
Functionality	**3.8 (1)**
Ease of use	4.1 (0.9)
Performance	3.7 (1)
Navigation	3.6 (1.3)
Integrability	3.7 (0.8)
Aesthetic	**3.9 (0.7)**
Layout	3.9 (0.7)
Information quality	**4.4 (0.6)**
Goals	4.3 (0.8)
Visual Information	4.4 (0.5)
Acceptability	**4.2 (0.8)**
Recommendation	4.6 (0.5)
Rating	3.8 (0.9)
Overall Mean Evaluation Score	**4.0 (0.6)**

"*Effectiveness and well help in tracking the ovitraps*", "*Ease the data collecting process and reduce the usage of paper*" and "*Easy to use when collecting ovitraps during outdoor. Ease the process to find by looking at picture taken*."

All users reported frequently usage of the features "deployment of ovitraps" and "collection of ovitraps" in the app. The feedbacks include "*The deployment and collection of ovitraps as I am involved in a lot on fieldwork*". One of the users also frequently used the "identification of species" feature as the comment was "*Recording the location ovitrap in field and picture. Record larvae species*".

Users suggested few aspects to improve the app. Majority of users suggested the "edit" button (5 of 7) and "back" button (4 of 7) to be added in the app. "*Add button edit and delete to make sure the list of localities is move effective and easily to be traced*". "*Edit button*". "*Add back button*". Two of the seven users requested the photo upload features for reporting purpose. "*(1) option to upload photos from photo gallery (2) Edit button on homepage so can make amendment at the key-in data (3) 'back' button on every page, instead of keep going back to the home page*". The other two users preferred the "delete" button to be added too. "*Add up edit, delete, back button and also add up block option for the high-rise building*". One of the users suggested the need for smooth interface for file management.

DISCUSSION

A mobile app to monitor the deployment of ovitraps, collection of ovitraps, identification of species and reporting is developed. The mobile app development process required the full commitment from the medical entomologists, system analysts and mobile developers. The main drive to the development of a comprehensive mobile app depends on to what extent the system analysts and mobile developers understand the problem of current practices and to what extent the users or stakeholders explain or highlight the problem. This is in line with Pandey et al. who commented the process of mobile app models should be explanatory, as much as possible (Pandey *et al*., 2020). Continuous discussions and reviews are essential. From our experience, system analysts and mobile developers constantly hold meetings and dialogues with the medical entomologists to understand existing limitations of current practices, conceive, design, develop and evaluate the prototypes. The prototype is then used and tested by the project members during field and laboratory works.

The advancement in the internetworking and touch screen phone maximize the capability of mobile app technology (Tracy, 2012). The centralised database manages bulk data in split seconds. Monitoring of ovitraps manually and not integrated are not recommended when the data grows bulkier with repetitive monitoring and larger coverage extent. PesTrapp is specially designed to integrate the mobile app technology with centralised database server via internet. The data integrity is ensured even if the works in field or laboratory are handled by different personnel. The data lost issue at individual desktop would be avoided by storing data centrally in dedicated and isolated database server away from existing project site due to improper handling of data, on-site fire disaster and virus-infected desktop. The mobile apps with centralised database are widely adopted by other mobile app studies such as mosquito vector surveillance (Lozano-Fuentes *et al*., 2012), sentinel sites reporting (Lwin *et al*., 2017) and disease symptoms surveillance (Stanton *et al*., 2015).

The entomological field and laboratory work progress are easily monitored by project manager with the mobile app. The different colour representations in the 'ovitrap status' page serve as work progress updates for the project manager. The completed (green), uncompleted (white) and not recovered (red) representations inform the real-time status of the trap whether it has been deployed or collected. The data transparency and forensic are guaranteed with the information that provided by the timestamps and user location when a task is added, modified, completed; when the app is installed and last launched in the device (Azfar *et al*., 2017). In this case, users are unable to tamper and modify the date of deployment, collection and species identification.

The user evaluation obtained a high overall score and in most of its subscales. The mobile app is well-accepted by the users that they would recommend this mobile app to people who might benefit from it. All users agreed that the visual explanation of concepts with images and maps were mostly clear, logical and correct. Most users found the app easy to be used and the content information were well-targeted and appropriate. The functions, buttons and menus of the app worked timely. The functionality and engagement of the app were generally accepted by the users. However, on "navigation", three users took some time and effort to move between screens uninterrupted. This is in line with the qualitative question 3 in which majority users suggested to add "back" button in the app for easy navigation. The "interactivity" subscale scored the lowest due to the availability of only basic interactive features of user input and notification. Most users suggested to add "edit" button in the app in the qualitative question 3. Hence, mobile developer added the functions based on the fed-back from users.

The features of the PesTrapp improve user experience through visual graphic presentation. Deploying trap is easy in the field, but collecting trap requires good recall memory after five to seven days of deployment. The image and maps serve as a better graphical presentation for the user to recall the location of ovitraps, in line with the studies that discovered geographical map increases recall of text (Kulhavy *et al*., 1993; Yen *et al*., 2012) and graphic enhances perceptual and cognitive processes (Winn, 1994) supported this idea. Besides, the real-time notification of alert 'saved' messages confirms the interaction and responsiveness of the mobile app.

Protection of the security, privacy and confidentiality of the mobile app users should be ensured. The users should be educated on the formal mobile policy including authentication, integrity and data transfer (Martínez-Pérez *et al*., 2015). The server should be regularly updated with the latest security control. The mobile developers should minimize the mobile data access permissions to avoid malicious virus such as spyware, Rootkit and Trojan horses (Zhu *et al*., 2014). The users should keep mobile operating system up to date, encrypt mobile phone and use mobile security software (Ahvanooey *et al*., 2017). To protect the privacy of the residents thereat, images obtained of the ovitraps should be captured without their occupants. If this is unavoidable, prior consent of the residents must be obtained. The access to the data should be protected with password.

The future directions to improve the app are the customization possibilities to other animal traps setting studies and integration with other technologies. PesTrapp is potential to be customised for different animal trapping studies such as flies, rats and squirrels by adjusting the number of animal species and density indices. Further research to integrate PesTrapp with other technologies, ranging from the digital eggs counting (Brasil *et al*., 2015), larval image identification (Muñoz *et al*., 2020), species identification (Sharma *et al*., 2019), QR code/barcode (Boob *et al*., 2014) and climate data (Cheong *et al*., 2013; Jain *et al*., 2019) are anticipated to improve and extend its capabilities. Nevertheless, there should be a balance of cost and benefit in applying new technologies to the existing low-cost intervention.

PesTrapp is a potential tool to gather species density data nationwide. Usually, in the entomological studies, mosquito density index is segregated for local study area for evaluating vector control interventions and larval survey during outbreak (Rozilawati *et al*., 2015; Rosilawati *et al*., 2017; Ali *et al*., 2020). Gathering the mosquito density index gives a better understanding of the distribution and movement of mosquitoes for macro- and micro-habitat studies. This mobile app is potential to be the data gathering and managing tool towards big data era, likewise the social media gathers user data for business intelligence (Goncalves & Cornelius Smith, 2018) while web questionnaire gathers research data for subject matter analysis (Gosling *et al*., 2004; van Gelder *et al*., 2010). If PesTrapp is to be applied nationwide, its database could be linked to the disease surveillance system and open source climate repository for integrating multiple ends – entomology, epidemiology and climate for dengue transmission prediction (Manogaran & Lopez, 2017) for better control measures to manage disease hotspots and handle outbreaks.

However, there are limitations to this mobile app. Firstly, it is developed for Android version phone, but not iOS phone. The reason is simple because Android phone is preferred by the users with a larger market share of around 85.4% in year 2020 (Chau *et al*., 2020). Secondly, the GPS satellites signal is undetectable inside building and generally poor in high-rise building. We designed the capture of coordinates differently for the landed and high-rise building. For high-rise, coordinates of ovitraps were not mandatory due to poor signal of GPS, whereas for landed houses, each ovitrap should be reported its coordinates. Nevertheless, record of levels and blocks are essential for high-rise building. Thirdly, the synchronization of the app from offline to online mode is prone to the source of truth issues that may resulted unintentional data overwrite from multiple devices (Pang & Szafron, 2014). Intelligent automatic data syncing capabilities is required to improve the app in the future development phase.

CONCLUSIONS

PesTrapp exhibits the potential to transform conventional trapping method to real-time trap managing intervention. The commitment from both users and developers in translating problem-solving ideas into solution, designing, implementing and testing the proposed app is essential. With the real-time trap setting and collecting mobile app, centralised and organized managing of the density of species contribute to strategic site selections for future vector control interventions. Furthermore, the potential integration of the mobile app with other digital platforms in vector control including disease surveillance, fogging monitoring system, disease hotspot mapping system will enable better vector control management in handling outbreaks. Future works will be the enhancement of the features of mobile app and customization of the application to other potential animal trap studies.

List of abbreviations

GPS: Global Positioning System; CDC: Centers for Disease Control and Prevention; app: application; FR: functional requirements; NFR: non-functional requirements; UI: user interface; API: Application Programming Interface; MARS: Mobile App Rating Scale; SUPR-Qm: Standardized User Experience Percentile Rank Questionnaire.

Availability of data and materials

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

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Conflict of interests

The authors declare that they have no conflict of interests.

REFERENCES

Ahvanooey, M.T., Li, Q., Rabbani, M. & Rajput, A.R. (2017). A survey on smartphones security: software vulnerabilities, malware, and attacks. *International Journal of Advanced Computer Science and Applications* **8**: 30-45. http://doi.org/10.14569/IJACSA.2017.081005

Ali, R., Azmi, R.A., Wasi Ahmad, N., Abd Hadi, A., Muhamed, K.A., Rasli, R., Yoon Ling, C., Anak Chua, H., Lian Wan, K. & Lee, H.L. (2020). Entomological Surveillance Associated with Human Zika Cases in Miri Sarawak, Malaysia. *The American Journal of Tropical Medicine and Hygiene* **102**: 964-970. http://doi.org/10.4269/ajtmh.19-0339

Alliance, O.H. (2010). *Android*. https://www.openhandsetalliance.com/android_overview.html. Accessed 5 May 2020.

Azfar, A., Choo, K.-K.R. & Liu, L. (2017). Forensic taxonomy of android productivity apps. *Multimedia Tools and Applications* **76**: 3313-3341. https://doi.org/10.1007/s11042-016-3718-2

Bakken, S.S., Suraski, Z. & Schmid, E. (2000). PHP Manual, Volume 1. iUniverse, Incorporated.

Bateman, H.L., Lindquist, T.E., Whitehouse, R. & Gonzalez, M.M. (2013). Mobile application for wildlife capture-mark-recapture data collection and query. *Wildlife Society Bulletin* **37**: 838-845. https://doi.org/10.1002/wsb.322

Boob, A., Shinde, A., Rathod, D. & Gaikwad, A. (2014). Qr Code based mobile app and business process integration. *International Journal of Multidisciplinary and Current Research* **2**: 1014-1017.

Brasil, L.M., Gomes, M.M.F., Miosso, C.J., da Silva, M.M. & Amvame-Nze, G.D. (2015). Web platform using digital image processing and geographic information system tools: a Brazilian case study on dengue. *BioMedical Engineering OnLine* **14**: 69. https://doi.org/10.1186/s12938-015-0052-2

Chang, M.S., Christophel, E.M., Gopinath, D. & Abdur, R.M. (2011). Challenges and future perspective for dengue vector control in the Western Pacific Region. *Western Pacific Surveillance and Response Journal* **2**: e1. https://doi.org/10.5365/wpsar.2010.1.1.012

Chau, Melissa & Reith, R. (2020). Smartphone Market Share, IDC Corporate USA. https://www.idc.com/promo/smartphone-market-share/os. Accessed 7 July 2020.

Cheong, Y.L., Burkart, K., Leitão, P.J. & Lakes, T. (2013). Assessing weather effects on dengue disease in Malaysia. *International Journal of Environmental Research and Public Health* **10**: 6319-6334. https://doi.org/10.3390/ijerph10126319

Eiran, B.-D. & Earle, D.M. (2017). Small animal trap. Google Patents.

Foundation, A.S. (2020). Apache Cordova. https://cordova.apache.org/. Accessed 4 May 2020.

Freudenberg, J.R., Diller, C.D. & Smyth, K.S. (2019). Analyzing images of pests using a mobile device application. Google Patents.

van Gelder, M.M.H.J., Bretveld, R.W. & Roeleveld, N. (2010). Web-based Questionnaires: The Future in Epidemiology? *American Journal of Epidemiology* **172**: 1292-1298. https://doi.org/10.1093/aje/kwq291

Global Health, D. of P.D. & M. (2017). Epi Info Vector Surveillance Application, Centers for Disease Control and Prevention. https://www.cdc.gov/parasites/education_training/epi_info_app.html. Accessed 7 October 2020.

Goncalves, M. & Cornelius Smith, E. (2018). Social media as a data gathering tool for international business qualitative research: opportunities and challenges. *Journal of Transnational Management* **23**: 66-97. https://doi.org/10.1080/15475778.2018.1475181

Google Developers. (2020). Google Firebase Cloud Messaging. https://firebase.google.com/products/cloud-messaging. Accessed 5 July 2020.

Gosling, S.D., Vazire, S., Srivastava, S. & John, O.P. (2004). Should we trust web-based studies? A comparative analysis of six preconceptions about internet questionnaires. *American psychologist* **59**: 93. https://doi.org/10.1037/0003-066X.59.2.93

Hoffmann, A., Faust-Christmann, C.A., Zolynski, G. & Bleser, G. (2020). Toward gamified pain management apps: Mobile application rating scale-based quality assessment of pain-mentors first prototype through an expert study. *JMIR Formative Research* **4**: e13170. https://doi.org/10.2196/13170

Jain, R., Sontisirikit, S., Iamsirithaworn, S. & Prendinger, H. (2019). Prediction of dengue outbreaks based on disease surveillance, meteorological and socio-economic data. *BMC Infectious Diseases* **19**: 272. https://doi.org/10.1186/s12879-019-3874-x

Karita, T., Francisco, M.E. & Watanabe, K. (2020). An Integrated mHealth App for dengue reporting and mapping, health communication, and behavior modification: Development and assessment of Mozzify. *JMIR Formative Research* **4**: e16424. https://doi.org/10.2196/16424

Kilpatrick, A.M. & Randolph, S.E. (2012). Drivers, dynamics, and control of emerging vector-borne zoonotic diseases. *The Lancet* **380**: 1946-1955. https://doi.org/10.1016/S0140-6736(12)61151-9

Kulhavy, R.W., Stock, W.A. & Kealy, W.A. (1993). How geographic maps increase recall of instructional text. *Educational Technology Research and Development* **41**: 47-62. https://doi.org/10.1007/BF02297511

Lee, H.L. (1992). Sequential sampling: its application in ovitrap surveillence of Aedes (Diptera: Culicidae) in Selangor, Malaysia. *Tropical Biomedicine* **9**: 29.

Lee, H.L. (1999). Aedes ovitrap and larval survey in several suburban communities in Selangor Malaysia. *Mosquito-Borne Diseases Bulletin* **9**: 9-15.

Loughlin, D. (2013). Developments in the world of insect detection. *International Pest Control* **55**: 88-90.

Lozano-Fuentes, S., Ghosh, S., Bieman, J.M., Sadhu, D., Eisen, L., Wedyan, F., Hernandez-Garcia, E., Garcia-Rejon, J. & Tep-Chel, D. (2012). Using cell phones for mosquito vector surveillance and control. The 24th International Conference on Software Engineering and Knowledge Engineering, pp. 763-767.

Lwin, M.O., Jayasundar, K., Sheldenkar, A., Wijayamuni, R., Wimalaratne, P., Ernst, K.C. & Foo, S. (2017). Lessons from the implementation of Mo-Buzz, a mobile pandemic surveillance system for dengue. *JMIR Public Health and Surveillance* **3**: e65. https://doi.org/10.2196/publichealth.7376

Manogaran, G. & Lopez, D. (2017). Disease surveillance system for big climate data processing and dengue transmission. *International Journal of Ambient Computing and Intelligence* **8**: 1941-6237. https://doi.org/10.4018/IJACI.2017040106

Martínez-Pérez, B., De La Torre-Díez, I. & López-Coronado, M. (2015). Privacy and security in mobile health apps: a review and recommendations. *Journal of Medical Systems* **39**: 181. https://doi.org/10.1007/s10916-014-0181-3

Mogi, M., Choochote, W., Khamboonruang, C. & Suwanpanit, P. (1990). Applicability of presence-absence and sequential sampling for ovitrap surveillance of Aedes (Diptera: Culicidae) in Chiang Mai, northern Thailand. *Journal of Medical Entomology* **27**: 509-514. https://doi.org/10.1093/jmedent/27.4.509

Monaca Onsen UI Team. (2020). Onsen UI. https://onsen.io. Accessed 8 July 2020.

Muñoz, J.P., Boger, R., Dexter, S. & Low, R. (2020). Mosquitoes and public health: Improving data validation of citizen science contributions using computer vision. In: Delivering Superior Health and Wellness Management with IoT and Analytics, Wickramasinghe, N. & Bodendorf F. (editors). Cham: Springer, pp. 469-493.

Oracle Corporation (2020). MySQL. Redwood, CA. https://www.mysql.com/. Accessed 8 July 2020.

Pandey, M., Litoriya, R. & Pandey, P. (2020). Validation of existing software effort estimation techniques in context with mobile software applications. *Wireless Personal Communications* **110**: 1659-1677. https://doi.org/10.1007/s11277-019-06805-0

Pang, C. & Szafron, D. (2014). Single Source of Truth (SSOT) for Service Oriented Architecture (SOA). In: Service-Oriented Computing, Franch, X., Ghose, A.K., Lewis, G.A., & Bhiri, S. (editors). Berlin, Heidelberg: Springer, pp. 575-589.

Rosilawati, R., Lee, H.L., Nazni, W.A., Nurulhusna, A.H., Roziah, A., MY, M.F. & Ropiah, J. (2017). Pyrethroid resistance status of Aedes (Stegomyia) aegypti (Linneaus) from dengue endemic areas in Peninsular Malaysia. *IIUM Medical Journal Malaysia* **16**. https://doi.org/10.31436/imjm.v16i2.327

Rozilawati, H., Tanaselvi, K., Nazni, W.A., Mohd Masri, S., Zairi, J., Adanan, C.R. & Lee, H.L. (2015). Surveillance of Aedes albopictus Skuse breeding preference in selected dengue outbreak localities, peninsular Malaysia. *Tropical Biomedicine* **32**: 49-64.

Sauro, J. & Zarolia, P. (2017). SUPR-Qm: a questionnaire to measure the mobile app user experience. *Journal of Usability Studies* **13**: 17-37.

Sharma, N., Colucci-Gray, L., Siddharthan, A., Comont, R. & van der Wal, R. (2019). Designing online species identification tools for biological recording: the impact on data quality and citizen science learning. *PeerJ* **6**: e5965. https://doi.org/10.7717/peerj.5965

Stanton, M.C., Mkwanda, S.Z., Debrah, A.Y., Batsa, L., Biritwum, N.-K., Hoerauf, A., Cliffe, M., Best, A., Molineux, A. & Kelly-Hope, L.A. (2015). Developing a community-led SMS reporting tool for the rapid assessment of lymphatic filariasis morbidity burden: case studies from Malawi and Ghana. *BMC Infectious Diseases* **15**: 214. https://doi.org/10.1186/s12879-015-0946-4

Stoyanov, S.R., Hides, L., Kavanagh, D.J., Zelenko, O., Tjondronegoro, D. & Mani, M. (2015). Mobile app rating scale: A new tool for assessing the quality of health mobile apps. *JMIR mHealth uHealth* **3**: e27. https://doi.org/10.2196/mhealth.3422

Tracy, K. (2012). Mobile application development experiences on Apples iOS and Android OS. *Potentials IEEE* **31**: 30-34. https://doi.org/10.1109/MPOT.2011.2182571

Winn, W. (1994). Contributions of perceptual and cognitive processes to the comprehension of graphics. In: Advances in Psychology, Wolfgang, S. & Raymond W. (editors). Kulhavy: North-Holland **108**: 3-27. https://doi.org/10.1016/S0166-4115(09)60105-9

Yen, J., Lee, C. & Chen, I. (2012). The effects of image based concept mapping on the learning outcomes and cognitive processes of mobile learners. *British Journal of Educational Technology* **43**: 307-320. https://doi.org/10.1111/j.1467-8535.2011.01189.x

Zhu, H., Xiong, H., Ge, Y. & Chen, E. (2014). Mobile app recommendations with security and privacy awareness. Proceedings of the 20th ACM SIGKDD International Conference on Knowledge Discovery and Data Mining. New York, USA, pp. 951-960. http://dx.doi.org/10.1145/2623330.2623705