HARNESSING THE POTENTIAL OF MOBILE DEVICES AS FIELD DATA COLLECTION TOOL IN A SATELLITE-BASED RICE MONITORING SYSTEM

Arnel B. Rala (1), Tri Setiyono (1), Gene Romuga (1), Emma Quicho (1), Cornelia Garcia (1), Aileen Maunahan (1), Emmali Manalo (1)

[1] International Rice Research Institute, Philippines, 4031
Email: a.rala@irri.org, t.setiyono@irri.org, g.romuga@irri.org, e.quicho@irri.org, cornelia.garcia@irri.org, a.maunahan@irri.org, e.manalo@irri.org

KEY WORDS: Mobile Field Data Collection, Open Data Kit, GeoODK, Mobile devices, Information Communication Technology

ABSTRACT: Field data collection is a laborious, time consuming, and resource intensive activity. The traditional paper-based approach is painstakingly slow to provide data analysts, scientists, and other stakeholders with near-real time insights of what is actually happening in the field. The advancement in information technology particularly mobile and cloud computing enables field data collection to be easier, more accurate, work effective, and time efficient. Field data collected by mobile devices are transmitted to servers that instantaneously aggregates, check for errors, and provide insights. Several IRRI-led projects together with country partners have leverage on these technologies in the last 4 years either as an ad-hoc tool or as an integral component of a satellite-based rice monitoring system. This paper described how mobile data collection (MDC) tool specifically Open Data Kit (ODK) and GeoODK have standardized and significantly improved the field data collection process as well as reducing the time it takes for data to be reported. Collected data are easily and readily incorporated in crop monitoring (calibration and validation of rice area and start of season maps derived from Sentinel 1 SAR images) and abiotic damage assessment (crop loss due to flood and drought) activities. Most importantly how MDC have positively change the mindset and increased performance of field data collectors. Challenges and resolutions were provided for others to consider when employing MDC tools.

1. INTRODUCTION

Accurate, comprehensive, reliable, timely, and cost-effective information on the area under crop production is an essential part of many countries national accounting process to support policies and interventions related to land use, water resources, and food security issues. Unfortunately, access to these information are uncommon, rare and most of the time non-existent.

Phase 1 of the Remote sensing based Information and Insurance for Crops in Emerging economies (RIICE), has demonstrated that actionable information can be delivered by using SAR-based remote sensing in combination with standardized field data collection activities, crop growth simulation models and cloud-computing (e.g. database, webGIS) platforms. The project was piloted strategically in prominent rice growing areas across six countries (India, Thailand, Cambodia, Vietnam, Indonesia and the Philippines) in South and Southeast Asia. (Nelson, *et. al*., 2014). Although, the project was very successful, one of the challenges was to improve the field data collection process. At that time, this proved to be very laborious, time consuming, and resource intensive activity involving the use of several field measuring devices (camera, GPS receiver, ceptometer, and portable computer) to capture the data. Observations and measurements were manually recorded in paper-based forms. Completed forms were later encoded in digital spreadsheet. This strategy is laden with several shortcomings spanning all stages of data management. Carano (2017) enumerated the same drawbacks in using paper-based system. During the data collection process issues of non-response to questions, data entry errors, and false data entries are possibilities. Data collation is also subject to errors during transfer to spreadsheets. These necessitate that a great deal of person-hours are spent in data cleaning, which is a painstaking process of correcting or removing incorrect, duplicate, or corrupt data entries. Data collation and cleaning is especially challenging when dealing with large sample size. Often, it takes weeks before the data collector can collate all field observations, encode and clean in the spreadsheet, and share the data to the scientist for analysis.

To make field data collection easier, accurate, effective, and time efficient, RIICE phase 2, the Philippine Rice Information System (PRISM), and the Andhra Pradesh Satellite-based Rice Monitoring System (APSRMS) leveraged on the technologies offered by mobile devices such as smartphones and tablets (Maloom, 2015) as well as the internet. The mobile device can be configured to fully utilize the combined feature of its hardware; communication (access to voice, text, and internet), computing (perform computation, data entry and management), GPS receiver (capture position information and aid in navigation), camera (take pictures), and other sensors (accelerometer and magnetometer). Advancements in mobile technology, its widespread availability and accessibility have promoted the use of ‘electronic survey forms’ (e-forms) for data collection. As of late 2013, rates of mobile phone penetration stood at 96% globally with 128% in developed countries and 89% in developing countries (Trucano, 2017). However, several questions have to be considered before embarking on using mobile devices for data collection (Trunano, 2017; Lamb, 2017).

Transitioning from paper to mobile data collection is an escalating trend. Basic cost-benefit analysis shows that the use of mobile-based data collection tools can drastically reduce administrative overhead and operational complexity. While there is inherent value in gathering structured data using mobile technologies, one should always be aware of local capacity to support a data collection project in the medium and long term.

1.1 Objectives

The central aim of this study was to create a digital environment to improve the field data collection process to support mapping initiatives using remote sensing and yield estimation models.

The objectives were:
1. To establish a standard field data collection protocol and parameters.
2. To facilitate rapid data collection, reduce data checking and correction, avoid data entry, and submit collected data in near-real time to a central server or database
3. To assess performance of MDC tool

1.2 Project sites

The use of mobile data collection tools were implemented in the following countries (Figure 1) to support the field work needed by PRISM, RIICE phase 2, and APSRMS research projects. The Philippines and Cambodia did a nation-wide data collection using MDC; while Vietnam focused in the main rice growing areas in Mekong River and Red River Deltas; 20 rice growing Provinces for Thailand; and all 13 districts in Andhra Pradesh, India.

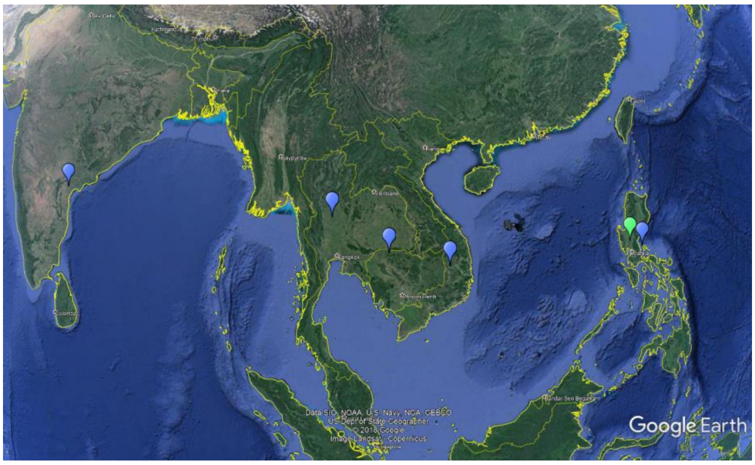


Figure 1. Countries where MDC tools were utilized

2. MATERIALS AND METHODS

2.1 Selection of mobile device

Smartphone with Android system was selected as the mobile platform. It is readily available, inexpensive, and capable of performing the required task. However, for field data collection, the device must be able to withstand extreme outdoor conditions along with other technical specifications that are important.

- Rugged design to protect from outdoor elements and while out in the field. To further prevent damage from submergence in water or mud, the use of protective casing is recommended.
- A sun-readable screen is essential in order to see what is displayed on the screen against the sun’s glare.
- Long battery life that can last for 1 or 2 days.
- Large storage capacity.
- Fast CPU.
- GPS/A-GPS to capture position information.
- Accelerometer and magnetometer sensor for leaf area index (LAI) measurement.

- WiFi or cellular data connectivity to transmit the collected data to the database server.
- Camera with pixel resolution 640x480 capable. This is to keep photo size within 1MB to hasten and reduce the cost of data transmission when submitting to the database server.

A summary of the smartphones used in each country and its features is presented in table 1. These phones are priced on the higher-end category because of the rugged design and battery capacity. However, in the long-run (3-5 years) the return on investment is worth considering the number of quality data that were collected

Table 1. Features of smartphones used in countries participating in RIICE phase 2, PRISM, and AP-SRMS projects.

	Samsung S4 Active	Samsung A5	Oppo F5 mini	LG G2	Sony Experia Z	Sony M4 Aqua	Asus Zenfone M1 Pro
Country	PHL	PHL	THA	KHM	VNM	PHL	Andhra Pradesh, IND
Android 4.x or higher	X	X	X	X	X	X	X
Sun-readable screen	X	X	X	X	X		
At least 2GB RAM	X	X	X	X	X	X	X
GPS/A-GPS	X	X	X	X	X	X	X
Accelerometer/Magnetometer (Compass)	X	X	X	X	X	X	X
WiFi/mobile data connection	X	X	X	X	X	X	X
Camera (capable of VGA resolution)	X	X	X	X	X	X	X
Long battery life (>=2000mAh)	X	X	X	X	X	X	X
Adequate storage (>=8GB)	X	X	X	X	X	X	X
Dual/Quad core CPU	X	X	X	X	X	X	X
Rugged (IP6/7 certified)	X				X	X	

2.2 Installation of mobile application

Mobile application or app, is a self-contained software designed to run on mobile devices such as smartphones. The main MDC app installed is a customized version of ODK collect (GeoODK collect used in RIICE phase 2, and PRISM collect used in PRISM). The app was customized to provide operational linkage with another app called PocketLAI. PocketLAI is the first mobile app for leaf area index (LAI) estimates (Confalonieri, 2013). Both versions of ODK collect render the e-forms, store data, and submit the completed e-forms. Other apps include Zxing barcode reader to read the Monitoring field ID (MFID) barcode, and the data collector QR code, GPS Essential to assist in navigation during ground-truthing activities. Optional apps are also installed like the Camera FV5 lite for smartphone camera which is incapable of VGA setting; while Rice Knowledge Bank Lite, and Rice Doctor are for reference purposes.

Open Data Kit (ODK) was utilized to harness the full potential of the smartphone as a field data collection device. ODK is a free and open-source set of tools which help organizations author, field, and manage mobile data collection solutions (https://opendatakit.org/). ODK collect renders a digital version of the paper survey form into a sequence of input prompts (questions) that apply form logic, entry constraints and repeating sub-structures. It is intended to replace the pen/pencil and paper method of recording data to facilitate rapid data collection, reduce data checking and correction, avoid data entry, and submit collected data in near-real time to a central server or database. The app not only supports the usual data types (text, numbers, date, and time) but also other data types such as geolocation, images, audio, video, and barcodes which the paper form cannot. The design of the digital survey form can be simple or complex consisting of a sequence of questions or input prompts that apply skip logic, constraint and validation rules, calculations, and repeating sub-structures. A plus feature of ODK collect is its ability to work offline (without cellular or internet connection) during the data collection process. The completed forms are saved and stored in the mobile's storage then submitted to a server or database (ODK aggregate, Google Sheet, etc.) when internet connection is available.

2.3 Data collection protocol and survey design

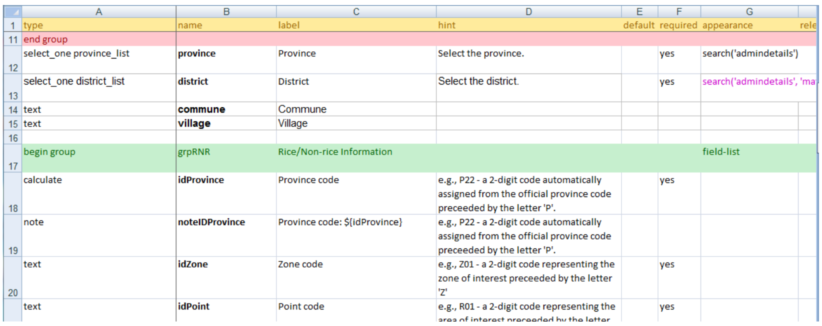
Standardized set of field data collection procedures were designed for data collectors. Table 2 shows the summary of data collected, the form used, and when the form was used. Both RIICE phase 2 and PRISM used the same questionnaires and data collection protocols originally designed in RIICE phase1.

Table 2. Summary of e-forms used at different growth stage

Form name	Purpose	When	Data to collect
Pre Season	Captures the initial field condition, farmer's cropping plan for the season, and historical utilization	Before the season starts	GPS coordinates, Area measurement, Field boundary measurement, Cropping history, Soil information
Tillering	Captures field, crop, and environmental condition, as well as farmer's management practices, seed information, and irrigation information	Tillering stage	Ecosystem, Planted area, Bund height, Planting date, Transplanting date, Crop establishment method, Planting distance, Seeding rate, Irrigation information, Seed information
Harvest	Captures the farmer's management practice and production information	After harvest	Production information, Area harvested, Farmer's crop management practice
Monitoring	Measure plant height and LAI, field and environmental condition	Land preparation to reproductive stage	Plant height, LAI, Growth stage, Photos, Soil moisture condition, Weather condition, Farmer's crop management practice
Rice validation	Provide ground truth points for the rice map accuracy assessment	Reproductive to harvesting	GPS coordinate, Landcover, Rice growth stage, Photos, Photo angle
Damage assessment	Assess ground condition during extreme weather events.	Anytime whenever an event occurs	GPS coordinate, Landcover, Rice growth stage, Cause of damage, Extent of damage, Duration of damage

2.4 Electronic survey form creation

Electronic survey forms (e-forms), were created based on a questionnaire designed to collect data related to mapping and monitoring, yield measurement, crop health assessment (PRISM only), and damage assessment. There are minor variations in the e-forms depending on the country where it will be used in, but essentially the forms are the same. The questions were coded in MS Excel (Figure 2) using a combination of brief and multiple choice questions (with embedded validation for quality checks). This was then uploaded to an online XML converter to generate the mobile ready e-forms (Figure 3). The e-forms were uploaded to the smartphone for initial testing and later uploaded to the ODK Aggregate server or to Google Drive to automatically build the equivalent database structure and storage repository. The electronic survey forms were regularly updated based on feedback gathered from the data collectors.



	A	B	C	D	E	F	G
1	type	name	label	hint	default	required	appearance
11	end group						
12	select_one province_list	province	Province	Select the province.		yes	search('admindetails')
13	select_one district_list	district	District	Select the district.		yes	search('admindetails', 'ma
14	text	commune	Commune				
15	text	village	Village				
16							
17	begin group	grpRNR	Rice/Non-rice Information				field-list
18	calculate	idProvince	Province code	e.g., P22 - a 2-digit code automatically assigned from the official province code preceeded by the letter 'P'.		yes	
19	note	noteIDProvince	Province code: ${idProvince}	e.g., P22 - a 2-digit code automatically assigned from the official province code preceeded by the letter 'P'.			
20	text	idZone	Zone code	e.g., Z01 - a 2-digit code representing the zone of interest preceeded by the letter 'Z'		yes	
	text	idPoint	Point code	e.g., R01 - a 2-digit code representing the		yes	

Figure 2. Sample coding of the rice and non-rice validation survey form in MS Excel.

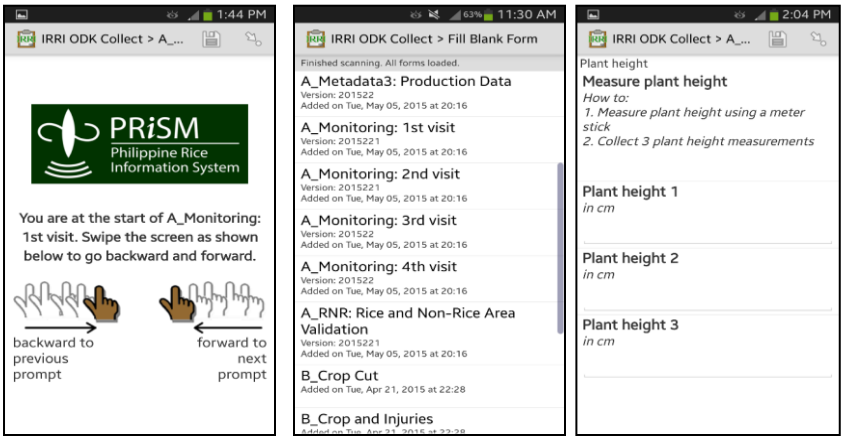


Figure 3. The PRISM ODK collect app featuring the opening page, list of e-forms, and data entry page.

2.5 Field data collection and transmission

Figure 4 shows generic scenario of when field data will be collected using specific e-form. The schedule is based on key stages of rice in a growing season. During the data collection, data collectors/users accessed the appropriate form and work through the prompts (questions) by answering or selecting pre-defined choices. After collection, the data collector must ensure the correctness and accuracy of the data before submitting (preferably on the same day) to the database server. If there is no network/internet connection, data can be uploaded later as soon as the users have connection to the internet.

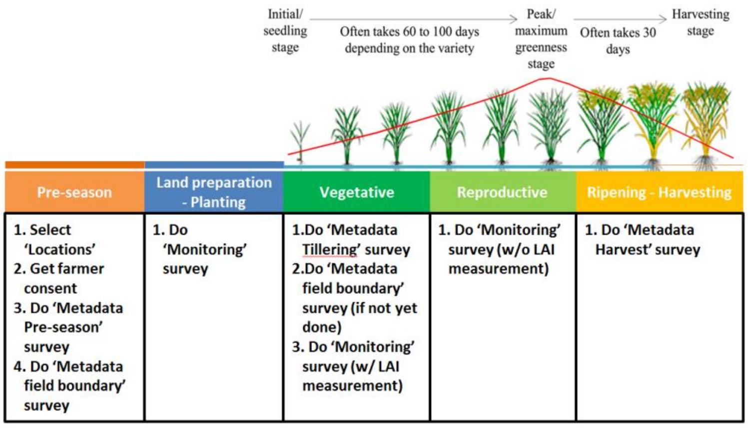


Figure 4. Data collection schedule relative to the crop growth stage

3. RESULT AND DISCUSSION

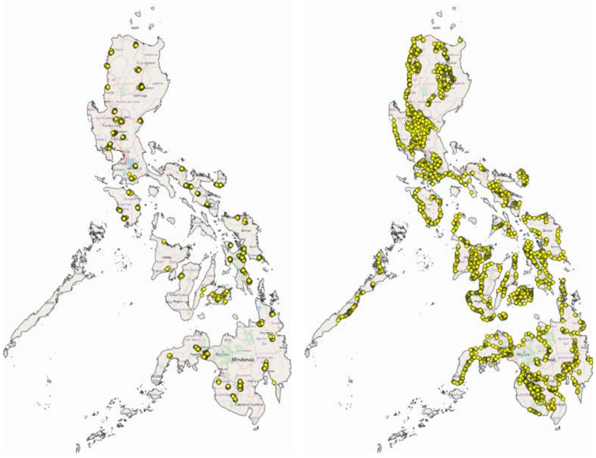
Field data collection is important in providing relevant information to substantiate the products (rice area map, start of growing season map, and inputs for yield estimation) generated from rice detection algorithm using satellite images. There are 3 field data collection activities where MDC was employed. First, the collection of crop and environmental parameters from location-specific monitoring fields (RIICE and PRISM) and from random locations (AP-SRMS) during the early stages of rice growth were used to calibrate the algorithm and fine-tune the products. Second, the collection of land cover data from random locations during the ripening to harvesting stage was used to provide a measure of accuracy to the products. Third, to provide location specific assessment during flood and drought events where damage to rice crop was suspected.

Earlier efforts required data collectors to carry several devices (laptop, GPS receiver, camera, measuring stick, and ceptometer) in addition to pen and paper (notebook), proves to be difficult to manage resulting to fewer sites surveyed and longer data collection time per field. In addition, data collectors were required to have skills in operating a computer to encode the data in spreadsheets. Using MDC, as an all-in-one tool, unburdens the data collectors with the extra devices resulting to shorter data collection time.

One of the advantages in using MDC is that the data can be stored in the database server in near-real time provided that there is a good and stable connection to the internet. Experiences in the countries did not disappoint by having data submitted within a day (< 12 hours) and between 3 and 5 days. Extreme cases of more than 7 days do exist and this is main attributed to internet access.

Below are specific country experiences:

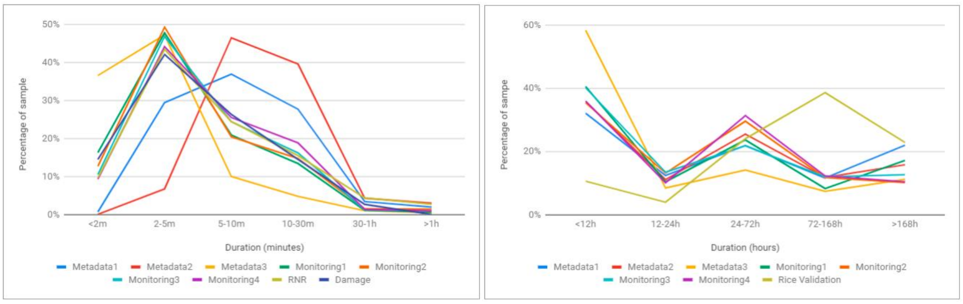
Philippines. The PRISM project was the firsts to adapt MDC both in research and development (R&D), and operation mode. Recognizing the need to improve and hasten the field data collection effort, IRRI together with PhilRice and the Department of Agriculture (DA) distributed customized smartphones to DA-Regional staff. They also trained them on its usage. The smartphones were used to collect seasonal information on field observations, farmer surveys, field coordinates, photos, and leaf area index measurements from thousands of monitoring fields (Figure 5a) strategically located throughout the country. Ground truth points (Figure 5b) were also collected nation-wide near the end of each growing season to assess the accuracy of rice maps derived from satellite images. Lastly, in the event there are flooding due to typhoons or excessive rain, the smartphones proved invaluable in documenting and providing information to aid in the assessment of damaged rice areas.



(a) (b)

Figure 5. Map of the Philippines showing the location of (a) monitored sites and (b) distribution of ground truth points for accuracy assessment of rice map

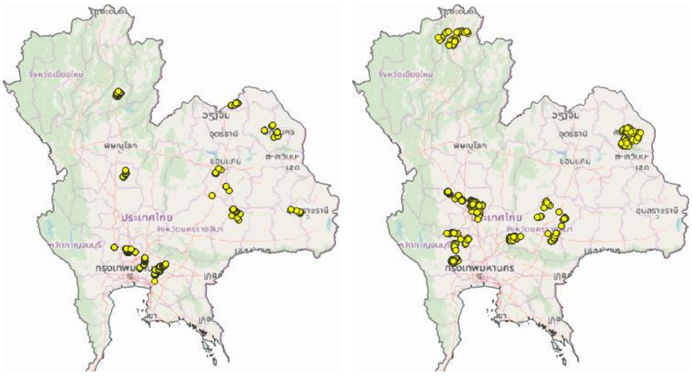
Data collectors were at first apprehensive in using the technology but through numerous training and retooling, and based on their hands-on experience, later recognized the contribution of MDC. They were able to visit more sites and data were transmitted and published in a matter of days as oppose to months using the tradition pen and paper approach. The built-in validation check in the e-forms ensures quality data are submitted. In general, the duration to complete a form is between 2 and 5 minutes (Figure 6a). Exceptions are Metadata1 and 2 which requires more time due to farmer interview. Submission to the database server on the same day (< 12 hours) was above 30% despite having poor to no access to internet facilities(Figure 6b). Therefore, data collectors were given 3-4 days to submit the completed forms.



(a) (b)

Figure 6. Performance distribution of samples based on form (a) completion and (b) submission time.

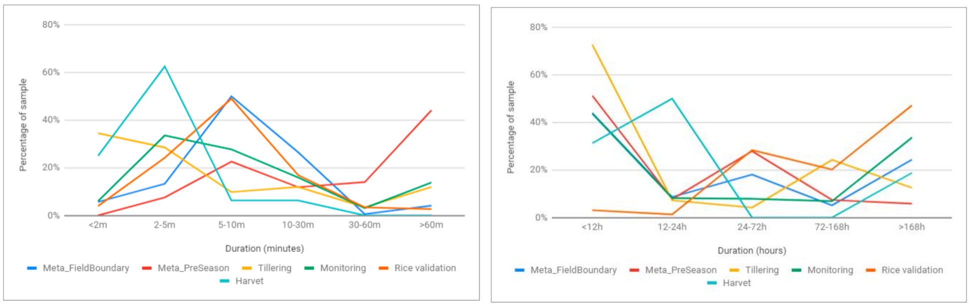
Thailand. The RIICE phase 2 project implemented MDC a year later taking advantage of lessons learned from PRISM. IRRI collaborated with the Rice Department (RD) for the seasonal collection of crop information and with the Department of Agricultural Extension (DOAE) to validate the rice map derived from satellite images. Field data collection were conducted in 20 provinces (Pisanulok, Chainat, Lopburi, Pathumthani, Klonglaung, Ratchburi, Suphanburi, Pathalung, Sakon Nakorn, Ubon Ratchatani, Surin, Nakorn Ratchasima, Roi Et, Khon Kaen, Nongkai, Phrae, Prachinburi, Ayudhya, Chiangmai, Chiang Rai). Figure 7a and 7b shows the location of the monitored fields and ground truth data.



(a) (b)

Figure 7. Map of Thailand showing the location of (a) monitored sites and (b) distribution of ground truth points for accuracy assessment of rice map.

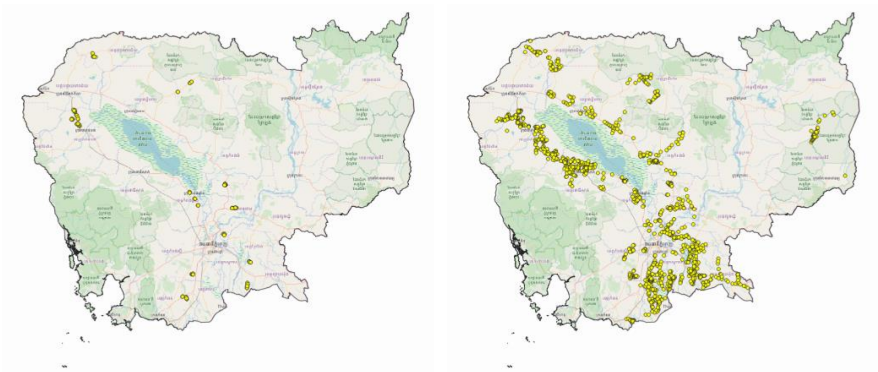
The staff of RD appreciates the shift to MDC considering their experience in field data collection during RIICE phase 1. No longer will they carry the bulky ceptometer, GPS receiver, camera, and laptop. The smartphone is able to do the function of these devices. In addition, they no longer have to encode and since data are saved in the server, the data managers are able to double check, visualize, and do basic analysis. Duration of data collection ranges from less than 2 minutes to between 2 and 5 minutes (Figure 8). Pre season form took longer time to complete because of the farmer's survey questions. DOAE staff were skeptical and apprehensive at first but were convinced because of the quick turn-around time (collection to reporting) and the visualization of the validation points. Form completion time was between 5 and 10 minutes while form submission was less than 12 hours.



(a) (b)

Figure 8. Performance distribution of samples based on form (a) completion and (b) submission time.

Cambodia. The seasonal field data collection (Figure 10a) and ground validation of the rice area map (Figure 10b) were led by the Department of Planning and Statistics (DPS) of the Ministry of Agriculture, Forestry, and Fisheries (MAFF) in RIICE phase 2. The same set of crop, environment, and management parameters were collected from monitored fields situated along the Tonle Sap lake and river channels. DPS concentrated most effort in the rice validation survey despite limited man-power. The submitted validation points were quickly mapped in real time by leveraging on the mapping feature of Google Fusion Table (GFT). This provides an opportunity to the data managers to immediately provide feedback to the data collector if the data submitted were incorrect.

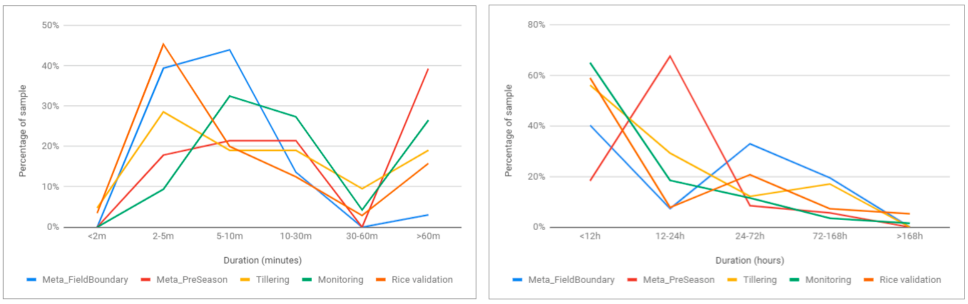


(a) (b)

Figure 9. Map of Cambodia showing the location of (a) monitored sites and (b) distribution of ground

truth points for accuracy assessment of rice map.

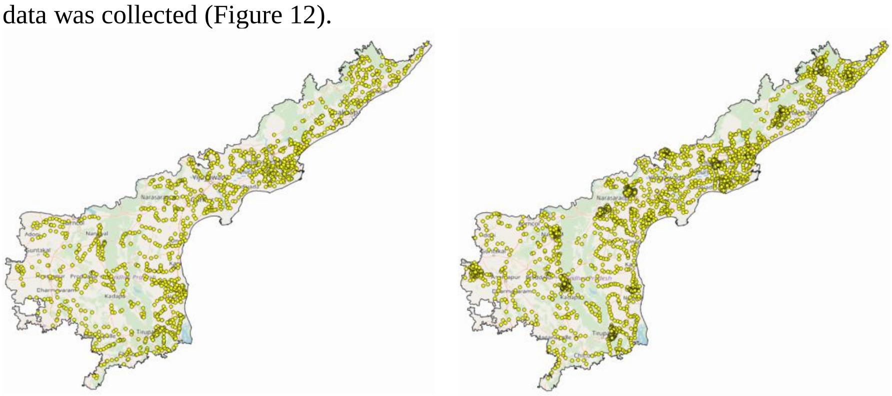
Performance of DPS was remarkable with most of the form completion done in 2-5 minutes and 5-10 minutes (figure 10a). Similar to RD of Thailand, the PreSeason form took longer time to complete because of the farmer's survey questions. Form submission was also impressive with above 40% at <12 hours.



(a) (b)

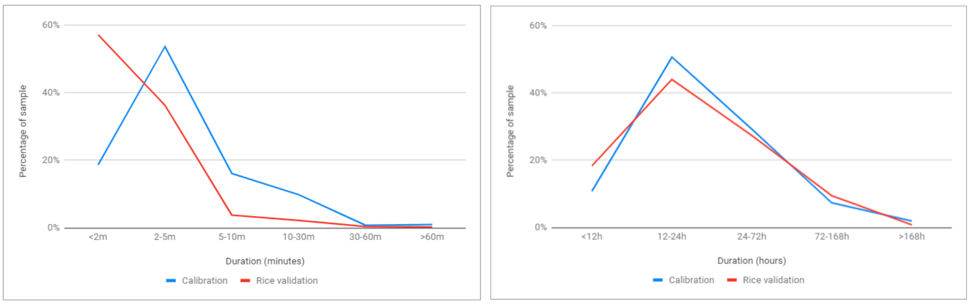
Figure 10. Performance distribution of samples based on form (a) completion and (b) submission time.

Andhra Pradesh. The Satellite-based Rice Monitoring System (SRMS) is a collaborated project between IRRI and Geospatial Technology Center (GTC) of the Acharya N. G. Ranga Agricultural University (ANGRAU). The use of MDC started midway in the project's timeline to improve and hasten the collection of field data for calibration and validation of rice maps generated from satellite images (Figure 11a and 11b). The field data collection protocol is different from the RIICE phase 2 and PRISM project but the manner of collecting the crop and other parameters are the same. Calibration data were collected in during the vegetative stage to fine-tune the rice detection algorithm while the validation data were at maturity stage for map accuracy assessment. MDC was also used in collecting field information for damage assessment due to flooding and drought. The data collectors already have experiences in using MDC and as shown in figure 13a have contributed to the fast completion of the validation forms (>50% of samples at < 2 minutes) and nominal for the calibration form (50% of samples at 2-5 minutes). Both calibration and validation form were submitted on the same day (51% and 44% respectively) when data was collected (Figure 12).



(a) (b)

Figure 11. Map of Andhra Pradesh state in India showing the location of (a) calibration, and (b) ground truth points.



(a) (b)

Figure 12. Performance distribution of samples based on form (a) completion and (b) submission time.

3.1 Challenges

The advantages of using MDC are well documented – increase efficiency, saves time and money, near real-time access to data, and more. The World Bank for instance has a useful series on some of the advantages of using MDC (Trucano, 2014). Software providers like ODK, KuBoToolbox, CommCare, and Magpi to name a few have published data collection guides that list out benefits in detail by moving away from paper-based surveying. However, it is also worth mentioning the challenges when implementing MDC. Below are a few from experiences in the field

GPS accuracy. The smartphones used in the projects have GPS receiver and augmented by cellular location to increase location accuracy. However, the GPS antenna used is inferior compared to those used in entry level consumer GPS devices. This causes GPS accuracy to go as low as 10 meters (especially in areas where no cellular tower) and worst no position is reported.

Network quality and coverage. The quality and accessibility to network communication particularly the internet is vital when completed forms are submitted to the database server. In areas where there is no or poor network connection, submission of forms will be delayed or worst corrupted. It is best to evaluate the quality and stability of the connection before submitting the completed forms.

Power source. Smartphone quickly depletes the battery of charge especially when the GPS is switched ON and display brightness set to maximum. A smartphone with high battery capacity (5000mAh or more) is recommended as well as having a backup source of power such as car charger and power bank.

Data Security. Care should be taken to prevent data from being lost or corrupted. The longer data stays with the smartphone the more it is exposed to risks. The smartphone can be misplaced, stolen, or damaged (accident, misuse, software and hardware failure). It is advised to submit completed form to the database server as soon as possible or make a copy of the data in an 'on-the-go' (OTG) USB flash drive. Submission of data can also lead to data loss and corruption especially when connected to an unstable network. Another factor commonly encountered is attributed to large photo size where the allotted bandwidth is not enough to complete the transfer or the allotted repository is not large enough.

Data management and retrieval. Submitted data are stored in a database (MySQL or Postgres) or spreadsheet (Google sheet). An individual or team must be able to retrieve the data in a form that can be utilized by analyst or scientists to create information. ODK aggregate serves as the storage backend of all submitted forms from ODK collect. It can be installed as a cloud service or on-premise (local server). It has a web-based front end for management and data retrieval. There are several informal online tutorials on how to work with ODK aggregate but the learning curve is steep. Intensive training on data management is necessary and important.

4. SUMMARY AND CONCLUSION

Field data collection is a laborious, time consuming, and resource intensive activity but is an essential component to confirm the products (rice area map, start of growing season map, and inputs for yield estimation) generated from rice detection algorithm using satellite images. The traditional paper-based approach is painstakingly slow to provide data analysts, scientists, and other stakeholders with near-real time insights of what is actually happening in the field. Data collectors are burdened with survey devices limiting their capabilities to survey more sites, data encoders are overwhelm with the amount to encode and quality check, and data manager or analyst trying to make sense of the data. The advancement in information technology particularly mobile and cloud computing enables field data collection to be easier, more accurate, work effective, and time efficient. The proliferation of smartphone, ease of use, and small form factor makes it as an ideal all-in-one mobile data collection device. Data collectors now have access to a computer, a GPS receiver, a camera, an audio recorder, and other measuring features of the smartphone. Cloud computing or the internet enables database driven servers to store, manage, and publish data submitted through smartphone.

Several IRRI-led projects together with country partners have leverage on these technologies in the last 4 years either as an ad-hoc tool or as an integral component of a satellite-based rice monitoring system. The smartphones were configured with ODK Collect, a mobile app that digitally renders questions in a form employing various data types including geolocation, and geotag photographic images to name a few. It also serves as a bridge to PocketLAI, another mobile app that indirectly measures the leaf area index of rice. Collecting and digitizing data right at the source makes data entry more efficient (2-5 minutes at most) and cleaner leading to improved data quality. Experience show significantly improved data collection process and yielded good or excellent data quality in all surveys conducted. These data are transmitted at most 2-5 days to the database servers and are instantaneously aggregated and further checked for errors. The cleaned data are then easily and readily incorporated in crop monitoring (calibration and validation of rice area and start of season maps derived from Sentinel 1 SAR images) and abiotic damage assessment (crop loss due to flood and drought) activities.

Although a formal user experience is yet to be conducted, current MDC users informally reported an overall positive experience considering the direct encoding of data (no need to transfer handwritten data into an electronic database), and the reduction/elimination of bulky devices.

5. REFERENCES

Arnold M., Kiker D. The Big Data Collection Problem of Little Mobile Devices, 21 Rich. J.L. & Tech. 10 (2015), from http://jolt.richmond.edu/v21i3/article10.pdf)

Carano C., C. Gale. Paper-based data collection: Moving backwards or expanding the arsenal?, 2017, from https://researchforevidence.fhi360.org/paper-based-data-collection-moving-backwards-expanding-arsenal

Confalonieri, R., et. al. Development of an app for estimating leaf area index using a smartphone. Trueness and precision determination and comparison with other indirect methods. 2013 - Computers and Electronics in Agriculture, 96, 67-74 from http://www.cassandralab.com/papers/14

GEOODK, 2017, (http://geoodk.com/about.html)

Jade Lamb, Andrea Selva. Better Evaluation: Mobile Data Collection. 2017 from https://www.betterevaluation.org/en/evaluation-options/mobile_data_collection

Maloom, J. M., et. al. "Philippine Rice Information System (PRISM): innovating the rice field data capture and monitoring using smartphone." *Philippine Journal of Crop Science (Philippines)* (2015). (http://agris.fao.org/agris-search/search.do?recordID=PH2016000233)

Michael Trucano. Using mobile phones in data collection: Some questions to consider. 2014 from http://blogs.worldbank.org/edutech/using-mobile-phones-data-collection-some-questions-consider

Michael Trucano. Using mobile phones in data collection: Opportunities, issues and challenges. 2014. (https://blogs.worldbank.org/edutech/using-mobile-phones-data-collection-opportunities-issues-and-challenges)

Mobile Data Collection from http://wash.unhcr.org/wash-monitoring-system/mobile-data-collection/

Nelson, A., et. al. National and Regional Scale Rice Crop Monitoring in Asia with the RIICE and PRISM Projects: From Research to Operation from https://ui.adsabs.harvard.edu/abs/2015AGUFM.B44A..03N/abstract

Nelson, A., et. al. Towards an Operational SAR-Based Rice Monitoring System in Asia: Examples from 13 Demonstration Sites across Asia in the RIICE Project. Remote Sens. 2014, 6, 10773-10812. (https://www.mdpi.com/2072-4292/6/11/10773)

Open Data Kit Documentation from https://docs.opendatakit.org/collect-intro/

Welte, J. et. al. “Autogenic Mobile Computing Technologies in Agriculture: Applications and Sensor Networking for Smart Phones and Tablets”. EFITA-WCCA-CIGR Conference “Sustainable Agriculture through ICT Innovation”, Turin, Italy, 24-27 June 2013.

What are the advantages of mobile data collection? (https://www.mydatascope.com/blog/en/2018/03/14/what-are-the-advantages-of-mobile-data-collection/