Reporting Water Quality – A Case Study of a Mobile Phone Application for Collecting Data in Developing Countries

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ABSTRACT

In this paper, we present the design of a set of mobile applications and their role in water quality management in rural and under-resourced areas in developing countries. As part of the Aquatest[1] project, several tools were developed to allow data relating to water quality to be collected remotely using low-cost mobile devices. The so-called "Water Quality Reporter" (WQR) tool is a J2ME application that allows collection of form-based data on mobile devices. The "Water Quality Management" (WQM) tool is a web-based system that allows managers to set up automatic data point threshold warnings, delivery of periodic reports, and provides a data overview using Google Maps. The WQM mobile application is built for the Android platform and provides managers with a daily overview of data collected. We present a case study of four pilot implementations of the tools, and discuss lessons learned and future work.

Categories and Subject Descriptors

H.1.m **[Models and Principles]**: Miscellaneous

General Terms

Management, Measurement, Design, Experimentation, Human Factors

Keywords

Remote data collection, mobile devices, water quality

1. INTRODUCTION

"*Count what is countable, measure what is measurable, and what is not measurable, make measurable.*" - Galileo Galilei

In order to meet Goal 7 of the Millennium Development Goals, 1.5 billion people must be provided with access to a safe and sustainable source of drinking water [1]. The United Nations World Water Assessment Programme, announced in 2000, states that one of its challenges is the governance of water and that,

"*...good governance means allowing every sector of society to participate in the decision-making process and that the interests of all stakeholders should be taken into account. However, mechanisms for doing so are not always in place ...*" [2]

Contamination or break-down of drinking water supplies in rural areas requires immediate action, as entire communities are often served from a handful of sources. In the case of a lengthy break-down, community members will be forced to seek water from alternative sources, which are often untreated; in the case of contamination, any time lag between sampling and detection of water-borne pathogens (and subsequent treatment/issue of warning notices) will place the community at significant risk. Whilst the importance of regular and periodic laboratory tests cannot be downplayed, the time and expense of collecting samples, analysing them, and then returning with the results does little to meet the above rapid response requirements – particularly in areas where the nearest certified and approved laboratory may be a few hundred kilometers away in an urban center.

The Aquatest project was initiated in 2007[2] with the aim to develop a low-cost rapid-response water test to be used in the field, without requiring electricity or skilled technicians to operate it [3]. The test was designed to provide a quantitative analysis of microbial contamination in water samples using the most probable number technique [4]. A cellphone-based application called Water Quality Reporter (WQR) was also developed as part of this project to allow technicians in the field to report their water quality results remotely. The application submits results to a central database and makes them available to the local municipal manager. The central database/backend system can be accessed using the web-based application, Water Quality Manager (WQM). WQM allows managers to log in and view results in real-time using an interface which incorporates Google Maps. Additionally, it allows managers to set up SMS warnings for results that fail to fall in defined limits, and to also receive reports in form of Excel files containing all of the collected data for a defined period. Municipal managers are often tasked with a variety of responsibilities that leave them out of the office for much of the day – with this in mind, an edition of WQM was developed for the Android platform (available on cellphone and tablet devices) that allows managers to view overview data and individual results whilst out of the office. These ICT (information and communication technology) systems create feedback loops and allow data to be collated and aggregated for analysis and dissemination, more so than a traditional paper-based approach.

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[1] http://www.bristol.ac.uk/aquatest/

[2] The project will come to a conclusion mid-2012.

This paper reports on the process of designing the WQ mobile tools and provides feedback on the process of implementation and a first evaluation of their usability within the context of information flow requirements in under-resourced settings.

2. MOTIVATION

Despite the many advances in ICTs and information management systems in the last thirty years, little of these have managed to filter down to rural areas. This is in part due to a lack of infrastructure, i.e. electricity, readily available hardware, internet/network access – but even in communities where the above are available (or provided by external parties) ICT systems have still struggled to take hold and become sustainable solutions.

"*Current practice, which is primarily paper-based, limits the scale and complexity of the services that can be provided, and thus the impact of the intervention.*" [5] Results recorded on paper have to be collated and captured by hand, and are vulnerable to loss and destruction (water damage, etc.) amongst other things. Typically these records will sit at the site where they were produced, without ever reaching decision makers and effectively not contributing to any planned information flow.

Replacing these traditional systems with computer-based systems is no silver bullet – apart from needing reliable electricity and internet connections, computer terminals need to be housed and secured somewhere near to where the technicians work. Technicians require in-depth training and technophobia or fear of "doing something wrong" often hampers this. Systems are extremely hard to design without an innate understanding of the context it will be used in, and the people who will be using it. Both are often overlooked in the rush and excitement of replacing an entire office with one computer. As noted by Toyama, computing by itself is not the solution [6].

"*For computing to truly address the information gaps in developing regions, information services must be composed by non-programmers, deployed by resource-constrained organizations, used by minimally-trained users, and remain robust despite intermittent power and connectivity.*" [5]

Using mobile devices to collect data is becoming increasingly popular, and with good reason. In South Africa (where our current largest implementation is being run), mobile penetration was 73% in 2010, whilst internet penetration on PCs trailed far behind at 7.2%. In rural settings this gap can increase even more, with PC-based internet access dropping to almost zero whilst mobile penetration still remains relatively high [Table 1]. Similar numbers can be seen across the globe in developing countries. Mobile devices provide a good platform to develop on; they are generally sufficiently advanced to handle the logic/functionality required for a data collection system, whilst still maintaining the appearance of an every day tool to the user (cf. a handheld calculator). Users who have interacted with mobile phones on a regular basis know these devices perform consistently and reliably, and that short of physical damage they will continue to work consistently. Coupled with a relative low cost, portability, and wireless network access where there is network coverage, makes these devices very attractive in developing contexts.

Table 1. Cellphone penetration and other statistics in South Africa.

	Chris Hani District	South Africa
Population	800000	49000000
Density (p/km^2)	21	41
No access to piped water	25%	10%
Cellphone ownership	59%	73%
Computer ownership	3%	15.6%
Internet access	1.1%	7.2%

A number of data collection systems for mobile devices have been developed over the last ten years, such as:

1. Open Data Kit (ODK)[3] is a collection of tools for the Android platform (smartphones and tablets) that allows one to design and deploy survey forms, and collect responses from them. Additionally one can set up interactive voice response (IVR) menus to collect user input via voice prompt.

2. RapidSMS[4] is a framework that allows data collection using even the most basic phones, through the use of SMS messages. No special software is required on the user's phone.

3. FrontlineForms[5] is part of the FrontlineSMS project and is a Java client application that communicates via data packed into SMS messages.

4. EpiSurveyor[6] is built on the JavaRosa[7] framework and is an end-to-end data collection service, made up of a hosted web service and Java client application.

Whilst these systems and others exist, we found that none of them were ideal in our context – either being disqualified by their target hardware, proprietary data format and storage, and/or lack of customisation prospects. We thus chose to develop a custom client application using the JavaRosa data collection platform, which also guided our decision to deploy on low-cost feature phones ("a modern low-end mobile phone that is not a smartphone" [Wikipedia]).

Our hypothesis going into this project was that better access to information enables better decisions, and as a result, improves service delivery (increased communication between managers and communities should result in faster decision-making). To create an environment in which information results in better decision making, appropriate tools have to be designed that are relevant in the context and accurately respond to the local needs.

[3] http://opendatakit.org

[4] http://www.rapidsms.org

[5] http://www.frontlinesms.com/resources/frontlineforms

[6] http://www.episurveyor.org/user/index

[7] https://bitbucket.org/javarosa/javarosa/wiki/Home

3. DECISIONS AND DESIGNS

Several of the team members involved in the WQR project were previously involved in Cell-Life[8] – a research project which explored the use of cellphone applications to provide information, communication, and interactive services to support the HIV sector. Cell-Life became a private, not-for-profit company in 2005, and in 2007 was one of the founding members of the OpenRosa consortium for mobile data capture (of which JavaRosa is an implementation). Thus there was a broad base of knowledge and experience to draw on coming into the WQR project.

Based on our experience and focus on rural environments, our approach to ICT development has been that the investigation of the local context and solutions responding to local needs are more valuable and sustainable than a general "one-size-fits-all" design. Whilst this speaks against the notions of "scalability", which is usually a desired outcome for IT solutions, we believe that rural and under-resourced environments require a more detailed and customised solution. Additionally, system design that requires the user to buy either particular hardware or software can be a show-stopper in rural environments where annual budget allocations are volatile. Rather than designing in the traditional context of "system requirements", rapid prototyping and engaging the stakeholders as co-designers has shown to be an invaluable approach to engaging successfully in under-resourced environments.

3.1 Pilot Site Selection and Methodology

For the design of the cellphone application it was decided that the project should go beyond a "lab" test and be implemented in a local context for a period of time to observe the perceived usefulness and ease-of-use as well as the integration into the work-flow of water quality management in an under-resourced environment. It was therefore decided that pilot sites should fulfill two criteria: having an existing reliable electricity supply, and the ability to implement the system within an existing government structure. A well-developed electrical infrastructure is a good indicator of the developmental level of a community [7][8]. Since water supply, similar to health care, forms part of the constitution of South Africa, the government is responsible to provide access to safe water to all citizens [9]. We therefore believe that any system implemented in this context has to integrate into the local regulations, policies, guidelines and general practices of government to ensure that is offers a sustainable solution. By integrating the system within the existing government structures, we were able to assess if a cellphone system would strengthen local government to fulfill functions better than it is currently doing. We will not report on the assessment of any improvements in government function in this paper.

As noted in section 2, failure to understand the local context will significantly reduce the likelihood of success of a new information management system. That is to say: an IT-based information management system is far more likely to succeed when a certain level of work-flow or process management already exists which can be "mapped" onto the IT structure. In an environment where the IT system defines for the first time a work-flow coupled with using a new technology, our experience has been that success is very unlikely. Also, users are more likely to provide key input to system requirements if they have a clear understanding of the existing workflow and the reporting requirements. In the water sector, where reporting and information management is usually highly regulated and managed nationally, it is to a certain extent easier to develop systems that support local communities in improving their data management.

With this in mind, we sought to supplement and compliment existing processes used at pilot sites. The process of assessing existing structures involved time on the ground, observing general practices, conducting interviews with managers and technicians, evaluations, questionnaires, and research into technology adoption models.

Details of implementations will be described in section 4.

3.2 Mobile Hardware

3.2.1 Water Quality Reporter

WQR is a mobile application designed to be used in the field, in rural areas, and as such both the software and the hardware had to be robust enough to survive the environment. Other requirements were for the hardware to be readily available, similar to phones technicians had access to, and cheap enough to deploy widely. Weighing these requirements left us looking at Java-enabled Nokia devices.

An unfortunate fact of the Java Micro Edition (J2ME) landscape is that whilst Sun Microsystems provides a reference implementation of the specification, it has relied on third-parties to develop and provide binary implementations of the runtime environment for mobile devices. Early security considerations around application independence (sandboxed runtime environments[9]) and user security have also forced devices to restrict access to permanent storage, network access, and various "external" hardware privileges (e.g. camera, GPS) – applications must be signed with a certificate before using these features, and even then, the user is forced to answer permission dialogues at least once per session. In addition, despite so-called Java capability "profiles", implementation of these features often differs from manufacturer to manufacturer, forcing developers to test every device that the application might be deployed on. This even occurs within a manufacturer's family of devices – for example, the full QWERTY keyboard available on Nokia phones behaves very differently to the traditional number-pad on low-end Nokia phones.

In order to mitigate the pain of launching on multiple devices, a decision was made early on in the project to limit deployment to single known device. This choice was the Nokia 3310c – a robust and capable phone that met JavaRosa's requirements (1MB JAR size, 2MB heap, MIDP 2.0). In 2010 this device choice was expanded to the Nokia 2700c and 2710n, as the 3110c was no longer readily available at stores. The specification of the 2700c is almost identical to the 3110c, but with a larger screen and redesigned key layout. The 2710n is similarly identical to the 2700c, but includes an internal GPS unit which can be used in location type questions.

[8] http://www.cell-life.org

[9] Environments where applications are isolated from the operating system and other applications and can only access their own data and allocated memory.

3.2.2 *Water Quality Manager (Mobile)*

In contrast to J2ME deployments, applications aimed at the Android platform are generally free of any device compatibility and hardware interface problems. Devices that carry the “Android” label are certified to comply with Google's “Compatibility Definition Document”, which ensures that hardware behaves in a standardised and well-defined way.

We wanted to develop a touch-screen application for managers to use on the go – at the time the target platform was narrowed down to the Apple iPhone, Windows Mobile devices, and Android devices – of the three, the Android platform is the only one that is completely open-source and free, which suitably matched our desire to release WQR and related code to the public under an open-source license.

The WQM mobile application will run on any certified Android device (including tablets), but for the purpose of our pilot studies we chose the HTC Desire as our target device, due to it's large screen size and build quality.

3.3 Software

Our aim was to develop an end-to-end system allowing survey or test forms to be loaded onto mobile devices, filled in by technicians in the field, and then submitted to a central database for reporting and dissemination purposes. The mobile data collection tool was envisaged as a robust and user-friendly application that permitted a variety of data types to be submitted by field technicians. The back-end system should accept data from the mobile tools and store it in a suitably generic database, and then make it available to managers in a logical manner.

As such, three separate systems were decided upon: WQR, WQM, and WQM mobile.

3.3.1 *Water Quality Reporter*

WQR is a J2ME application targeted at low-end Nokia “feature phones”. Based on the JavaRosa platform, WQR interprets and renders test/survey forms described in the XForms format. WQR provides a way to collect variable location-based data from a variety of sample points or sites, by a variety of users.

“*XForms is an XML format for the specification of a data processing model for XML data and user interface(s) for the XML data, such as web forms. XForms was designed to be the next generation of HTML / XHTML forms, but is generic enough that it can also be used in a standalone manner or with presentation languages other than XHTML to describe a user interface and a set of common data manipulation tasks.*”[10]

Upon completion, forms are submitted as an instance of the XForm to WQM via a HTTP POST call (a standard web request).

A typical WQR user session proceeds as follows:

1. Select sample point/site to collect data for using navigator keys and menus [Figure 1].
2. Select form to be filled in using navigator keys and menus [Figure 2].
3. Answer form questions as prompted, using the keypad [Figure 3].

[10] http://en.wikipedia.org/wiki/XForms

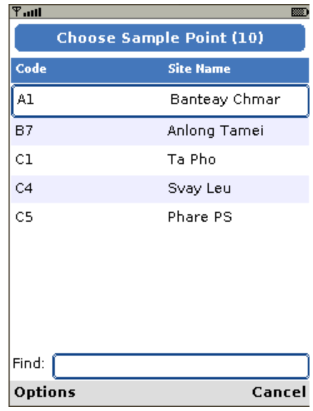

Figure 1. Sample point selection.

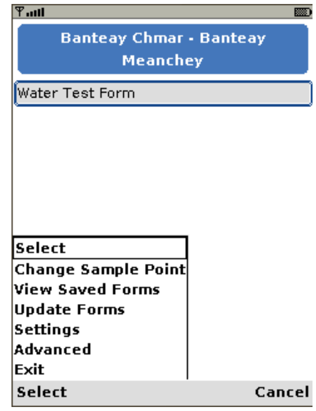

Figure 2. Form selection and menu.

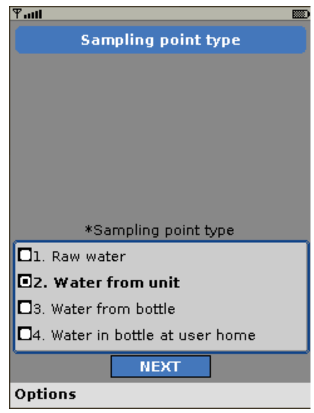

Figure 3. Answering a question.

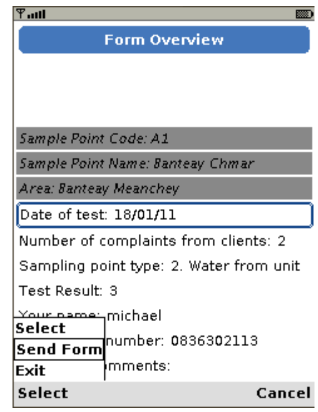

Figure 4. Completed form ready to send.

4. Confirm form inputs and submit to WQM (or save it to send later if there is no network coverage) [Figure 4].

JavaRosa supports multiple questions, including: string, decimal, float, and date types. Questions can be defined as compulsory in the test form and users are not allowed to continue or submit a result until they are answered.

WQR supports several features that at the time of writing were fairly novel – some of these features were developed in collaboration with the JavaRosa community:

1. Automatic sample point synchronisation with WQM – WQR regularly checks WQM for new/updated/deleted sample points and synchronises them to local storage.
2. Adding additional sample points – points can be added directly on the phone, and are picked up by WQM after the first result associated to them is submitted.
3. Automatic form synchronisation with WQM – new forms can be uploaded to WQM and WQR will retrieve and allow users to immediately start using them.
4. Sample point filtering – users can define several default properties: name, phone number, language, and area. Selecting an area filters the sample point list to only show sites in this area.

5. Full localisation – all text in WQR is available for translation using external text resource files. WQR also takes note of locale-specific decimal separators. This includes form questions. Users can specify their language in the properties page of the application.
6. Custom question types, including: current location field that fetches coordinates from the device GPS if available, phone number field that preserves leading zeroes, and a compound minimum, maximum, average and count question that allows users to submit the four listed fields as one entry.

Changes made to the JavaRosa core enabled proper support for float data types, and error handling that saves forms to storage for later sending if there are network access issues.

In the early stages of the project, an alternative data submission path was set up, in the way of RapidSMS. Users could use any type and make phone to submit results via structured SMS messages – these results were parsed, normalised and stored alongside the results received from the WQR application. After a time it was decided to switch off this system as despite intensive and lengthy user training, users were still submitting results that could not be correctly parsed. Well-defined question types in WQR make it virtually impossible for a user to submit a result that cannot be parsed. Erroneous data can also be detected (up to a point), using the question type and context to infer what type of data is expected.

3.3.2 Water Quality Manager

WQM was started as a fork of Dimagi's CommCare[11] web system, but has since evolved into system that whilst retaining much of CommCare's backend, has also added a variety of useful features and interfaces relevant to our project.

CommCare was originally designed as a job aid for community health care workers, and comprised of a server and mobile component. The mobile component is similar to WQR, whilst the server component allows one to register test forms and start collecting data from the mobile application. CommCare supports multiple "domains" - allowing one to create and associate users and forms with them, and to thus collect different data for each domain. All submissions are verified against their matching XForm definition and invalid submissions are rejected.

WQM extends this system and implements a number of useful features for managers.

After associating a form with a domain, parameter types and normal/abnormal ranges for specific parameters are defined. Data received is automatically parsed and saved as their relevant parameter types (e.g. pH, turbidity, etc.). Notifications are then set up to monitor the parameter normal ranges – if a sample falls outside of the expected range, SMS messages with specific instructions or warnings can be configured to be sent immediately to the technician, and also to their manager. These notifications can further be limited to certain sample points. SMS messages are sent via an external bulk SMS provider.

New technicians and sample points are registered on the system on an ad-hoc basis – as results are received, they are checked against existing reporters and sample points, and added if needed. Reporters profiles are updated with their latest sample point after every submission.

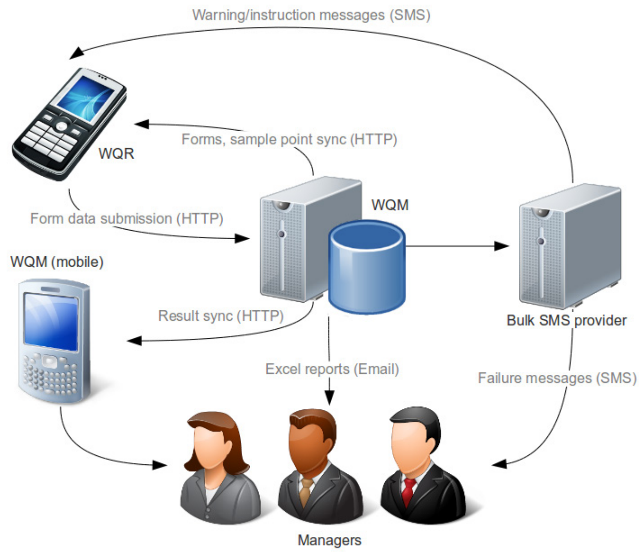

Figure 5. System flow overview.

An automated report module was also developed – this module allows reports to be sent to specific managers at certain time intervals (weekly, fortnightly, monthly). Reports are sent in a Microsoft Excel format as it generally a technology people are familiar with. The tabular results can be graphed using Excel charts and macros. Managers are also able to define certain areas to receive reports from, whilst ignoring others.

A central interface to manage the sample points, parameters, notifications and reports was developed separately from the main CommCare interface as we felt that much of the available functionality was of little interest or relevance to our managers.

This interface uses Google Maps to show an overview of all the sample points in a domain. Sample points without defined coordinates are still accessible in a list format in the management section. Reports over specified date ranges can be generated from this interface for sample points, areas, or subsets of either. Managers are able to choose from several reports, including: collected data, results per operator, and results per sample point. An easy-to-use control panel for managing notifications and reports is accessible from this interface.

3.3.3 Water Quality Manager (Android)

This application provides a read-only interface to the collected data, and offers several views of it to the manager. Data is synchronised daily from the central web WQM using web-service that supplies data in JSON (JavaScript Object Notation – a data-interchange format). The manager is able to view sample points organised by area (town), and to drill down to view individual parameters recorded. The calendar view provided is probably the most useful in the application as it provides a rapid visual summary of the quality of water collected.

Drilling down further into specific days displays a breakdown of all parameters collected that date, with associated colours. The colours chosen are not related to national water quality standards, but rather indicate the following: green – within normal range

[11] http://www.dimagi.com/commcare

(pass, yellow – outside of normal range, but within acceptable range, red – outside of acceptable range (failure).

A Google Map view is also available that shows points at their locations, with their markers coloured to show the compliance over the last 30 day rolling window.

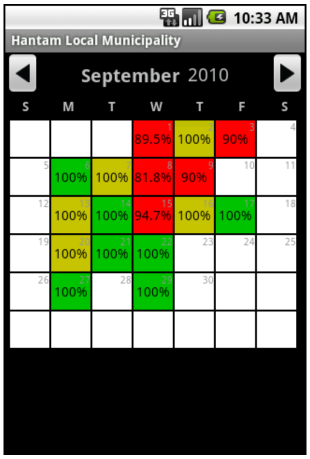

Figure 6. Calendar view.

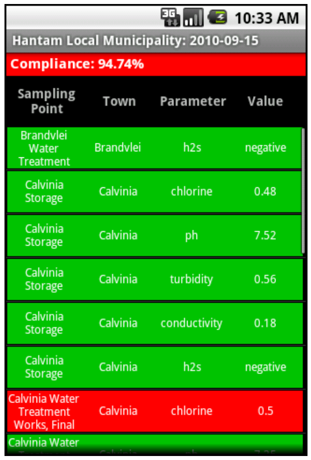

Figure 7. Result view.

3.3.4 *Development Methodology*

Whilst no formal software development process was followed, the best approximation would be a form of agile development and rapid prototyping . The design, development and implementation of the WQR system was undertaken as participatory action research. Interaction with stakeholders was kept at a high level, and applications went through many quick iterations and prototypes in order to stay in line with stakeholder expectations. Needs were constantly monitored, and reviews of the software were made regularly, without becoming exercises in lengthy analysis with little output.

3.3.5 *The Decision to Go Open-Source*

Given the primary target audiences, context (rural communities, government agencies), and goals of the project (increased communication and transparency) the decision to release all of the tools under a open-source license seemed natural.

Christopher May says of free and open-source software (FOSS):

"*[FOSS] encourages the development of computer programming, maintenance and developmental skills within the local user community.... FOSS allows local engineers to develop skills related to their local needs. This can also allow a form of ongoing apprenticeship in programming communities, with more experienced programmers helping newer practitioners through email discussion lists and bulletin boards.* " [10]

Additionally, governments are becoming reluctant to use software that they cannot modify internally or where they are required to pay annual license fees. To ensure sustainability and a successful handover of our software to government it was important to provide an open-source solution.

WQR, WQM, and WQM mobile packages and source-code will be available in late August 2011.[12]

[12] Available at http://www.icomms.org

4. PILOT SITE IMPLEMENTATIONS

4.1 South Africa

Four sites were chosen in South Africa, each targeting a single Water Service Authority (WSA) responsible for one or more communities. The sites were chosen on the basis of representing different water quality monitoring and water service provision contexts. By selecting sites in this way, we were aiming to represent challenges common to other countries with remote rural community supplies. Additionally we engaged with the national and provincial government to ensure that the research project itself was not based in areas where capacity was too low to accommodate our requests for engagement during the four year project.

The four sites chosen were the Hantam Municipality in the Northern Cape, Chris Hani District in the Eastern Cape, Alfred Nzo District in the Eastern Cape, and Amathole District in the Eastern Cape. We present the first three sites below.

4.1.1 *Hantam Municipality*

The Hantam Municipality is composed of several small towns in the Northern Cape, each between one and two hours drive away from the central town, Calvinia. There is one manager in Calvinia that has approximately ten field technicians working for him. Water quality management is only one part of the technicians jobs.

During the course of the project, this municipality has consistently performed well with the WQR application, submitting results regularly, and keeping us informed of any problems. We feel the success of the project here can be attributed to several factors:

1. Technicians are formally employed by the municipality and thus see using WQR as part of their job.
2. Hantam consists of farming communities, and as such community members have grown up in an environment that values participation and looking after the interests of the community as a whole.
3. There was a well-defined and understood process for testing and reporting water results in place – WQR took the place of paper log-books and left the rest of the flow unchanged.
4. The relatively low number of technicians allows training sessions to proceed quickly and efficiently, with greater audience participation than would be possible with a larger group.

Interviews with the technicians have revealed that they feel using WQR is a form of status boost – community members will ask them what the cellphone is for, and what are they doing with it, which leads to discussions about water quality and increased interest and participation of the various stakeholder groups.

4.1.2 *Chris Hani District*

Chris Hani District is comprised of eight local municipalities spread over 37,294km^2 – which made this implementation significantly more complex than the launch in Hantam Municipality. Close on 250 sample points were added to system, with approximately 30 technicians tending to them. Two environmental health practitioners (EHPs) were chosen to manage the technicians under the guidance of the local office manager in Queenstown.

Several important issues come to light during this implementation:

1. Browsing through a large set of sample points on the cellphone is unwieldy, even when using a list filtered by area. WQR's response times in the sample point select screen are also significantly impacted when using a data set as large as was present in this implementation.

2. Sample points are currently not pre-loaded into the application, and instead retrieved during an initial synchronisation step. This method performs admirably in regions where cellphone network coverage is good (city centers, etc.), but in practice downloading this many points (~250) in a rural setting is slow and prone to timeouts.

3. Sample point names are often qualified with leading identifiers, for example, "Mthingwevu Mahlungulu A", "Mthingwevu Mahlungulu B", and "Mthingwevu Mahlungulu C" – these names often exceed the length of text that we are able to display on the cellphone screen. WQR does not support text scrolling and operators are forced to remember which order the sample points are listed in; if the wrong one is selected they must return to the selection screen and choose again.

4. We made the mistake of running training sessions with the entire group of technicians, instead of breaking them into smaller groups. This lead to lengthy sessions where users lost interest and motivation. Apart from the obvious training and adoption issues this caused, it was further compounded because in large rural contexts, such as Chris Hani, technicians often have to travel many hours to the training session, which means that anytime they spend with us is time taken away from their jobs in their local community. This is a concern as in small communities one person could be responsible for many tasks that other community members are unable to perform.

Despite these problems, the system performs adequately well in this area, and there are several technicians who consistently and regularly send in data. We were fortunate in this setting in that the two EHPs and the manager are very motivated and follow up with technicians weekly to see if there are any pending issues.

4.1.3 Alfred Nzo District

Alfred Nzo District is the smallest and poorest district in the Eastern Cape. Our implementation here confirmed our suspicion that the biggest barrier to technology adoption might not be the technology itself.

Apart from some training challenges similar to the ones mentioned in the Chris Hani district, we encountered capacity challenges within the middle-management sector. Whilst we had the full support from the provincial Department of Water Affairs and the municipal manager, it became clear that in this under-resourced setting that a number of challenges had a high priority. As the WQR deployment was a university research project, it naturally took a low priority when the capacity within the municipality was low. However, it was a clear lesson learned for us that it is more important to have complete buy-in from middle-management (who form part of the daily engagement), than from the top management (who are generally removed from the day-to-day runnings and activities). Whilst this might have been an isolated occurrence and its cause unrelated to the project, it is important to note that sometimes a single well-placed person (or lack of) can make or break an entire deployment.

Something to note was that during training we discovered that our assumption that most technicians we would be interacting with would be comfortable with the chosen Nokia handset was incorrect. Whilst some of the older technicians had mobile phones, they were of a previous generation (monochrome screens, no navigation buttons), and the four-way navigator and center select key that is popular on most phones today caused a great amount of confusion and consternation with the users.

4.2 Vietnam

We interacted with a private water utility in Hue City in Vietnam, who wished to supplement their already extensive testing procedure with the WQR application. The integration of the WQR application into this well-established and regulated organisation was different to our other pilots, and we learned much from the context of the implementation.

Due to the very different organizational structure – a private company providing water – water quality monitoring has a very different priority compared to the settings in rural South Africa. The company's focus is to deliver safe water and the existing processes and information flow is a testament to this. A variety of detailed water quality information was collected by rural borehole operators daily. Given the quantity of data technicians were recording, we developed a custom question type that prompts the user for the minimum, maximum, average, and sample count values for a parameter. These values are compacted and stored as one field in the database. The ability to develop additional forms "on the run" was highly useful in this context.

As with most large organisations, the utility had an internal IT team who wanted to be involved in the project and use the data collected within the existing reporting structures. After some deliberation we came to the agreement that the supplied Excel reports could be imported into their system by the IT department to do with as they wish – discussions were left open to possibly implement a web-service that sends raw data on to the utility immediately as it is received by WQM.

As pointed out earlier, similarly to the implementations in South Africa, technical difficulties during deployment can sometimes only be identified locally. An interesting problem only became apparent after a couple days of arriving in Vietnam – the bulk SMS provider we had chosen to deliver SMS messages had not yet negotiated a contract with the local network provider that we had SIM cards for. Whilst this was easily fixed by purchasing replacement SIM cards it speaks to the challenge of the mobile sector and the detailed local knowledge required to implement mobile solutions

4.3 Cambodia

The context of the pilot is a small French-run NGO that was empowering communities by providing them with necessary hardware and support to monitor and treat their own water. Operators in villages are given grants to build pre-planned "cookie-cutter" water treatment plants – this consisted of a small treatment unit (filters and UV-based) housed in a secure shed, storage tanks, bottles, pipes, and a motorbike and trailer to deliver bottles to the community.

Operators regularly tested parts of the system for contamination using presence/absence tests, and recorded them in logbooks which were collected monthly by the head office. Combined with an extraordinary motivated and skilled team in the head office made this implementation a pleasure.

We decided beforehand to approach the training sessions using a "train-the-trainer" method, i.e. for one day we trained only the managers in all aspects of the application. The following day we observed the managers training the operators. This is often a preferred arrangement in foreign contexts where a language barrier exists. The enthusiasm of team members in this organisation resulted in not only the wide acceptance of the tool but also a set of excellent ideas for changes that we had not thought of. The first was to set the phone background to a picture of the name of the operator and the site they managed – a small change, but very worthwhile. The operator is constantly reminded that the phone is a work phone, and it also makes trouble-shooting and collection of phones easier as one does not have to record which phone belongs to which person. The second idea involved recording a video of one of the managers using the application and talking through every step – this video was then encoded to a suitable mobile format and placed on every phone.

A seemingly significant challenge was the language barrier – the majority of the population in Cambodia speaks and writes Khmer, a language with a syllabic alphabet that we were unable to render on the phone. To get around this, we provided detailed translation tables that listed every English word/phrase in the application and the Khmer translation of it. After a few tries using the phone, most operators were comfortable enough to submit results by themselves.

4.4 Mozambique

"*More than one million people in the central region of Mozambique will have improved access to adequate sanitation facilities and water sources as a result of the One Million Initiative.*" [8]

As part of this initiative UNICEF is overseeing a large well-point drilling campaign on Mozambique; in May 2011 they decided to begin a trial implementation of the WQR system, using several custom survey forms to collect data about water quality, well-site conditions, and corrective actions taken to fix problems.

It is too early to draw any meaningful conclusions from this pilot study, but we have already seen and corrected some issues.

Early on in the launch it was discovered that switching the phone to the Portuguese language changed the decimal separator from a dot (.) to a comma (,), which in turn caused WQM to incorrectly interpret decimal values as "-999999". This was rectified by allowing the phone/user to enter the decimal separator as defined by the current locale, but then subsequently replacing it with a dot as soon as the question was answered. The issue of poor network coverage and synchronising sample points to the phone was again raised, and we are currently looking for a solution.

One of the major needs identified by UNICEF is a reporting module that can produce detailed breakdowns, graphs, and summaries of data collected. A proposed solution is to expose data from WQM and develop another application tier below that accepts this data and can be programmed to produce custom reports. In this way, a custom reporting application could be developed for each separate user of the system.

4.5 Issues Common to All Sites

During the course of our pilot implementations we noted several issues that were universal across the implementations:

1. The WQR application was prone to what seemed at first as random "out of memory" errors – trying to reproduce these errors remotely based on a phone-call/email is an exercise in frustration, and much time was spent tracking them down. This was only a problem with the Nokia 2700c handset, the 2710n was not as susceptible to running out of memory.
2. Displaying lengthy sample point names on the narrow screen is not ideal.
3. Users were able to delete the application from the phone's storage – this happened regularly despite warnings against it. Our assumption is that this happens because when you are browsing Nokia applications and you press the Menu key, the first option in the menu is Delete, and this coupled with non-English speakers results in it being pressed more than it should.
4. Users would fill up the phone with music and video downloads, sometimes to such an extent that the WQR application could not be reinstalled without removing some of it.
5. GPRS settings and network coverage – both are hard pieces of information to come by without someone on the ground in your target country.
6. Application reinstallation – new application versions can be sent via SMS or downloaded using the phone's web-browser. Both options are complicated and unfamiliar actions to technicians who have just been taught the basics of the phone.
7. The use of airtime is an administrative challenge in all of the settings. Field technicians are provided with airtime to submit data, however, sometimes this airtime is used up by calls, downloads, and so on. It is key to discuss this aspect of a mobile implementation with the relevant stakeholders at the beginning of the project.

5. FINDINGS AND CONCLUSION

This paper reflects on our experience of the design and the implementation of a mobile water quality data collection tool.

Whilst water quality management and access to safe water is a commitment from all countries through the Millennium Development Goals, the implementation of systems that allow timely decision making and data collection is still a new field within the sector. By using mobile phones – a technology that is widely used in developing countries – we hoped to develop an application that allows fast technology adoption. The mobile WQR application was embedded within the reporting structure of South Africa's policies and guidelines and implemented within the structures of government to ensure sustainability and integration within the bodies accountable for the delivery of safe water. In Cambodia we implemented the system in conjunction with an international NGO, and in Vietnam at a private water utility. In all three cases it was a key learning that the support of middle-management is key. The ability to change forms "on the go" when receiving feedback proved to be a key feature to ensure ongoing user engagement.

Designing and developing systems from afar is an immensely difficult task – these pilot implementations have shown again and again that a solid understanding of the local context is vital to a successful deployment. Of equal importance is the ability to adapt an ICT-based solution to compliment systems already in place instead of replacing them outright.

Even when the system is well-planned and thought through, there are other external factors that might compromise the success of the project – factors that are seemingly unrelated to ICT work. Buy-in from the primary users is important, as it has been shown that the cooperation of upper-management is not enough by itself to ensure successful adoption of a new system.

Whilst the feedback shows that managers and field technicians/municipal foremen and environmental health officers are more "in touch" and aware of the situation in the various areas, it is currently unclear in how far this will impact on a long-term improvement of the water provided to communities.

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