University of Nairobi

School of Engineering

WEB-BASED GIS BOREHOLE INFORMATION MANAGEMENT SYSTEM:

A CASE STUDY OF WAJIR COUNTY

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Declaration

I, Ngondi Stephen Sande, hereby declare that this project is my original work. To the best of my knowledge, the work presented here has not been presented for a degree in any other Institution of Higher Learning.

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Ngondi Stephen Sande Date

This project has been submitted for examination with my approval as university supervisor.

………………………………………… …………………

Dr D. N. Siriba Date

Dedication

I dedicate this project to my family and friends for the moral and material support they have given throughout my life and for their great investment in my education. May the Almighty Lord bless them abundantly.

Acknowledgement

I express immense gratitude to my project supervisor Dr. D.N. Siriba of the Department of Geospatial and Space Technology, University of Nairobi for his invaluable advice, guidance and commitment.

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To my friends and classmates, I wish to express my appreciation for their invaluable encouragement and support that enabled the success of this project.

Above all, I am most grateful to the Lord Almighty for the opportunity and strength to work on this project.

Abstract

In Kenya, just as it is in most parts of the world, natural resources are being depleted at high rates. In particular, the extraction of groundwater via boreholes has been going on for over half a century in Kenya. The Ministry of Environment, Water and Natural Resources is in charge of groundwater extraction but due to its broad mandate, there has not been proper management of the borehole records and this has hindered development in the water sector in Kenya. However, in the recent past the government has set up the Water Resource Management Authority (WRMA) to specifically fast-track the management of groundwater extraction. The authority handles most of its data and information relating to boreholes in an analogue form which presents a challenge of data retrieval, information analysis and decision making though there are on-going efforts to digitise them into Ms Excel format.

The objective of this project was to develop a web-based GIS borehole information management system that will enable efficient and effective decision making. Stand-alone GIS systems are limited in data sharing abilities towards the public. Web-based GIS platforms provide resourceful means of data sharing and analysis. The system was based on open source applications. Programming languages such as HTML and JavaScript were used in defining elements within the system; Postgres was used to manage the database. OpenLayers was used for map rendering and display.

The output was a fully functional web-based GIS borehole information management system in which information relating to boreholes was held and various query and analysis can be done. It is with such benefits in mind that a web-based GIS borehole information management system was developed with the case study of Wajir County which heavily relies on underground water. To enhance the functionality of the system, further studies should focus on enhancement of the application to allow for direct updating of the database where only hardcopy borehole data is available, more so, the application should be improved to enable borehole data collected in the field using applications running on a mobile device to be populated in the database in real time (or near real time) using 3G mobile networks.

Table of contents

List of Figures

List of Tables

CHAPTER 1: INTRODUCTION

1.1 Background

In recent times, most natural resources are getting depleted or are being used unsustainably. The ever increasing human population is exerting pressure on the natural resources available.

Key among the natural resources is water. The water wars "tempest" appears to be part of a mindset ranging from the famous quote apocryphally attributed to humourist Mark Twain "Whiskey is for drinking; water is for fighting over" to comments by United Nations Secretary Generals. Zeitoun and Miramachi (2008) chronicled the proclamations from Boutros Boutros-Ghali known for his 1991 quote "the next war will be fought over water, not politics," Kofi Annan for his 2001 quote "fierce competition for freshwater may well become a source of conflict and wars in the future," and Ban Ki Moon in 2007 for his opinion piece for the Washington Post, stating that "Darfur is an environmental crisis—a conflict that grew at least in part from desertification, ecological degradation and a scarcity of resources, foremost among them water."

Environmental flows and ecosystem health are more dependent on groundwater than previously thought. Gautier (2008) estimates that 36% of river runoff comes from groundwater, yet water management has long suffered from a case of "hydroschizophrenia"- the creation of separate surface water and groundwater governance and policies despite the recognition of the hydraulic connection between both hydrologic regimes (Llamas 1975). Groundwater use is increasing because it is a "common" resource available to anyone with the financial resources to drill, equip and power a well (Moench 2004). A "Silent Revolution" is occurring where millions of farmers pursue short-term benefits associated with the intensive use of groundwater for agricultural use. Proactive governmental action is needed to avert water conflicts between neighboring users, user groups, states, provinces and nations (Llamas and Martınez-Santos 2005). The number of wells or shallow "water extraction mechanisms" is in the order of millions in many parts of the world as dramatic changes in drilling technology, pumping technology and the availability of electrical and diesel power have increased over the past 60 years.

Pumping of groundwater is among the most intensive human-induced changes in the hydrologic cycle. According to Zekster and Everett (2004) and Shah (2009), groundwater is the world's most extracted raw material, with withdrawal rates approaching 800 to 1000 km^3 per year. The majority of the world's cities rely on ground-water to some degree for their urban water supplies, and Giordano (2009) reports that developed groundwater contribute to the global urbanization underway today. As a consequence, the global economy is becoming increasingly dependent on groundwater.

In Kenya, one of the most affected resources is water, more so underground water. The extraction of underground water over the past few decades in the country has continued without much institutional monitoring. Since independence, the management of underground water extraction has been managed by the Ministry of Water and Irrigation. The efficacy of the ministry has not been up to par due to its expansive obligation. This therefore necessitated the formation of Water Resource Management Authority (WRMA), under the Ministry of Water and Irrigation, whose broad mandate is to be the government's caretaker when it comes to water resource management in the country. One of its mandates is to manage the extraction of water through boreholes. The management of data on boreholes at the institution has been mostly in analogue format in which after a contractor submits borehole data after drilling it is kept in hard-copy files. As such, vital spatial information cannot be easily retrieved and any spatial analysis is unimaginable.

In this regard, a web-based GIS for boreholes comes in handy for the storage, display and analysis of such information. Geographic Information System (GIS) is a computer-based tool for mapping and analysing things and events that happen on earth's surface. It integrates common database operations such as query and statistical analysis with the unique visualization and geographic analysis benefits offered by maps. Traditional GIS are stand-alone systems thus limiting the wider population from accessing information. This makes many service seekers to travel long distances to relevant offices so as to get hold of the much needed information or abandon the mission altogether. With the integration of these stand-alone systems to the web, information is able to be shared faster, efficiently and serve a wide array of interested users and stakeholders in the water sector.

1.2 Problem Statement

One of the basic requirements by WRMA when managing extraction of groundwater resources is that the borehole details need to be submitted to the authority for record keeping and to aid further analysis and general management of water resources. The current methods of storing and retrieving data at most government offices is analogue in nature, thus leading to tedious, error-prone and manipulative systems. WRMA is in the process of digitising the borehole records though the digitisation process is still at basic levels of capturing data in formats such as Ms Excel. Geo-technologies on the other hand offer more efficient ways of solving these issues.

It is due to the need to create an easier, more efficient and meaningful system for management of borehole data that this project is being undertaken.

1.3 Objectives

The general objective of this project is to develop a web-based GIS borehole information management system for Wajir County that will facilitate efficient access and retrieval of information.

The specific objectives are;
 i. Design an interactive borehole web-map application.
 ii. Demonstrate remote access of the borehole information.

1.4 Justification for the Study

The current way of data storage regarding water resources in the country is largely still manual and analogue involving lots of hardcopy maps and sheets. Data analysis in such a scenario is quite difficult if not impossible.

Geo-technologies offer the solution to this in an effective and cost-efficient way compared to traditional methods. This in turn results in better data storage and retrieval, enhanced decision making through visualisation and spatial analysis and enhanced service delivery to the public.

1.5 Scope of work

The scope of this project is to develop a web-based GIS borehole management information system that will enable various stakeholders in the underground-water to be able to access information about boreholes in a quick and easy manner. The study area is limited to Wajir county. The county was chosen because most of the water in the county is extracted from boreholes. The county is bordered in the north, north-west, west and south by Mandera, Marsabit, Isiolo and Garissa counties; and to the east by Somalia. Figure 1 shows the study area.
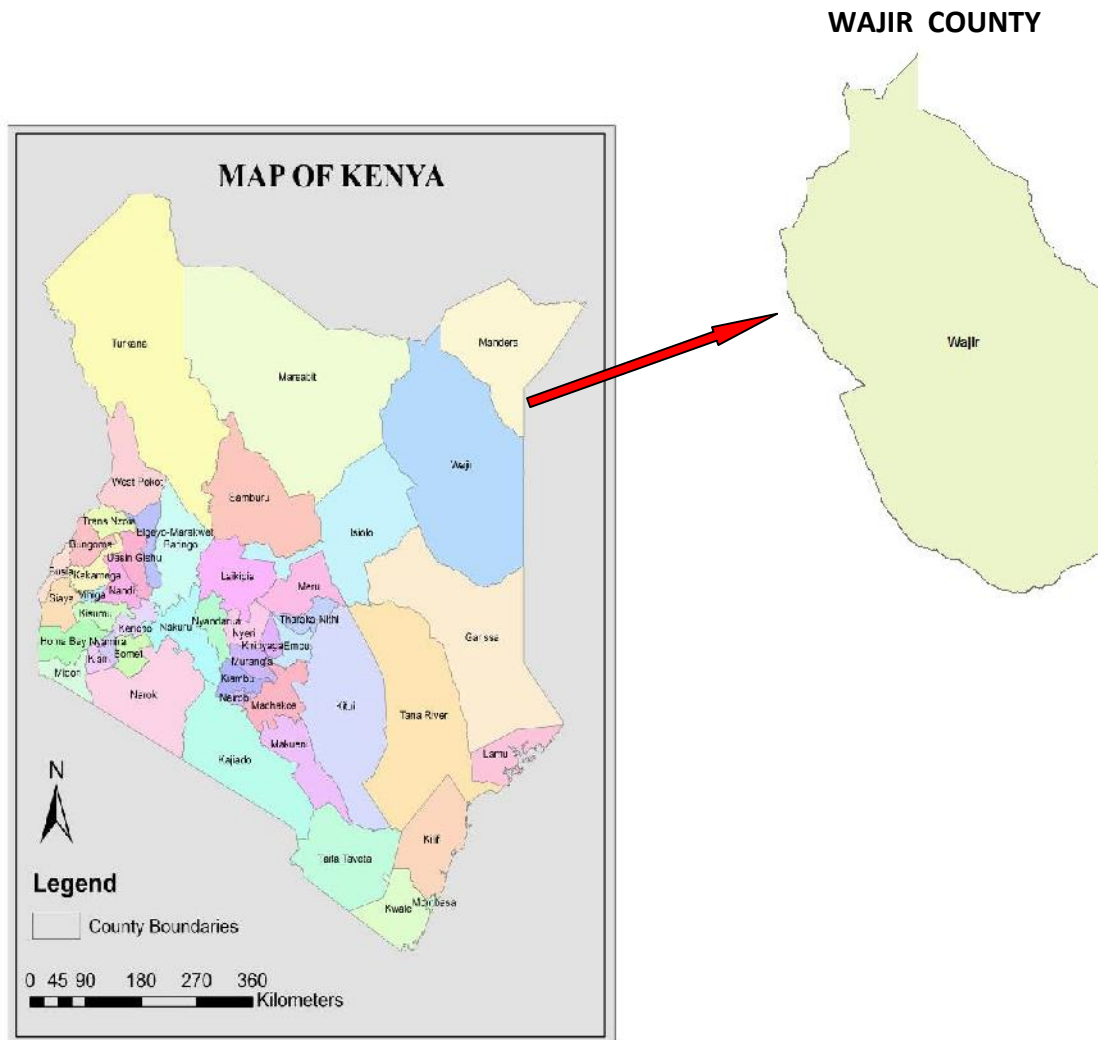

Figure 1: Study Area

CHAPTER 2: LITERATURE REVIEW

2.1 Current Borehole Data Management

The current system of borehole data management in Kenya is largely analogue in nature. Recently, there have been efforts to map how the low income people access their water and from which water sources. In this regard, the majidata project (Majidata, 2014) initiated by the then ministry of water and irrigation was conceived. The project largely focused on developing a pro-poor database covering all the urban low income areas of Kenya. The online database assists the Water Service Providers (WSPs) and Water Services Boards (WSBs) to prepare tailor-made water supply and sanitation proposals for the urban slums and low income planned areas located within their service areas.

However, the database has little information regarding boreholes. Water Resource Management Authority too has little information on boreholes in Kenya as a whole (WRMA, 2014).

2.2 Web Mapping and Web GIS

Web mapping is a form of distributed computing based on the client-server architecture. It affords the benefits attributed to distributed computing. In principle, in web mapping any user with internet connectivity can benefit from web mapping services. Notably, it is not required that a user be a GIS expert in order to benefit from web mapping services. Nonetheless, web mapping services are faced with several challenges some of which arise from the distributed nature of web mapping services while some are due to the nature of geographic data.

Web GIS is the process of designing, implementing, generating and delivering maps on the World Wide Web. Web mapping looks similar to web GIS but web GIS deals with processing of geo-databases, analysis, exploratory issues (Kraak, 2004). The web mapping basically deals with technical issues, web based cartography, theory and social issues and usability of maps. It is the presentation media for web maps and gaining more analytical capabilities.

GIS integrates and relates data with spatial component and supports users to view in proper format which provides support in making complex spatial decisions through visualization,

interactive modeling and analysis environments. GIS is utilized in understanding of spatially distributed phenomena in many areas of decision making and evaluating problems (Sakamoto and Fukui 2004). Generally, Geographical Information System were considered as monolithic and platform-dependent applications (Wong et al., 2002). The development and rapid growth of web and web-based application created a new platform for traditional GIS to grow and spread. Unfortunately, not everyone has access to GIS, nor would be able to spend time necessary to use it effectively. Web GIS became a cheap and easy way of disseminating geospatial data and processing tools (Alesheikh et al, 2002). Web GIS have the highest number of users, although typically Internet users focus on simple display and query tasks. (Goodchild et al, 2005). The capability of Web GIS for interacting dynamically in distributed environment from cross platform to client/ server computing system made it more interesting to develop and use for accessing spatial information.

The major development of cartography is using the web as a distribution medium. By the means of web, now it has opened the possibility of the availability of real-time maps, cheaper maps sharing, more frequently updated database sources and cheaper software and hardware requirement. There are some problem and difficulties to full development of web mapping. Some technical difficulties such as bandwidth, lower resolution of image are common. Reliability issues and security issues have limited the expansion of web mapping.

The development of web cartography and GIS is steady compared to web technologies. Web 2.0, a new generation of Internet services and technology (Deshpande et al, 2006), support user interaction significantly. This evolution leads GIS away from data browsing, analyzing and managing for individual decisions, and more towards group participating and communicating on social decision issues (Carver 1999). As Craig et al. (1999) describe the Public Participation GIS principles as accessibility, understand ability, and accountability, Web GIS continues to draw attention as a public participation tool (Sakamoto et al 2004). Nowadays, Google Maps, Google Earth, OpenStreet Map, Yahoo Maps, Microsoft's Live Search Maps and other many commercial as well as non-commercial applications provide many kinds of geographical related information such as detailed maps, satellite images and terrain maps covering all over the world and allow users to use their APIs (Zhelu, 2009).

Advantages of web mapping

Web mapping improves communication with the users who understand maps and it is the easiest way to improve internal and external communication (Stachowicz, 2004). In distributed and heterogeneous network environments Web GIS provides interoperability, reusability and flexibility (Tsou et al, 2002). The clients or users are free to use the stored large amount of data. It reduces the major problem of database collection and searching.

2.3 Components of Web Mapping

Figure 2 shows the client-server three-tier architecture for creating web applications. It is composed of client (presentation), server (application) and data (database) tiers. This architecture is preferred over other architectures because it allows developers to develop, maintain, upgrade or replace any tier independently without affecting the other tiers. The client sends a request to the server which in turn processes and executes the query and directs it to the database. The database returns the result which is fetched by and processed by the server and delivered to the client.
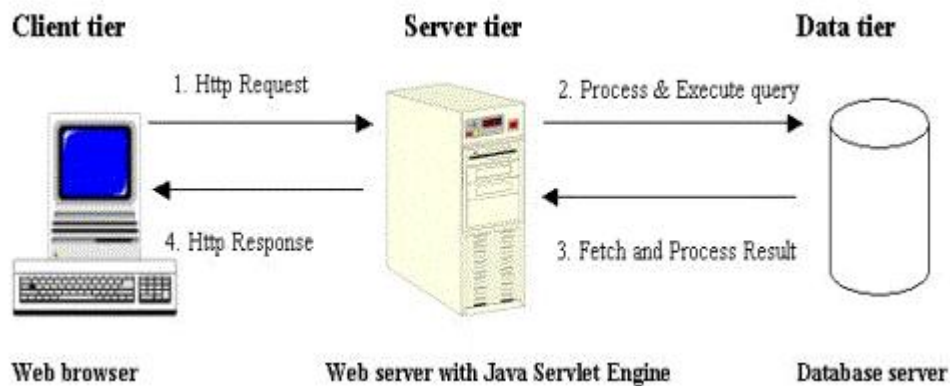

Figure 2: Components of Web Mapping

2.3.1 Presentation tier

The presentation tier contains a number of client side environments. This side takes input from the users and is responsible for displaying maps. It includes a number of web browsers linked with the world. Web browser is presentation tier of the web mapping architecture which involves mainly for finding the right web page and then making sense of its content (Dzbor et al., 2003). Uniform Resource Identifier (URI) identifies the information resource and may be a web page, image, video or other piece of content (Ian et al, 2004).

OpenLayers

OpenLayers is used in the presentation/client tier for rendering maps. OpenLayers is an OSGeo supported project and works in browser (JavaScript/AJAX) application for accessing and displaying map tiles, features and markers from different and wide range of data sources. Open source JavaScript library is released under a Berkeley Software Distribution (BSD) style license for displaying a dynamic map in web browsers and provides the functionality of managing and manipulating data in the browser. It is open source hence it can be used for re-development, re-use and updating. It supports different data formats and web services which includes Keyhole Markup Language (KML), Geography Mark-up Language(GML), Web Map/Feature Services (WMS/WFS), Representational State Transfer Requests (REST), Geographic JavaScript Object (GeoJSON), GeoRSS, TileCache web accessible caches and other many commercial and free web map services like Google maps, Yahoo! Maps , Microsoft bing map, World Wind, etc. OpenLayers allows using JavaScript to display feature information on a map. This feature information might come directly from a UI, GeoJSON feed, originate from a GML or KML data source (Ganesan, 2009). OpenLayers was chosen for the project because it offers quite a rich library that can be used to enhance map functionality.

2.3.2 Logic tier

Logic tier consist of web server, application code and web GIS server. Web server takes user request and transfer output map result to the clients. Users request information is transferred to the application code where the request of user is compiled; it detects the user required information and sends the information to the map server. The map server detects which map is requested and sends information to the database. After receiving map data from database server

the map is processed. Editing, map processing and generating an output map are done in this tier. Output maps are sent to the client web browser through the Internet.

Web servers connect different software components with a scripting language. Web server applications can communicate with the API of a GIS, web server and with the spatial database of other applications. These Web servers are also very useful when developing complex web mapping applications, real time web maps or Web GIS. The two main types of web server are Internet Information Service (IIS) and Apache. Internet Information Service is a high performance Web Server from Microsoft which is proprietary software. Apache is an open source software and can be installed on almost all operating systems including Linux, Unix, Windows, FreeBSD, Mac OS X and more. Due to these reasons, Apache was used in the implementation of this project.

2.3.3 Database tier

GIS and geospatial data are growing in importance for the Community, because they allow users to examine new types of information in new ways (Meyer, 2004). The Database tier is responsible for keeping map data in organized way. Relational database model is responsible for making relational database table for efficient retrieval of data. It sends and receives instruction and information through maps server and application code compiling centre. Map file stores the whole map in a file which is accessed by map server. Figure 3 shows the web GIS architecture connecting Web GIS portal to geo-data through the Internet in standard HTTP protocol using WFS and WMS.
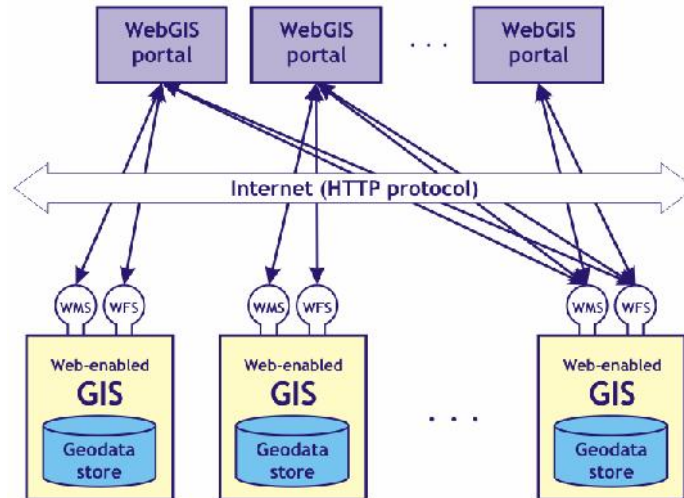
Figure 3: Schematic view of an overall WebGIS architecture

(Milosavljevic, et *al)*

Postgres

Postgres, also known as PostgreSQL, is an open-source, object-relational database management system (ORDBMS) that is not owned or controlled by one company or individual. PostgresSQL software is open-source, and it is managed mostly through a coordinated online effort by an active global community of developers, enthusiasts and other volunteers. First released in the mid-1990s, PostgresSQL is written in C. Its primary competitors include Oracle DB, SQL Server and MySQL (Cory Janssen, 2014).

PostGIS

PostGIS turns the PostgreSQL Database Management System into a spatial database by adding support for the three features: spatial types, indexes and functions. Because it is built on PostgreSQL, PostGIS automatically inherits important "enterprise" features as well as open standards for implementation. Spatial data types refer to shapes such as point, line, and polygon; Multi-dimensional spatial indexing is used for efficient processing of spatial operations while spatial functions, posed in SQL, are for querying of spatial properties and relationships (Boundless, 2014). Postgres and PostGIS were the preferred choice because of their open-source nature and efficiency in handling spatial datasets.

2.4 Available Web Mapping Technologies

Web mapping, being one of the newest fields in Geographic Information System, different commercial as well as open source softwares and technologies are being developed. For commercial purposes, commercial companies develop softwares which are well documented and contain advance features but the price for that technology is high while open source system is developed by communities and can be used free of charge but they may contain poor documentation though the open source system is developing rapidly with the involvement of a large number of peoples. The major technologies involved in the realm of web mapping today are (Detwiler et al, 2009):

i.   Commercial: ArcGIS Server by Environmental Research Institute (ESRI), GeoMedia WebMap by Intergraph, MapXtreme by MapInfo and MapGuide by Autodesk.

ii. Open source: GeoServer, MapServer, OpenLayers, Scalable Vector Graphics (SVG), Adobe Flex (part open, part proprietary).

iii. Public APIs: Google Maps, Yahoo! Maps, Microsoft Virtual Earth (2D), MapQuest's Open API.

iv. Globes: Google Earth, Microsoft Virtual Earth (3D), ArcGIS Explorer, NASA WorldWind

2.5 Web Technologies for Web-based GIS

Some of these open source software and tools will be used to prepare web based GIS.

2.5.1 Web server

A web server accepts HTTP requests and serves the contents of web pages to the client in the form of text, image, style sheet and scripts. There are different types of web server developed by different companies like IIS by Microsoft, Apache Tomcat, Sun Java system web server etc, but Apache Tomcat is popular and widely used. Figure 4 shows typical client server architecture.
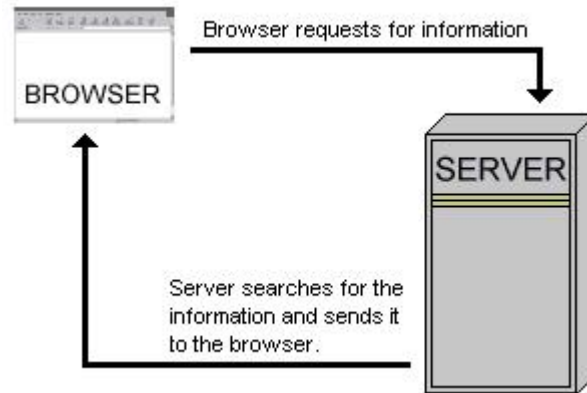
Figure 4: Client Server Architecture

HTTP clients use the TCP transport protocol to contact Web servers and request content. The client opens a TCP connection to the server and transmits a HTTP request header that specifies the requested content. The main task in the server is virtual hosting of many websites using IP, store large amount of data, run server side scripting to generate dynamic pages and limit the speed of responses to serve more clients. The Web servers play a key role in satisfying the needs of a large and growing community of Web users (Pai et al, 1999).

2.5.2 Scripting language and JavaScript

A scripting language allows controlling one or more software application. Scripts are different from core programming language often interpreted from source code and embedded in other applications. In web based application, scripts are embedded in HTML code. Client side scripting are executed in client side by web browsers whereas in the server side scripting, the scripts runs on server side or application servers. The popular server side scripts are PHP, ASP and JSP.   JavaScript is a client side object oriented scripting language and is popular for developing client side application. It was developed by Netscape in 1995 and it is closely related with Java programming language and influenced with other programming languages but easier to program. It is dynamic, prototype based, weakly typed scripting language with first class functions.

JavaScript can interact with HTML source code, enabling web authors to spice up their sites with dynamic content. JavaScript is endorsed by a number of software companies and is an open language that anyone can use without purchasing a license. It is supported by recent browsers

from Netscape and Microsoft, though Internet Explorer supports only a subset, which Microsoft calls Jscript (Webopedia, 2014).

2.5.3 Application Programming Interface

Application Programming Interface (API) which constitutes a language and message format is a set of data structures, routines or protocols used by an application to communicate with other control program, communication protocol or operating system. Almost every application depends on the APIs of the underlying operating system to perform such basic functions as accessing the file system (Orenstein, 2000). APIs are implemented by writing function calls in the program, which provide the linkage to the required subroutine for execution. An API entails program module in a computer to perform the operation or links to the existing program to perform the tasks.

Based on functions and interactions, the API also differs in the implementation in that environment. Generic APIs are full set of APIs included in library of programming languages. These API interacts with operating system, DBMS and other applications and facilitate interaction between users and the computers. Specific API like yahoo and Google only addresses defined specific problems. Language specific API operate in a specific language using syntax and components of that language whereas language independent APIs can operate in different application and programming language. This feature of language independent APIs is a required feature of service oriented API which doesn't limit on specific system, process or platform and useful for web services.

The API itself is largely abstract in that it specifies an interface and the behavior of the objects specified in that interface. The API acronym may sometimes be used as a reference not only to the full interface but also to a single function or even a set of multiple APIs provided by an organization. Thus, the scope is usually determined by the person or document that communicates the information. Based on the API documents, the user could learn and combine existing functions in the application more easily and efficiently.

2.5.4 Cloud computing

Nowadays, computing resources are moving from the desktop PC to the cloud. Cloud computing involves distributed computing over a network, where a program or application may run on many connected computers at the same time. It specifically refers to a computing hardware machine or group of computing hardware machines commonly referred as a server connected through a communication network such as the Internet, an intranet, a local area network (LAN) or wide area network (WAN). Any individual user who has permission to access the server can use the server's processing power to run an application, store data or perform any other computing task. Therefore, instead of using a personal computer every-time to run the application, the individual can now run the application from anywhere in the world, as the server provides the processing power to the application and the server is also connected to a network via the Internet or other connection platforms to be accessed from anywhere. Some of the advantages of using the cloud are maximizing the effectiveness of the shared resources through economies of scale, elasticity of cloud resources and on-demand nearly instant access to resources. Some of the cloud vendors include Google, Amazon, IBM, Oracle Cloud, Rackspace, Salesforce, Zoho and Microsoft Azure (Vaquero et al, 2009).

Amazon web services (AWS) was the preferred choice amongst the vendors because of their low upfront costs and versatility in the cloud resources they offer. The main cloud services that were utilized from Amazon web services were Amazon Elastic Compute Cloud (Amazon EC2) and Amazon Simple Storage Service (Amazon S3). Amazon Elastic Compute Cloud (Amazon EC2) is a web service that provides resizable compute capacity in the cloud. It is designed to make web-scale computing easier for developers. Amazon EC2 allows one to obtain and configure capacity with minimal friction. It provides you with complete control of your computing resources and lets you run on Amazon's proven computing environment. Amazon EC2 reduces the time required to obtain and boot new server instances to minutes, allowing you to quickly scale capacity, both up and down, as your computing requirements change. Amazon EC2 changes the economics of computing by allowing you to pay only for capacity that you actually use. Amazon S3 provides a simple web-services interface that can be used to store and retrieve any amount of data, at any time, from anywhere on the web. It gives any developer access to the same highly scalable, reliable, secure, fast, inexpensive infrastructure that Amazon uses to run its

own global network of web sites. The service aims to maximize benefits of scale and to pass those benefits on to developers (Amazon, 2014).

2.6 Open Source and Open Standards

The OGC was founded in 1994 as an international voluntary consensus standards organization for geospatial data and web services. Now, OGC has more than 475 organizations specifically from government, Academia, industry, non-profit and research organizations (Opengeospatial, 2014). The Consortium was founded for providing open specifications at free of charge to acquire and/or implement, thus it provides standards based interfaces for geographical data discovery, access, manipulation, visualization and processing. The open specification provides information about a given specification as well as specific programming rules and advice for implementing the interfaces and/or protocols that enable interoperability between systems (Sanchez et al, 2007).

The OGC leverages existing efforts from other standards organizations such as the W3C, ISO, and the Organization for the Advancement of Structured Information Standards (OASIS) and builds upon them in reference to the spatial data domain (Kralidis, 2008). OGC standards depend on a generalized architecture captured in a set of documents collectively called the Abstract Specification, which describes basically the data model for representing geographic features.

The members of abstract specification are developing and growing the number of specification and provides the reference model for implementation of the consortium specification. According to Kottman the main areas covered by the Abstract Specification include (Kottman, 1999 and Kralidis, 2008):

  i.   Spatial Referencing by Coordinates
 ii.   Feature Geometry
iii.   Features
 iv.   The Coverage Type
  v.   Relationships between Features
 vi.   Feature Collections

vii.   The OpenGIS Service Architecture

The OGC has an advanced and progressive development process for its specification which requires common consensus between specific working group members. These specifications developed, tested in OGC testing environments called "testbeds'' and pilot project. Typical specification development takes place by defining, adopting and publishing the specification document for vendors and others to implement (Kralidis, 2008).

Open specifications standards

Web Services Management Agent (WMSA) Web Map Service is a standard protocol for serving geo-referenced map and images over the internet that are generated by a map server using data from a GIS database (http://www.opengeospatial.org/, accessed 7 February 2014). The WMS contains a HTTP interface for requesting geo registered maps from different distributed databases. A WMS sends a request to server defining map layer and area of interest in the layer to be processed. The response to the request is generally rendered in a pictorial format such as Portable Network Graphics (PNG), Graphics Interchange Format (GIF) or Joint Photographic Experts Group (JPEG) or occasionally as vector-based graphical elements in Scalable Vector Graphics (SVG) or Web Computer Graphics Metafile (WebCGM) formats (OGC, 2002) which can be displayed in browser.

WMS specifies different request types, out of which two are used by any WMS server;

  i.   GetCapabilities - returns parameters about WMS service, such as image formats which it can serve and provides the lists of one or more map layers available in the service.

  ii.   GetMap - with parameters provided its requests returns a map from the server. Clients are allowed to specify reference system, layers, geographic area and other parameters.

Some other supported Request types that WMS providers include:

  a. GetFeatureInfo
  b. GetLegendGraphic
  c. DescribeLayer

Web Feature Service: The OGC WFS defines interfaces for data access and manipulation operations on geographic features using HTTP as the distributed computing platform. This

standard specifies operations to retrieve a description of the maps offered by a service instance, to retrieve a map and to query a server about features displayed on a map (Hampe et al., 2006). Data manipulation operations include the ability to create, update, query and delete spatial and non-spatial features. The user generates the request and sends it to a WFS server using HTTP. The WFS server then executes the request. Two encoding defined for WFS operations are GET and POST. The figure below shows the relationship between different specifications defined by OGC.
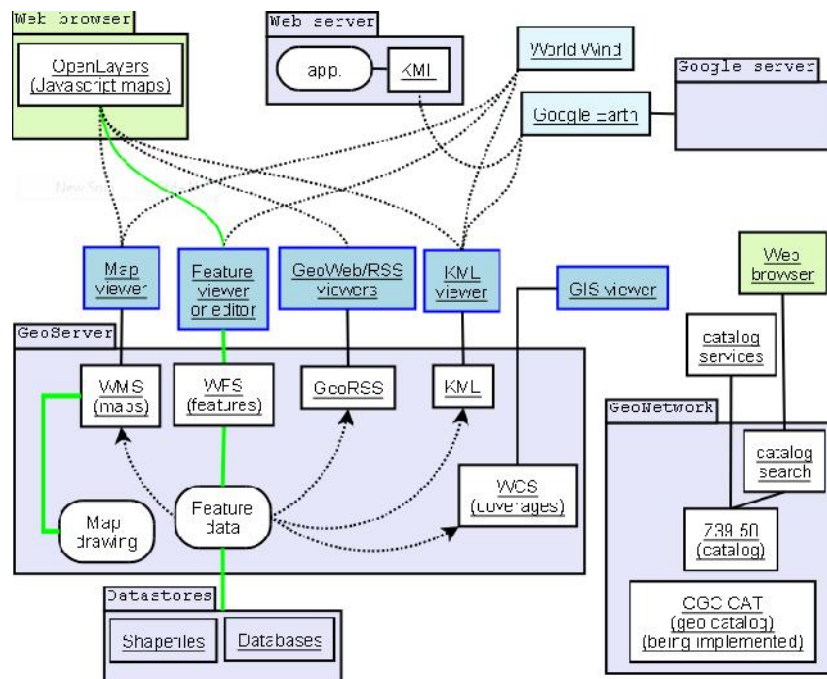

Figure 5: Relationship between clients/servers and some OGC protocols

A WMS request defines the geographic layer(s) and area of interest to be processed. The response to the request is one or more geo-registered map images (returned as JPEG, PNG, etc) that can be displayed in a browser application (Openspatial, 2010). The interface also supports the ability to specify whether the returned images should be transparent so that layers from multiple servers can be combined or not. Therefore, it allows for a smooth integration of different (raster or vector) maps in web mapping applications over the Internet (Schütze, 2007).

The publishing way of traditional Web GIS includes raster-map mode and vector-map mode. Recently, with the increasing popularity of global on-line web mapping applications (e.g. Google

Maps, Microsoft Virtual Earth, Yahoo Maps), the raster TileMap mode replaces vector map gradually. A Tile cache service has a set of map images that have been pre-rendered for rapid display (Quinn et al, 2008). Map Tiles are a set of map images that have been pre-generated based on geographic vector data and the adoption of tile-map technique in the developed system dramatically decreases the loading time consumed for high quality image visualizations (Haiting et al, 2009). Map tiles are extremely efficient and capable of running large images over the Internet. Google maps commonly have zero to twenty pyramid layers covering entire globe.

2.7 Geovisualization

Geographic visualization (Geovisualization) is a set of tools and techniques which support spatial data using interactive visualization in research related field which integrates disciplines such as computer science, human-computer interaction design, cartography, cognitive sciences, graphical statistics, data visualization, information visualization and image analysis (Dykes et al, 2005). It builds on the established tenets of map production and display (Goodchild et al, 2005). Closely related with other fields of scientific visualization (MacEachren, and Kraak, 1997) and information visualization (Stuart et al. 1999), Geographic visualization focuses on knowledge construction through knowledge storage and knowledge transmission (MacEachren, and Kraak, 1997). To accomplish this, geovisualization communicates with spatial information and combines with human vision and domain expertise, which allow data exploration and support decision-making processes (Jiang et al. 2005 and MacEachren, 2004).

Static maps have a limited exploratory capability while the animated maps spans the spectrum of disseminating spatial knowledge to a wide audience to data exploration for knowledge discovery by experts (Harrower, M., 2008). Examples of such animations are weather maps and animation in television. It also allows more interactive options like changing visual appearance, zooming in or out and explores more layers (Jiang et al. 2003). Geovisualization characterizes a further improvement in cartography that takes advantage of the modern computer power to render changes to a map, allowing users to adjust the mapped data on the fly (MacEachren and Kraak, 1997). Owing to its roots from cartography, geovisualization helps one to visualize other non-

geographic attributes from other fields by the way of map metaphor in the domains of information and knowledge visualization (Jiang, and et al. 2005).

CHAPTER 3: MATERIALS AND METHODS

3.1 Materials for the Study

The materials for the study included the following;

3.1.1 Data

The data used in the project was as follows;

Table 1: Data used in the project and its source

DATA	SOURCE	CHARACSTERISTICS
Borehole data	WRMA	Excel format
Administrative Boundaries	Survey of Kenya	Shapefiles
Road Network	Kenya Roads Board	Shapefiles

Borehole Data

This was point data for all the boreholes in Wajir county together with their attribute information. The attributes were 18; longitude, latitude, inspecting agency, division, name of nearest settlement, name of borehole, type of use, operational status, date installed, model, serial number, water lifting technology, maximum yield per hour, drawdown levels, static water levels, rain-gauge availability, number of taps, number of troughs.

Administrative Boundaries

With the introduction of county governments, some administrative boundaries have been changed. The Survey of Kenya is the custodian and final authority on boundary demarcation thus this vital data was obtained from the institution. The attributes in this dataset were the names of administrative units and their size in square kilometres.

Road Network

Road network is critical in showing accessibility to services and water is no exception. The Kenya Roads Board provided information on accessibility to such facilities. The attributes in this dataset were the various road classes and their respective lengths.

3.1.2 Tools

The tools that were used include the following;

Hardware – Personal computer.

Software – ArcGIS, programming languages in particular HTML, JavaScript, ExtJS and PHP and PostgresSQL for the database were used.

3.2 Methodology for the Study

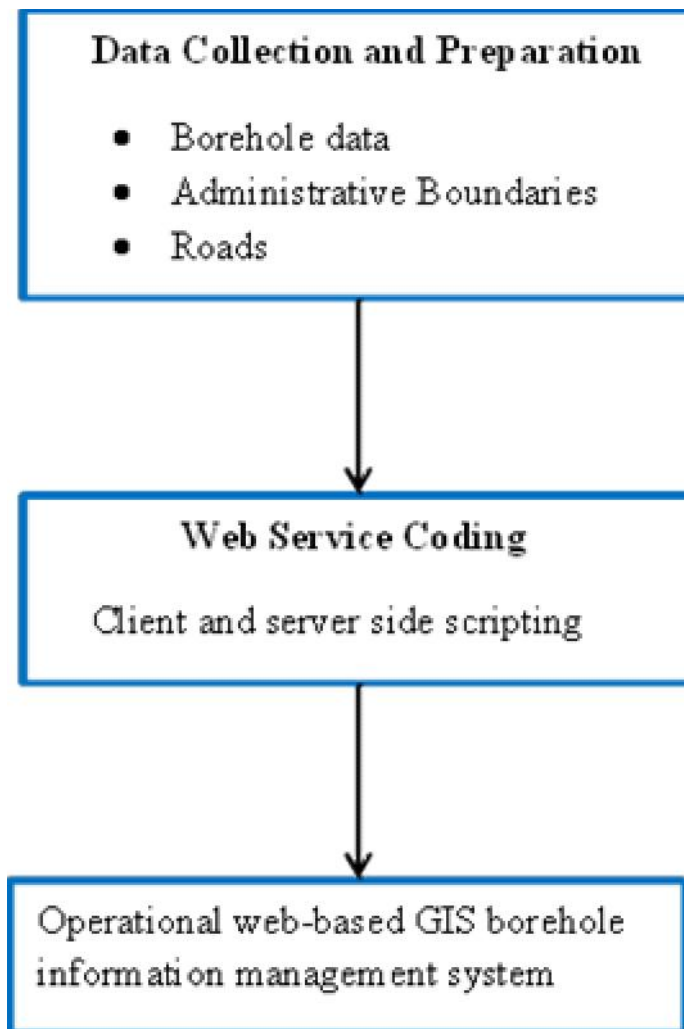 Figure 6 illustrates the processes that were carried out for the development of the borehole application.

Figure 6: Workflow diagram

3.2.1 Data collection and preparation

Data collection involved gathering the requisite data from various institutions, field work was not carried out to verify the data.

Roads Network

The roads data was acquired from the Kenya Roads Board. The roads were for the whole of Kenya and ranging from Classes A, B, C, D and E. The roads that were relevant to the county of Wajir were extracted via clipping from the dataset using ArcGIS (see Figure 7).
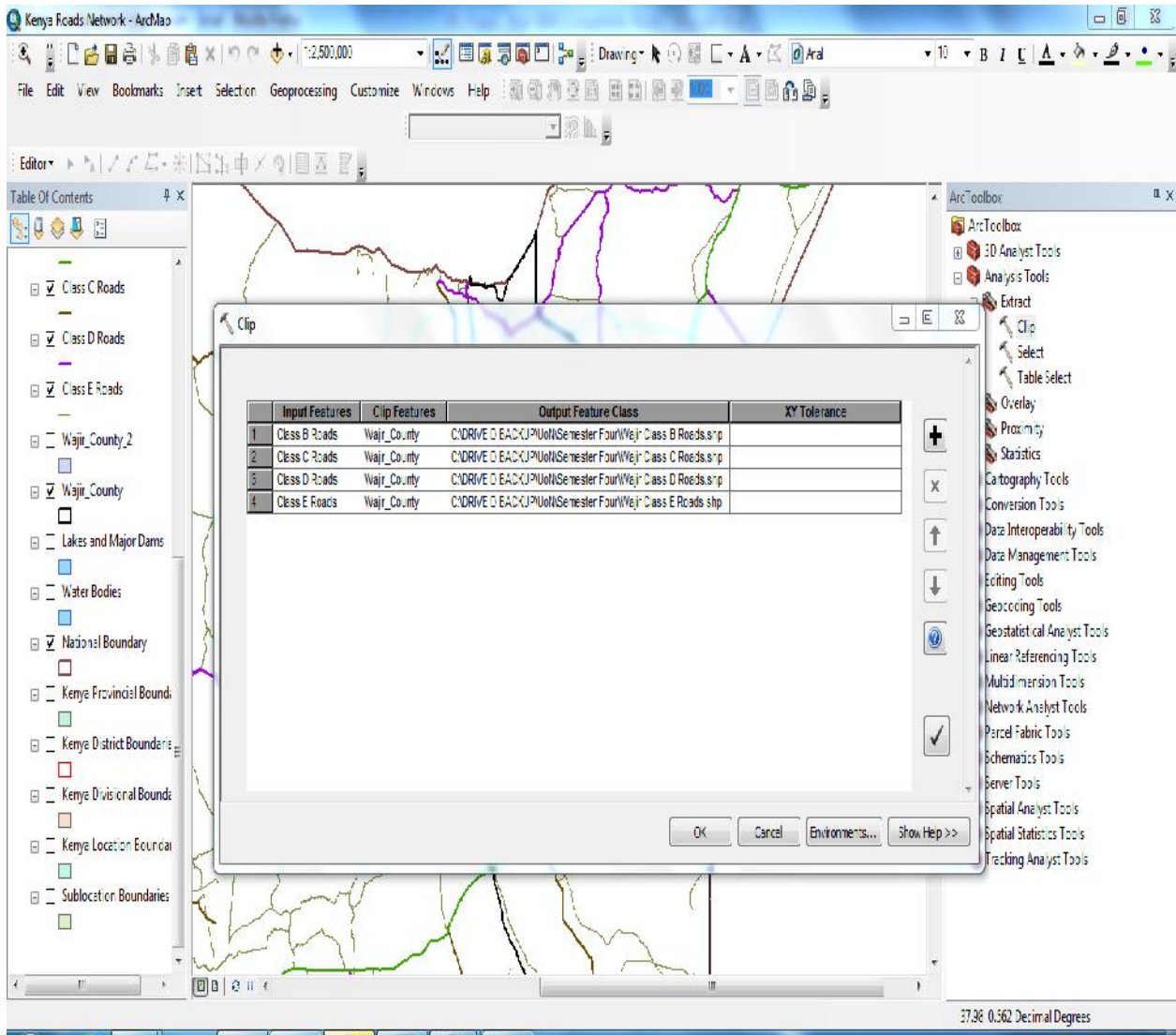
Figure 7: Clipping Wajir road network using ArcGIS

The resulting Wajir road network is illustrated in Figure 8.
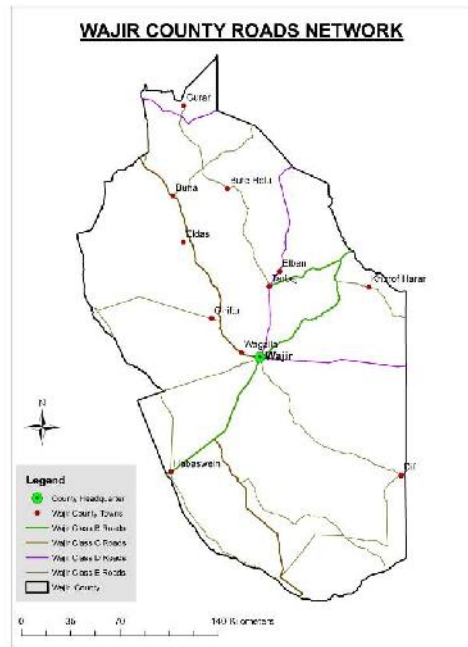
Figure 8: Wajir county roads network

Administrative Boundary

The administrative boundary data was acquired from the Survey of Kenya. The administrative boundaries were for the whole of Kenya and ranging from national, county and sub-county boundaries. The boundaries that were relevant to the county of Wajir were extracted from the dataset using ArcGIS.
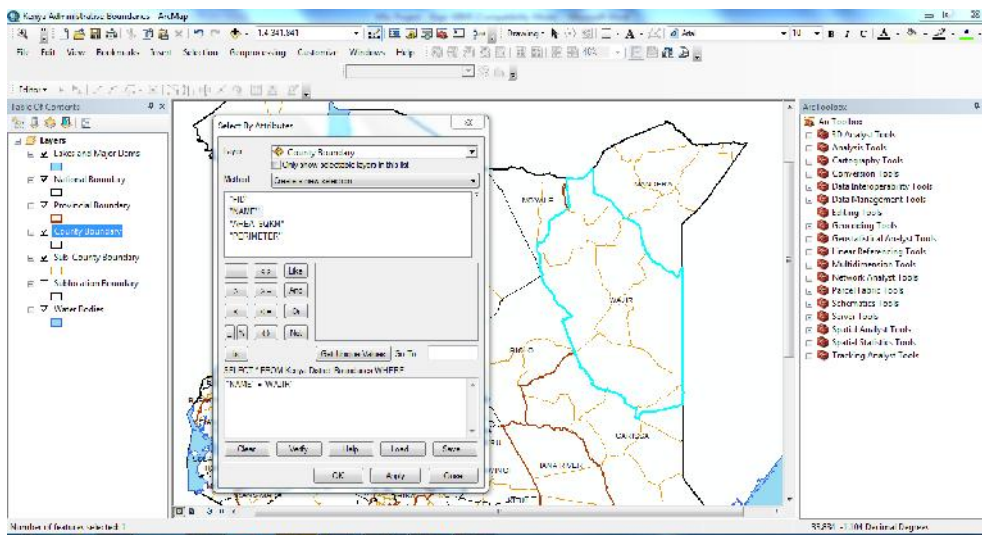

Figure 9: Extracting Wajir administrative boundaries from national dataset using ArcGIS

Figure 10 shows the resulting Wajir county administrative boundary, with six sub-counties namely; Bute, Buna, Central, Griftu, Habaswein and Wajir-Bor.
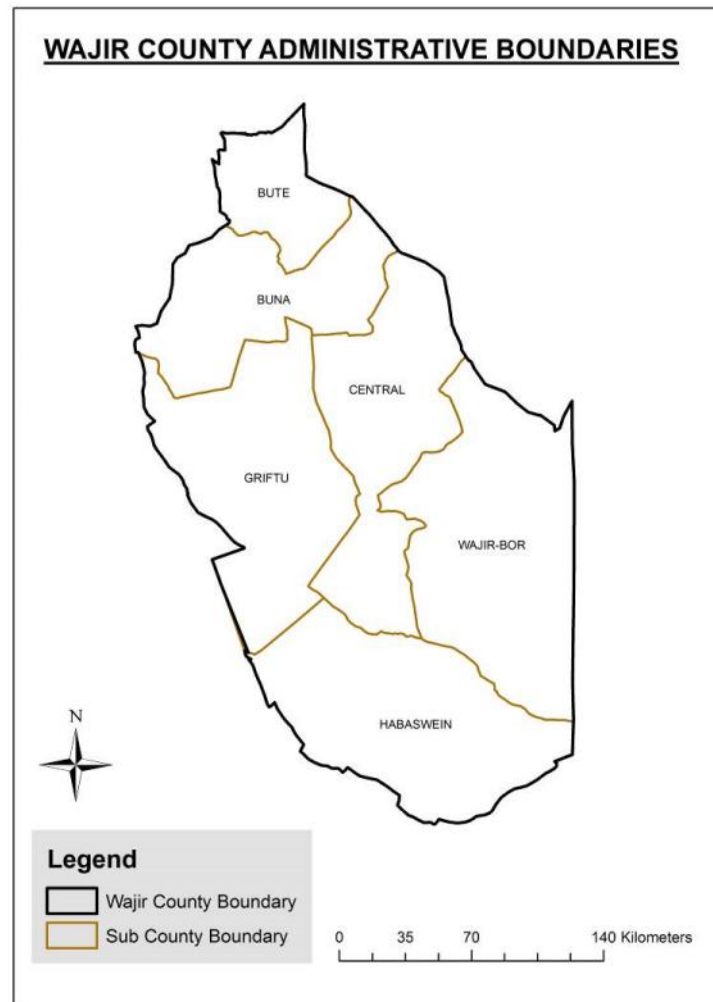

Figure 10: Wajir county administrative boundaries

Borehole Data

The borehole data was acquired from the Water Resource Management Authority (WRMA). The attributes are section 3.1.1. The attributes which had information pertaining to them were selected so that they can be incorporated in the application. These were: longitude, latitude,

inspecting agency, division, name of nearest settlement, name of water borehole, type of use, operational status and date installed.

	Lat	Lon	Date:	Inspected by:	Inspecting Agency	Name of water point:	Name of nearest settlemen
1							
2	0.415225076770000003	40.0151249697230004	14/12/2012	Hassan	OXFAM GB	Fini borehole	Fini
3	0.926953901905	40.717672023127	16/12/2012	Abdirizak M.B	WASDA	salalma borehole 1 (0ld)	salalma
4	2.2959132187180002	39.5555043214130004	15/12/2012	mohamed abdi	OXFAM GB	abdiwaqo	abdiwaqo
5	0.637722863727	39.7130168185875	14/12/2012	Abdirizak M.B	WASDA	Abakore Borehole 2	Abakore
6	1.397931857077	40.251995284429	15/12/2012	abdirizak	WASDA	Hubsoy old borehole	Hubsoy
7	0.492101516638	39.847705821132	14/12/2012	Abdirizak	WASDA	Meri borehole	Meri
8	0.614555962679	40.410830026316	16/12/2012	Abdirizak M.B	WASDA	Biyamathow Borehole 1 (old)	Biyamathow
9	2.4056094909500003	40.0166418142166	11/12/2012		ALDEF	Dambas borehole 1	Dambas
10	2.42607892894	39.55137732531	15/12/2012	mohamed abdi	OXFAM GB	kilkile borehole	kilkile
11	0.5372517944540001	40.874036451446	15/12/2012	Abdirizak M.B	WASDA	Dadajabulla Borehole 2 (Old)	Dadajabulla
12	1.036546573853	39.497357237095	13/12/2012	Abdirizak	WASDA	Hadado South borehole	Ademasajida
13	0.45698613332	39.9209153473880004	14/12/2012	Hassan	OXFAM GB	Dalsan borehole	Dalsan
14	1.5722074836870001	40.6316899061940005	18/12/2012	Abdirizak	WASDA	Ibrahim Ure Borehole	Ibrahim Ure
15	3.466886022563	39.6115011113105	11/12/2012	mohamed abdi	OXFAM GB	erestiro borehole	erestino
16	1.811552470549	39.158814726846	14/12/2012	Edward	ALDEF	Garseqoftu	Garseqoftu
17	2.4085467601670003	40.017293534891	11/12/2012		ALDEF	Dambas borehole 2	Dambas
18	2.746815517562	40.201497354413	12/12/2012	Edward	ALDEF	Ogorale	Ogorale
19	2.701312361756	39.9740044579700004	11/12/2012	Edward	ALDEF	Dunto Borehcle 2	Dunto
20	0.34452400172700004	40.119849853246	14/12/2012	Hassan	OXFAM GB	Sabuli new borehole 2	Sabuli
21	0.841019813259	40.3968982188690005	16/12/2012	abdirizak	WASDA		Dabley
22	3.1737498571750002	39.8245281074330004	10/12/2012	ahmed billow	WASDA	qudama borehole	qudama
23	1.1503020326170001	39.8186374757510004	14/12/2012	Hassan	OXFAM GB	Mathanlibah borehole	Mathahlibah
24	1.125072848893	40.671003196488	15/12/2012	Abdirizak M.B	WASDA	Aktalahel Borehole	Aktalahe
25	1.39827853246	40.2517803725130004	15/12/2012	abdirizak	WASDA	Hubsoy 1	Hubsoy
26	2.0667997657290003	39.0050193350877	14/12/2012	mohamed abdi	OXFAM GB	arbajahan borehole	arbajhan
27	1.8467785787650002	40.094077773859	7/12/2012	Edward	ALDEF	Lafarey	Lafarey
28	2.30506181111	40.188722500623	12/12/2012	Hassan	OXFAM GB	Elben Borehole	Elben
29	2.994229843373	39.247550633205	10/12/2012	mohamed abdi	OXFAM GB	koroncilek-yata	korondile
30	1.876739680315	40.2608349199988	6/12/2012	Hassan	OXFAM GB	Dasheg	Dasheg

Figure 11: Sample borehole attributes

3.2.2 Web Service Coding

The application was developed using the following programming languages and tools: HTML, JavaScript, OpenLayers, PostgresSQL and PostGIS. Figure 12 shows the web-service architecture that was adopted to facilitate the client and server side scripting.
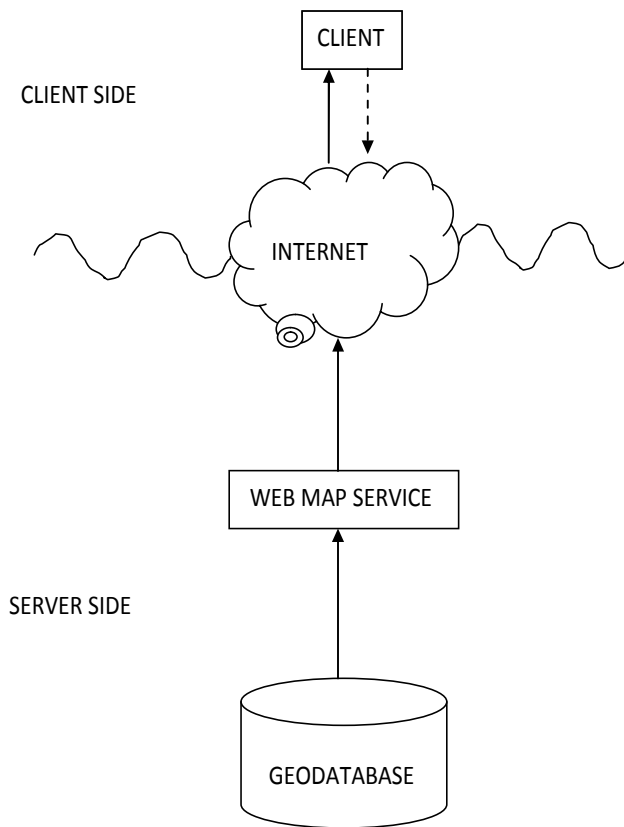
Figure 12: Web Service schema

The server side was based on PostgresSQL and PHP to work on the geo-database while the client side required JavaScript interacting with HTML and OpenLayers to allow interaction with the users.

Webserver, HTML and JavaScript

The Apache web server was installed using the Xampp installer. Using the htdocs directory, a folder was created called 'Wajir' where the application resided. Inside the Wajir folder, the MVCS (model, view, controller & store) architecture for developing web applications was adopted (see Figure 13).
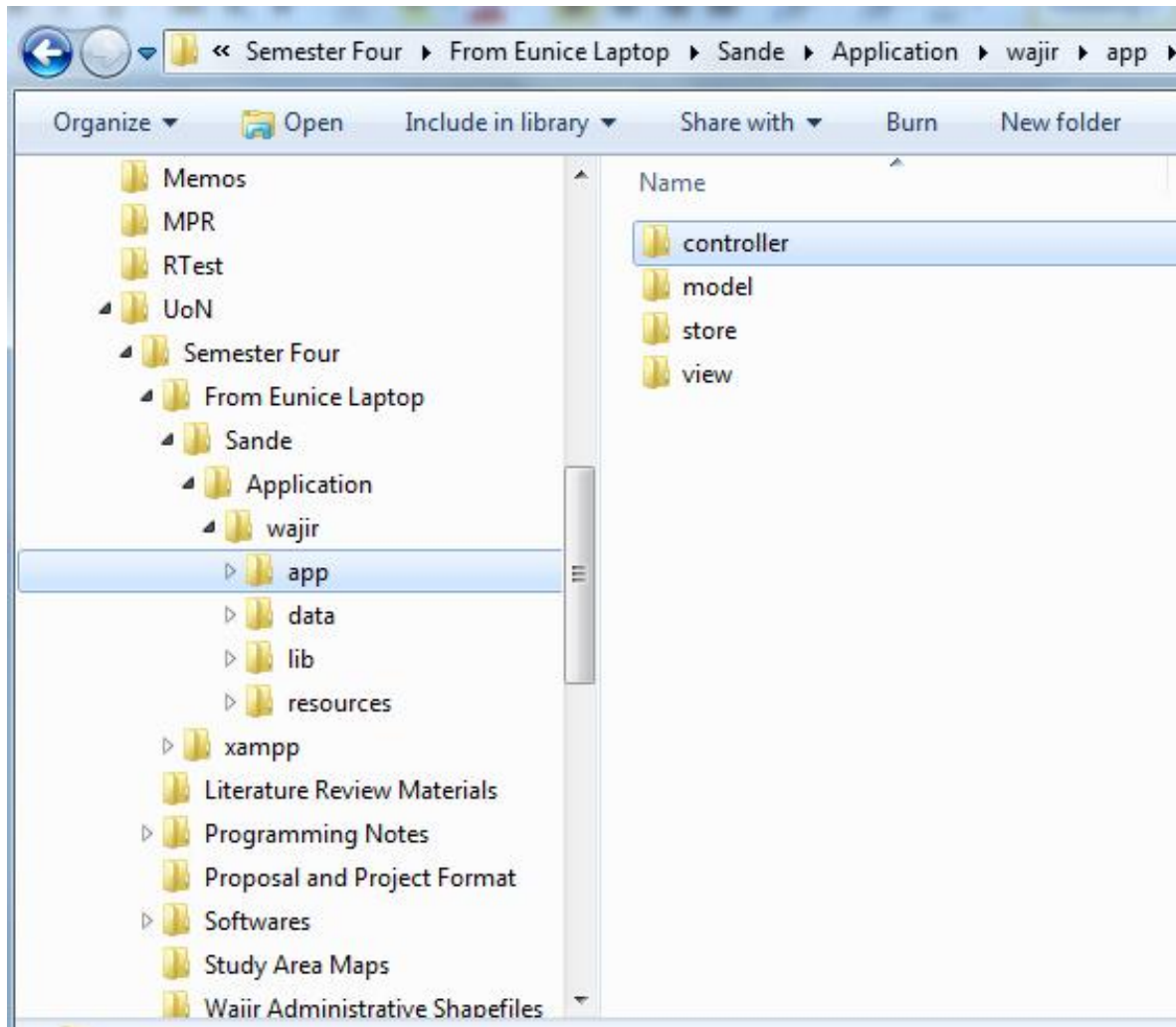
Figure 13: MVCS architecture

The model contains the definition of the application data, which is, in effect a definition of the data entity. The model is usually bound to the store. Both the model and store have scripts written using the HTML and JavaScript programming languages so that they can execute their functions.

The view contains scripts for the User Interface (UI) components/widgets e.g. panels, forms, grids and windows. The scripts running in the view folder generate the application interface in Figure 14.
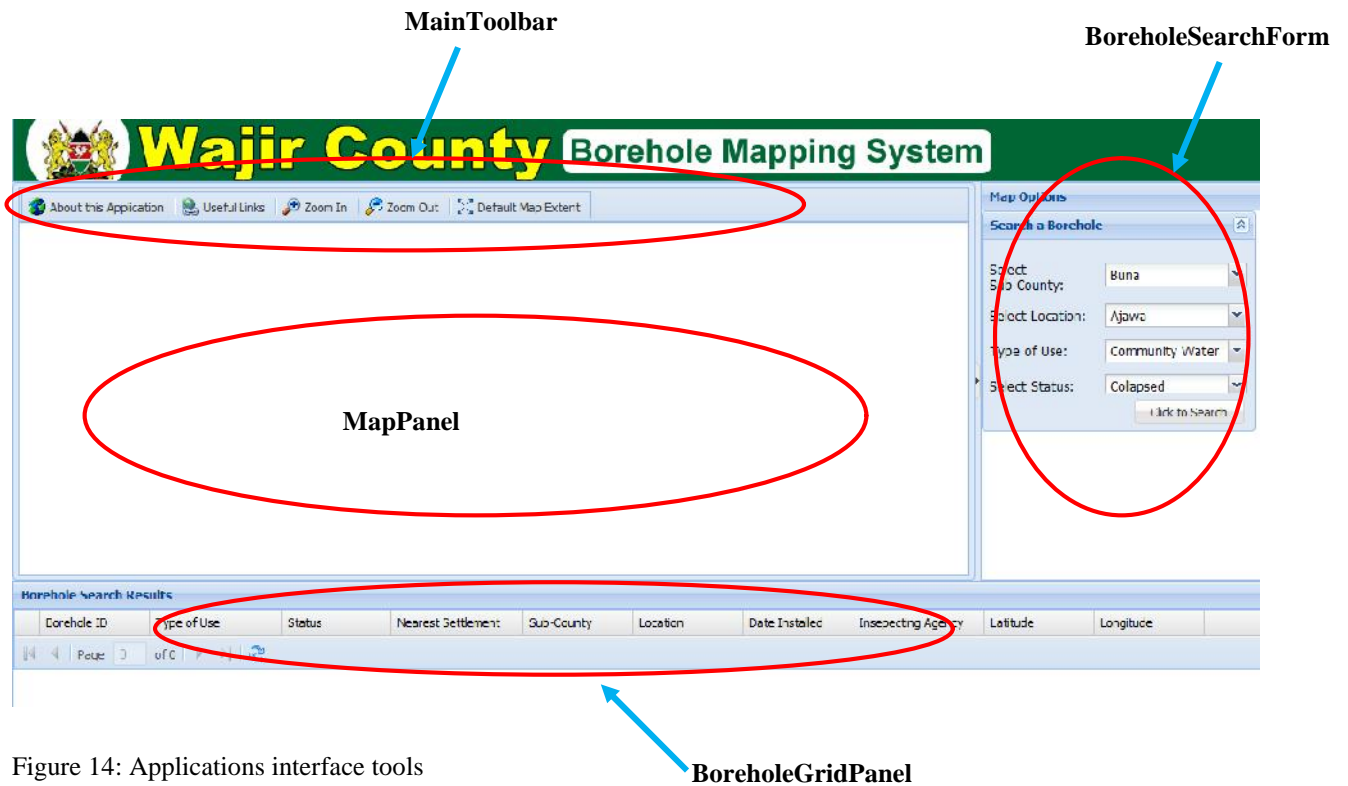
Figure 14: Applications interface tools

The controller pulls everything together. It contains the application's logic and performs tasks, such as referencing stores and models from views. It is also in charge of listening for events from views e.g. button clicks and hooking actions up to them. A snapshot of part of the code used in creating the map panel is shown in Figure 15. The code defines the parameters, such as width, height and position for the main toolbar.

Figure 15: Code snippet used in creating the map panel section of the application's interface

OpenLayers

Using the OpenLayers library, the library provided tools that would enhance visualisation. These included providing for Google maps to act as a base layer whilst boreholes, roads and administrative units act as overlay layers. Furthermore, zoom in and zoom out tools were incorporated to enhance interactivity with the map. This is illustrated in Figure 16 by the circled areas.
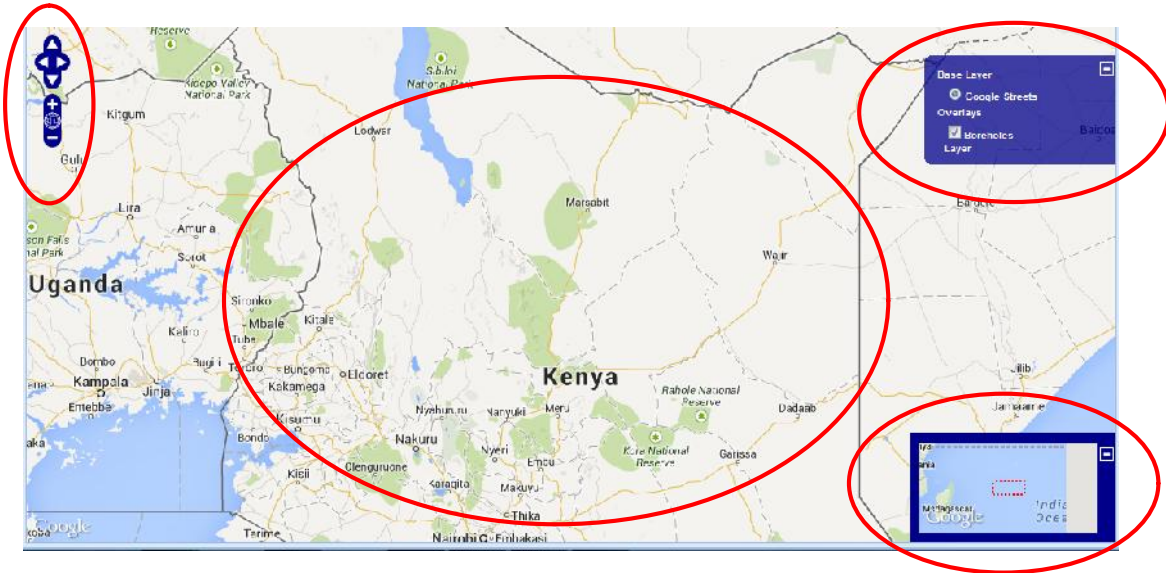

Figure 16: Features created from OpenLayer library on the application's interface

A snapshot of part of the code from OpenLayer library is shown in Figure 17. The code sets the map base layer to be that of Google maps.

```
    {isBaseLayer: true, displayInLayerSwitcher: true, visibility:true}
);

var gphy = new OpenLayers.Layer.Google(
"Google Physical Terrain",
{isBaseLayer: true, type: google.maps.MapTypeId.TERRAIN, visibility:false}
);

var gmap = new OpenLayers.Layer.Google(
    "Google Streets", // the default
    {isBaseLayer: true,numZoomLevels: 20,visibility:false}
);
```

Figure 17: Code snippet utilizing OpenLayers library

Postgres and PostGIS

The datasets mentioned above i.e. roads, administrative boundaries and boreholes have to reside in a geo-database. Both PostgresSQL and PostGIS were installed and the Wajir database set-up in PostgresSQL database. PostGIS Shapefile and DBF Loader Exporter was used to import the shapefiles into the PostgresSQL database as illustrated in Figure 18.
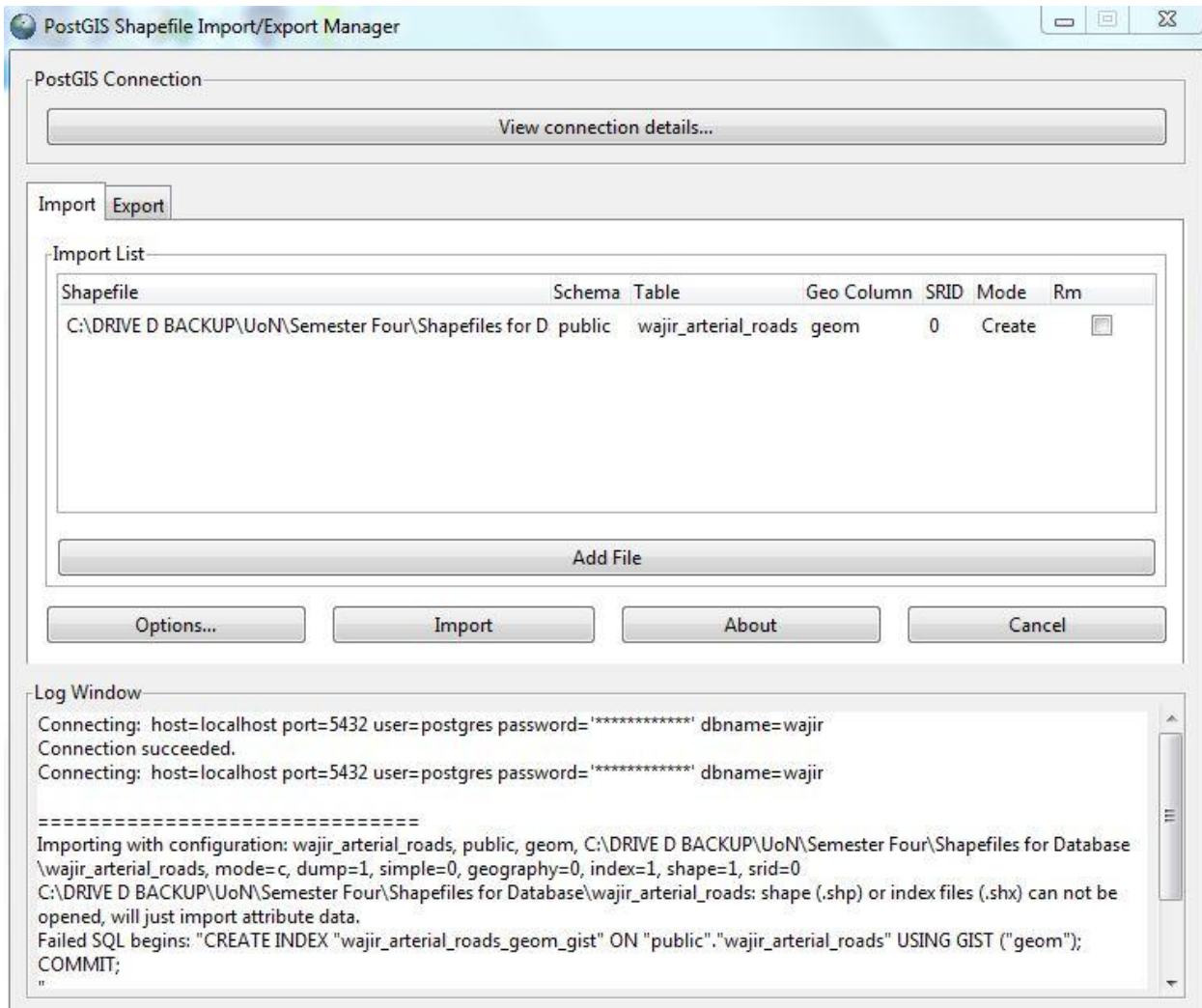

Figure 18: Importing shapefiles using PostGIS

Figure 19 shows the shapefiles as tables in the Wajir PostgresSQL database.

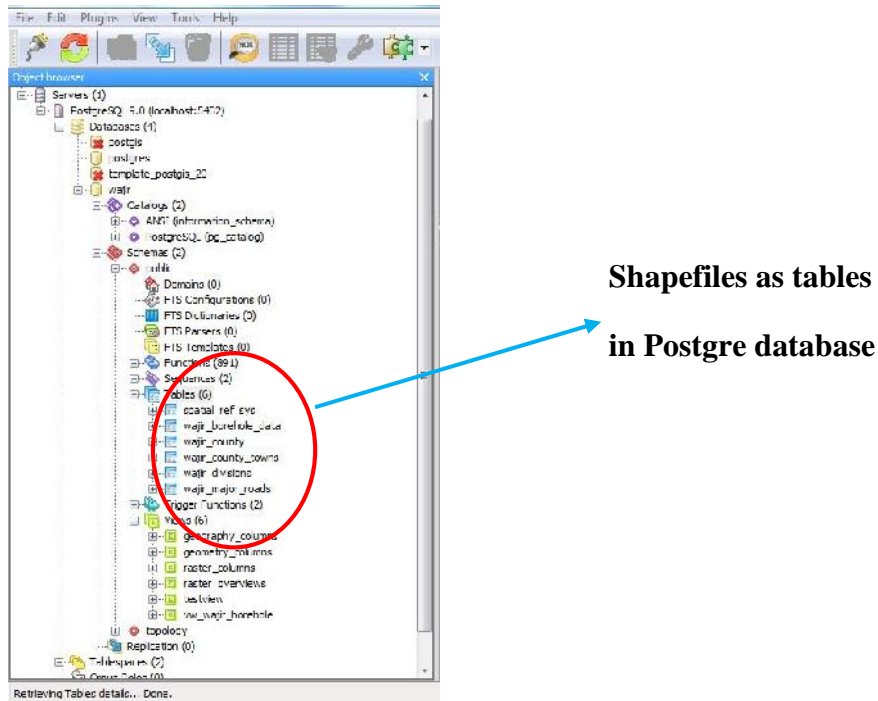**Shapefiles as tables in Postgre database**

Figure 19: Shapefiles in PostgreSQL database

Even though the borehole data had several attributes, the attributes which had information pertaining to them and were relevant towards enhancing the usability of the application by a wide audience were selected (see Figure 20) so that they can be incorporated in the application. These were: longitude, latitude, inspecting agency, division, name of nearest settlement, name of water borehole, type of use, operational status and date installed.
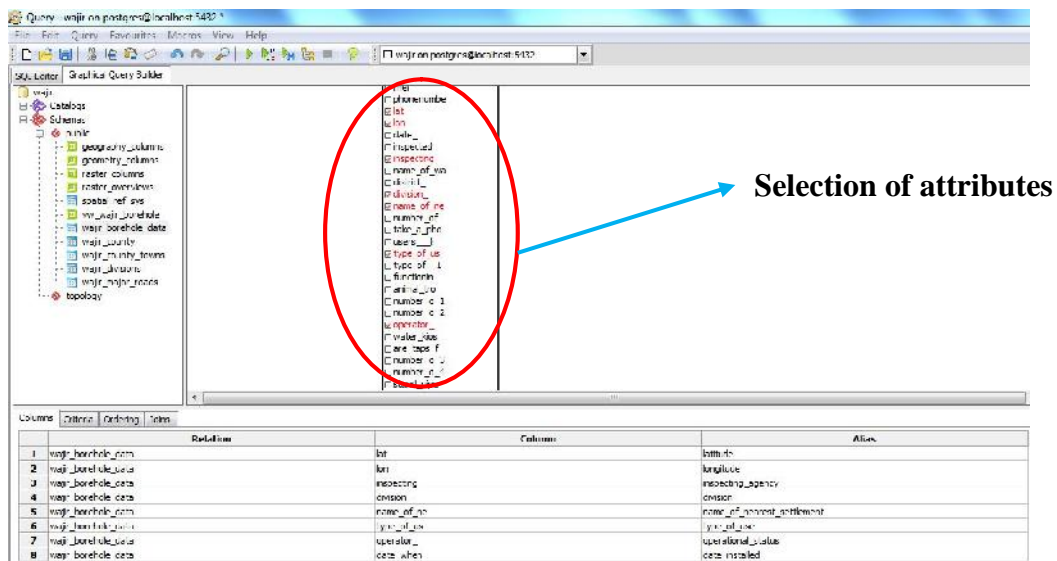

Selection of attributes

Figure 20: Selection of attributes to run in the application

To enable the application to be accessed remotely, Amazon Web Services were used for hosting the application in the cloud. Figure 21 shows the Amazon Web Services interface after registering for an account.
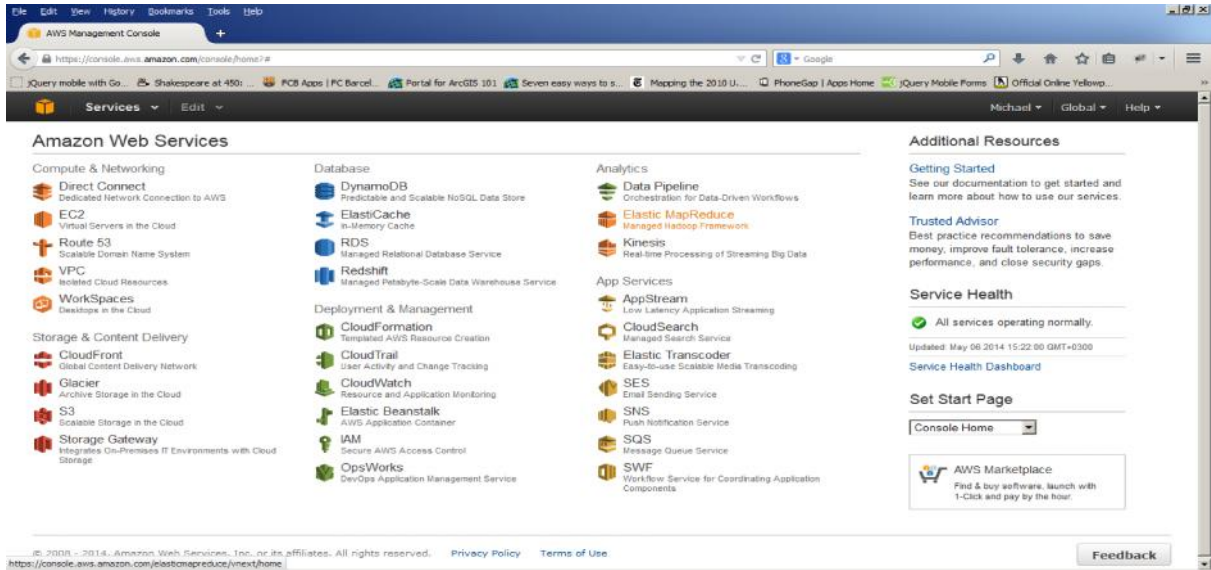

Figure 21: Interface for Amazon Web Services

The Amazon Simple Storage Service (Amazon S3) enables one to store and retrieve the Wajir datasets. Figure 22 shows Wajir datasets and application codes being uploaded to the Amazon S3 service.
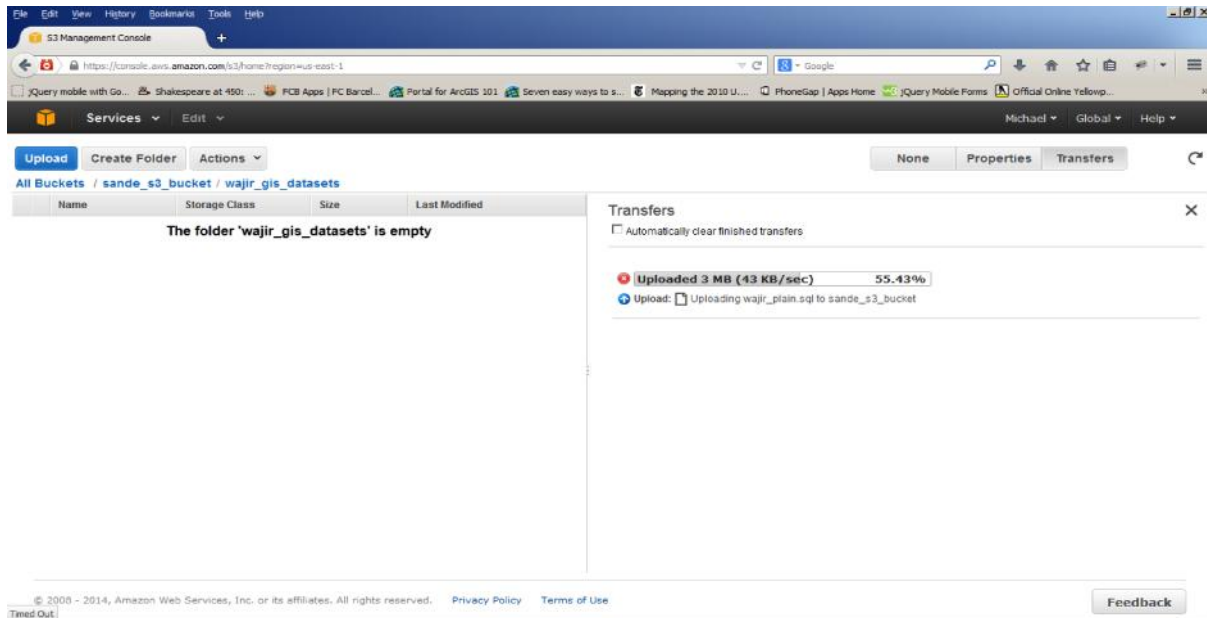

Figure 22: Wajir datasets being uploaded to the Amazon S3 service

Once the relevant files were stored in the Amazon S3 service, the Amazon Elastic Compute Cloud (Amazon EC2) service was setup, the Amazon EC2 provides resizable compute capacity in the cloud, ideally its setting up a server. Figure 23 shows an EC2 instance being set-up.
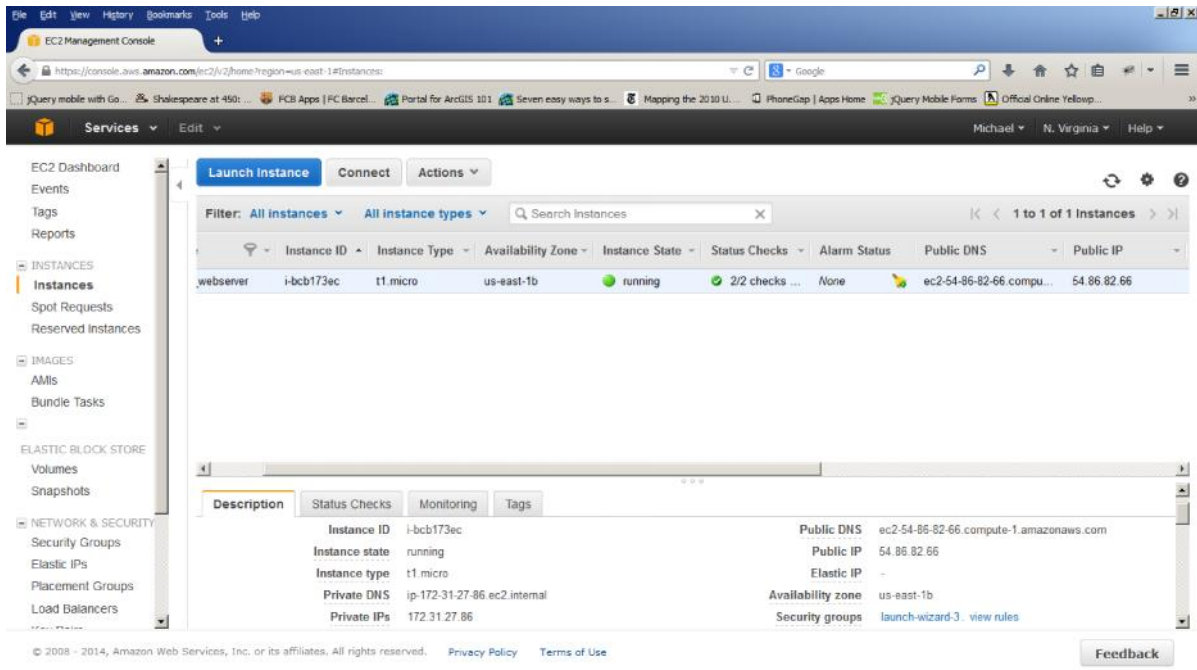

Figure 23: Setting up Amazon Elastic Compute Cloud instance

As the instance is set up, the system allocates the user a public Internet Protocol (IP) address that allows one to use the resource remotely; in this case the IP was 54.86.82.66:81/web/wajir

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Results

i) Design an interactive borehole web-map application.

The interface for the interactive web-based GIS borehole information management system is shown in Figure 24. On the extreme right the user selects the boreholes that s/he wishes to view based on a number of criteria such as administrative division, type of use and the status. On clicking the 'click to search' button, the results are displayed on the map. Further, more details regarding the boreholes selected on the above criteria are displayed on the southern part of the application in the panel labelled 'Borehole Search Results'.
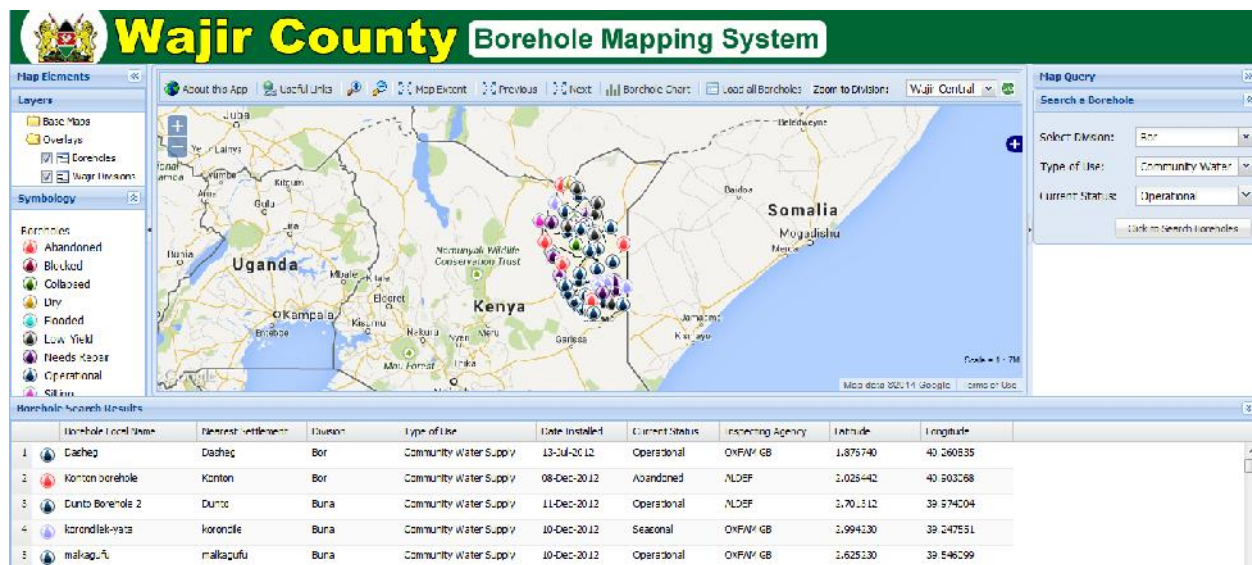

Figure 24: Interface for the interactive web application

ii) Demonstrate remote access of the borehole information.

The interface for the interactive web-based GIS borehole information management system running on a mobile device is shown in Figure 25. Since the application is web-based, any mobile device can access it remotely as long as the device has Internet connectivity; this is

through the IP address 54.86.82.66:81/web/wajir allocated by the Amazon Web Services. This enable users who are accessing the application from mobile devices such as tablets and smartphones to enjoy the same services just like those who are accessing the same from a personal computer or laptop.
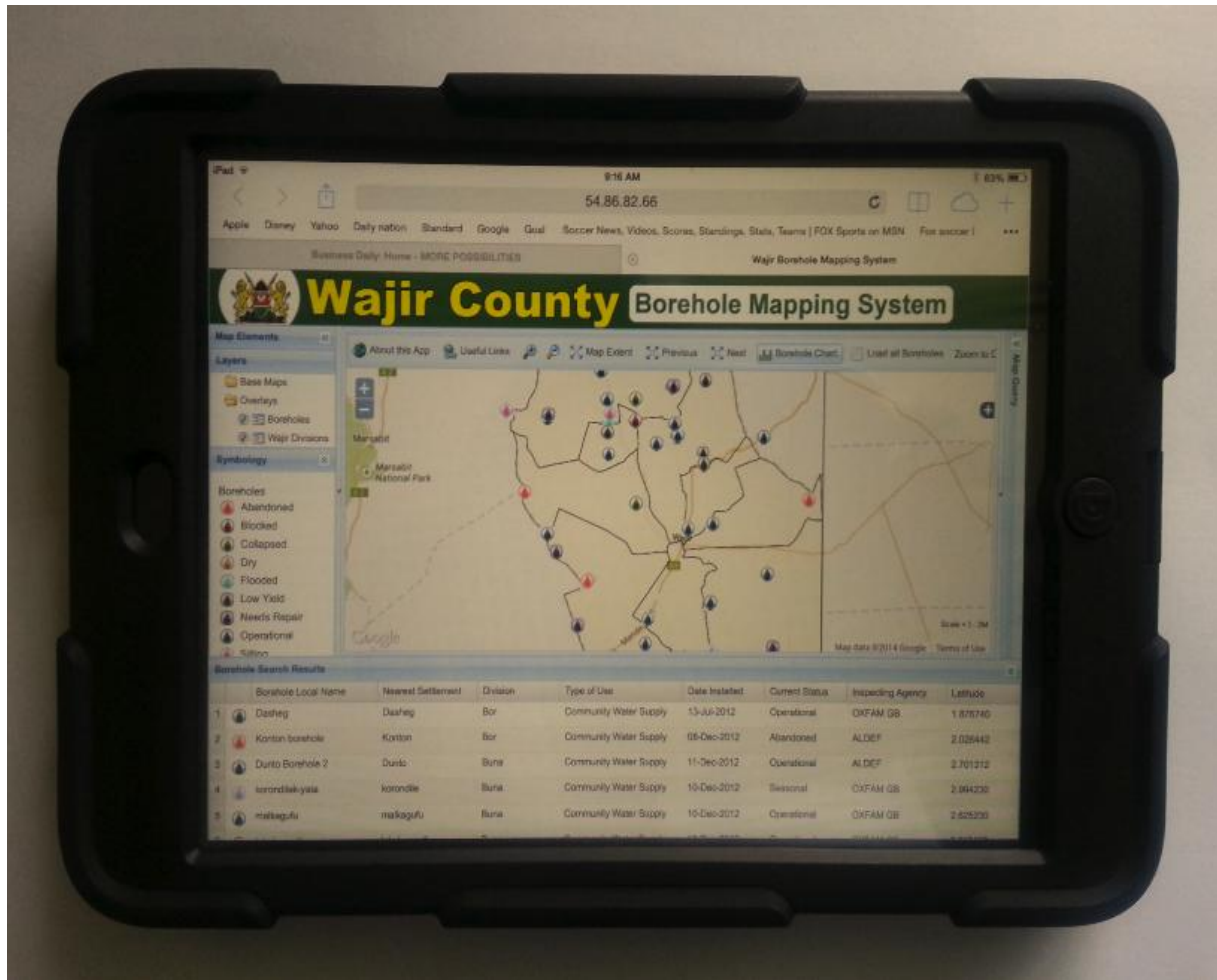

Figure 25: Interface for the interactive web application running on a mobile device

4.2 Discussions

The project was implemented using open-source softwares. The application allows a user to formulate a query/carry out analysis e.g. Figure 26 shows a query to find out the number of operational boreholes being used for community water supply in Buna division.
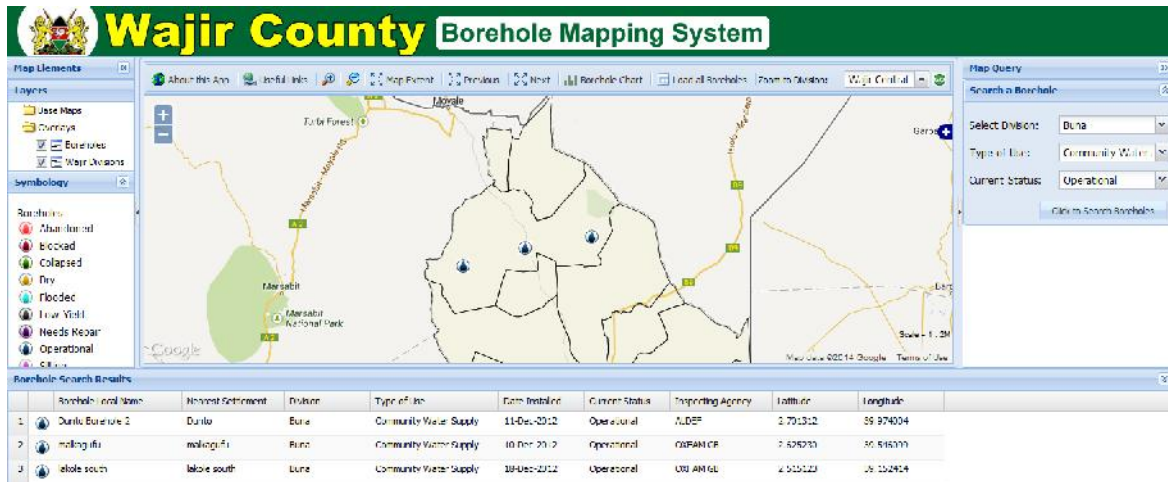
Figure 26: Result of a query operation on the application

Figure 27 shows a graphical analysis of all the boreholes in Wajir County.
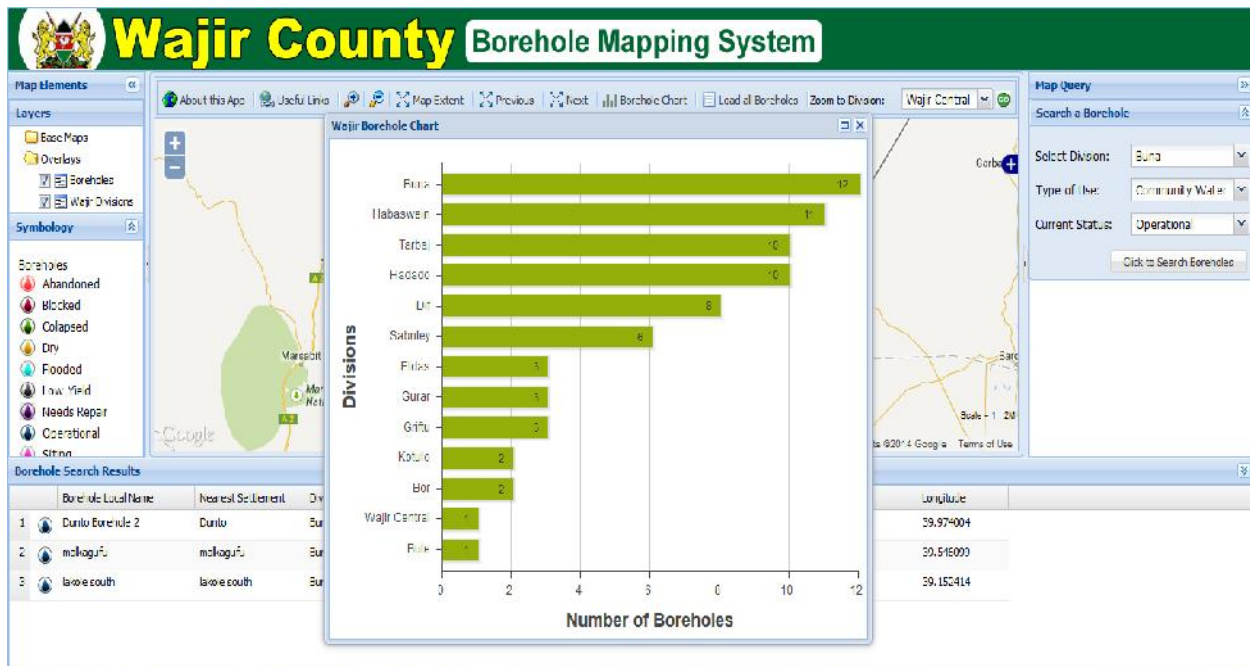
Figure 27: Result showing graphical analysis of all the boreholes in Wajir county

One of the challenges experienced was lack of a continuous access to Internet while scripting so as to test the scripts as one progress. Challenges regarding the scripts on the baselayer were however overcome by using the national boundary to act as a baselayer thus at any one given time when scripting offline, one can try and see the changes and progress made.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Geo-technology was used in place of the conventional hard-copy maps to display borehole information. This was accomplished by using open source software's to display, query and analyse information relating to boreholes. The web has the ability to disseminate spatial information to a wide audience. The information disseminated through this application can be used by borehole drillers, the public and other decision makers and interested stakeholders in the water sector.

5.2 Recommendations

The following needs to be implemented, so as to further improve the application;

a) Further development of the application to allow it to have an interface whereby hardcopy borehole data can be fed into the database.

b) Further development of the application to allow borehole data collected in the field using applications running on a mobile device to be populated in the database in real time (or near real time) using 3G mobile networks.

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7.0 APPENDICES