Google Android mobile phone applications for water quality information management

A. Jonoski, A. Almoradie, K. Khan, I. Popescu and S. J. van Andel

ABSTRACT

This paper introduces some experiences with developing mobile phone demonstrator applications for water quality information management using the Google Android platform. The work presented is part of an EU research project named LENVIS (Localised ENVironmental and health Information Services for all). The applications are focused on delivery of water quality information related to outdoor bathing waters in two case study areas in the Netherlands. Both monitored and modelled water quality information is delivered via mobile phone applications that are integrated with web applications. The applications also have functionalities for collecting user feedback on bathing water quality from the field and integrating it with the information provided by the water management authorities. Initial test results of the applications with targeted user groups are also presented, which demonstrate the promising potential of this technology for water quality information management applications and they indicate potential use in other application areas.

Key words | Android, bathing, citizen involvement, mobile phone, swimming, water quality

A. Jonoski
A. Almoradie
I. Popescu (corresponding author)
S. J. van Andel
Department of Integrated Water Systems and
    Governance,
UNESCO-IHE Institute for Water Education,
P.O. Box 3015,
2601 DA, Delft,
The Netherlands
E-mail: *i.popescu@unesco-ihe.org*

K. Khan
Sub-Divisional Engineer,
Planning-III,
Bangladesh Water Development Board,
Dhaka-1000,
Bangladesh

INTRODUCTION

The explosive growth of mobile phone usage, together with the increasing power, capabilities and sophistication of the actual mobile phone devices has opened new opportunities for developing hydroinformatics applications oriented towards a very broad user base. While such applications can be developed for water systems managers in support of their operational activities, the greatest potential is in fact in the area of developing applications for the broadest user base of individual citizens. These users are seen not only as recipients of knowledge, but also as suppliers of information which can bring added value, if properly assimilated in the overall information system in question. Prospects for usage of mobile phones in hydroinformatics applications for large user bases were presented in Abbott & Jonoski (2001). A number of demonstrator applications have recently been developed, such as usage of SMS messaging for operational interventions in water supply systems (Segura 2006), usage of Java Midlets technology (J2ME) for flood forecasting (Naz 2006), or use of mobile phone web browsers for applications in support of field sampling of data (Fenrich *et al.* 2009).

Since the introduction of the third generation of mobile phone networks (3G) a multitude of possibilities has been opened in addition to the wireless telephony, such as video calls, broadband wireless data transmission, and location-based services enabled via Global Positioning System (GPS). This has enabled the integration of the mobile environment with the Internet and the development of a new brand of integrated web-mobile phone applications. The mobile devices capable of utilising this new environment are known as 'smart phones'. Several different operating systems (platforms) for smart phones are currently competing on the market such as Symbian, RIM Blackberry, Windows Mobile, iPhone OS and the Google Android platform. These technologies offer new possibilities for hydroinformatics applications development by which localised information on the state of the water and environmental systems can easily and effectively be delivered to a large user base, including ordinary citizens.

At the same time, these users can contribute by providing information via the same mobile phone devices (see van Geen *et al.* (2006) for an example related to water well contamination). The potential of using environmental information provided by concerned citizens has already been widely recognised. Developments in which information provided by citizens is used for better understanding and management of environmental systems have been recently described using the term 'citizens science' (Paulos *et al.* 2008).

This article demonstrates the potential of using mobile phones for bi-directional information provision on water quality of surface waters, primarily used for recreational activities such as swimming and bathing. Authorities responsible for water quality monitoring and management (with responsibilities for issuing water quality alerts) provide official monitored and modelled water quality data via mobile phone applications to citizens, and citizens provide real-time feedback information using the same phone application. The applications have been developed for case studies in the Netherlands, within the framework of an EU research project named LENVIS (Localised ENVironmental and health Information Services for all – www.lenvis.eu), using the Google Android platform, which has become increasingly popular and available on many mobile devices. The work presented here is a revised extension of the material provided in Jonoski & Almoradie (2010).

The structure of the article is organised as follows: a short overview of the Google Android platform and its main advantages is given, followed by presentation of environmental water quality issues where citizens' involvement may be beneficial from a European perspective, and especially with respect to the Netherlands. Then a short description of the LENVIS project and the two case studies is provided. The actual mobile phone applications and their integration with associated web browser applications are then described, which is followed by the results from testing of the applications carried out by end users and finally the concluding section.

GOOGLE ANDROID PLATFORM

Google Android is a relatively new platform for developing mobile phone applications. First versions of it appeared in 2007, although the first device that used this platform (the G1 phone made by HTC) appeared at the end of 2008/beginning of 2009. Although the platform is known as Google Android, it is in fact an open source platform developed by joint efforts of the Open Handset Alliance, which includes 65 technology and mobile companies led by Google.

Although in the beginning the platform had a relatively small share of the mobile phone market of only a few percent, it has seen an explosive growth in recent years. The leading smart phone operating system in terms of diversity and sophistication of applications development is currently iPhone OS, but Android is probably the most serious challenger of iPhone OS on this front. The primary reason for this is the fact that Android is an open source platform, which is increasingly being adopted by many different mobile phone producers. Samsung, HTC and Motorola are among the big manufacturers who have decided to adopt this platform for their devices. Consequently, as from the second half of 2011, Android has become the most widespread mobile phone platform in the world. In comparing smart phone manufacturers, Apple's iPhone is still leading ahead of Samsung and HTC, but in terms of the market share of the operating systems Android already has 54% (Millennial Media 2011).

The popularity of Android for mobile phones comes from the facts that it is an open source platform, the use of Java as a programming language for Android, and the easy deployment of applications on mobile devices by making use of the Android market. This last aspect has proved to be particularly beneficial for developers since they can offer consumer applications which can be either free or at a cost. Currently, the Android market offers hundreds of thousands of applications to consumers who have Android-enabled phones. On this front, the leader is still iPhone with more than half a million applications offered via their App Store, but the expectations are that the higher rate of growth of Android may soon close this gap. Even though the competition in this area is fierce, with many uncertainties, the Android platform needs to be seriously considered as potentially one of the dominant platforms in the future.

The Android platform is in fact a software stack composed of operating system, middleware and key applications. The underlying operating system is a version of Linux, while the applications are coded in the Java programming language. The core libraries of Java are included in Android together with additional Android libraries. The

Java applications are run by a Dalvik virtual machine, which is a version of a Java virtual machine, although with some modifications for optimised performance on mobile devices. The Android platform comes with Application Programming Interface (API), which is used by other developers to develop their own applications that can then be deployed on the mobile device.

Application development is enabled by providing Android plug-in for Eclipse, which is a popular application development environment for Java programmers. This comes with an Android emulator, on which the applications can be tested during development. Final versions of applications can easily be deployed on actual mobile devices from Eclipse.

Given all the advantages of Android presented above, the applications presented in this article were developed with this platform.

WATER QUALITY INFORMATION AND CITIZEN INVOLVEMENT

In recent years, the European Union has increased its level of attention to the collection, provision, and usage of environmental information. The diversity of environmental information, such as soil quality, air quality, water quality, etc., is reflected in the departmentalisation of institutions responsible for collecting and providing environmental data. While this may be understandable from an organisational point of view, it has been realised that for the broadest user base of concerned citizens such information needs to be provided in a different manner. The main area of concern for citizens is human health, but also health of ecosystems that are dependent on environmental conditions. In addition to this, citizens as end users increasingly demand such information to be localised for any area of interest and readily available at any time.

These demands have presented new challenges to organisations responsible for the collection and provision of environmental data, and to those that are responsible for the management of environmental resources. These challenges require improved inter-agency cooperation, and maximisation of the potential benefits that can be provided by the latest advances of Information and Communication Technologies (ICTs). However, it is also realised that meeting the new requirements needs active engagement of the end users – concerned citizens themselves. Their contributions become invaluable for both proper contextualisation of environmental data and for provision of timely and localised information. The final goal is to improve environmental management by enabling the integration of the structured information coming from responsible institutions with less structured information provided by the citizens as end users.

One of the main concerns for citizens is environmental water quality, which is also the main focus of this article. Water quality in general, and bathing water quality in particular, are mainly threatened by algae and external inflow of polluted water. The algae concentration is usually monitored by a number of point measurements in some of the bathing lakes and water bodies. The monitoring of water quality of the connected canals and streams, which discharge into bathing waters, is in general quite limited, and the progression of polluted water towards the bathing water is seldom analysed and modelled.

In the Netherlands, water quality alerts are provided by the regional authorities (Provinces, Water Boards) and the national government using notice signs on location and news items on radio, television, websites and TV-text. The notice signs are often missed, or actively ignored by bathers, and the effectiveness of warnings on websites depends on whether or not the bather checks the website before going for a swim. As such provision of warnings through websites is a passive way of alerting. SMS alert services for bathing water quality are not yet offered. The decisions by the authorities on issuing warnings for bad water quality or even closing a particular location also has an economic impact for the private owners of these bathing waters. Up-to-date information on good water quality, e.g. on a website, could be beneficial for a beach exploiter in the sense that it could increase the number of visitors, but similar information on poor water quality may sharply reduce the number of visitors. Providing such information is fully justified from a health safety point of view. However, even in cases when the poor water quality is a result of an extraordinary incident and the water quality is subsequently restored, visitors may continue avoiding the location in question even for several seasons. Therefore, beach owners and exploiters are stakeholders strongly interested in timely, accurate and continuous provision of water quality information.

The frequency of sampling of bathing waters (monthly to bi-weekly) for water quality variables that are related to health problems of bathers is not sufficient to provide the actual state of the bathing waters at all times. The processing of the samples in the laboratories takes a relatively long time (3 days) and the updating of information on bathing websites is also not frequent enough (monthly to bi-weekly). The communication of bathing water quality data and bathers' health complaints amongst professional organisations involved is mostly fast and reliable, but needs continued attention.

Observations of bathers are not yet used in updating the actual information on bathing water quality. Such information provided by citizens, when combined with official monitoring by the authorities, could help in keeping information up to date. Moreover, water quality models are increasingly being initiated and tested by different institutions in charge of water quality monitoring. However, the uncertainty and error bounds of such models are still high, and their usefulness and real contribution to providing actual status of bathing water quality necessitates their validation by a much denser observation network and more frequent observations in time, which significantly increases the costs for monitoring. One way to reduce these costs is to obtain assistance from citizens and to make use of the observations of bathers who can provide real-time information to professional users, to improve their models and forecasts.

DEMONSTRATION CASE STUDIES

LENVIS project

The LENVIS project has been initiated with the aim of developing a collaborative decision support network of services for combined provision of environmental and health information to public authorities and citizens. The domains of health and environment have traditionally been approached rather separately in the design and development of information systems. While the vast knowledge on causality between environmental factors and human health (as well as health of other ecosystems) is currently available, systems are needed for targeted information that would more effectively contribute to exposure and hazard assessment, risk estimation, risk communication and possible mitigation measures/actions. The goals of LENVIS are to fill some of these gaps by developing a platform to share, elaborate, analyse, and disseminate data and information concerning environment and health, while making use of the latest ICTs, such as web services, peer-to-peer networking, and integration with web and mobile phone interfaces.

The developed network of services was tested on several different case studies in the Netherlands, Italy and Portugal. The case studies in the Netherlands were developed in collaboration with the Province of Noord-Brabant (North Brabant), with focus on potential risks associated with poor water quality. The main focus is water quality of surface water bodies (rivers, canals, and particularly small lakes) which are often used for bathing, swimming, surfing and other recreational water activities.

Bi-directional information communication (from authorities to citizens and vice-versa) is again the central idea of the applications developed for these case studies. The aim is to realise this communication through both web applications embedded in computer browsers and via mobile phone interfaces, which can be either browser-based or as separate applications. These applications can also become integrated web-mobile applications, as will be demonstrated later in this paper.

Case study descriptions

The demonstrator Android applications developed within the LENVIS project are for water quality information on surface waters in two catchments belonging to the Province of Noord Brabant: the Brabantse Delta and the Dommel. Two different demonstrator applications have been developed: (1) dissemination of modelled water quality information for the Dommel catchment; and (2) dissemination of measured and modelled water quality information for a number of small lakes in the catchment Brabantse Delta, with user feedback.

The following section will present the description of the two case studies in terms of water quality problems and the approach taken to address these problems, including modelling support. Presenting details of the models is beyond the scope of this paper since the main focus of the paper is on the mobile phone and web applications that were developed for accessing the results of the models.

The Dommel catchment

The Dommel river is a tributary of the river Maas, and it flows from France via Belgium into the Netherlands. The catchment is of a transboundary nature having an area of about 1,350 km^2, and it is quite flat with elevations between 5 and 78 m above mean sea level (a.m.s.l.) (Figure 1). Because of its geophysical characteristics, the Dommel catchment is mainly used for agriculture, which creates threats to water quality through diffuse pollution. A distributed hydrological model, such as the Soil Water Assessment Tool (SWAT), can be helpful in assessing sources of pollution and testing possible management measures. The second source of threat to the water quality in the catchment is the point source pollution coming from waste water of the cities and from industrial waste water. This kind of pollution can be easily incorporated in a distributed model, such as SWAT.

The catchment hydrology and water quality of the Dommel river was modelled by the distributed SWAT modelling tool (Gassman *et al.* 2007), and then the case study was used for testing applications that access modelled results from the server via mobile phones. SWAT is a hydrological modelling tool which uses sub-basin separation of the catchment under study to determine the sub-basin runoff. Routing of the computed runoff to the river is done using relatively simple hydrological routing techniques. The concept of hydrological response units (HRUs) is used to generate the runoff production within the sub-basins. HRUs are areas that demonstrate hydrological similarity in terms of runoff production and are determined by classification based on terrain elevation, land use, soil type and management practices. These operations are carried out within a GIS (Geographical Information System) interface in ArcGIS (of ESRI), known as ArcSWAT. Additional components for water quality on top of the hydrology are also available in SWAT and were used in the Dommel case study.

The developed model was used for evaluating the impact of the management strategies, such as introduction of buffer strips to control the diffuse pollution and waste water treatment plants for the point source pollution. The results indicated possible reduction of up to 30% for nitrogen and up to 50% reduction in phosphorus pollution with these measures.

The Brabantse Delta case

The Province of Noord-Brabant is situated south of the river Meuse, and covers an area of about 5,000 km^2. The province has almost 2.5 million inhabitants, of which by far the most live in urban areas. In between the cities there are numerous
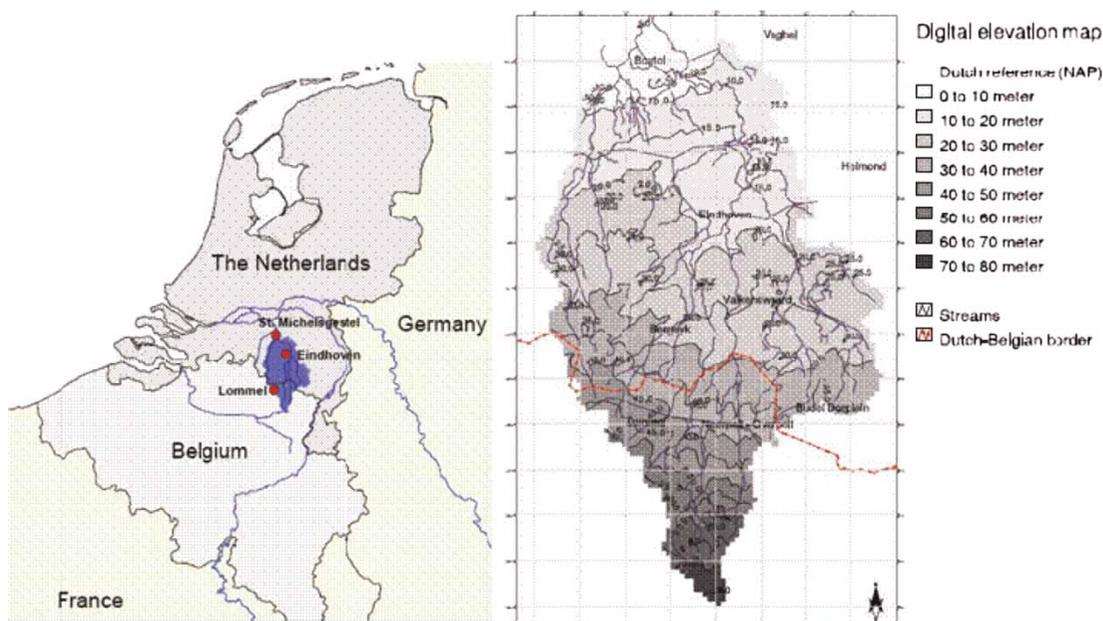

Figure 1 | Location area and elevation of the Dommel catchment (from Pieterse *et al.* (1998)).

lakes that are used extensively for recreational activities during summer. Both the air quality in the province and the bathing water quality of the lakes sometimes drops below health risk thresholds.

This case study has two components. The first deals with information dissemination of monitored water quality data for a number of small lakes located in the area. Out of 40 such locations in the Brabantse Delta, 14 were selected for such information dissemination. Monitored water quality data provided by the province were to be delivered to citizens via mobile phone applications and web browsers in such a way that users could also provide feedback in real time from these locations.

The second component of this case study was related to water quality modelling for predicting water quality in the largest lake of the area – Binnenschelde. The average area of this lake is 178 ha and average depth is 1.5 m, which results in an average water volume of 267,0000 m^3. There is a new swimming area in the lake, situated at its north-eastern part and covering approximately 1% of the total surface area (Figure 2).

The maximum depth of the lake is 3.5 m. Water depth fluctuates at the swimming zone from 0.6 to only 0.3 m due to infiltration, evaporation and closing of an inlet from the neighbouring lake of Zoommeer, which occurs in the period between May and September (Waterchap Brabantse Delta 2008). Around the beginning of April, the water level is set on purpose to a maximum of +1.6 m a.m.s.l. by pumping from the Zoommeer (Waterchap

Brabantse Delta 2009). From the beginning of May, the inlet from Zoommeer is no longer used due to risk of inflow of blue algae, e.g. in the form of microcystine that creates a visible layer on the water surface. A spillway on the southern boundary of the lake is used to prevent water levels exceeding +1.6 m a.m.s.l. (Waterchap Brabantse Delta 2008).

A bathing water quality alert in Lake Binnenschelde is maintained with respect to the presence of blue algae, which is one kind of cyano-bacteria and is measured by the concentration of microcystine in cells ml^{-1} or in µg l^{-1}. High concentrations of these blue algae create a visible layer on the water surface, and beyond certain levels the water may be toxic for bathers.

According to the EU Bathing Water Directive (European Union 2006), other indicators for bathing water quality alerts are toxic algae (including blue-green algae), chlorophyll-a, thermo-tolerant coli-group, *Escherichia coli* (*E. coli*), and intestinal enterococci, which are considered in the case of the Binnenschelde. Table 1 presents the quality standards and alerting practices for *Microcystis*, which was the main modelled parameter.

The water quality model for the water quality of this study used the open source MOHID modelling package, downloadable at www.mohid.com. The MOHID Water Modelling System is a fully nonlinear three-dimensional baroclinic modular finite volumes (finite volume method) water modelling system, created and developed by Instituto Superior Technico (Viegas *et al.* 2009). It uses an object-oriented programming philosophy, integrating diverse

Figure 2 │ Binnenschelde lake.

Table 1 │ Water quality standards and alerts

Water quality parameter	Value for alert	Alert
Microcystis	$<= 20{,}000$ cells ml^{-1} (4 µg l^{-1})	Pre-alert for water managers
	$50{,}000$ cells ml^{-1} (10 µg l^{-1})	Warn not to swim if frequent monitoring is not possible
	$100{,}000$ cells ml^{-1} (20 µg l^{-1})	Warn not to swim even though daily checking is possible
	Conc. $200{,}000$ cells ml^{-1} (40 µg l^{-1}) or more	Swimming prohibited

Source: Waterchap Brabantse Delta (2008).

mathematical models and supporting graphical user interfaces that manage all the pre- and post-processing. It is an integrated modelling tool able to simulate physical and biogeochemical processes allowing different scales in the water column, as well as in the sediments. It is also able to simulate the coupling between the sediment and the water column, and the latter with the atmosphere.

A simple MOHID model was set up for the Binnenschelde lake by making use of the available water system data. The purpose of water quality modelling for the Binnenschelde lake was to establish the extent of algae concentration from the inlet pumping from Zoommeer. The model revealed how far the pollution coming from the Zoommeer inlet contributes to the bathing area, and whether it is in fact necessary to stop pumping from the inlet during summer. This is important because a low water level during summer, as a consequence of the closed inlet, prevents bathing. The model could show how pollutant concentration (microcystine) propagates from inlet discharge to the bathing zone and thereby affects the quality of water during different pumping periods with different input concentration of blue algae. These results can also be used for testing the performance of possible management options in the lake.

The model output is then also used in the subsequent mobile and web applications for water quality monitoring services. These applications contain monitored data for 14 lakes in the Brabantse Delta area, whereas for the Binnenschelde lake, the monitored data are delivered together with the modelled data.

Mobile phone applications

The mobile phone applications were used as examples of bidirectional water quality information communication for the two case studies presented above. Both examples make use of the Google Maps API which, similarly to web-based applications, is also available for mobile phone applications. The map applications running on the phone are linked with server-side scripts that provide additional location-specific information, such as time series of measured or modelled water quality parameters. All communication between the client application running on the phone and the server-side scripts are handled using the standard HTTP protocol, which is also used in most web applications. The server-side scripts for both applications are written in the PHP scripting language.

Modelled water quality for the Dommel catchment

This first application was developed with the main purpose of testing some standard functionalities provided by the Android platform. Water quality problems in the Dommel catchment arise mainly from spatially distributed pollution in the form of nutrients such as phosphorus (P) and nitrogen (N) used for agriculture. In addition to this, there are some point sources of pollution coming from untreated waste water. In order to assess the status of water quality in the catchment, a spatially distributed hydrology and water quality model has been constructed using the SWAT. As explained in the Dommel catchment case study, this model was used in a separate study for investigating different measures for improving surface water quality, such as introduction of waste water treatment plants or construction of buffer strips.

In this application, the modelled results from the SWAT model are disseminated via a map-based interface on the mobile phone. The components of the application operate like any standard web-based application, except that the client-side is the application running on the mobile phone (Figure 3).
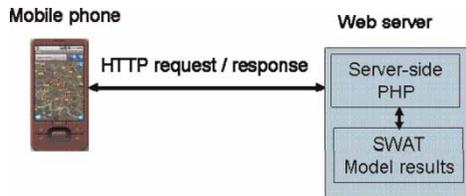
Figure 3 │ Structure of mobile phone application for accessing SWAT results.

The application has a couple of introductory screens about the Dommel catchment and the SWAT model, and some help instructions on usage of the implemented functionalities. The first screen with the map interface presents the domain covered by the model, the distribution of sub-catchments used by SWAT and the geo-referenced locations of the sub-catchment outlets for which flows and water quality parameters are available. In this map interface all standard functionalities of Google maps are available (zooming, panning, different map views such as standard, satellite or hybrid, etc.). After selecting a particular outlet (via the map interface or from a separate drop-down menu) the user can select the time period for data presentation and then view all available data from the SWAT model. In addition to the discharges as flows from the outlets, the model provides a variety of modelled water quality parameters.

Acquiring the actual data is carried out by formulating and sending an HTTP request to the server-side PHP script which retrieves the required data from the result files of SWAT, prepares a graph according to the user specification in an image format, and sends this image back to the phone for display. Additional information on minimum and maximum values, together with functionalities for viewing individual data, is also provided.

Visualisation of some of the steps described above is presented in Figure 4. (All snapshots presented here are from the Android emulator for purposes of clarity, but the applications have also been deployed and tested on an actual mobile device, the G1 phone.) Several extensions of the application are planned for the future, such as combining modelled results with measured data, GPS-enabled localisation of measuring stations in the field, and, possibly, provision of forecasts of expected water quality. All the tests of the application up to the current stage of development have been successful.

Measured water quality of small lakes in Brabantse Delta

This second example application is similar to the first, but deals with dissemination of measured water quality information of several small lakes which are being used by the general population for swimming, bathing, surfing, etc. The data are provided by the Province of Noord Brabant. In addition to the data collected by the authorities, this application is designed to enable the mobile phone users to send feedback from the lake locations on actual water quality status. This feedback can be either in the form of text messages or images taken by the phone camera. The

Figure 4 │ Snapshots of the steps for viewing SWAT results of Dommel catchment.

combined information from the measured data and users' feedback can then be presented on a comprehensive website, which can be accessed by people interested in visiting the lakes in the area. The same information from that website can then also be viewed via the mobile phone itself.

As indicated in Figure 5, the steps in using the application are very similar to the previous case, except that the data come from databases of measured data and not from model results.

Only for one lake – the Binneschelde – such data are also available from the developed MOHID model described in the Brabantse Delta case study.

The interface for provision of user feedback is currently only for textual information (Figure 6(a)). This information as provided by the users/citizens appears on a dedicated website together with all other relevant water quality information for the area provided by the authorities (see the following section).

An interesting additional functionality included in the application is presentation of the relevant points with water quality information within an 'augmented reality browser' named 'Layar'. The Layar enables visualisation of the information embedded in the natural landscape as seen via the phone camera. The Layar utilises the phone compass and the GPS coordinates of the current location

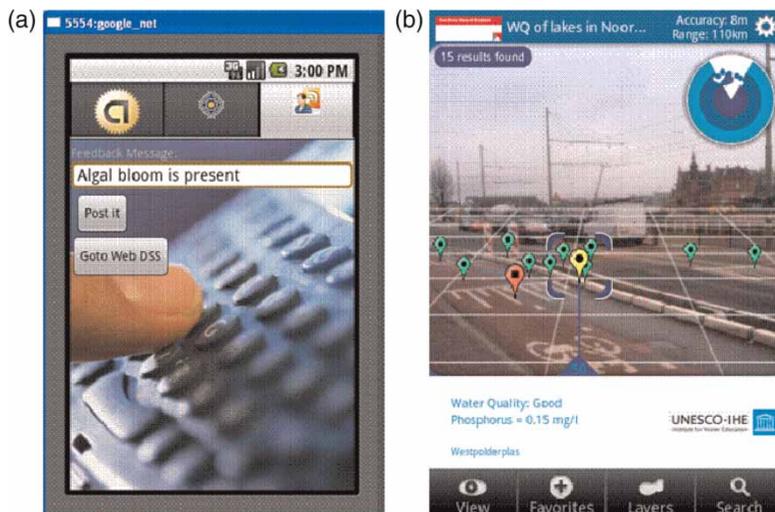**Figure 5** │ Snapshots of accessing measured water quality information in Brabantse Delta.

Figure 6 │ User feedback (a) and Layar interface (b) of the Brabantse Delta application.

of the phone and calculates distances to geo-referenced relevant points that are loaded from a database. The points are presented within an intuitive viewing interface that covers the viewing angle and shows points at different distances with different colours and other attributes. Similar to the map interface, the points from the Layar are associated with additional information (in this case water quality records), which is accessible via the touch screen of the phone. A screenshot of the Layar interface for the Brabantse Delta application is presented in Figure 6(b).

Layar is a third party application developed for Android-based mobile phones (www.layar.com). Future applications for dissemination of water and environment-related information can benefit much more from applications like Layar, especially if modelled landscapes or modelling results can be embedded in the natural landscape and viewed via the phone camera.

Integrated web-mobile phone water quality application

For bathing water quality of freshwater lakes in Brabantse Delta, a dedicated website has been developed that focuses on communication with and from the public users visiting these recreational lakes during the summer months.

The website has been designed with a simple overview and a clear layout for users to intuitively understand the purpose of the website and find the lakes in their neighbourhood using a map with clear icons. Mouse-hovers show labels with the names of the lakes. When clicking on a particular lake, a tabulated pop-up shows up-to-date information on health risk warnings or closures of the lake, water temperature, EU classification of the quality of the lake, and more general touristic information, such us the location of bathing areas for small children, and restaurant and sanitary facilities. Relevant address and route directions are provided via the third tab, with direct links to Google map driving directions and Dutch public transport sites (Figure 7).

Users can visit this website to check current conditions in lakes in their neighbourhood or in the area they intend to visit for holidays. For alerts that also include user feedback, the users also have access to a website where water quality data and feedback through mobile phones is integrated in one single page for 14 lakes in the area. Measured water quality and quantity data of these lakes has been supplied by the Water Board of Brabantse Delta for the past 5 years. These data are processed and stored on a server. The same data were used to build the MOHID water quality model for the Lake Binnenshelde. Output of the water
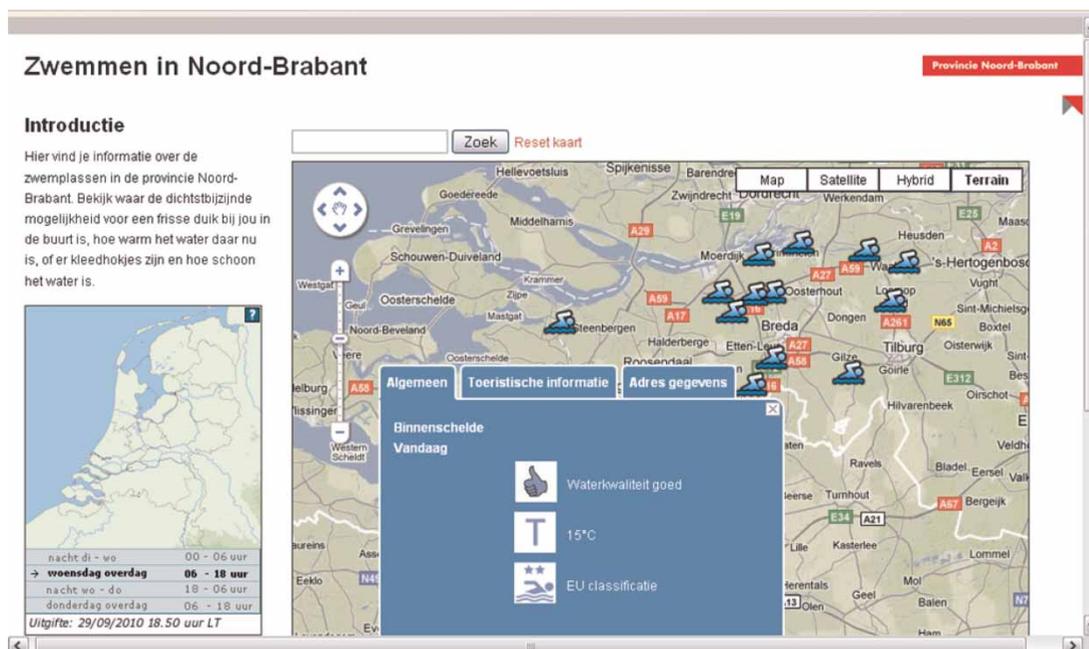

Figure 7 │ Bathing water quality and health alert website.

quality model is also stored on the server. Mobile phone and web-based alerting systems are developed to provide the real-time bathing water quality information, based on measured data and model results. Water quality alerting services are then made available on both the web and mobile phone interfaces via a map-based platform. User feedback sent from the field via mobile phone both in text format (for general users) and data format (for authorized user professionals) are collected and displayed on the web, along with the monitored and modelled data (Figure 8).

RESULTS FROM USER TESTING OF THE APPLICATIONS

The applications presented in this paper have been evaluated and validated by both public and professional users. The first stage in user evaluation was the continuous user involvement and feedback combined with interactive development of the

case study application products. In this stage, mainly professional users have been involved from provinces, water boards, national health, environment and water organisations, and consultancy bureaus. The application product in development was presented and hands-on tested by the users present at the meetings, and feedback would be given and discussed, including ways of implementing suggested changes or additions. In addition to these face-to-face meetings, users have been asked to give a more formal evaluation and feedback on intermediate products through e-mail. It was chosen to use plain e-mail (e.g. instead of structured forms) at this stage to keep the threshold for response as low as possible and to be open for unexpected input from the users. A major source of feedback was the LENVIS project mid-term seminar, during which a large group of various users received demonstrations and hands-on tests.

The second phase of validation focussed more on public user evaluation, concentrated in clearly defined testing periods in the summer of 2011. Evaluations via face-to-face
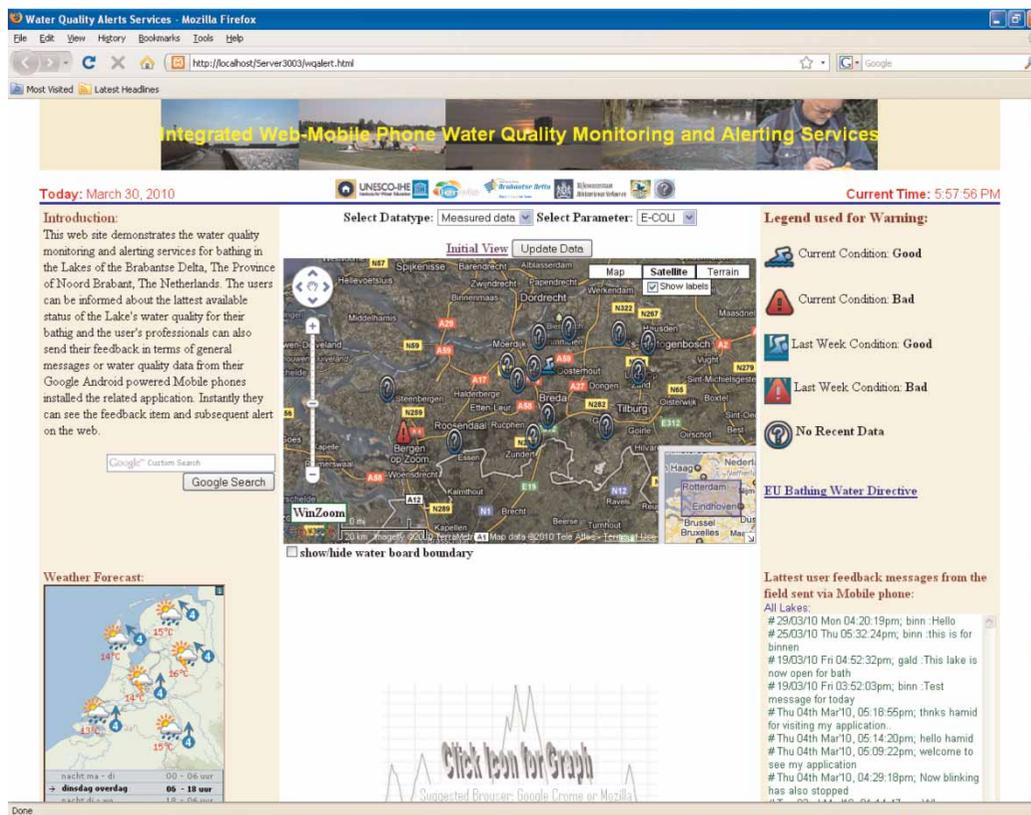

Figure 8 | Mobile phone feedback messages incorporated into the web-page.

meetings with the users were combined with structured evaluation questionnaires. One main conclusion emerged during the meetings, related to the type and level of detail in the presentation of bathing water quality data for different users: while for professional users graphs and numerical data on water quality parameters were suitable, for public users qualification of water quality in linguistic terms (e.g. 'good', 'bad', 'swimming not advisable', 'swimming not allowed') appeared to be more appropriate.

It was also concluded that the bathing water health warnings should not be provided automatically, because measurement errors cannot be automatically detected and interpretation by human experts is needed. Also, the clear responsibility structure and information flow from laboratory, to water board, to province needs to be adhered to by the warning system. The province always has the responsibility of issuing an official warning, or temporarily closing a bathing location.

The developed applications were tested by five professional users and eight public users through questionnaires; in general they were positively evaluated. A user friendliness test was carried out to see whether the application could be used intuitively, without the need of explanation or a user guide. This test had positive results. Critical feedback was provided regarding the poor readability of part of the information provided, and an important point was made that dedicated mobile phone applications should be used for the unique mobile phone functionalities, such as graphs, GPS, location-based services, etc. Otherwise compatible web-applications will be sufficient in a society where mobile phones increasingly have good web-browsing facilities. The structured and unstructured mobile phone feedback applications were considered very useful. It was suggested to show more clearly whether the feedback was submitted and received successfully or not (yet), e.g. using progress indicators. Also the Android G1 phone's touch screen was not easy to use directly by a number of users. This is considered normal, and users soon adapt after having used their own smart-phone for a while.

Validation of the water quality website through questionnaires evaluated five indicators: system quality, information quality, user impact, user satisfaction, and information use. Validation results of these five indicators, by public and professional users are presented in Figures 9 and 10, respectively. The scale used for representation is 1–5 (1 – the lowest value, 5 – the highest value).
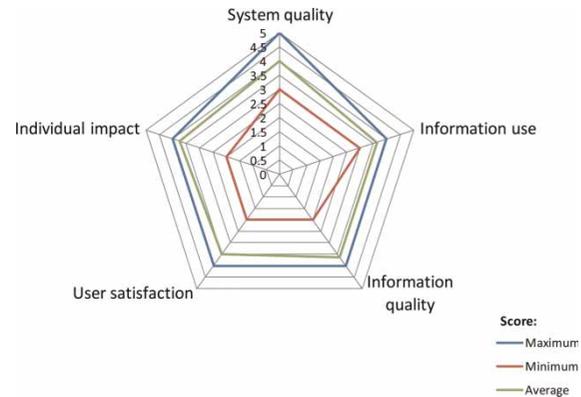

Figure 9 │ Appreciation of the water quality integrated web-system by public users.
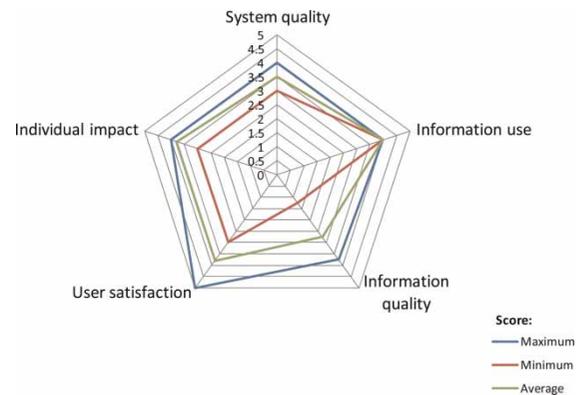

Figure 10 │ Appreciation of the water quality integrated web-system by professional users.

The overall evaluation is positive. Members of all user groups have expressed their clear appreciation for the integrated web-system, and in particular for the mobile applications.

CONCLUSIONS

The presented study demonstrates the benefits of using mobile phone and web applications for bi-directional water quality information communication between authorities responsible for environmental water quality and citizens as end users. The approaches and applications demonstrated here are initial pointers towards new ways of dealing with water quality information (and, in general, environmental information), in which water authorities,

citizens, and other stakeholders may develop new kinds of *partnership* relations with shared benefits.

The applications presented in this paper have been successfully tested for their designed functionalities and their usability has been evaluated by a set of tests organised with professional and public users. The overall evaluation of the applications is quite positive, even though a number of possible improvements and directions for future development have been indicated by these user groups.

The study also showed that the Android platform can be used quite successfully for developing hydroinformatics applications. In the presented applications, only a very limited number of the potential functionalities available in Android have been tested. In future, much more sophisticated applications can be developed in more diverse application areas, such as floods and emergency management, drinking water quality and quantity, and other environmental problems.

The field of hydroinformatics needs to embrace mobile phone applications development much more openly as the opportunities offered by these technologies are truly unprecedented. More platforms need to be tested but, more importantly, more diverse networked applications need to be developed, which have the advantage of both collecting and delivering useful information from/at the end nodes of the network, where individual citizens are located and where such information has the greatest value.

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REFERENCES

Abbott, M. B. & Jonoski, A. 2001 The democratisation of decision making processes in the water sector (II). *Journal of Hydroinformatics* **3**, 35–48.

European Union 2006 EU Bathing Water Directive. Available from: http://ec.europa.eu/environment/water/-bathing/index_en.html#2006 (last accessed October 2011).

Fenrich, E., Brodt, A. & Nicklas, D. 2009 WODCA: a mobile web-based field sampling support system. *Proceedings of the 8th International Conference on Hydroinformatics*, Concepción, Chile, January 12–16th, 2009, pp. 1161–1170.

Gassman, P. W., Reyes, M. R., Green, C. H. & Arnold, J. G. 2007 The soil and water assessment tool: historical development, applications, and future research directions. *Transactions of the American Society of Agricultural and Biological Engineers* **50**, 1211–1250.

Jonoski, A. & Almoradie, A. 2010 Google android mobile phone demonstration applications for water quality information dissemination. *Proceedings of the 9th Interrnational Conference on Hydroinformatics 2010*, Tianjin, Chemistry Industry Press, Beijing, pp. 2463–2470.

Millennial Media 2011 Mobile Mix –The mobile device Index, 2011. Available from: www.milennialmedia.com (last accessed October 2011).

Naz, N. N. 2006 Urban Flood Warning System with Wireless Technology: Case Study of Dhaka City – Bangladesh. MSc Report, UNESCO-IHE, The Netherlands.

Paulos, E., Honicky, R. J. & Hooker, B. 2008 Citizen science: enabling participatory urbanism. In: *Handbook of Research on Urban Informatics: The Practice and Promise of the Real-Time City*. Information Science Reference, IGI Global, Hershey, New York.

Pieterse, N. M., Schot, P. P. & Verkroost, A. W. M. 1998 Demonstration Project for the Development of Integrated Management Plans for Catchment Areas of Small Trans-Border Lowland Rivers: The River Dommel: 3. Simulatie van de Regionale Hydrologie in het Stroomgebied van de Dommel, Technical report, Faculty of Geographical Sciences, Utrecht University.

Segura, J. L. A. 2006 Use of Hydroinformatics Technologies for Real Time Water Quality Management and Operation of Distribution Networks. Case Study of Villavicencio, Colombia. MSc Report, UNESCO-IHE, The Netherlands.

van Geen, A., Trevisani, M., Immel, J., Jakariya, M., Osman, N., Cheng, Z., Gelman, A. & Ahmed, K. M. 2006 Targeting low-arsenic groundwater with mobile-phone technology in Araihazar, Bangladesh. *Journal of Health, Population, and Nutrition* **24**, 282–297.

Viegas, C., Nunes, S., Fernandes, R. & Neves, R. 2009 Streams contribution on bathing water quality after rainfall events in Costa do Estoril – a tool to implement an alert system for bathing water quality. *Journal of Coastal Research* **SI 56**, 1691–1695.

Waterchap Brabantse Delta 2008 Evaluatie zwemwater Binnenchelde 2008. Report. In Dutch. English title: Evaluation bathing water Binnenschelde, pp. 1–8.

Waterchap Brabantse Delta 2009 Memo: Toelichting waterbalansen Markiezaatsmeer en Binnenschelde. Report. In Dutch. English title: Explanation of the water balance of Lakes Markiezzaats and Binnenschelde, pp. 1–2.