

Full Length Research Paper

An open source Geographic Information System (GIS) approach to water supply management, distribution and billing

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In this work a comprehensive solution for the Gatanga Water Trust (GWT) has been developed to assist it in managing its water supply and distribution. The solution comprises two subcomponents: a mapping component and a billing component which are tightly coupled together. The proposed system uses stable open source products for the mapping component and the database. At present the GWT uses outdated maps and sketches for design and installation of a new water supply infrastructure. A billing system is in place which is used to manage client accounts, record meter readings, prepare bills and record payments made. This presents a somewhat disjointed approach to management of the water supply and its attendant infrastructure. The database that stores the account information is very different (softcopy) from that storing the spatial information (hardcopy/paper based). In the proposed solution, a single database is used, centralized or distributed. The mapping component provides an interface through which preliminary design of new and planned infrastructure can be done. After installation, these are reflected in the database and the information becomes available as soon as it is stored. The billing component uses the same database to manage account information. Since the information is managed in one system, there is a streamlined and orderly flow from data collection to the final products from the system. The proposed solution leverages advancement in technology by providing two approaches - a desktop application for users within the Trust's intranet and a web mapping application for users utilizing the wider internet.

Key words: Open source, Geographic Information Systems (GIS), water supply, billing, distribution.

INTRODUCTION

Progress made in information technology has greatly opened up the number of opportunities supporting data analyses and communications in the recent years. Geographic Information Systems (GIS) have provided new and exciting ways of acquiring natural resource data and are also providing efficient means of processing, managing and integrating this data (Opadeyi, 2007). A Geographic Information System (GIS) in a narrow sense

is a computer system for the input, manipulation, storage and output of digital spatial data (Konecny, 2003). The more encompassing definition considers it to be a digital system for the acquisition, management, analysis, and visualization of spatial data for the purposes of planning, administering and monitoring in the natural and socio-economic environment (Konecny, 2003).

A Geographic Information System allows one to create and manage spatially referenced data which is useful for any field or situation that utilizes spatial information (Longley et al., 2005). In the recent past GIS has been mainstreamed, since every conceivable field can

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potentially be enriched by using GIS technology to manage the location based information, that is, education (Kuria et al., 2011), water resource management (Kuria et al., 2012), among a host of others. There are a number of GIS products that can be used – proprietary (closed source) and open source. Commercial products while possessing powerful analysis features are expensive and for most clients, such solutions may not be fully utilized when procured. On the other hand, while open source products may not have the same level of complexity, they have features that can be used to answer some simple analyses. In some cases though, they are excellent alternatives since some have advanced analysis features.

With the advent of internet and associated technologies such as mobile and wireless technology, internet based applications have proliferated, greatly lowering costs to the end consumers who do not need to procure expensive software to realize solutions to their problems. On the other hand, desktop applications are able to utilize the full power of the host computing infrastructure. They are less likely to be targeted for attacks since they are not easily reachable and hence present a level of security that internet applications do not have.

For planning and design, the GWT uses outdated topographical maps and sketches drawn when pipes are laid out. At present it does not have any softcopy spatial management system in place. This approach implies that it is very difficult to visualize this information in real-time incorporating proposed designs and new infrastructure installations. There is an electronic billing system in place which the management says is fraught with some inconsistencies. Since this system is not connected with the spatial management system, it is not easy for employees to visually connect between client accounts and their locations in space. This current approach is thus very limited and the Trust is not able to leverage technological advances to improve the management of the water trust.

This work sought to develop an open source geocomputing solution to assist the Gatanga Water Trust manage its water supply infrastructure and distribution network. This solution comprises a desktop mapping and billing solution targeted for the intranet user and a web mapping and billing solution for both internet and intranet users.

To realize this, the following specific objectives were formulated: (i) determine current and future system needs for the Trust, (ii) formulate a desktop GIS strategy to solve the needs, (iii) formulate a web based GIS strategy for internet users, (iv) combine the two solutions (strategies) into one overall solution for the Trust.

Study area

The Gatanga Water Trust (GWT) forms part of the original Kandara water project which was constructed in

the early seventies. The project was a community initiative with the then local leaders spearheading the sourcing for funds (Figure 1).

GWT was formed as a result of the water sector reforms initiated in 2002. It is run by a board of trustees drawn from Gatanga District representing individual locations. The distribution system in the scheme is wholly gravity serving a rural set up. It is served by two water intakes constructed inside the Kimakia Forest. The intakes draw water from the Kimakia and Thika Rivers. Initially the GWT had 2000 active connections but since the injection of the funds the number rose to 4000. The current water production stands at 7000 m³ per day. It is serving approximately 9000 active consumers of which 4000 have been metered. The core functions of the GWT are sourcing of water, treatment and conservation of water, distribution of water, billing and revenue collection.

The scheme has two subsystems which are independent of each other. They are referred to as North and South of Kiama. The North of Kiama River system gets its water from the old intake constructed on the Thika River. It serves Kigoro, Mukarara, Kiriaini and Kihumbuini locations. The laid pipeline stretches from the forest edge (Kimakia) to Wanyaga – Kimandi – Ndakaini – Ndunyu chege – Mukarara, Gitiri – Mukurwe – Jasho. The South of Kiama River system gets water from the newly constructed intake on the Kimakia River. It serves Kariara, Gatanga and Mugumoni locations. The pipe network stretches from Kinguri –Gatura – Chomo – Kirwara – Kigio and Gatunyu. Gatanga Water Company (GWC) was formed in 2004 mandated to manage the GWT, and was registered as a licensed water provider with Athi Water services board. The company headquarters are situated at the Gatanga divisional headquarters in Mabanda (Gatanga Constituency, 2010).

METHODOLOGY

Planning is crucial to the successful implementation of the GIS supported solution as recommended by Tomlinson, (2007). The work was undertaken in a two pronged fashion; fieldwork coupled with system development, and the eventual system deployment and subsequent maintenance scheduling. Field data collection was done using Global Positioning System (GPS) receivers. Details picked were decided after the user needs assessment analysis.

The composite system uses two design approaches geared at coming up with (i) an internet application and (ii) a desktop application.

Figure 2 captures this design viewpoint where two types of users are anticipated: the intranet user and the internet user. The intranet user is a staff member of the Trust while the internet user is thought of as (i) an account holder or (ii) a general internet visitor or (iii) a staff member working from home or office. For this purpose two application approaches have been adopted, with the desktop solution addressing the needs of the intranet user, while the web mapping application addresses the needs of the internet users. The composite system uses the same underlying database server to manage the information. The desktop application connects and communicates with the database server but does not make use of the map server. On the other hand, the internet application

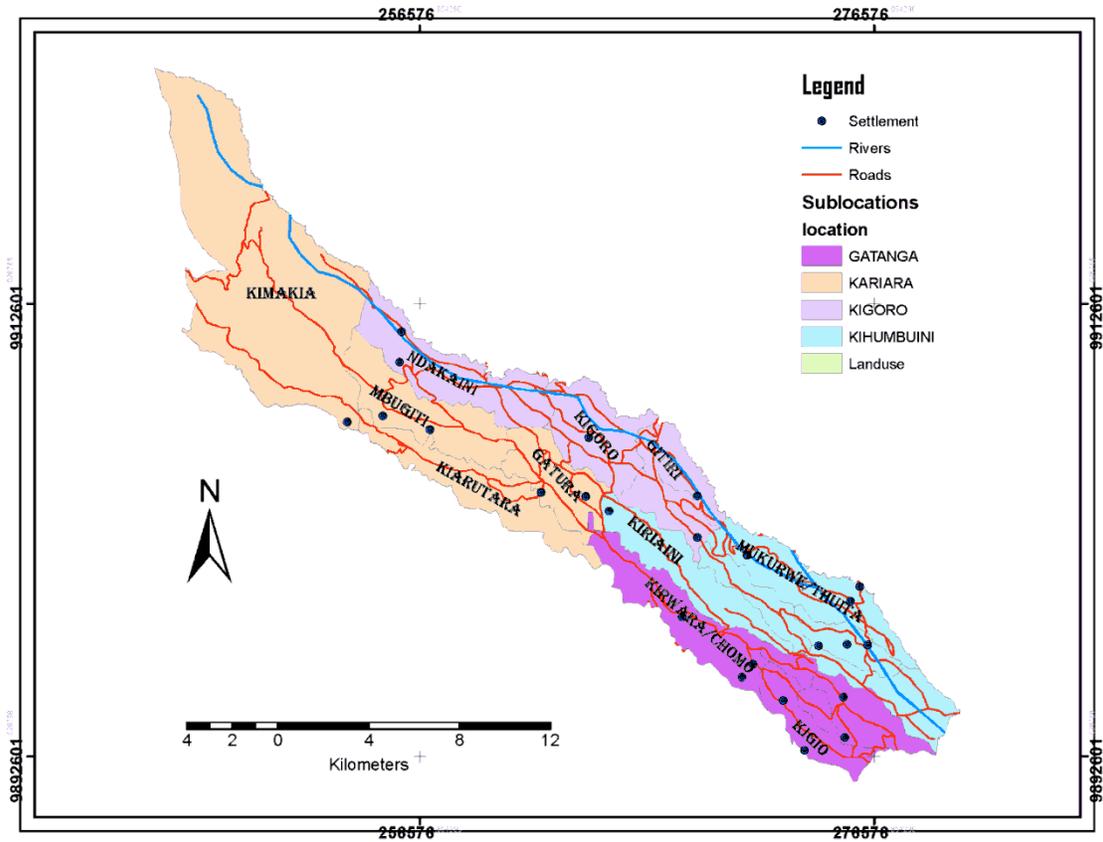


Figure 1. The study area.

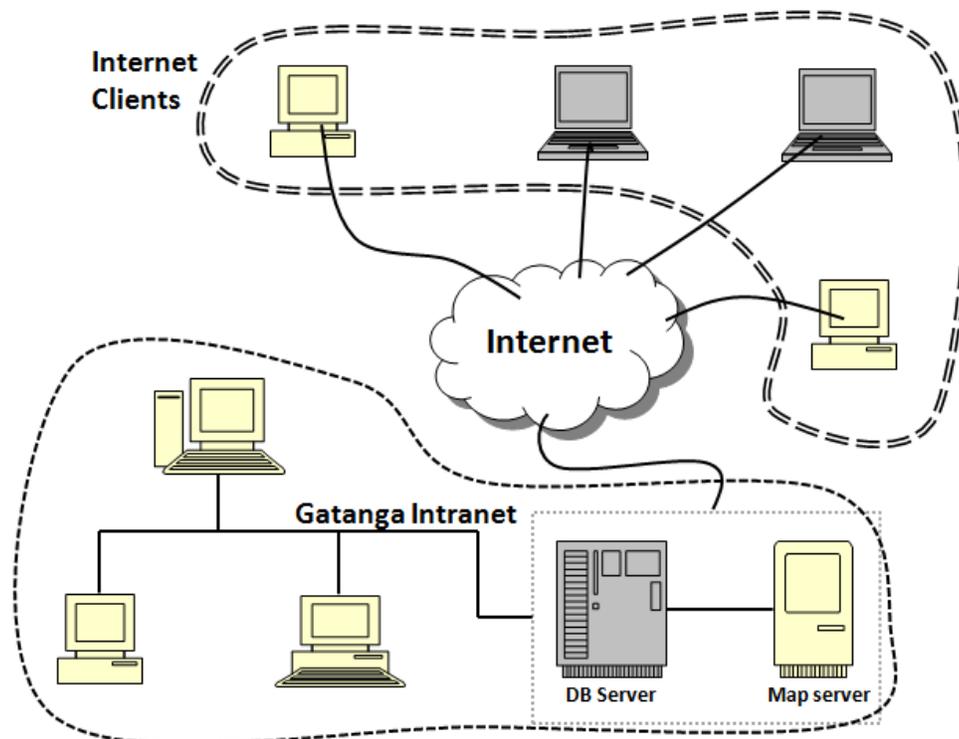


Figure 2. The envisaged system infrastructure.

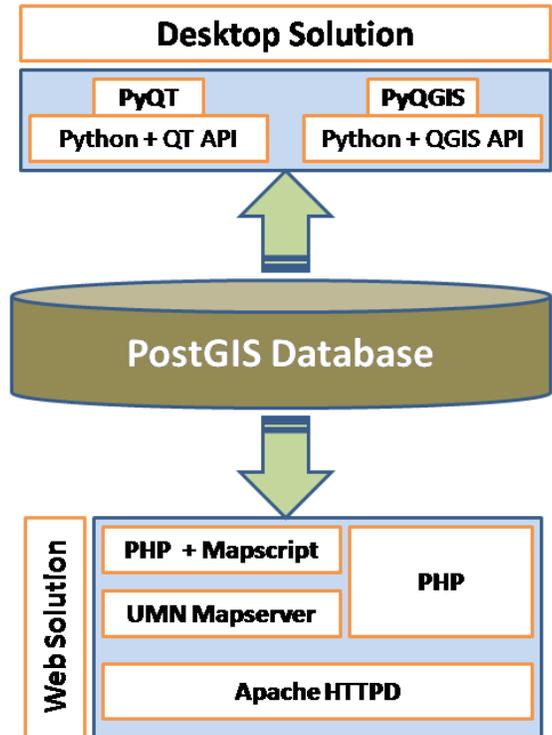


Figure 3. Open source tools used.

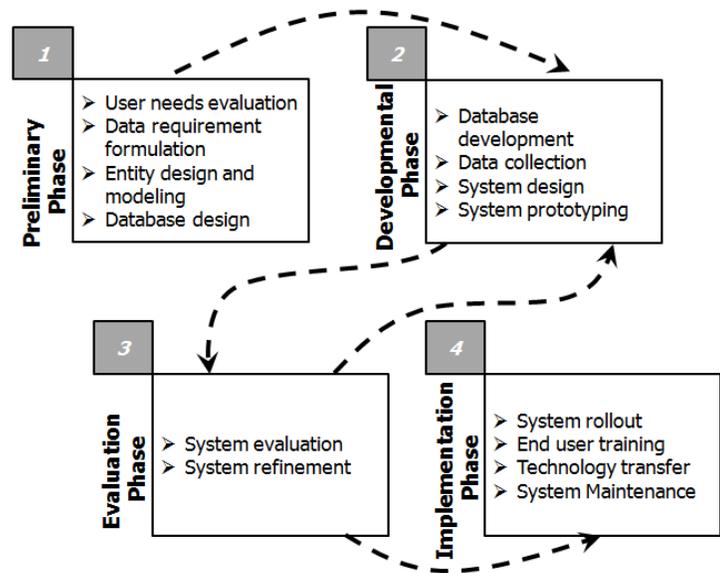


Figure 4. Project workflow.

connects to the database via the map server. In this case the map server serves as a proxy and as a rendering engine to prepare the maps for onward transmission to the internet client.

Figure 3 shows the various open source tools used in the solution development. For the desktop solution, a standalone application was developed using Python and the Python bindings for QT (PyQT version 4) and QGIS (PyQGIS) allowing access to the respective Application Programming Interfaces (APIs). The web

solution uses P. Mapper framework, which is a custom PHP Mapscript application that utilizes PHP Mapscript and University of Minnesota Mapserver as the map rendering interface, with billing implemented using PHP and extending the P. Mapper based application. Both systems utilize a PostGIS database which is a spatially aware PostgreSQL database.

Figure 4 captures the flow of activities that were undertaken to realize this research. It comprises four phases (i) a preliminary

Table 1. Clients' needs analysis.

S/N	Functionality/Feature	Average rank
1.	Indicating meter location	3
2.	Interaction with map	3
3.	Finding out billing status of a particular client	2
4.	Confirming client's meter reading	1
5.	Should the WSP information be accessible online?	1
6.	Access to internet enabled devices	3
7.	Specialized views with map data	4
8.	Reporting problems on the system	2

Table 2. WSPs staff expected functionalities ranking.

S/N	Feature/Functionality	Average rank
1.	Receiving bill payments	1
2.	Recording meter readings	1
3.	Adding new meters/accounts	1
4.	Indicating new/old meter locations	2
5.	Editing water network infrastructure	2
6.	Being able to work on the system remotely	2
7.	Interacting with map elements	3
8.	Identifying leakages on the infrastructure	3
9.	Performing zone summaries and statistics	3
10.	Reducing non-revenue water	2
11.	Scheduling meter reading outings	2
12.	Maintaining a journaling system	3
13.	Use free and open source approaches	3
14.	Consider commercial approaches	4

(conceptualization) phase, (ii) a development phase, (iii) an evaluation and assessment phase and, (iv) an implementation phase.

During conceptualization phase, a detailed inventory of the current and anticipated future needs was carried out based on interviews. This yielded information on the data required to address those needs. In this phase all entities that needed to be stored in the database and their relationships were identified. 300 questionnaires were distributed to the clients in the catchment region of the WSP. Of these 102 responses were collected back and used to draw up a list of features they desired to have offered. Table 1 illustrates the relative importance of features that the clients would want implemented. The ranking was done on a scale of 1 to 5 with 1 being the most significant and 5 being the least significant. From the analysis, clients expect the system to be able to support querying of billing status, meter reading and report incidences occurring on their metered accounts. There was consensus that the WSP needs to embrace Internet approaches in disseminating and allowing clients interrogate the database.

To determine the level of functionality to support for the WSPs staff, 60 questionnaires were distributed to these staff members. 45 questionnaires were collected. The ranking adopted was similar to that for the clients. Table 2 illustrates the importance of the features that the staff desired to be implemented.

During the developmental phase, the necessary database schema for the entities identified was implemented. In parallel, all necessary data was collected and aggregated into this database.

The entire system was designed identifying the various features and functionalities that needed to be implemented to answer all (or most) of the user needs. In this phase a prototype of the whole system was made available incorporating as many of the features as possible. The system was developed following the Object Oriented Programming concepts due to the advantages the paradigm possesses (Gamma et al., 1995).

Table 3 shows the main entities, their attributes and methods following the OO model. These main entities are pipelines, customers, meters, bill payment, meter reading and users.

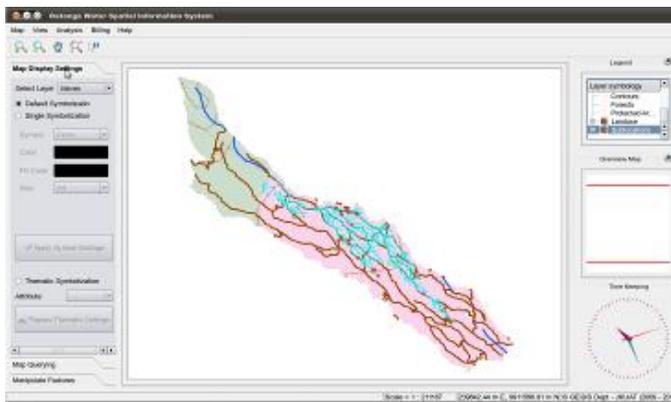
The evaluation phase was used for rigorously testing all the implemented features of the prototype, carefully assessing how well the proposed system was able to address all the needs of the end users. In this phase any refinements required were undertaken. In case of major refinements, these were developed and incorporated in the prototype and reevaluated. Hence the development and evaluation phases fed back and forward until a stable prototype was achieved. It is during this phase that user manuals and system documentation were written.

At the implementation phase, the prototype was migrated to the Trust's network, installed and configured for daily usage. To ensure proper use of the solution, end user training was conducted. This training served as a means to transfer knowledge about the underlying technologies to the Trust. A maintenance schedule is currently being discussed with a view of keeping the system up-to-date and incorporating new ideas and needs.

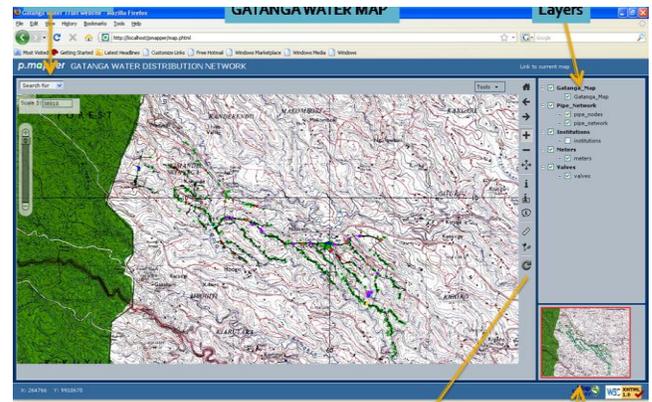
After the roll out of the implementation, some problems inherited

Table 3. Main objects identified with their associated properties and methods.

Entity (Object)	Properties (Attributes)	Methods
Pipelines	ID, diameter, material, date installed, geometry, status	addPipe(), removePipe(), getProperties(), getStatus(), updatePipeline()
Customers	Last name, First Name, customer id, meter no, date connected, address	addCustomer(), updateCustomer(), removeCustomer(), disconnect(), reconnect(), connect()
Meter	Meterno, user type, zone, date installed, sewered, geometry	addMeter(), replaceMeter(), updateMeter(), checkLeakage()
Users	Name, username, password, department	addUser(), removeUser(), updateUser(), login()
Meter reading	Meterno, date read, reading, reader	readMeter(), updateReading()
Bill payment	Meterno, amount, date paid,	payBill(), updatePayment()



(a)



(b)

Figure 5. The main interface for (a) the desktop solution and (b) the web-based solution.

from the database held by the WSP were revealed. These include duplicated meters, illegal connections and logistical challenges in pinpointing leakages in the system. This system was able to identify 298 duplicated meters which were subsequently cleaned; and highlight illegal connections collected from the GPS field collection exercise.

RESULTS AND DISCUSSION

The following mapping features were included in the solution: (i) interface with a map window with tools that allow users to zoom in/out, pan, zoom to full extent or zoom to a window of interest, (ii) tools to allow turning on/off of data layers in the window, (iii) tools to allow users to interrogate the map displayed to retrieve non spatial attribute information for the point under a cursor, (iv) tools that allow the users to display a layer using default symbolization (using symbols from the Gatanga) or allow the user to use other symbolization, display a thematic display of the layer using any of the available

attributes, (v) allow the users to perform attribute querying using available attributes, (vi) tools to allow entering of GPS coordinates for new features and their attributes, (vii) tools for deleting data that may need to be removed. Figure 5 show the main interfaces to the system. To access this interface the user has to log into the system using credentials that allow tracking in case there are changes made and therefore can assign responsibility for any actions made.

On the billing front, the following features were implemented: (i) tools to allow addition of new clients, edit client details, delete former clients, (ii) tools to record meter readings, edit or delete erroneous meter readings and printing out of meter reading forms, (iii) tools to process account billing, allowing printing of receipts. These tools are a sampling of the collection of tools that were developed in this project venture. Figures 6 and 7 show some of the interfaces exposing these functionalities.

The total client based was pegged at 9350 members

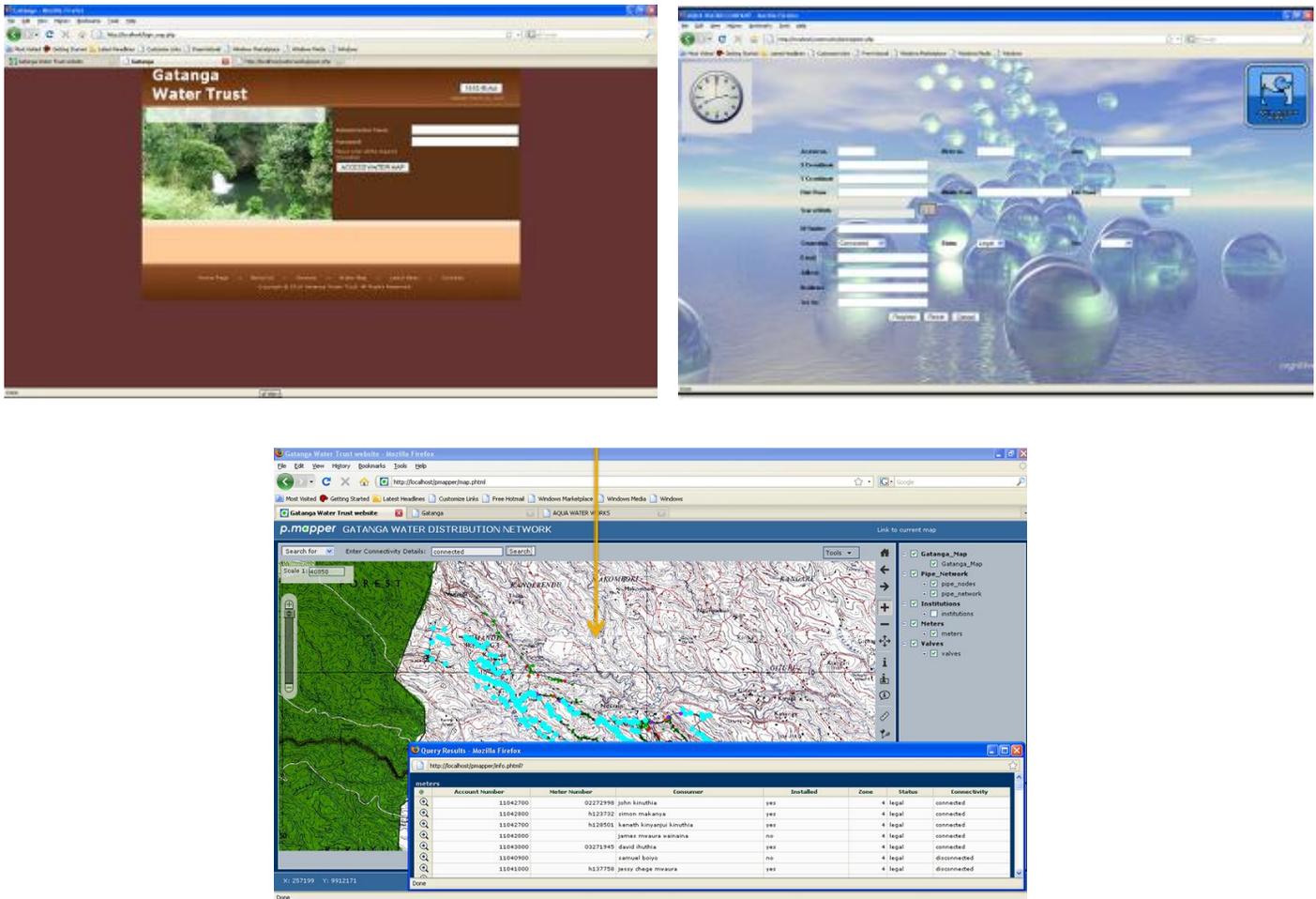


Figure 6. The web-based interfaces to the functionalities.

Table 4. Improvement in Revenue Collection (in Million KSh).

Month	Collection in 2009 (Prior)	Collection in 2010 (After)
January	1.49	1.94
February	1.35	1.97
March	1.34	1.98
April	1.42	2.01
May	1.39	2.07
June	1.50	2.14

spread across the 9 zones. Within the first six months that the system was in use in the WSP, there was marked increase in revenue collection while streamlined workflows can now be generated.

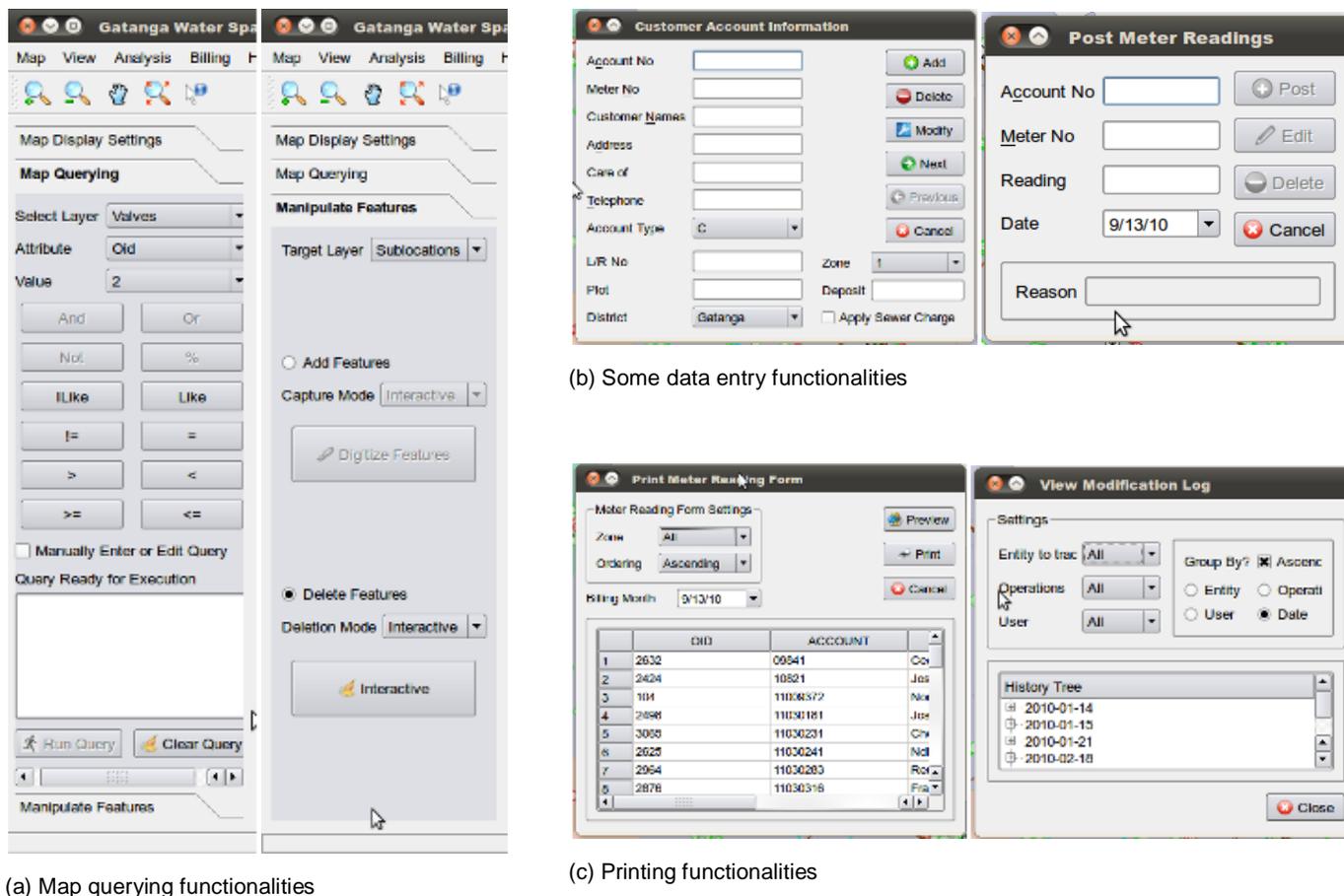
Table 4 shows the improvement in revenue collection over a similar period prior to the onset of the project. Over this period, there was no significant increase in connections and thus the improved revenue collections

can be attributed to ability to rope in illegal connections and reductions in non-revenue water.

Conclusion

The proposed system has been demonstrated as meeting the objectives set out. The following products have been delivered: (i) an open source desktop geocomputing application featuring GIS tools and a billing system, (ii) an open source web mapping solution featuring scaled down GIS tools and billing capabilities. To support this system, (iii) a spatially aware database system with the Gatanga water infrastructure database.

This system has already been deployed on the Gatanga Water Trust’s offices and is currently being evaluated and used before it can be fully rolled out. It is therefore recommended that the system once satisfactory be cascaded to other water service providers. This solution has also demonstrated the utility of open source GIS software and the coupling of systems to enhance infrastructure and asset management.



(a) Map querying functionalities

(b) Some data entry functionalities

(c) Printing functionalities

Figure 7. Some of the implemented functionalities in the desktop application.

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