DEVELOPMENT OF A WEB-BASED SPATIAL DECISION SUPPORT SYSTEM FOR WATER DEVELOPMENT AND MANAGEMENT

(A Case Study of Samburu District Water MIS, Kenya)

By
JOSEPH MUTUA
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Declaration

This Project Report is my original work and has not been presented for a degree in any other university:

Name: Joseph Mutua

Date _30ᵗʰ August 2010_

Signature _[signature]_

This Project Report has been submitted for examination with my approval as university supervisor:

Name: Professor J.B.K. Kiema

Date _30.08.2010_

Signature _[signature]_

Dedication

To my Dad and Mum

Acknowledgement

My special appreciation goes to my supervisor Professor John Bosco Kyalo Kiema of the Department of Geospatial and Space Technology, in the School of Engineering for his constant support, instruction, guidance and facilitation throughout the duration of this study. I am also grateful to my colleagues and Mugo Joseph Gatheru who guided me in programming and scripting.

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Abstract

Advances in technology continue to change the way geographic data is acquired, processed and applied. Specifically, advances in information and communication technology (ICT) continue to present new and innovative ways of handling and using geographic data in decision making. The main objective of this study was to develop a web-based spatial decision support system for water development and management

The framework of the developed system is a hybrid structure model composed of clients and servers, which not only extends the capability of spatial decision support service space but also makes the system easy to use and maintain. The system was developed based on Open Source database software and web servers which offered a complete integration of spatial data types in a RDBMS. This took advantage of the new generation of spatially enabled database systems to build "faster, cheaper, smaller" GIS technology, coupled with data handling capabilities of new generation DBMS

Strategic planning and appropriate development and management of water resources can be strongly assisted by accessibility to reliable spatial information. This research found out that the web can offer cost effective and reliable database systems and mapping applications which can be customized to meet the needs of decision makers in the water sector at low investment costs compared to costly commercial GIS software which are expensive and biased toward Geographic Information (GI) professionals

Abbreviations

ASAL	Arid and Semi Arid Lands
CAD	Computer Aided Design
COOPI	Cooperazione Internazionale
CGI	Common Gateway Interface
DBMS	Database Management System
DSG	District Steering Group
ECHO	European Commission Humanitarian Aid Office
GIS	Geographic Information System
GUI	Graphic User Interface
GRASS	Geographic Resource Analysis Support System
HTML	Hyper Text Markup Language
HTTP	Hyper Text Transfer Protocol
KML	Keyhole Markup Language
KNBS	Kenya National Bureau of Statistics
LAN	Local Area Network
MIS	Management Information System
NGO	Non Governmental Organization
OGC	Open Geo-Spatial Consortium
OWS	OpenGIS Web Service
PHP	HyperText Processor
RDBMS	Relational Database Management System
SLD	Styled Layer Descriptor
TCP/IP	Transmission Control Protocol/ Internet Protocol
URL	Unified Resource Locator
XML	Extensible Markup Language
WBSDSS	Web Based Spatial Decision Support System
WFS	Web Feature Service
WMS	Web Mapping Service
WWW	World Wide Web

CHAPTER ONE

1.0   INTRODUCTION

1.1   Background to the Study

Appropriate water source development and management is an important component in promoting sustainable livelihoods. This is particularly so in arid and semi-arid areas (ASAL) where access to and reliability of water sources have such a large influence on the economy and there are significant environmental impacts associated with those water sources. Strategic planning and appropriate development and management of the water sources can be strongly assisted by accurate and accessible spatial information.

The availability of reliable information has proved critical in identifying appropriate and timely drought responses and other development needs. Strategic planning and appropriate development and management of water resources can be strongly assisted by accurate and accessible information. The Samburu District Water Management Information System (MIS) was a major step in cutting down the cost of data collection which has a very high cost element in a GIS project and providing a pool of reliable data, mapping functionality and maps from which strategic planning and development decisions can be done. The project was supported by the European Community (ECHO) and Cooperazione Internazionale (COOPI) as part of their long-term commitment to support water supply development and management in Samburu District among other state and non state players to curb expensive data collection exercises, duplication of efforts in water related humanitarian activities and data paucity (Samburu District Water, Schools and Health Management Information System, Rural Focus, 2007)

In recognition of the power of Geographic Information System (GIS) to support strategic planning in the water sector, and driven by the need for reliable spatial information to aid in water related decision making and planning among state and non state players in Samburu District, COOPI an international Non Governmental Organization, the District Steering Group (DSG) (district based co-ordination body) decided to undertake a Water, Environment and Sanitation Assessment and Mapping Project in Samburu District. A census was carried out on the water sources, schools and hospitals. Primary data was archived in a MS Access database which was coupled with a GIS database containing secondary data for enhanced spatial analysis and production of maps.

The challenges faced by this system were; the cost of ESRI GIS software, capacity building of NGO and government officials to be able to utilize fully the GIS software for water decision support, this system was desktop based which was a major challenge in promoting meaningful data sharing between different institutions, updating of the data due to the segmented desktop stand alone systems in different institutions was also a major challenge to the data integrity and consistency as there were various data holding institutions.

1.2   Statement of Research Problem

Although desktop GIS enables a wealth of new analytical possibilities for users, the systems face several challenges which have been a stumbling block to the full utilization of the Samburu Water Management Information System among the different stakeholders. These include but are not limited to the following: Interoperability as most of the secondary database is in ESRI software format which cannot be directly ported to other vendor software and Open Source GIS applications without rigorous time consuming format transformation.

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The ESRI software called for long learning curves and follow up activities before the stakeholders could effectively use conventional GIS thus limiting the usage across different departments, institutions and interest groups. Also given the fact that different GIS are rather different in the way they are operated, a user once trained is likely to keep to the same system regardless of the merits and/or demerits of this. The situation was exacerbated by rather high cost of training. Overall there is a danger of "vendor-locking" where users are forced to use specific systems by the prohibitive cost of migration to a different system.

For the stakeholders to fully utilize the Samburu District Water MIS it's critical for them to acquire GIS software (specifically ArcGIS 9.X). However, in general proprietary GIS software is rather costly. One of the reasons for the high cost is because the systems have much redundant functionality. For instance, it has been said that 90% of the users mostly use about 10% of the functionality offered by their systems. In essence, this means that a typical user pays for about 90% excess functionality, i.e., functionality they actually can do without (Herring, 2001)

In a bid to resolve the stated challenges, and taking advantage of modern advances in distributed computing, in particular the Internet and the World Wide Web, a Web Based Spatial Decision Support System (WBSDSS) is proposed.

This approach will also help in alleviating the current existence of segmented databases in the custody of the different stakeholders within the district as well as realization of cost effective benefits of data sharing and updating mechanism and the pool of other advantages related to a centralized database system.

1.3   Objectives of the Study

1.3.1   General Objective

To develop a web-based system for supporting spatial decisions on water development and management for Samburu District

1.3.2   Specific Objectives

The specific objectives of the research are:

  i. To develop a web enabled Database Management System (DBMS) for water sources in Samburu District;

  ii. To create a web enabled geo-spatial database for water related data, natural resource and socio-economic data for Samburu District;

  iii. To design a web-based user interface for entering and updating archived and collected data on water sources in Samburu District;

  iv. To link the developed web enabled DBMS and Geo-Spatial databases to Google Earth for visualization and display of thematic maps.

1.4   Significance of the Study

Advantages of the Web include openness, user-friendly interfaces, interactivity, flexibility, and fast communication. It is relatively cheap and therefore gives the general public access to a variety of both GIS systems and data of varying degrees of sophistication. This direct access, as a means of allowing wider involvement and participation in decision making, is an important prerequisite of any decisions support system. Interface familiarity, portability across many computer platforms and capability to display different multimedia and hypermedia formats are all possible outcomes of improved accessibility.

Integrating the water MIS with the Web will give users and the various stakeholders' access to GIS benefits without platform limitations. The benefits include more opportunities for public feedback and widening involvement of potential audiences in the decision-making process (Carver *et al.*, 1997).

The Web can be used to great advantage for the enhancement of participatory spatial decision support and decision making (Kingston *et al.*, 2000) in not only the water sector but in other arms of the government and non-governmental organizations. As Graham (1996) argues, the Web will "generate a new public sphere supporting interaction, debate, new forms of democracy and cyber cultures which feed back to support a renaissance in social and cultural life of societies".

1.5   Limitations of the Study

The foreseen limitations to this study include and are not limited to the following: The project implementation will require reliable internet connectivity as many resources to be utilized for this project are internet-based. In addition, research on web-based spatial decision support systems remains a topical issue in which case there exists scarcity of textbooks and references on the subject.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

Geographic Information Systems (GIS) have become an effective tool for decision support. Spatial Decision Support Systems (SDSS) are decision support systems where spatial properties of the data to be analyzed play a major role in decision making. Maps and geographic features can be used to show decision related information and relationship between objects to solve important problems. A combination of technological improvements regarding GIS and web leads to the modern management support environments. Data can be maintained and be updated in a centralized location or distributed locations. Many users can reach this information in a common platform such as a web browser.

2.2 Samburu Water MIS

The Samburu District Water MIS is made up of two components, a DBMS based on Microsoft (MS) Access software and a GIS geo-database based on ArcGIS 9.x software. The two components are "hot" linked so that the Graphic User Interface (GUI) developed in MS Access and the ArcGIS 9.x Software access the same data. Updating the database therefore automatically updates the GIS and pre-defined maps.

Figure 2.1 shows the architecture that was adopted for Samburu Water MIS. This architecture enabled user without ArcGIS 9.x GIS software to run the customized database on Microsoft Access where they could update or input collected data into the MIS and generate tabular report and view static maps. Users with ArcGIS 9.x GIS software can establish a hot link to the database and be able to equally update the database and the maps

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Additionally, with the GIS database the water source attribute data is overlaid with key thematic layers such as ground water potential, rangeland conditions, livelihood zones among others to give spatial relationships and for further geoprocessing functionalities.
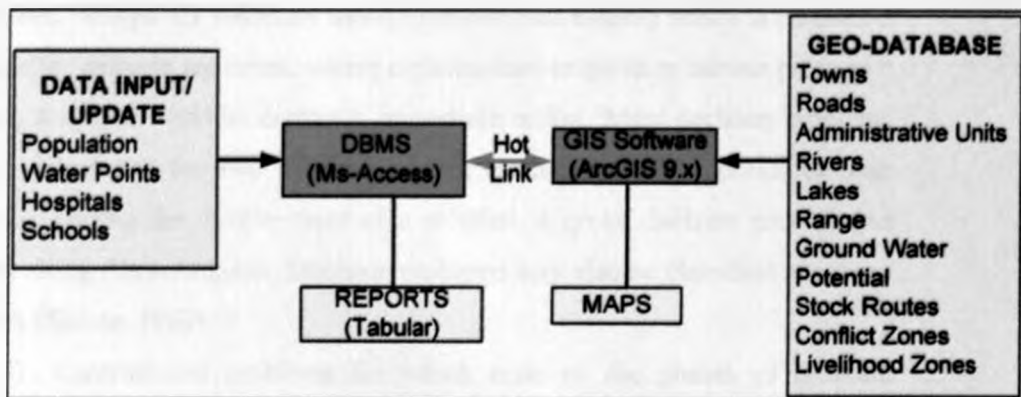
Figure 2.1: Architecture of the Water MIS (Source, Rural Focus, 2007)

The two tier structure of the Samburu Water MIS is driven by the need to: improve water source data at the district level; the need for a proper water source database; the capacity of a GIS to support data management and strategic planning; provide a digital database for data archival and retrieval; provide a mechanism to undertake spatial analysis; to seek spatial relationship within the data, and to query the database; as well as providing a mechanism for data quality control and mapping. (Herring, 2001)

2.3   The Classical Decision Making Paradigm

Decision making is the process of generating and evaluating alternatives and choosing a course of action in order to solve a decision problem. Not every problem is a decision problem based on the approach used to remedy it. According to Ackoff (1981), a decision problem is said to exist where an individual or group perceives a difference between present state and a desired state, and where the individual or group has an alternative courses of action available or the choice of action can have a significant effect, that is, not all

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the actions will yield the same outcome and where the individual or group is uncertain *a priori* as to which alternative should be selected.

Decision problems may be categorized by the stimuli that evoke them (Mintzberg and Theoret, 1976). At one extreme are opportunities, as those initiated on a purely voluntary basis, to improve an already secure situation. At the other extreme are crises, where organizations respond to intense pressures; here, a severe situation demands immediate action. Most decision problems fall in between the two extremes, being evoked by milder pressures than crises. During the development of a solution, a given decision process can shift along this continuum. Decision problems may also be classified into three types (Simon, 1960);

i)   Unstructured problems for which none of the phases of decision making can be formalized and no pre-established procedures exist. These types of problems are difficult to support with models and computers.

ii) Structured problems: here all the phases of decision making can be formalized and it is possible to develop standard operating procedures for addressing the problems. The decision making process can easily be delegated or automated.

iii) Semi-structured or ill-structured problems: These are somewhere intermediate between the above two types. The main challenge here is to find the formation in problems that seem to have no precise structure.

Problems can be either resolved, solved or dissolved (Ackoff, 1981). Resolving a problem involves selecting a course of action that yields an outcome that is good enough, or "satisfies" (satisfies and suffices). It is a qualitatively oriented, "clinical" approach rooted in common sense and subjectivity. Most managers are problem resolvers, citing a lack of information and time to do otherwise (ibid). Solving a problem on the other hand, involves selecting a course of action that is believed to yield the best

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possible and most optimal outcome. Mainly employing scientific tools, techniques, methods, this is a "research" approach that is preferred by technologically oriented managers whose organizational objective is growth rather than mere survival (ibid).

Dissolving a problem involves changing the nature and the environment of the entity in which the problem is embedded so as to remove the problem. Considered a "design" approach, it aims at changing the characteristics of the larger system into a state in which the problem cannot or does not arise. The designer makes use of the methods, techniques and tools of both the clinician and the researcher, but he uses them synthetically rather than analytically. This approach is used by managers whose principle organizational goal is development and not just growth and survival (ibid).

Based on earlier work by Simon (1960), Sharifi *et al* (2004) propose a framework for a systematic approach to decision making consisting of three phases namely intelligence, design (here , the word "design" is used in a slightly different context from the one earlier presented) and choice.

Intelligence involves searching the environment for conditions calling for decisions. Design relates to inventing, developing and analyzing possible courses of action, while choice involves selection of a course of action out of those available. In figure 2.2 "Evidence" refers to the total set of data and information that the decision maker has at his/her disposal, including the skills necessary to handle this information. It may consist of facts, values, knowledge or experience and is a key resource at all stages of the decision making process. A major part of decision support is the collection, evaluation, organization and translation of this data into forms suitable for analysis

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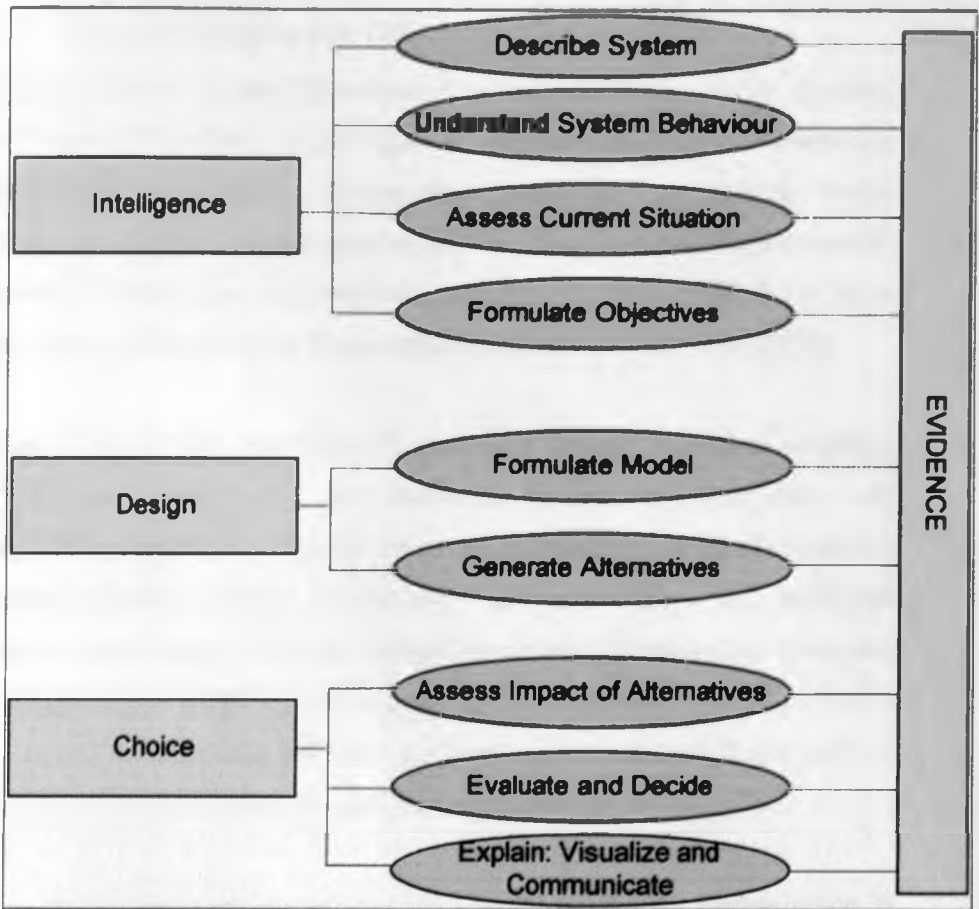
Figure 2.2: Frameworks for a Systematic Approach to Decision Making (Source, Sharifi et al, 2004, based on Simon 1960)

2.4 Decision Support System

Decision Support System (DSS) is a class of information system that draws on transaction processing systems and interacts with other parts of the overall information system to support the decision making activities of managers and other knowledge workers in the organization. Bhatt and Zavery (2002) describes a DSS as computer software that facilitates and accepts input of a large number of facts and methods and converts them into meaningful comparisons that can enhance a decision maker's problem solving abilities. In general, it can be said that DSS provide support to "management activities" at either strategic planning, management control or operation control level.

2.5   Recent Developments in GIS

A large number of recent GIS projects have taken advantage of the Internet, the Web, and related technologies to replace geographic information dissemination via paper, photographic, magnetic, and optical media (Goodchild, 1998). In such approaches, four functions information search, discovery, assessment, and retrieval can be supported from three basic viewpoints: technological, software engineering, and the user (Tao, 2000).

Technologically, GIS architecture has evolved through mainframe, desktop, network-based client-server, and distributed systems. The next phase will likely see heterogeneous networks based on inexpensive ubiquitous computing devices, wireless, mobile, or nomadic, with autonomous and intelligent software proxy agents. From the software engineering viewpoint, GIS systems have typically provided a wide range of functionality which is not selectable by a user. Future systems will need to allow a user to customize, and pay for, only those functions needed for a particular application (Herring, 2001

Given that a user can customize a GIS's functions, further customization is available through a Web-based application interface. Software tools are easily obtained and customized system can be easily assembled. Arrangements such as access, and rights to viewers (browsing for theme wise maps) and Contributors (viewing and contributing data but not editing), collaborators (contributing data and editing), and the owners can be implemented.

Current GISs primarily serve research needs and do not provide appropriate access for the expected class of end users. Future systems will need to be designed with the user in mind. Hawthorn and Engen (1997) conclude that the Internet provides a way of deploying such systems through a combination of equal access and cost effectiveness. Abel *et al* (1998) stress the importance of the Web for spatial information systems. Recent research work which has been done in this field includes research on Water Supply Management in an Urban Utility, a prototype of decision support framework by Kizito (2009).

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2.6   Current Web Technologies

2.6.1   Overview of Internet and World Wide Web

The Internet began as a U.S. Department of Defense project in the late 1960s, responding to concerns that the communications infrastructure could be destroyed by a nuclear attack. During the 1980s, it was opened to government agencies and education and research institutions, and in the early 1990s to the public and commercial organizations. The Internet with as many as 160 million Internet users worldwide (Morgan, 2000), it is expanding at a rate of 80-100% a year. Although no committee or federal agency manages the Internet, some organizations do direct aspects of its design, including the Internet Society (ISOC), the Internet Engineering Task Force (IETF), and the Internet Architecture Board (IAB).

The World Wide Web, was created in 1991 by Tim Berners-Lee at the European Particle Physics Laboratory (CERN) in Geneva, WWW is an application that operates on the Internet. It is based on a client-server model in which a client, using a Web browser, retrieves documents from a Web server.

2.6.2   Client Server Computing

The Web comprises four types of components, the browser, the server, the *hypermedia document,* and the *Uniform Resource Locator* (URL). Its underlying network protocol is the *Hypertext Transfer Protocol* (HTTP). A hypermedia document is a file, often called a *Web page*, written in the *Hypertext Markup Language* (HTML). A browser displays such a file by interpreting its HTML commands. A URL, often called a *hypertext link*, is a reference within a hypermedia document to a location in the same or another hypermedia document. A Web server stores hypermedia documents (W3C).

HTTP, a simple protocol performing one task at a time, is simple but inefficient in that it establishes a TCP27 connection for every request. Moreover, HTTP does not permit a client to issue parallel multiple requests in the same work session. A URL has two basic parts, the *address* and the

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protocol name. The address can be an IP28 address (e.g., 195.147.147.140) or a domain name (e.g., www.uon.ac.ke), an IP address that has been resolved by a *Domain Name Server* (DNS). The protocol name specifies one of the Internet protocols such as the *File Transfer Protocol* (FTP) or HTTP. For a local file, the protocol name is "file."

Lynx, the first Web browser, developed by Lou Montulli in 1992 at the University of Kansas, displayed text-based HTML only. *Mosaic*, developed in 1993 by the National Center for Super-Computing Applications (NCSA) at the University of Illinois, allowed platform-independent data presentation and was itself multi-platform. The current major browsers, Netscape Communicator, Microsoft Internet Explorer, Mozilla, and Google Chrome display a limited number of document formats regulated by the WWW Consortium (W3C).

Before the Web, client-server data access was not in general use and often was built using a limited set of component types: clients, networks, servers, and databases. The Web changed client-server data access by providing a universal infrastructure, millions of users, a global scope of access, and thousands of potential developers (Chang and Harkey, 1998)

2.6.3   Client Server Network Architecture

Client-server systems are characterized by a clean separation of function between the customer and the provider of service, concurrent access to shared resources, client initiation of dialog, server-location masking, platform independence, communication by message passing, implementation-independent server interface design, scaling of client or server numbers or computing power, and central control of server implementation (Orfali *et al.*, 1996).

The Internet's TCP/IP protocol is not a single protocol, but a suite of protocols. Its specifications are publicly available as *Requests For Comments* (RFCs) which document Internet standards and are maintained by the Internet

Architecture Board (IAB, 2003). TCP/IP fits loosely within the Open Systems Interconnection (OSI) Reference Model. Following the OSI model, a framework for protocol design, helps to identify the functionality of a protocol and encourages standardization. Microsoft's TCP/IP, for example, is compliant with RFC-published TCP/IP standards. However, the Microsoft implementation includes a number of features not found in other versions of TCP/IP.

2.6.4 Web servers

A Web server comprises three major software components: the HTTP interface, the HTML page generator, and the server interface. Additional functions include Common Gateway Interface script handling, database access for search engine requests, and administration features. The major Web servers currently available include: Apache, a UNIX platform (Ricart, 1996); Microsoft Internet Information Server, a Windows platform; and Netscape Enterprise Server, a UNIX and Windows platform. Other servers include FreeBSD (FreeBSD, 2003), Web Commander, Lotus Domino (Domino, 2003), and Servertec Internet Server (SIS, 2003).

2.7 Web-Based Spatial Decision Support System

In the last two decades, Geographic Information System (GIS) applications have been developed, implemented, and enhanced by scientists in many fields including geography, computer science, environmental science, and others. GISs have revolutionized many aspects of modern spatial decision making approaches, especially with the advent of the Internet and the World Wide Web (WWW or Web), the use of GIS has grown dramatically from obscurity in the 1980s to become commonplace in businesses, universities, and governments, where they are now used for many diverse applications. (Worboys, 1995)

The major developments important to growth and utilization of Web Based Decision Support System (WBDSS) are; in 1994, the Open Geo-Spatial Consortium (OGC) was established to manage consensus processes that result in interoperability among diverse geoprocessing systems. In OGC, geoprocessing technology users work with GIS software vendors, earth imaging vendors, database software vendors, integrators, computer vendors, and other technology providers to reach agreements on the technical details of open interfaces that allow these systems to work together (OGC, 1994). Also the WWW Consortium was formed in 1994 to develop interoperable technologies specifications, guidelines, software, and tools to lead the Web to its full potential as a forum for information, commerce, communication, and collective understanding (WWW, 1994).

Coupling the Web and GIS functionalities will provide a new and interesting tool which not only provides easy access to spatial data and information but an easily used spatial data manipulation tool (Dragicevic *et al.*, 2000). The Web offers new application areas, such as urban planning and watershed analysis, water management, utility development among others for communication and interaction between planners, concerned citizens, and clients. Furthermore, it simplifies access to and distribution of geographic data among many users (Coors and Flick, 1998).

Web-based technologies can support the forecasting of patterns in different application areas (Bell *et al.*, 2000). The Web provides cheaper, faster, and more frequently updated data distribution (Kraak, 1999). Web-based GISs can provide easy access for local or international users via standard, low-cost equipment (Dunham *et al.*, 1999) and opportunities for public feedback, participation, and collaboration in decision-making processes (Carver *et al.*, 1997; Densham, 1991; Densham and Armstrong, 1994; Bhargava and Tettelbach, 1997; Carver *et al.*, 1999; Fisher and Wilson, 1997). Such meetings are not geographically restricted and can be relatively anonymous and non-confrontational (Kingston *et al.*, 2000).

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In summary, the Web, with its properties of openness, interactivity, speed, spatial distribution, hierarchical structure providing protected domains, and flexibility, can provide an exceptionally important environment for spatial decision support in water as well as guide development of water related infrastructure and general regional management (Voinov and Costanza, 1999). But problems of accessibility and usability of spatial data remain significant bottlenecks to increasing the number of GIS users and applications (Li *et al.*, 1995). There is a lack of a broad range of users with access to integrated spatial data. Local communities and casual users do not have the necessary hardware, software, and training to assimilate and analyze such data. Consequently, a usable Web-based GIS is needed (Dai *et al.*, 1997).

2.7.1 Spatial Decision

According to Burrough, 1997 the following types of questions can be answered by a spatial decision support system for enhanced decision making and strategic planning in both a conventional GIS environment or through a Web Mapping Service (WMS). These questions can be categorized as follows:

Location: What is at...?

The simplest of these questions seeks to find out what exists at a particular location. For example, a user might wish to find a water point name, latitude?, longitude?, whether it's functional or non functional.

Condition: Where is it?

This query requires answers that meet certain conditions or are the intersection of multiple conditions. For example, a user may wish to find the population of a location unit and the corresponding number of functional water points at a given time period.

Trends: What has changed since...?

This question seeks to find the difference within an area over a period of time. For example, MacEachren and Dibiase (1991) depicted the spread of HIV through the use of animated mapping techniques. A series of maps from the same area but different periods of time were ordered chronologically. When displayed in sequence as a computer animation the movement of HIV virus across the study area was quite evident and provided a more complete conceptual model of this temporal geographic data.

Patterns: What spatial patterns exist?

This type of question ascertains whether or not events exhibit a systematic pattern, some form of regularity or clustering that can be used to estimate the intensity of events over a study region for which data are not available. Such patterns are relevant to the management and development of water sources in the ASAL regions as availability of water can be depicted as a pattern over a given period

Modeling: What if...?

This question is posed to determine what happens, for example, if a toxic substance seeps into the local groundwater supply or if the sea level rises as a result of global atmospheric warming. The model may, for example, estimate future sea levels and determine which areas would be flooded

Generally spatial data analysis and presentation is not only useful for professionals and decision makers but also for a public that demands openness. This is reflected in the Arahus convention which states: "Improved access to information and public participation in decision-making enhance the quality and implementation of decisions, contribute to public awareness of environmental issues, give the public opportunity to express its concerns, and enable public authorities to take due account of such concerns."

2.7.2 The Web Environment as a Spatial Decision Support Tool

With the advent of the internet and web technology in the 21st century, the web environment is emerging as a very important spatial decision support tool through various web mapping services (WMS) and OpenGIS web services (OWS)development and delivery platforms. Only text and images could be browsed over the Internet some years ago. HTTP (Hyper Text Transfer Protocol) and CGI (Common Gateway Interface) programming technologies initiated preliminary applications. (www.w3.org. March 2000)

The primary Web tools are Web servers using Hypertext Transfer Protocol (HTTP) containing Web pages created with Hypertext Markup Language (HTML) and JavaScript accessed by client machines running client software known as browsers. This environment has started to develop in 1990 by Tim Berners-Lee. The first Internet GIS applications have started to develop in 1994. While internet technologies were improving, web based applications have continued to develop. New technologies like Java, ActiveX provide a lot of new opportunities for Internet GIS. A variety of programs which different vendors have created are available nowadays. (Arnold and Gosling, 1996)

General working principles have to be explained to understand application components. Client and server communicate across a computer network either on Internet or Intranet by means of a HTTP. It lies in creating software systems that are platform independent and run on open TCP/IP (Transmission Control Protocol/ Internet Protocol) based networks. A web browser such as Netscape Navigator or Internet Explorer is a usual client program. The browser program sends a request to the server and finally a file is transmitted from the server to the client by means of URL (Uniform Resource Locator). Different strategies have advantages and disadvantages when used in Internet applications. These are server side, client side strategies or hybrid strategy including the common features of other strategies. Server-side strategies allow users (client) requests to a Web browser (WWW 1994).

The server processes the requests and returns data or a solution to the client. Client side strategies allow the users to perform some data manipulation and analysis locally on their own machine. Hybrid strategies combining server and client processes optimize performance and meet special user needs. Internet has many technical advantages for GIS or SDSS. Data can be maintained and be updated in a centralized location or be integrated with many sources on broad spectrum platforms. A web-based map can be used both privately and publicly. Access can be regulated and redundancy eliminated.

The end-user software is an easy and cheap web browser, not an expensive and complex GIS program. The web browser provides a much more dynamic map tool than a static map display. Such a system can support various needs of the end users. When people save and publish these data on the Internet, other people can access and browse these data simultaneously. Maps can be copied easily on the Internet and be downloaded for a more detailed use. Over the past 20 years, one of the most significant trends has been the evolution from individual stand-alone computers to the highly interconnected network environment of today.

Initially, computers within firms were connected via local area networks (LAN), allowing teams and workgroups to share decision-making information more easily. Then, firms began to connect their networks in wide area networks to facilitate sharing of information across organizational boundaries. Finally, the Internet and web created an environment with almost ubiquitous access to a world of information. At the same time, many organizational decisions migrated from individual decisions to ones made by small teams to complex decisions made by large diverse groups of individuals within a firm or even from multiple firms.

2.7.3 Internet Security

It is important to make a mention of this subject since like any web server; an Internet GIS server is susceptible to attacks. Internet security refers the practice of protecting and preserving private resources and information on the internet (International Engineering Consortium, 2002)

The problem of internet Security comprises three major parts, namely:-

a) Securing the web server and the data that is on it

b) Securing information that travels between the web server and the user

c) Securing the user's own computer

There are many types of attacks that can be targeted on a server, some of which are listed below (Behr, 2002).

a) Executable code penetration

b) Executable code manipulation

c) Exploitation of safety loopholes, bugs

d) System configuration weakening

e) Theft of files, registry attack

f) DNS Spoofing masquerade

g) DNS Spoofing

h) Firewalls tunnels

i) Flooding (Denial Of service Attack)

j) Fragmentation Attack

k) Hijacking

l) Man in the middle attack

m) IP Spoofing

n) Passwords Eavesdropping

o) Penetration of the DNS Caches

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Several solutions exist which can be used in any combination. These are discussed briefly in the subsections that follow.

1. Security policies

2. Security tools

3. Logging

4. Backups

5. Minimizing services offered by the server

6. Firewalls

7. Physical Security

2.7.4. Security policies:

These refer to directives and decisions concerning system security (IEC, 2002) which are set at the organizational level and include the following:-

a) Who is allowed to access, what is the nature of that access, and authorization

b) Who is responsible for security, for upgrades, for backups, and for maintenance

c) What kind of material are allowed on served pages

d) Which sites and external users are to be allowed access to pages and data served

e) What kinds of testing and evaluation must be performed on software and pages before they are installed

f) How are complaints and requests about the server and page content to be handled

g) How should the organization react to security incidents

h) How and when should the policy itself be updated

i) Who is allowed to speak to members of the press, law enforcement, and other entities outside the organization in the event of questions or an incident

2.7.4. Security Tools

These are:-

a) Tools that take a snapshot of the system and look for potential weaknesses

b) Tools that monitor the system over time, looking for unauthorized changes

c) Tools that scan the network, looking for network-based weaknesses

d) Tools that monitor the system and network, looking to identify attacks in progress

Logging

This is valuable when recovering from a security related problem because they tell how attacker broke in and clues on who the attacker is. Unfortunately, they are the first target for attackers (Garfinkel *et al.*, 1997).

To protect log files, a secured log server should be set up, which collects entries from other computers. Such a log server should not offer services to the network and should not support log in accounts. Only authorised personnel should be enabled access to the log server of all the servers in order to examine the log files. This should be on a regular basis.

Log files are useful for gauging the capacity of a system since they help in spotting security violations and determining when upgrades are necessary.

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Backups

These are important since they offer the following protection and services to the system

- Protection from equipment failures

- Protection from accidental file deletions

- Protection from break-ins, as files that are deleted or modified by an attacker can be restored from a backup

- Ability to determine the extent of an attacker's damage, because the administrator can detect changes in the system by comparing its files with the files stored on the backup tapes

2.8   Data and Databases on the Web

More recent databases use a DBMS, a collection of inter-related programs that access data (Elmasri and Navathe, 1994). The Web-based client-server paradigm offers further improvements for database access. The deployment of such databases on the Web has been rapidly evolving (Newton *et al.*, 1997). Efforts to improve connectivity between databases have also been made.

The major Relational DBMS (RDBMS) vendors provide databases accessible from the Web (Jepson and Hughe, 1998; Oracle, 1999; and Microsoft, 1999). Web sites with such databases can provide excellent online information (Zhu and Lu, 2000). The hypermedia interface capabilities of the Web provide an improved environment for database applications over previous client-server systems (Dai *et al.*, 1997). Java and its associated technologies provide all the necessary platform- and database-independent interfaces for such Web-based systems, making it possible to connect distributed databases (Burton and Marek, 1998). The Web has made it possible to now use a single interface to access all Internet databases (Bouguettaya *et al.*, 1999).

Users can interact with a Web-based database using their preferred browser without concern for compatibility, configuration, or additional cost. Table 2.1

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summarizes the main differences between traditional and Web-based database applications (Ju, 1997). Tools for accessing databases via the Web (Kramer, 1997) fall into three groups: Java, CGI, and ActiveX.

Traditional	Web-Based
Platform dependent	Platform independent
Client compiles and therefore executes faster	Client is an interpreter and is therefore slower
Installation necessary	No installation required
Fat client; maintenance needs incurred	Thin client; maintenance is minimized
New, unfamiliar interface	One common, familiar interface across application
Rich, custom GUI constructs possible	Limited set of GUI constructs
Difficult to integrate with existing applications	Easy to integrate with existing applications
Difficult to add multimedia	Easy to add multimedia
Persistent connection to database	Non persistent connection to database

Table 2.1: Difference Between Traditional and Web-based Database Applications (Source, Ju, 1997)

2.8.1   PostgreSQL and PostGIS

PostgreSQL is *Open Source software with an advanced database server.* PostgreSQL's ancestor was Ingres, developed at the University of California at Berkeley (1977.1985). The Ingres code was later enhanced by Relational Technologies/Ingres Corporation. PostGIS turns PostgreSQL into a spatial database by adding the three key features: spatial types, spatial indexes and spatial functions. Because PostGIS is built on PostgreSQL, it automatically inherits important "enterprise" features from PostgreSQL: Transactions have the standard ACID (atomic, consistent, isolatable, and durable) property, transaction guarantees, reliability, crash recovery, hot backup, replication, full SQL92 support (Bruce Momjian, 2001)

2.8.2 Hypertext Processor (PHP)

PHP is a server-side scripting language that can be used on a host of web servers and platforms. What server-side scripting language ensures that the script is put into the HTML files that makeup a site, and the server processes the script before it is sent to the client browser. PHP code is not visible if you view the source of a page because the server processes the code and returns only the output. PHP offers the ability to directly connect to relational databases using full featured internal functions. It supports a whole fleet of databases including Oracle, DB2, PostgreSQL and MySQL.

2.8.3 Dynamic-Map Display

The MapServers help in visualization and display dynamic of spatial maps over the Internet. Some of its major features include:

• Support for display and querying of hundreds of raster, vector, and database formats

• Ability to run on various operating systems (Windows, Linux, Mac OS X, etc.)

• Support for popular scripting languages (PHP, Python, Perl, Java, C, Ruby)

• On-the-fly projections

• High quality rendering

• Fully customizable application output

• Many ready-to-use Open Source application environments

2.8.4 Web Mapping Service (WMS)
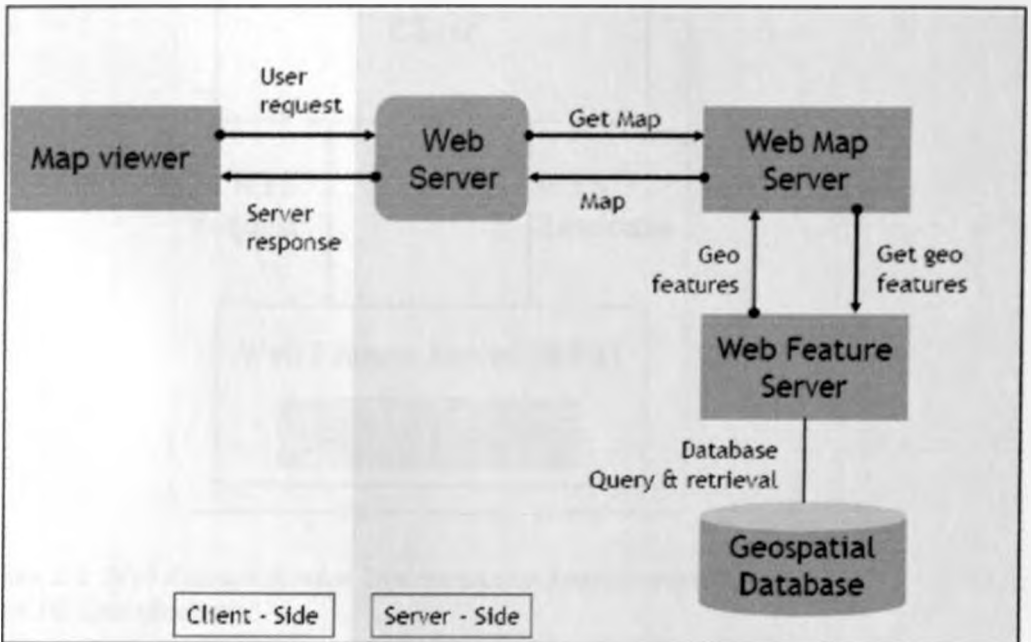
Figure 2.3: Architecture of a WMS, (Source, WMS reference, 1999)

A web mapping service is made up of the following generic components: Web client (map viewer) which is employed by users to request and receive services, the Web server receives the requests from users and relays them to the WMS (OGC document 01-068r3). The WMS creates requested map and relays it to the Web server for onward transmission to the Web client, the Web Map Server creates the requested map according to specifications and finally the Web Feature Server (WFS) and Database servers geographic features and data to be mapped. (WMS reference, 1999)

2.8.5 Web Feature Service (WFS)

The OGC Web Map Service allows a client to overlay map images for display served from multiple Web Map Services on the Internet. In a similar fashion, the OGC Web Feature Service allows a client to retrieve and update geospatial data encoded in Geography Markup Language (GML) from multiple Web Feature Services. (OGC document 04-094)

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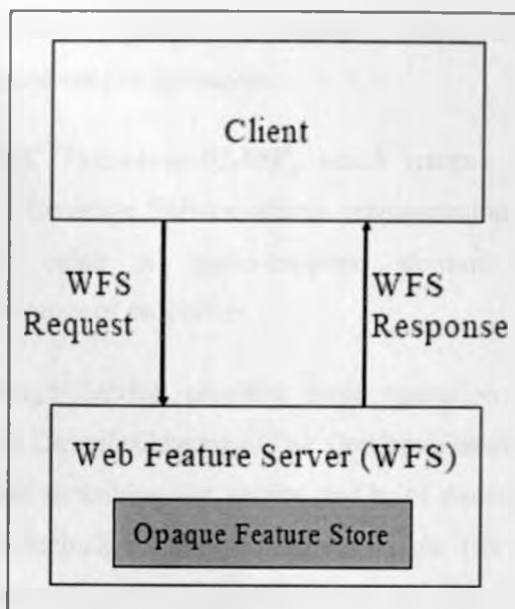
Figure 2.4: Web Feature Service Implementation Specification, (Source, OpenGIS Specification)

2.8.6 Web Coverage Service (WCS)

The Web Coverage Service (WCS) supports electronic interchange of geospatial data as "coverages" – that is, digital geospatial information representing space-varying phenomena. A WCS provides access to potentially detailed and rich sets of geospatial information, in forms that are useful for client-side rendering, multi-valued coverages, and input into scientific models and other clients. (OGC document 03-065r6)

The WCS may be compared to the OGC Web Map Service (WMS) and the Web Feature Service (WFS); like them it allows clients to choose portions of a server's information holdings based on spatial constraints and other criteria.

Unlike WMS (OGC document 01-068r3), which filters and portrays spatial data to return static maps (rendered as pictures by the server), the Web Coverage Service provides available data together with their detailed descriptions; allows complex queries against these data; and returns data with

its original semantics (instead of pictures) which can be interpreted, extrapolated, etc. and not just portrayed.

Unlike WFS (OGC Document 02-058), which returns discrete geospatial features, the Web Coverage Service returns representations of space-varying phenomena that relate a spatio-temporal domain to a (possibly multidimensional) range of properties.

The Web Coverage Service provides three operations: GetCapabilities, GetCoverage, and DescribeCoverage. The GetCapabilities operation returns an XML document describing the service and brief descriptions of the data collections from which clients may request coverages. The DescribeCoverage operation lets clients request a full description of one or more coverages served by a particular WCS server. The server responds with an XML document that fully describes the identified coverages. The GetCoverage operation of a Web Coverage Service is normally run after GetCapabilities and DescribeCoverage replies have shown what requests are allowed and what data are available. The GetCoverage operation returns a coverage (that is, values or properties of a set of geographic locations), bundled in a well-known coverage format. Its syntax and semantics bear some resemblance to the WMS GetMap and WFS GetFeature requests.

2.8.7   Web-based GIS Query and Analysis
A Web-based approach allows a user to assimilate and analyze data according to specific needs. The Web provides the capability to develop customized subsets of GIS functionality which can provide more appropriate solutions for information generators than dedicated GISs (Burk and Lime, 1997).

Display options differ in terms of the skills needed by users and providers (Kraak and Driel, 1997). Static bitmaps can be viewed simply. Indirect interaction with a map image can occur via a menu. Direct interaction with a map image can occur via mouse clicks on "hotspots" predefined areas in the

map that are linked to additional information or another image. Direct interaction allows accessing and querying the data behind the map.

Advanced analytical GIS functions, such as querying, overlaying, networking, reclassifying, and site searching, can also be provided via the Web (Dragicevic et al.,2000). Tao (2000) presents a number of examples of complex Web-based GIS analyses: *geo-spatial display* services provide zoom, pan, select, identify, layer control, and colour-style control; *geo-data access* services provide data downloading, uploading, and overlaying; *data transformation* services provide common transformation functions such as those between geographic coordinates and projected Universal Transverse Mercator (UTM) coordinates; *map annotation and symbolization* services provide useful computations such as determining the centroid of a polygon so that its attributes can be annotated; *terrain analysis* services provide interpolation algorithms along with shading and profile analysis; and *three-dimensional visualization* provides both terrain and city models.

CHAPTER THREE

3.0   METHODOLOGY

3.1.   Study Area

Samburu District covers 20,988 km^2 of some of the most arid parts of Kenya. Samburu is located in Rift Valley Province and borders Turkana to the west, Marsabit to the north, Isiolo to the east and Laikipia and Baringo to the south west (see Figure 3.1). The District is made up of 6 divisions, 35 locations and 108 sub-locations. (KNBS 2003) Samburu district has various physiographic units viz.

i)   The high parts of Leroghi Plateau and mountain ranges of Nyiru, Ndoto and Mathews. The altitude ranges between 1,500m and 2,500m above sea level (a.s.l).

ii)   The Central plains around Baragoi and Barsaloi range from 1,000m to 1,300m a.s.l.

iii)   The lowest parts of the district have an altitude of about 750m a.s.l.

Most of the district is a continuous basin which slopes towards Lake Turkana and from the Mathews range eastward to Isiolo and Marsabit. The district is classified as one of the arid districts of Kenya. However the climate of the district varies with altitude. The highest mountains receive over 1,250mm of rain per year (Swartz, *et al.,* 1992). Generally the highlands receive between 600 and 1000mm of annual rainfall. The lowlands receive between 200 and 500mm of rainfall. The rainfall is highly variable and unreliable. The rainfall is in two main seasons - long (March to May) and short (October to December). The rainfall pattern varies in the south-west with peak amounts being experienced in the months of July and August, with significant rainfall in March and November. The district is characterized by severe and recurrent droughts.

According to the range management handbook, 8% of the district is agriculturally high potential with annual rainfall of over 875mm, enough for

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production of wheat, barley and maize. This area also contains forest reserves and important watersheds which provide grazing in cases of extreme drought. The rest of the district is rangeland. The traditional form of livelihood is nomadic pastoralism.

The total district population is estimated at 143,547.00 (as per the 1999 National Census). The annual population growth rate is estimated to be 3.3%. The district has a District Steering Group (DSG) which was established through the initiative of the Arid Lands Resource Management Project (ALRMP) to strengthen sectoral co-ordination for drought management and pastoralist development activities.

Successive droughts through the 1980s and 1990s have demonstrated the vulnerability of the pastoral livelihood system to the ravages of drought. Severe droughts appear to recur every 3 to 4 years. Additional factors, such as insecurity, inaccessibility, and poor government services and infrastructure have also impacted on the strength of the pastoral economy within the district. Supporting and strengthening the pastoral livelihood system has been the target of many government and donor-supported initiatives (Schwartz.et al 1992).

The main factors associated with the water resources in Samburu District are:

- Lake Turkana at the northern edge of the district. The water is not fit for human consumption and it is difficult to access it through the rough lava terrain for livestock watering.
- Ewaso Ng'iro river- a major source of water on the southern part of the district. It is perennial for most parts in the district and is a source of water for many settlements, livestock and wildlife.
- The upper parts of the Seiya, Ngeny, Amaya, Wamba, Ngurunit and Arsim streams are perennial except for extreme drought periods.
- Springs- there are a number of springs some of which have enough yields to supply water to villages. Most of them are located in high rainfall areas.

- Other water sources include boreholes, wells, pans and dams
- In most of the district the main reliable permanent water resource is groundwater, especially associated with the shallow groundwater aquifer associated with dry riverbeds. It is also of better quality than most of the surface water sources in the district.
- Most of the district is classified as having low to medium groundwater availability.
- Ephemeral rivers provide significant water sources mainly via shallow wells. Shallow wells on seasonal rivers are the most abundant source of water in the district.
- Migration of livestock into and out of neighbouring districts. The timing and extent of migration is highly dependent on water and pasture availability, and security.

Map of Study Area
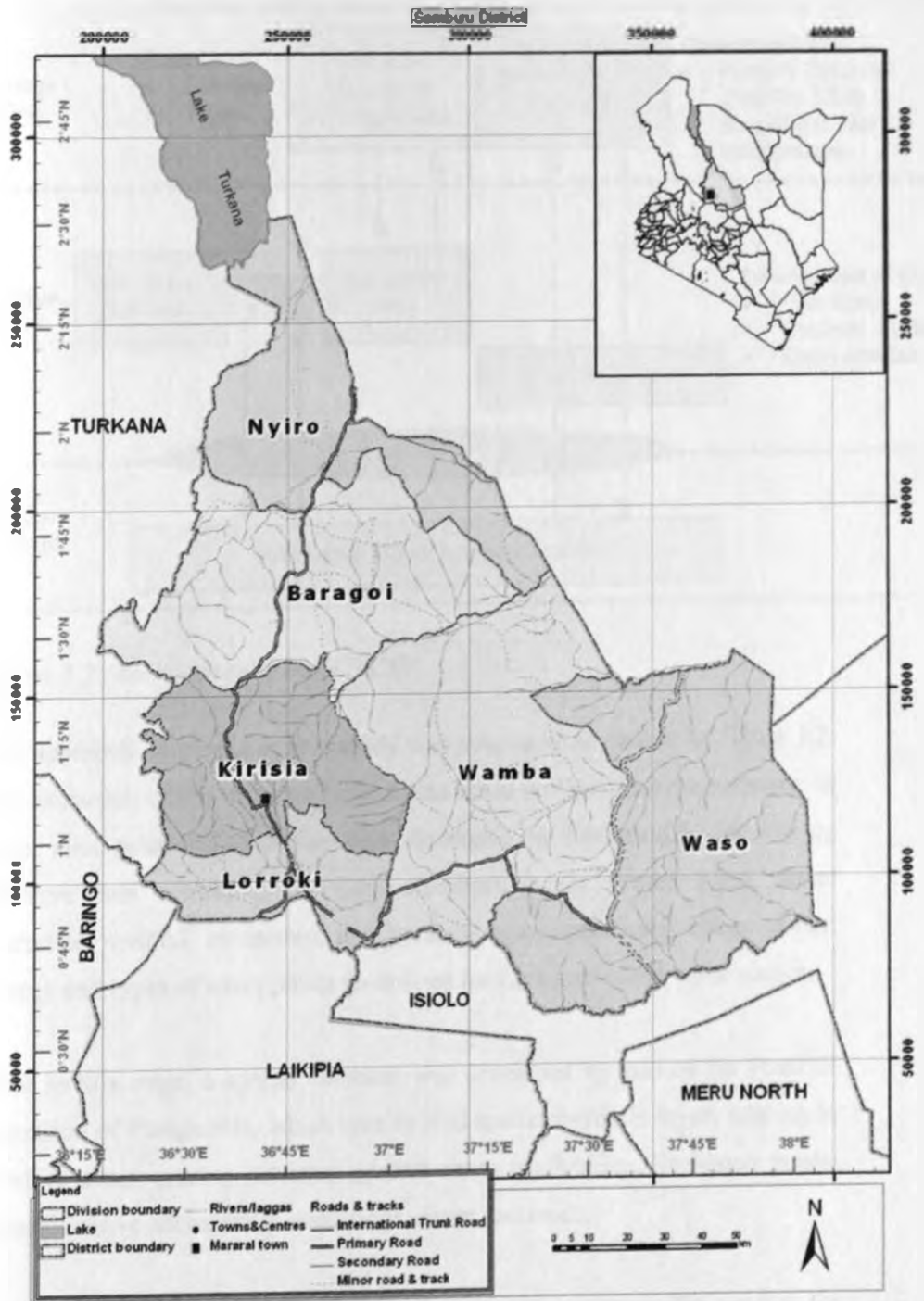
Figure 3.1: Map of Study Area.

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3.2 Project Approach
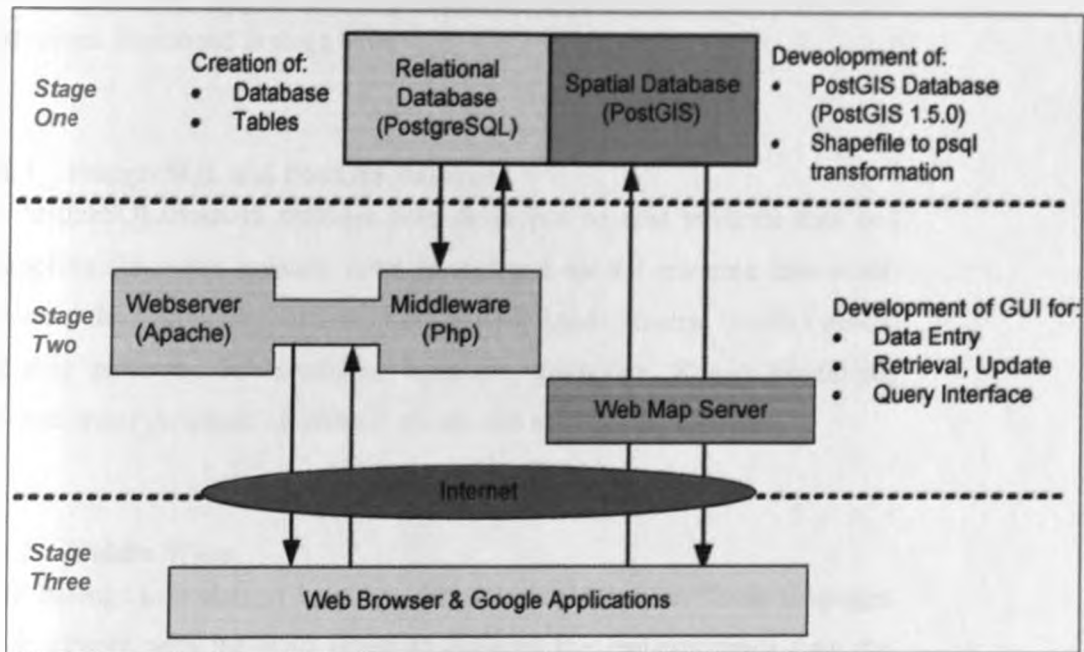
Figure 3.2: Architecture of the WBSDS.

The approach employed in this study was structured as shown in Figure 3.2. The execution of this research project was based on Open Source software. In stage one, relational database was developed in PostgreSQL for storing attribute data describing the data collectors, water source types, water extraction method, ownership, management type, operational status, donor, energy and types of water points as defined for each individual water source.

Also in this stage, a spatial database was developed by use of the PostGIS extension of PostgreSQL which was to hold spatial thematic layers relating to conflict areas, grazing patterns, ground water availability, livelihood zones, administrative zones, range conditions, rivers and roads.

In Stage two and three, server configurations was done for apache for retrieving the attribute data and displaying it on a client web page and for open geo suite for retrieving the spatial thematic data and displaying it as well on a

Web page where a client with necessary privileges' as granted by the administrator can edit the data and carry out overlay analysis via the client web pages developed in stage three.

3.2.1 PostgreSQL and PostGIS Database

A PostgreSQL/PostGIS database was developed to host attribute data and shapefiles for water sources, water related and natural resource data which included the following: water sources, Towns, Roads, Rivers, Conflict trends, Grazing patterns, Sub-locations, locations, Divisions, Range conditions, Ground water potential, Livelihood zones, and neighboring districts.

3.2.2 Middle Ware

PHP belongs to a class of languages known as middleware. These languages work closely with the Web server to interpret the requests made from the World Wide Web, process these requests, interact with other programs on the server to fulfill the requests, and then indicate to the Web server exactly what to serve to the client's browser. For this project PHP will be used for server side scripting and development of GUI for posting, getting and querying data from the PostgreSQL database and onward transmission to the Google fusion tables for display in Google Earth

3.2.3 Web Server

The Web server has what seems to be a fairly straightforward job. It runs on top of the operating system, listening for requests that somebody on the Web might make, responds to those requests, and serves out the appropriate Web pages. There are many Web servers out there, but two Web servers dominate the market. They are Apache and Microsoft's Internet Information Server (IIS). There is a certain amount of integration between the programming language and Web server. The Apache Web server like Linux, PHP, and PostgreSQL, is an open-source project. Apache web server was utilized in this project

3.2.4   Web Map Server

GeoServer was used as the map server for rendering spatial features into a web browser. It was configured with the PostgreSQL server to read spatial tables from the PostGIS database, applying of symbols and labels and displaying them on a browser. The GeoServer helped in overlaying, applying condition rules to the layers and turning layers on and off.

3.2.5   Web Client Google Chrome and Google Earth Applications

Google chrome was used as the web browser for this project (Client Side) forming the interface that hosted the GUI. Google Earth was embedded on the web browser for spatial display of maps as per user requests. Google Application programming was used for creating the embedded interface. The Internet facilitated the communication and resource allocation among the different components

3.3   Data Sources, Software and Hardware

Table 3.1: Data Sources, Software and Hardware

	Source	Remarks
PostgreSQL V8.4	http://www.postgresql.org/	Open Source
PostGIS V1.5.0	http://www.postgresql.org/	Open Source
PHP V5.0	http://www.php.net/docs.php	Open Source
OpenGeoSuite V1.1	http://www.opegeosuite.com	Open Source
Quantum GIS Encaladus	http://www.qgis.org/	Open Source
Water Sources Data	Rural Focus Ltd	No Data Fees

Table 3.1 above tabulates the software's and water sources data that was used in this research work. The software's used for this project were Open Source software. Use of Open Source software's had the following advantages: they are cost effective (free); they are been improved all the time; they are cross platform; and there is readily available support from peers worldwide.

The project was executed in a Personal computer that meets the following specifications; 2.01GHz processor speed; 3 Gigabytes (GB) of Random

Access Memory (RAM); Microsoft Windows XP operating system and hard disk storage of 80 GB and above.

3.4   Database Design

In designing and implementing the database the following steps were followed; Requirements specification, Analysis, Conceptual design, implementation design, physical schema design and optimization. In consultation with all potential users of the database state and non-state players, a data requirements document was drawn. The requirements document contained a concise and non-technical summary of what data items needed be stored in the database, and how the various data items relate to one another.

The database development design phases brought up the concept of "data models" Data models are diagrams or schemas, which are used to present the data requirements at different levels of abstraction. The first step in the Database Development Life Cycle was to draw up a requirements document. Further analysis was done to give meaning to the data items, e.g., define the more detailed attributes of the data and define constraints needed. The result of this analysis was a preliminary specifications document that was used to model how the information is viewed by the database system, how it is processed and conveyed to the end user as shown in Table 3.2. In the implementation design phase, the conceptual design was translated into a more low-level, DBMS specific design. Figure 3.3 shows the different attribute tables to be considered for the water sources and their respective attribute fields.

TABLE NAME	ATTRIBUTES
Operationalstatus	OperationalStatus ID,OperationalStatusName,
Nonoperational	NonOperational ID, WaterSource ID, OperationalStus ID, Comments
Sublocation	SLID, LocID, SLName
Location	LocID, DivID, LocName
Division	DivID, DivName
Watersourcetype	WatetSourceType ID, WaterSourceType Name
Waterextractionmethod	WaterExtractionMethodID,WaterExtractionMethodName
Donor	DonorID, DonorName
Energyused	Energy ID, EnergyName
Datacollector	DataCollector ID, DataCollectorName
Ownership	Ownership ID, OwnershipName
Managementtype	ManagementType ID, ManagementTypeName
Watersource	WatersourceID,WatersourceName,DataCollectorID,RecordNumber,DateofCollection WPserialNumber,WRMAPermitNumber,GridReflatitude,GridReflongitude Photo,SublocID,WaterSourceTypeID,Typeofwaterpoint,WaterExtractionMethodID, EnergyID,YearConstructed,DonorID,OperationalStatusID, Quantity, Quality, Reliability,HouseHoldServed,,OwnershipID,ManagementTypeID, IndicatorofMngt,IndicatorofGovernance,,FinancialMngtIndicators, PaymentSystem, Comments

Table 3.1: A Database Data Set

(The Result of analyzing the Information from the Requirements Phase. The Primary Keys are Underlined)
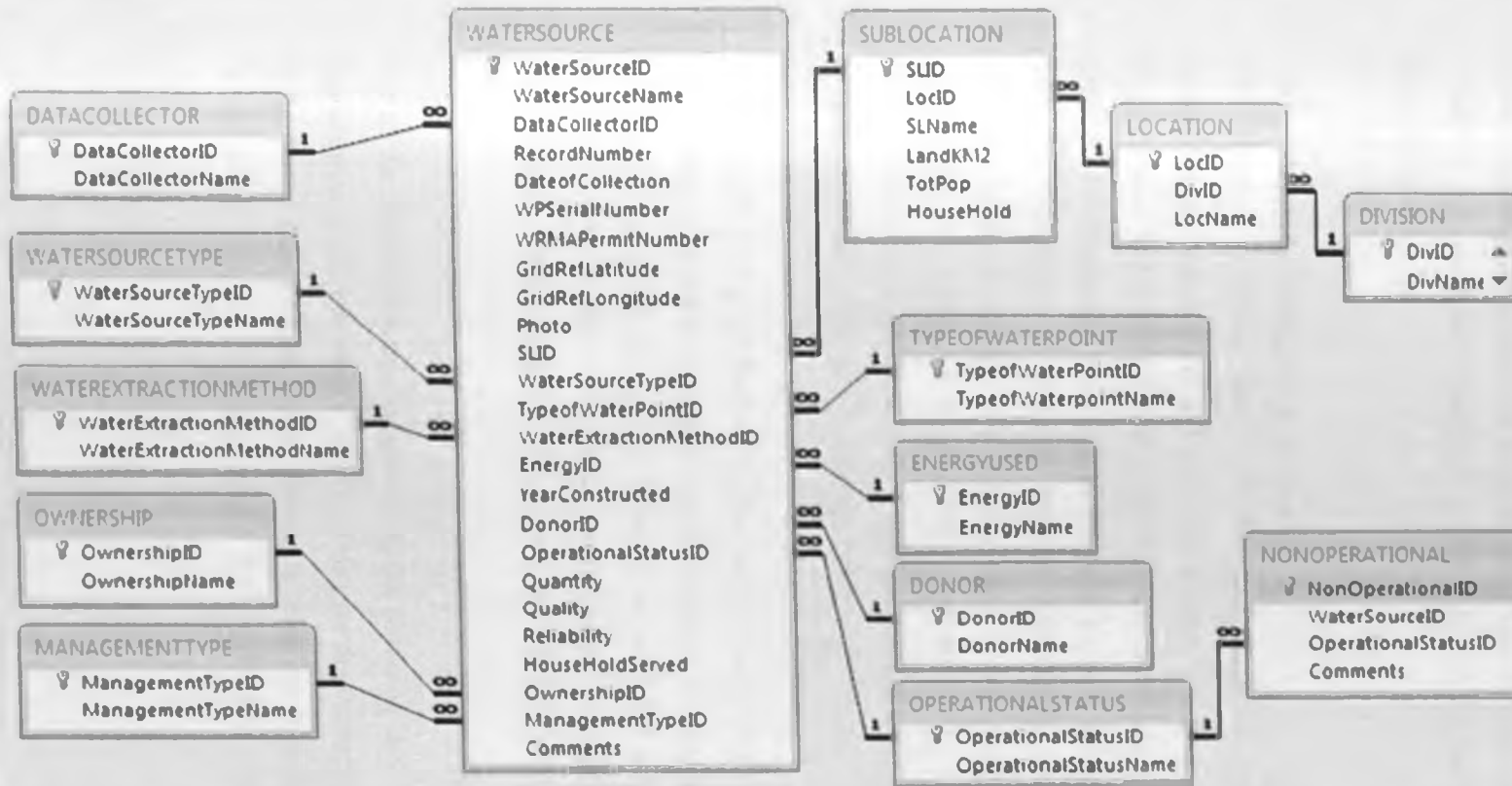
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Figure 3.1: Normalized Entity Relationship Model

(Conceptual Data Model, provides information on how the database system will eventually be implemented)

During the implementation design phase, the conceptual data model was translated into a logical representation of the database system. The logical data model conveys the logical functioning and structure of the database and describes how the data is stored (Dan *et al.*, 2007) (e.g. what tables are used, what constraints are applied but is not specific to any DBMS. Logical database model is a lower-level conceptual model, which must be translated to a physical design.

3.5   Database Design Implementation

The Physical modeling dealt with the representational aspects and the operational aspects of the database, i.e. the internal DBMS specific operations and processes and how the DBMS is to interact with the data, the database and the user. The translation from logical design to physical design was a step of assigning "functions" to both the machine (the DBMS) and to the user, functions such as storage and security, and additional aspects such as consistency (of data) and learn ability were dealt with in the physical model/schema. Practically speaking, a physical schema is the SQL code used to build the database (Benyon & Murray, 1993)

A benchmark of a good database is one which is complete, integral, simple, understandable, flexible and implementable (Moody & Shanks, 2002). Batini *et al.*, (1986) says that database modeling strives for a non redundant, unified representation of all data managed in an organization. By following the above methodology, and by using the data models, the database design ideals were fulfilled.

Use of the data models was paramount in the capturing and conveying data requirements of the information system. This gave the following advantages:
(i) By drawing up a logical model, extra data items can be added more easily in that model than in the physical model. This resulted in a database design

that can change easily according to needs of the users, because it ensures the final database system is complete and up-to-date.

(ii) Another consideration is understandability. By initially creating a conceptual model, both the designer and the users were able to understand the database design and decide if it is complete or not. If there was no conceptual model, the users would not be able to conceptualize the database design and make sure that it actually represents all the data requirements

(iii) By creating a physical model, the designers can have a low level overview of how the database system would operate before it is actually implemented.

Table 3.2: Implementation Design Phase (Source, Author 2010)

(The Conceptual data model is translated into a Logical Representation – Logical Schema of the database system as shown above. The contents rows have not been filled as the attributes are self explanatory. PK stands for Primary Key and FK for Foreign Key)

TABLE NAME	ATTRIBUTE NAME	CONTENT	TYPE	FORMAT	RANGE	PK/FK	REFERENCE
WaterSource	WatersourceID		Number(4,0)	9999	1-99	PK	
	waterSourceName		Varchar(30)	xxxxxx			
	DataCollectorID		Number(2,0)	99	1-99	FK	Datacollector
	RecordNumber		Varchar(20)	xxxxxx			
	DateofCollection		Date	dd-mm-yy			
	WPSerialNumber		Varchar(20)	xxxxxx			
	WRMAPermitNumber		Varchar(20)	xxxxxx			
	GridRefLatitude		Number(7,5)	99.99999			
	GridReflongitude		Number(7,5)	99.99999			
	Photo		Varchar(20)	xxxxxx			
	SLID		Number(3,0)	999		FK	Sub location
	WaterSourceTypeID		Number(2,0)	99	1-99	FK	Watersourcetype
	TypeofWaterPointID		Number(2,0)	99	1-99	FK	Typeofwaterpoint
	WaterExtractionMethodID		Number(2,0)	99	1-99	FK	Waterextractionmethod
	EnergyID		Number(2,0)	99	1-99	FK	Energyused
	YearConstructed		Date	yyyy			
	DonorID		Number(2,0)	99	1-99	FK	Donor
	OperationalStatusID		Number(2,0)	99	1-99	FK	Operationalstatus
	Quantity		Varchar(256)	xxxxxx			
	Quality		Varchar(256)	xxxxxx			
	Reliability		Varchar(256)	xxxxxx			

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	HouseHoldServed		Number(5,0)	99999	1-99999		
	OwnershipID		Number(2,0)	99	1-99	FK	Ownership
	ManagementTypeID		Number(2,0)	99	1-99	FK	Managementtype
	IndicatorofMngt		Varchar(50)	xxxxxx			
	IndicatorofGovernance		Varchar(50)	xxxxxx			
	FinancialMngtIndicators		Varchar(50)	xxxxxx			
	PaymentSystem		Varchar(50)	xxxxxx			
	Comments		Varchar(256)	xxxxxx			
Sublocation	SLID		Number(3,0)	999		PK	
	LocID		Number(3,0)	999		FK	Location
	SLName		Varchar(50)	xxxxxx			
	Landkm^2		Number(6,3)	999.999			
	Male		Number(5,0)	99999	1-99999		
	Female		Number(5,0)	99999	1-99999		
	TotPop		Number(6,0)	999999	1-999999		
	HouseHoldS		Number(5,0)	99999	1-99999		
	Density		Number(4,2)	99.99			
	PersonsPerHH		Number(2,0)	99	1-99		
	DomesticWaterDemand (m^{3}perday)		Number(4,2)	99.99			
	LivestockWaterDemand(m3perday)		Number(4,2)	99.99			
	GrowthRateCorrection		Number(4,2)	99.99			
	CorrectedPop		Number(6,0)	999999	1-999999		
Operationalstatus	OperationalStatus ID		Number(2,0)	99	1-99	PK	
	OperationalStatusName		Varchar(50)	xxxxxx			
Nonoperational	NonOperational ID		Number(2,0)	99	1-99	PK	
	WaterSource ID		Number(2,0)	99	1-99	FK	

	OperationalStus ID		Number(2,0)	99	1-99	FK	Operational
	Comments		Varchar(256)	xxxxxx			
Location	LocID		Number(3,0)	999		PK	
	DivID		Number(2,0)	99	1-99	FK	Division
	LocName		Varchar(50)	xxxxxx			
Division	DivID		Number(2,0)	99	1-99	PK	
	DivName		Varchar(50)	xxxxxx			
Watersourcetype	WatetSourceType ID		Number(2,0)	99	1-99	PK	
	WaterSourceType Name		Varchar(50)	xxxxxx			
Waterextractionmethod	WaterExtractionMethodID		Number(2,0)	99	1-99	PK	
	WaterExtractionMethodName		Varchar(50)	xxxxxx			
Donor	DonorID		Number(2,0)	99	1-99	PK	
	DonorName		Varchar(50)	xxxxxx			
Energyused	Energy ID		Number(2,0)	99	1-99	PK	
	EnergyName		Varchar(50)	xxxxxx			
Datacollector	DataCollector ID		Number(2,0)	99	1-99	PK	
	DataCollectorName		Varchar(50)	xxxxxx			
Ownership	Ownership ID		Number(2,0)	99	1-99	PK	
	OwnershipName		Varchar(50)	xxxxxx			
Managementtype	ManagementType ID		Number(2,0)	99	1-99	PK	
	ManagementTypeName		Varchar(50)	xxxxxx			

3.6   SQL Statements -Implementing the Databases

The final step is to physically implement the logical design which illustrated in Table 4.2. To physically implement the database, SQL was be used. These are the main steps that were followed in implementing the database:

1. Creating the Database Tables.

The tables came directly from the information contained in the data dictionary as shown in Table 4.2. The following blocks of code each represent a row in the data dictionary and are executed one after another. The blocks of "create table" code contain the details of all the data items (WATERSOURCE, TYPEOFWATERPOINT, ENRGYUSED, DONOR, OPERATIONASTATUS, NONOPERATIONAL,DATACOLLECTOR, WATERSOURCETYPE, WATEREXTRACTIONMETHOD, OWNERSHIP, MANAGEMENTTYPE etc) and their attributes. The relationships between the data items, the keys and data integrity rules information detailed in Table 3.3 and Figure 3.3 were converted to and implemented into a physical database system.

An Example of the Sublocations Table;

```
CREATE TABLE "Sublocations"
(
   gid serial NOT NULL,
   slname character varying(19),
   areakm2 number (6, 2),
   slid smallint,
   locid integer,
   totpop number (5, 0),
   household number (4, 0),
   the_geom geometry,
   CONSTRAINT "Sublocations_pkey" PRIMARY KEY (gid),
   CONSTRAINT enforce_dims_the_geom CHECK (st_ndims(the_geom) = 2),
```

CONSTRAINT enforce_geotype_the_geom CHECK (geometrytype(the_geom) = 'MULTIPOLYGON'::text OR the_geom IS NULL),

CONSTRAINT enforce_srid_the_geom CHECK (st_srid(the_geom) = 4326)

)

WITH (

OIDS=FALSE

);

ALTER TABLE "Sublocations" OWNER TO postgres;

Explanation:

a) The create table statement indicates that you want a table to be created.

b) The name of the table precedes the first (

c) The table attributes and data integrity rules are defined within the two parentheses. How the table relates to other tables is also defined within the two parentheses (e.g. by defining FOREIGN KEYS)

d) The not null statement means that if you try to populate the table with values, but leave the value of that attribute empty, you will get an error.

e) The character varying means a string of a maximum of 19 characters.

f) The number (6, 2) means a number which can have a number of up to 6 digits, 2 of them being after the decimal place, e.g. you can have a number from 0.0 to 1234.56.

g) The date means that that attribute will be represented as a date within the database system.

h) The CONSTRAINT statement means that a constraint is being defined. This statement will be used to describe which of the attributes are primary keys and which (if any) of the attributes are foreign keys (referencing another table).

i) The CONSTRAINT statement is in the form CONSTRAINT xxx PRIMARY

KEY(name_of_attribute_that_you_want_as_the_primary_key)

or CONSTRAINT yyy FOREIGN

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KEY(name_of_attribute_that_references_another_table) REFERENCEShhh(n
ame_of_attribute_that_references_another_table) where the values of xxx and
yyy are just arbitrarily made up names which are not important. hhh is the
name of the base table being referenced. Also constrained is the geometry of
the feature and the spatial reference system by the statements; CONSTRAINT
enforce_dims_the_geom CHECK (st_ndims(the_geom) = 2),

CONSTRAINT   enforce_geotype_the_geom   CHECK
(geometrytype(the_geom) = 'MULTIPOLYGON'::text OR the_geom IS
NULL),

CONSTRAINT enforce_srid_the_geom CHECK (st_srid(the_geom) = 4326)
where CHECK (st_ndims(the_geom) = 2), checks whether the geometry of the
feature is a polygon and CHECK (st_srid(the_geom) = 4326) ensures that the
coordinate system is WGS 84

2. Populating the Tables.

SQL statements were used to populate each table with relevant data derived
from the Samburu District water MIS. Figures 4.1 and 4.2 illustrate the criteria
used to populate the spatial tables from the respective shapefiles using the
shapefile to PostGIS importer plug-in in PostgreSQL V8. Information and
knowledge about the different data contained in the RDBMS about water
points in Samburu District can be derived by overlaying them with other
thematic layers for enhanced information on the water situation among other
multi criteria information touching on the area of study e.g., overlaying
operational water sources with range conditions, grazing patterns, ground
water availability, livelihood zones etc.

3. Spatial Layers

The spatial thematic layers were imported into the PostGIS database using the
shp2psql plug-in of PotgreSQL. This helped in importation of the following
layers: Administrative Units (Sub Locations, Locations, Divisions and
Districts), Rivers, Roads, Livelihood Zones, Grazing patterns, Conflict areas,
Range conditions, Water sources and Ground water potential. These layers

could be overlaid leading to information on how various factors relate with one another and portraying different scenarios related to water sources, livelihood and pasture conditions in the area of study

CHAPTER FOUR

4.0   RESULTS AND DISCUSSION

4.1   Introduction

This chapter gives a detailed description of the how the project objectives were achieved. This chapter also outlines the results of the approaches used in developing the relational DBMS. Graphical User Interface. Data migration to the developed system, Database and server connections and configuration and eventual testing of the system. The primary method of implementation was to design, develop, and test a prototype system for data management, acquisition and visualization.

4.2   Database Design Results

Figure 4.1 below illustrates the different database tables created using the methodology adopted as outlined in chapter 3 for both the relational and spatial tables in a database named project.

From figure 4.1, the number of database tables developed was as follows;

- 12 tables for storing spatially referenced features which included the following features; roads, rivers, range condition, ground water potential, towns, neighboring Districts, divisions, locations, sub locations, livelihood zones, grazing patterns and conflict areas.

- 11 tables for storing attribute information and they included the following; water source, Data collector, donor, energy used, management type, type of water point, ownership, water source type, water extraction method operational and non operational status.

- 2 tables were programme generated for storing information relating to geometry of the spatial features (polygon, lines and points) and their spatial reference system
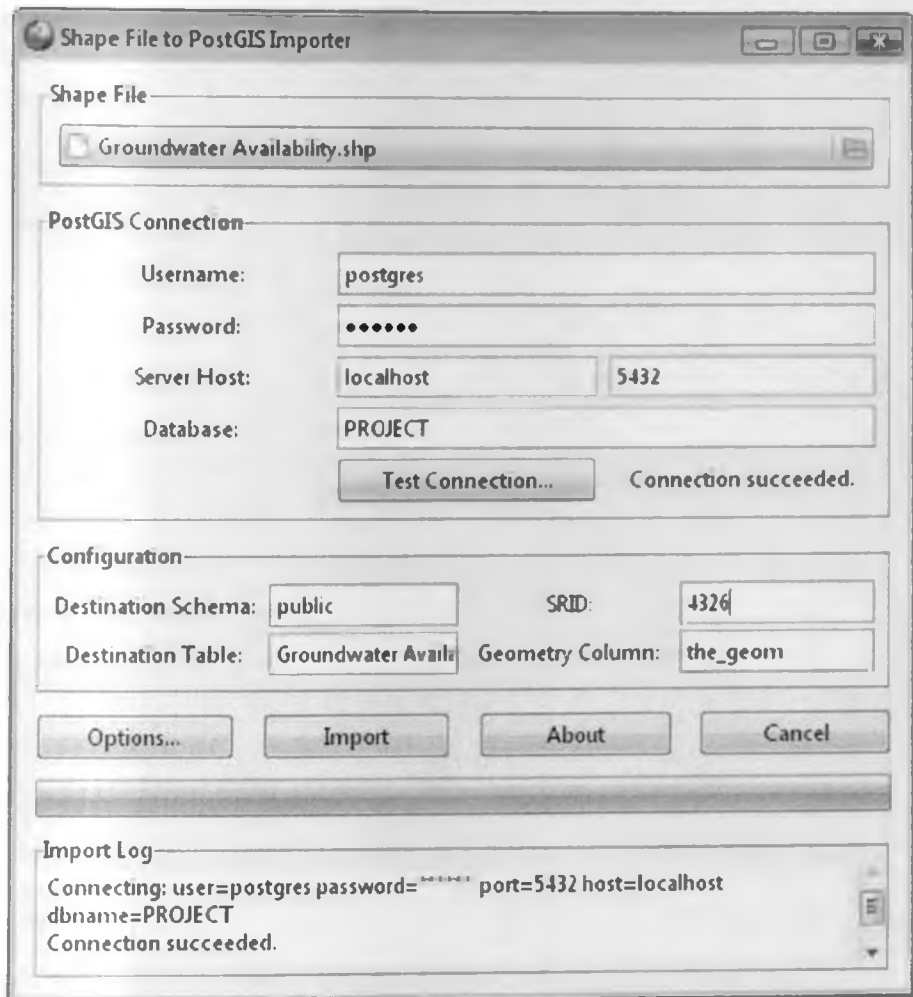
Figure 4.1: The PostGIS Database Developed

Figure 4.2: Importing of Shapefiles to PostGIS Database

Figure 4.3: Parameters Required for Importing Shapefiles

After the Spatial layers were imported into PostGIS, a server connection was established between PotgreSQL server and GeoServer to help in spatial rendering of these layers in a web environment. The PotgreSQL server was used as the database server for this application whereas GeoServer was used as the map server for rendering of spatially referenced features to a web browser. This connection was made possible by developing a Workspace and a Data Store respectively in the GeoServer for caching data retrieved from the PostgreSQL database.

Figure 4.4 shows how the GeoServer – PostGIS connection was established and figure 4.5 outlines the process followed in publishing the spatial layers in GeoServer

Create PostGIS Connection

Connect to a PostGIS database

Workspace*
Select a workspace for this connection or create a new workspace

ProjectWorkspace ▾

Name *

Samburu Water MIS

Description

Connection Parameters

Connection type *

Default ▾

Host *   **Port ***

localhost   5432

Database *

PROJECT

User name *

postgres

Password

••••••

▸ **Connection pooling**

Other parameters

Database Schema

public

☐ Exclude tables that don't contain spatial information
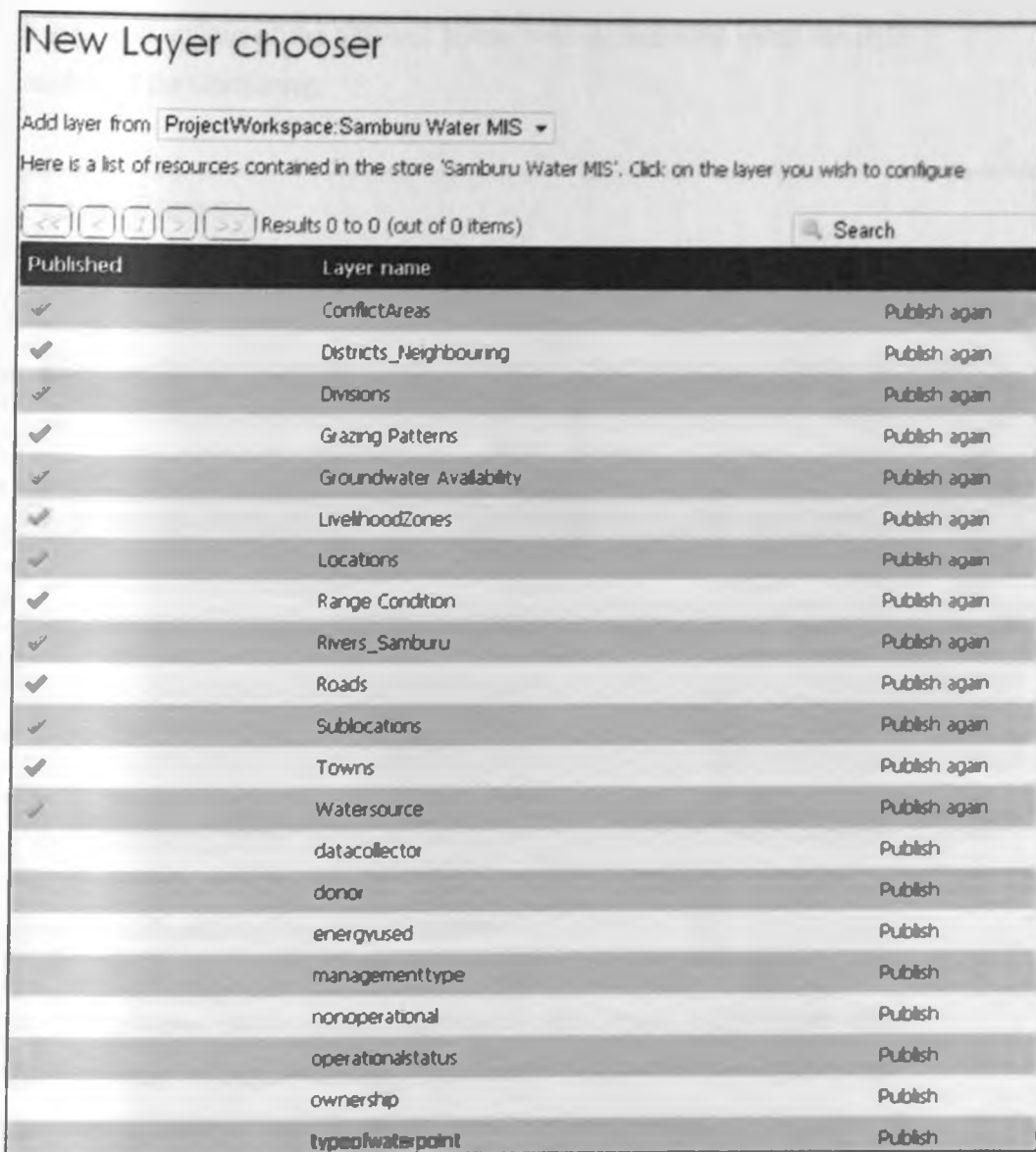
▸ **Advanced**

Figure 4.4: GeoServer – PostGIS Connection Setup

New Layer chooser

Add layer from ProjectWorkspace:Samburu Water MIS ▾

Here is a list of resources contained in the store 'Samburu Water MIS'. Click on the layer you wish to configure

◁◁ ◁ 1 ▷ ▷▷ Results 0 to 0 (out of 0 items)		Search
Published	**Layer name**	
✓	ConflictAreas	Publish again
✓	Districts_Neighbouring	Publish again
✓	Divisions	Publish again
✓	Grazing Patterns	Publish again
✓	Groundwater Availability	Publish again
✓	LivelihoodZones	Publish again
✓	Locations	Publish again
✓	Range Condition	Publish again
✓	Rivers_Samburu	Publish again
✓	Roads	Publish again
✓	Sublocations	Publish again
✓	Towns	Publish again
✓	Watersource	Publish again
	datacollector	Publish
	donor	Publish
	energyused	Publish
	managementtype	Publish
	nonoperational	Publish
	operationalstatus	Publish
	ownership	Publish
	typeofwaterpoint	Publish

Figure 4.5: Publishing Layers

Using the dialogue shown in Figure 4.5 only tables containing Spatial features in the RDBMS were selected to be published into the GeoServer workspace created. This is because only spatial features can be rendered by the map server. This makes the data flow between the two servers to be effective and thus the rendering of this layers geometry in the web browser. By using the GeoServer, the spatial layers can be previewed in either open layers or Google

Earth, with styling of the different layers been implemented using the styler module of the GeoServer.

Layer Preview

List of all layers configured in GeoServer. Click the links to preview the layer in OpenLayers, Google Earth, or choose Styler to interactively edit the layer style.

		Results 1 to 13 (out of 13 matches from 33 items)		projectworkspace		
Type	Name		Title			
	ProjectWorkspace:ConflictAreas		ConflictAreas	OpenLayers	Google Earth	Styler
	ProjectWorkspace:Districts_Neighbouring		Districts_Neighbouring	OpenLayers	Google Earth	Styler
	ProjectWorkspace:Divisions		Divisions	OpenLayers	Google Earth	Styler
	ProjectWorkspace:Grazing Patterns		Grazing Patterns	OpenLayers	Google Earth	Styler
	ProjectWorkspace:Groundwater Availability		Groundwater Availability	OpenLayers	Google Earth	Styler
	ProjectWorkspace:LivelihoodZones		LivelihoodZones	OpenLayers	Google Earth	Styler
	ProjectWorkspace:Locations		Locations	OpenLayers	Google Earth	Styler
	ProjectWorkspace:Range Condition		Range Condition	OpenLayers	Google Earth	Styler
	ProjectWorkspace:Rivers_Samburu		Rivers_Samburu	OpenLayers	Google Earth	Styler
	ProjectWorkspace:Roads		Roads	OpenLayers	Google Earth	Styler
	ProjectWorkspace:Sublocations		Sublocations	OpenLayers	Google Earth	Styler
	ProjectWorkspace:Towns		Towns	OpenLayers	Google Earth	Styler
	ProjectWorkspace:Watersource		Watersource	OpenLayers	Google Earth	Styler
		Results 1 to 13 (out of 13 matches from 33 items)				

Figure 4.6:Preview of Layers in GeoServer

Figure 4.6 above shows already published spatial layers in GeoServer where the layers can be explored using Open layers, Google Earth or styler in open geo suite. Figure 4.7 and 4.8 below illustrates the process of symbolizing the spatial layers with equivalent functionalities like desktop GIS and the process of selecting layers that will be available for overlay analysis in a client web page respectively

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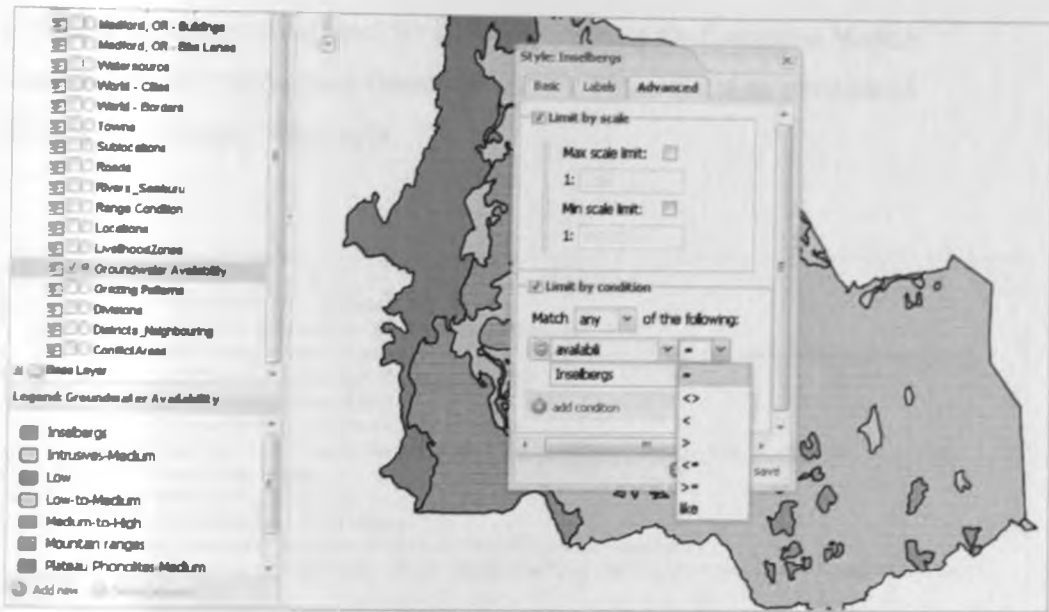
Figure 4.7: Symbolizing Layers in GeoServer
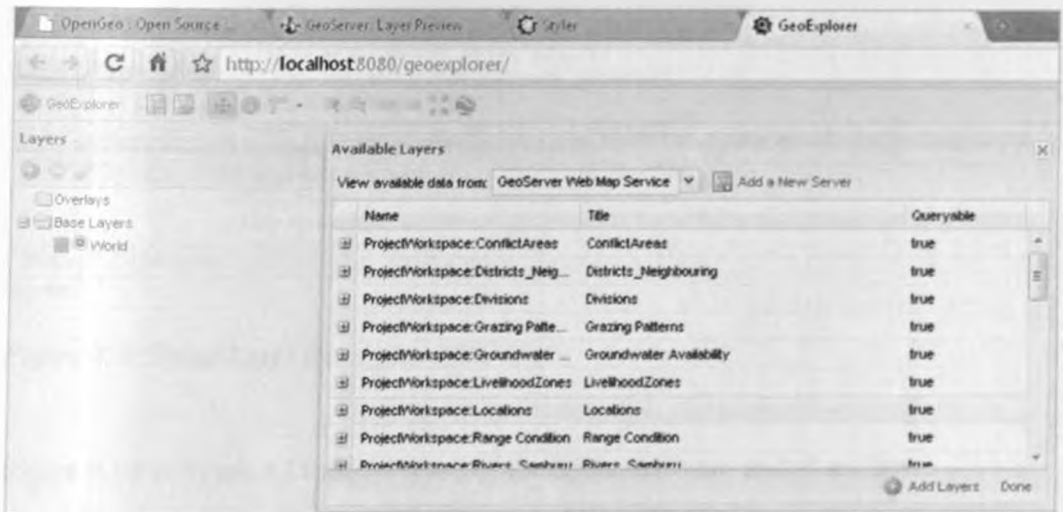
Figure 4.8: Selecting Layers for Overlays

To enforce data security of spatial data to be rendered over the internet using the map server (GeoServer), data access rules were set to read access mode to clients and write access mode to the administrator who can alter the spatial layers as required by the clients. The administrator can also set service access rules, managing of users and catalog security.

Different styles were developed for all the layers using the Extensible Markup Language (XML) Style layer Descriptor (SLD). Figure 4.9 is an example an SLD script for towns' layer style.

Figure 4.9: Styled Layer Descriptor XML script

Figure 4.10 to figure 4.14 shows some of the layers that were styled and how they will appear in the client web page
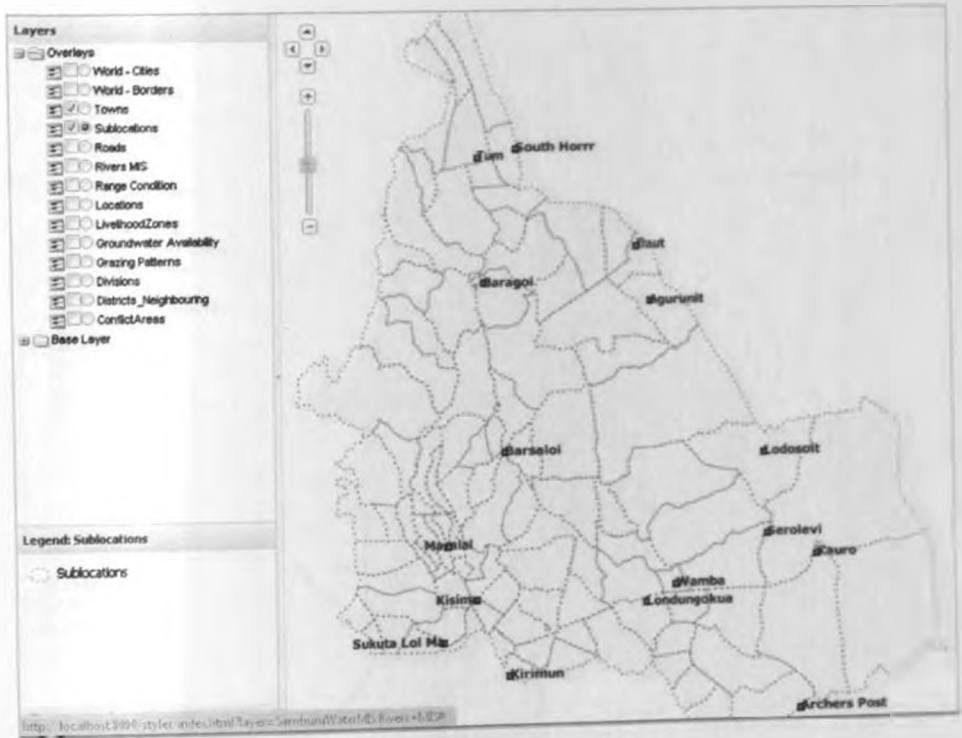
Figure 4.10: Layer Style for Towns and Sub-locations
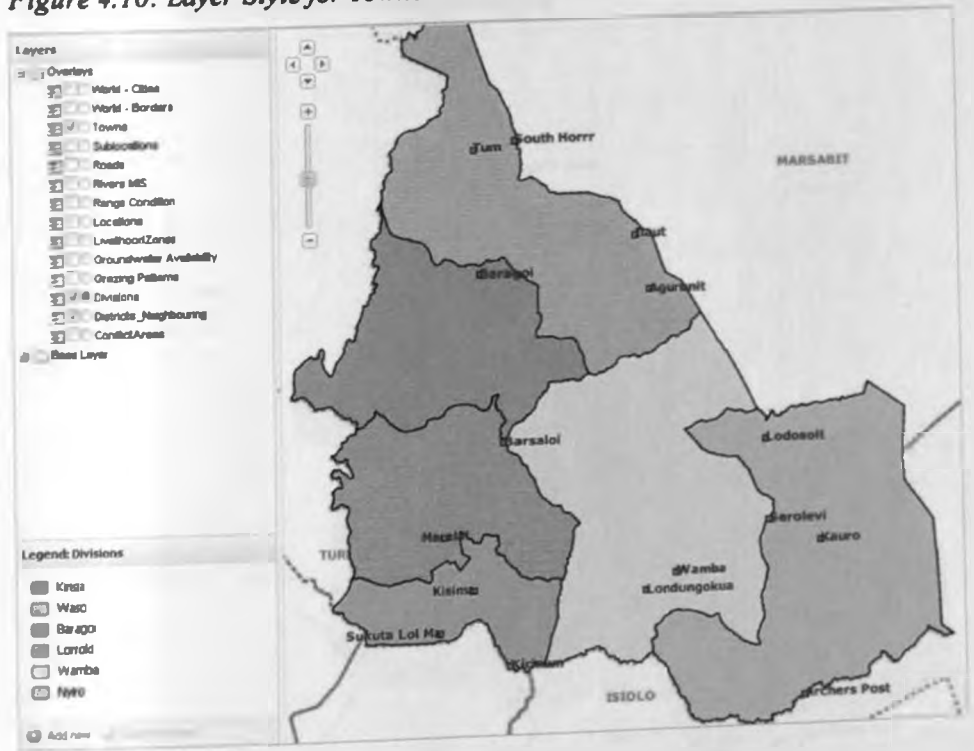
Figure 4.11: Layer Style for Divisions
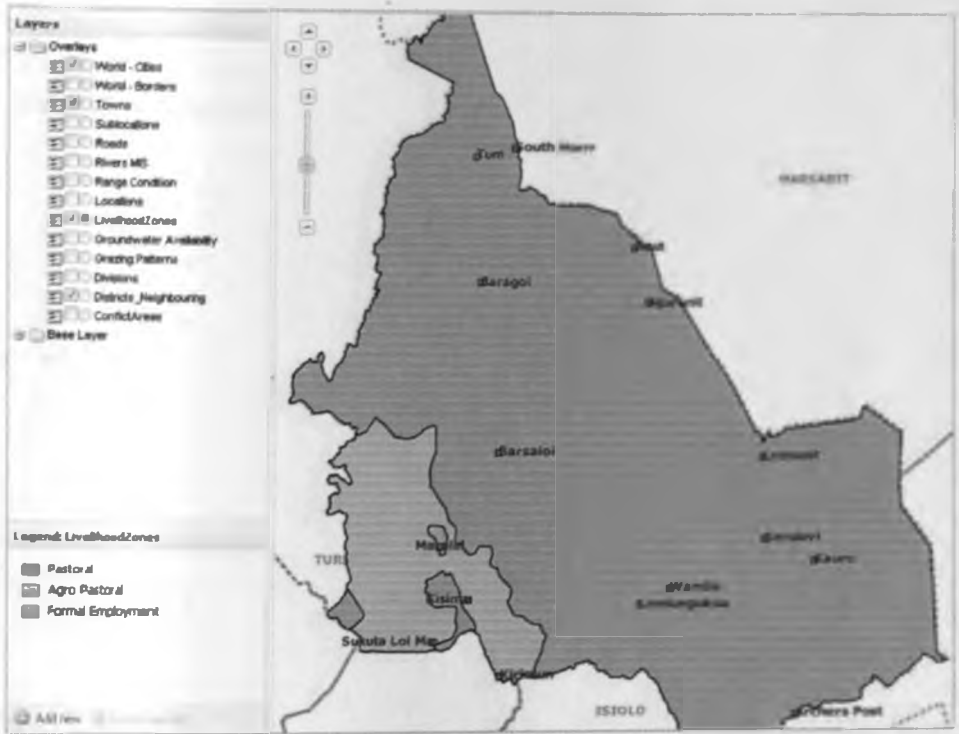
Figure 4.12: Layer Style for Livelihood Zones
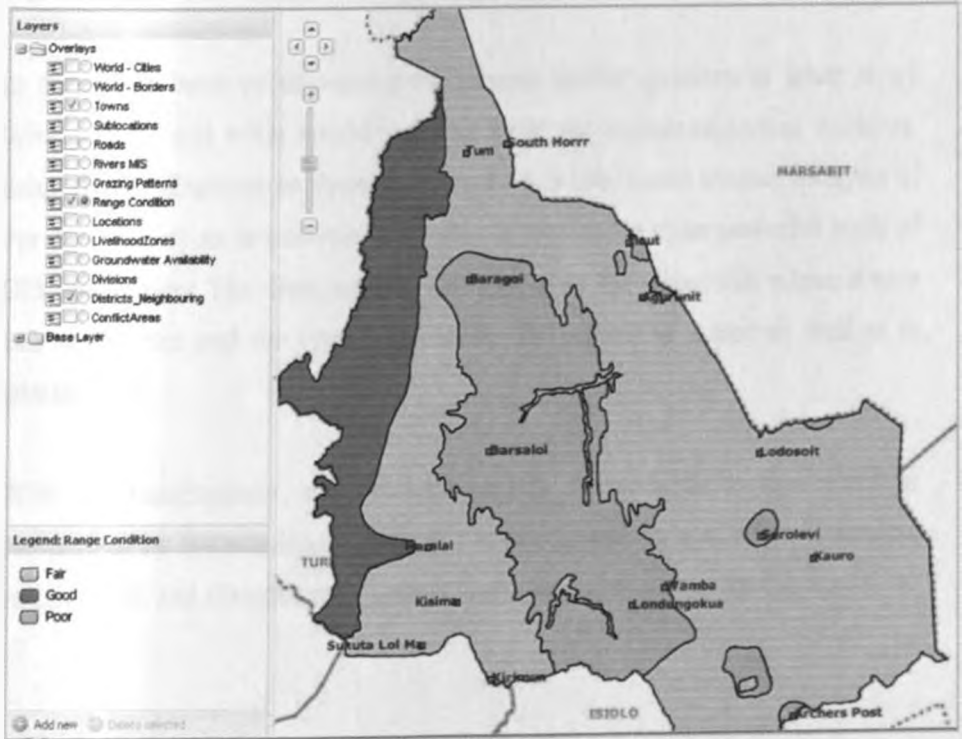
Figure 4.13: Layer Style for Range Condition
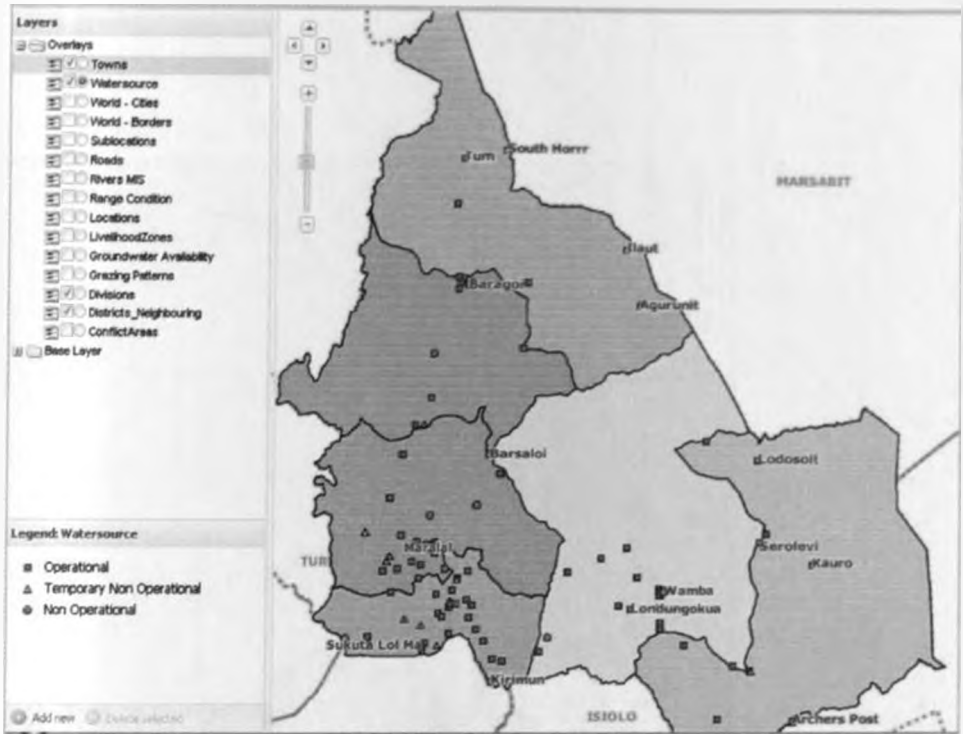
Figure 4.14: Layer Style for Water Sources

In forming a basis of answering the generic spatial question of what is at? Where is it? and what spatial patterns exist for enhanced spatial decision, using the GeoExplorer as show in figure 4.15, a user based overlay analysis of the thematic layers is possible as overlay is one of the most powerful tools of GIS applications The GeoExplorer was tagged in the client side where a user can run queries and the system returns results inform of a map as well as in tabular form.

With the GeoExplorer, an elaborate legend is available to the client as customized by the administrator, with a set of layer overlays, zoom functions, enquiry tool, and distance measurement on a background map of the world.
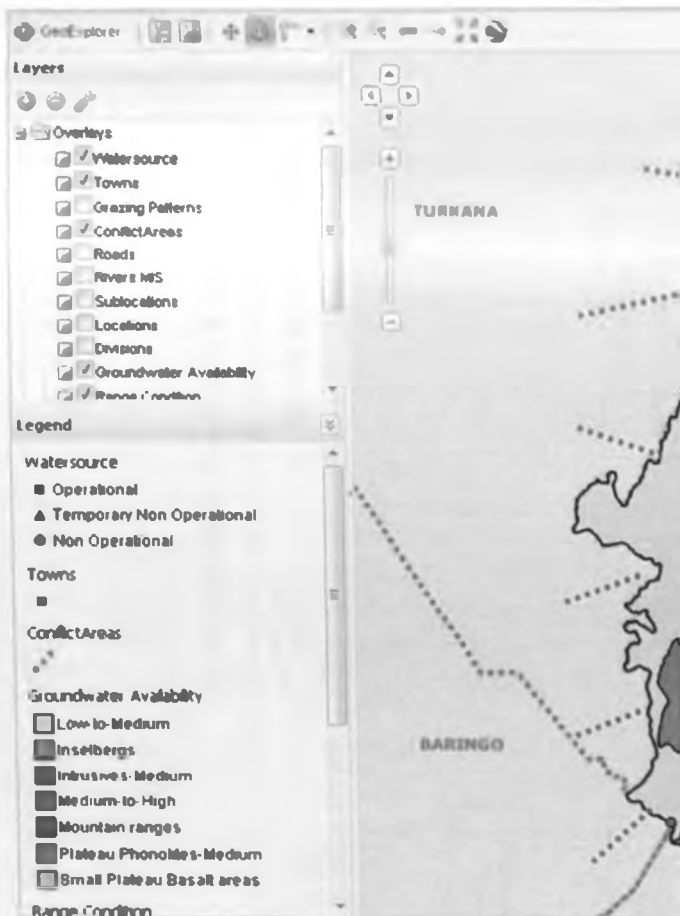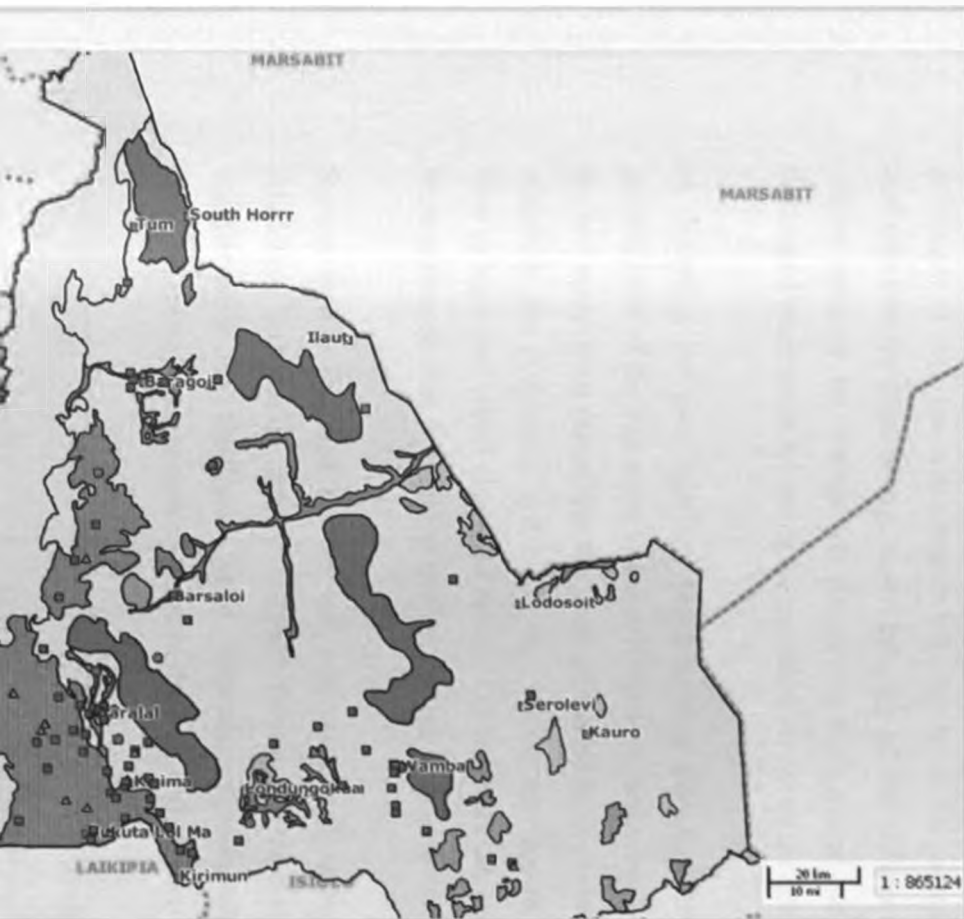
Figure 4.15: A Map View of GeoExplorer

4.3 Graphic User Interface Design

Using PHP, user interfaces were designed for use by both the database administrator and the client. There was a clear separation of access levels and privileges to both the administrator and user level. The administrator could add data into the database e.g., a new category of data collector, donor, water source category etc whereas on the on the hand a user can add a newly developed water point following the provision set out by the administrator.

In designing the user interface, the following considerations were made; Involvement of the end users in the development, designing the interface for the end users needs rather than the needs perceived by the developer, flexible, adaptable and updateable system, an easy to use interface requiring limited time to learn and visual display of results. Other factors that were considered were system quality, information quality, and information presentation.

System quality included ease of use, convenience of access, and system reliability, information quality included information relevance, accuracy, completeness and timeliness while information presentation related to graphics, colour, presentation style and navigational efficiency.
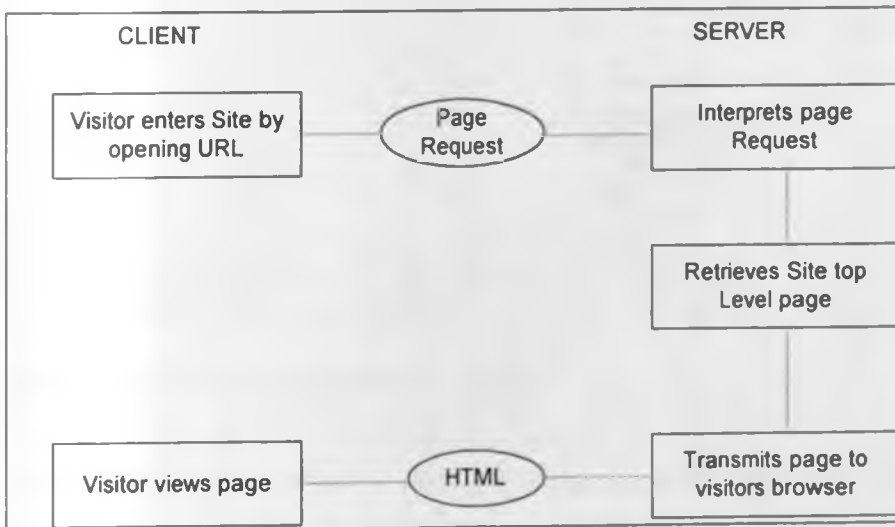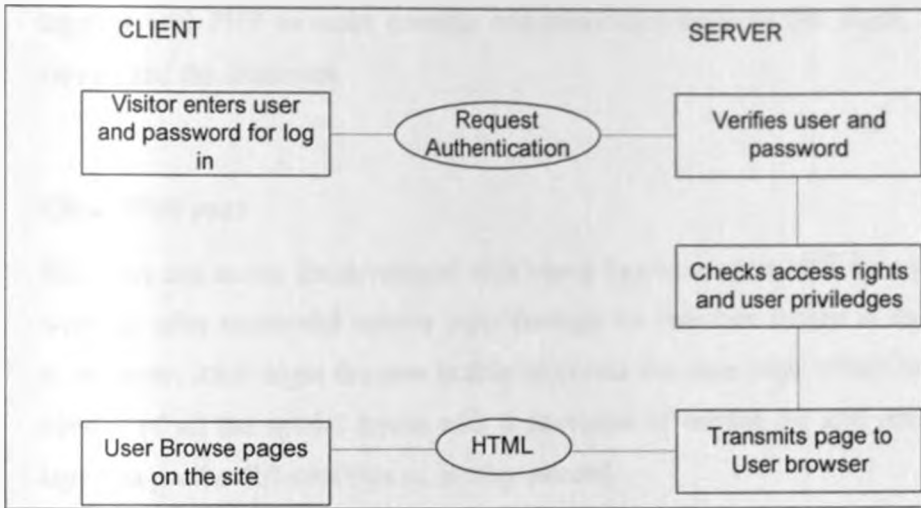

Figure 4.16: Conversation Scenario A in CGI
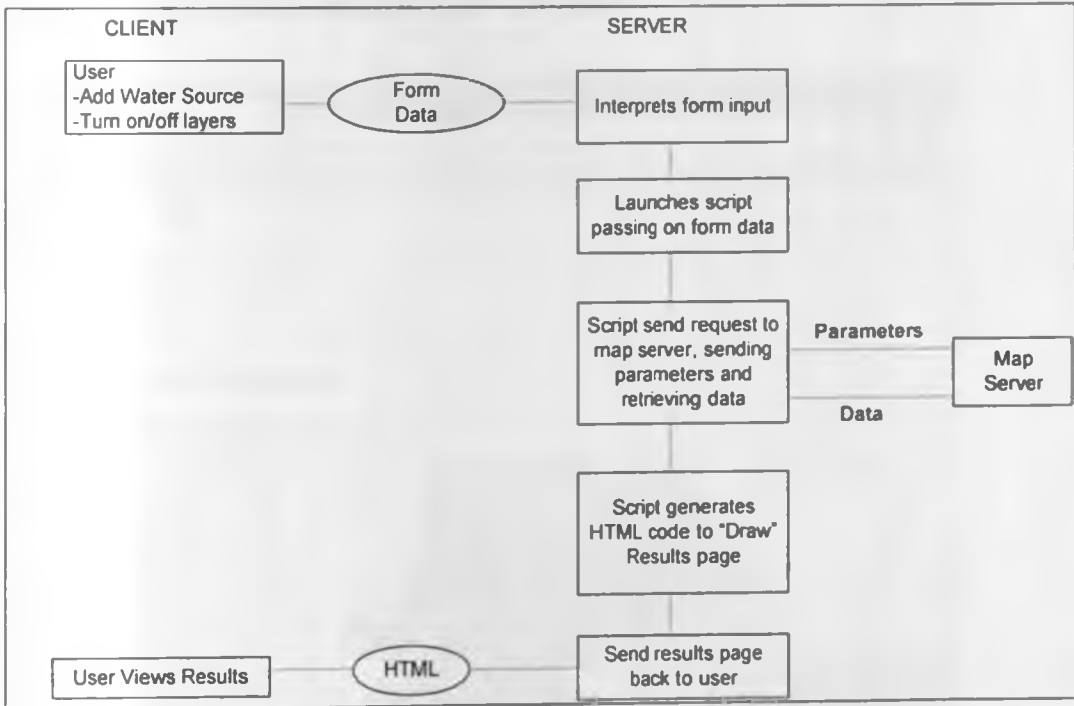
Figure 4.17: Conversation Scenario B in CGI

Figure 4.18: Conversation Scenario C in CGI

Figures 4.16 through to figure 4.18 above displays in a schematic view how the requests and responses are implemented using HTML which is used

together with PHP to make possible communication between the client, the servers and the databases.

Client Web page

The users can access the developed Web based Samburu water MIS through a webpage after successful session login through the interface shown in figure 4.19 below. After login the user is able to access the main page which has a display of all the spatial layers with a provision of turning on and off the layers as per the different type of overlay needed.

The water sources are styled as points and categorized as either operational, Temporary operational and permanently operational and they appear overlaid on the spatial layers as shown in figure 4.20 below
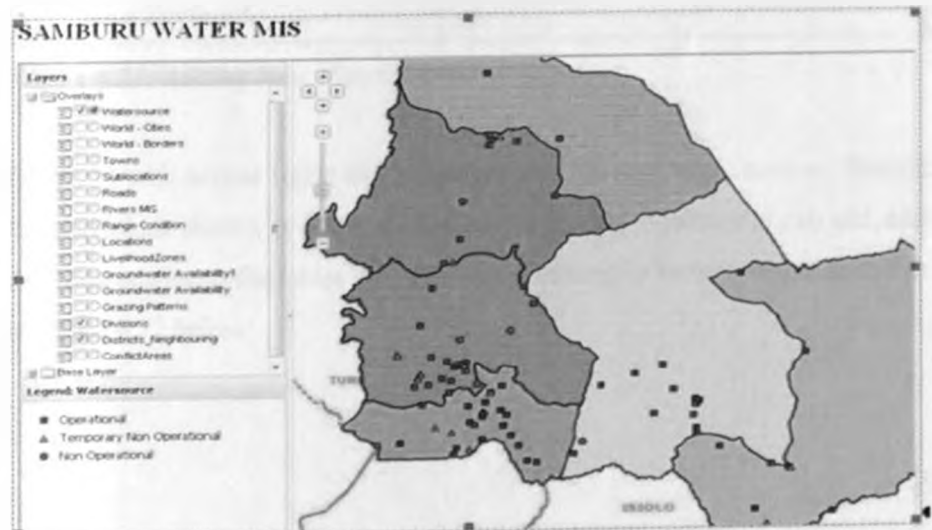

Figure 4.19: User Login

Figure 4.20: The Web map Page

Figure 4.21: Adding New Water Source

For users with access rights and privileges can add new water sources through the provisions shown in figure 4.21, whereas the administrator is can add, edit or delete entries to the tables with attributes relating to water sources as shown in figure 4.22 below

```
            Data Collectors
  Add Data Collector
  # Data Collector Name
  1 WSB              Edit Delete
  2 WSP              Edit Delete
  3 GOK              Edit Delete
  4 NGO              Edit Delete
  5 CBO              Edit Delete
  6 Contractor       Edit Delete
  7 Individual       Edit Delete
  8 Other            Edit Delete
```

Figure 4.22: Adding, Editing and Deleting Water Sources Attribute Data

4.4   Discussion of Results

The results of the various activities carried out during the study are presented. The discussions of results are organized first according to the problems identified and the objectives established in chapter 1.

i. Web enabled Database Management System (DBMS) for water sources in Samburu District

This research has demonstrated an approach to develop a web enabled DBMS complete, integral, simple, understandable and flexible to use under different web environments enforcing both entity and referential integrity rules. This has been made possible by the postgreSQL which is Open Source database software with spatial enhancement from postGIS extension. The database developed was configured to be accessible by web application by using the PotgreSQL server as the application data server. Use of open, modular architecture, allowed for ease of upgrading of component modules as well as addition of new modules in response to changing needs with time.

ii. To create a web enabled geo-spatial database for water related data, natural resource and socio-economic for Samburu District

This research has further demonstrated a method to develop a spatial web enabled database using PostGIS extension of postgreSQL. This helped in developing of the spatial database and importing of the relevant spatial features that were been considered for this research work. This provided a foundation application with tools and a high level of integration with the web environment. GeoServer was used as a web map server for rendering the spatial features for enhanced visualization in a browser. This coupling provides an intuitive visualization and spatial-analysis functions that are not available in traditional simulation models. The advantages of such integration are: Full integration of GIS functionality for manipulation of input and results and no redundancy or consistency problems due to several instances of the same database as well as ease to maintain and update within the web environment using quantum GIS.

iii. **To design a web-based user interface for entering, updating and querying archived and collected data on water sources in Samburu District.**

An important objective was to design a web-based user interface for use in updating and querying archived data on water sources in Samburu District. A prototype GUI running on a web page was designed to allow users to access and interact with a water source data from Samburu District Water MIS directly over the Web. The prototype demonstrates that Web-based GISs and GUI are useful vehicles for accessing distributed spatial and non spatial data and conducting GIS processing and spatial visualization among a particular user community. The Geographic and physical constraints are removed, and the need is reduced for users to own the data or software system. The public can interact with processed data, such as the output of a water source functionality map and other thematic overlays regarding public access, quality, quantity, reliability and participation in updating the data to make it more reliable as a basis of planning and decision making.

A study reported by Princeton Economic Research and Haklay in (1998) demonstrates that public interest in processed data is far greater than in raw

data. Accessibility was achieved because of user interface familiarity, portability across many computer platforms, and the capability to display different multimedia and hypermedia formats. Insight into the applicability of Web-based GISs in developing open Spatial Decision Supporting Systems (SDSSs) has been gained. A decision-making process for solving spatial problems demands significant input from the public. Interactive web based SDSSs provide an interface that allows non-specialists to test different water related scenarios and management scenarios by linking dynamic models with GIS data, analysis tools, and visualisation tools. Combined, these qualities permit, and indeed encourage, scenario testing and experimentation.

The approach taken has a number of significant advantages over traditional methods. It overcomes the difficulties of data access and participation by developing an interactive Web-based SDSS tool. With these interactive pages, users can access and analyze various water and water related data from computers at public libraries, schools, or their homes. Another benefit of the approach is that the interactive modeling and analysis environments are highly visual. The Web provides an enterprise-wide DSS that supports a large group of managers in a networked, client-server environment. Important characteristics of DSSs for sustainable water management and development include accessibility, flexibility, ease of learning, and ease of use.

iv. **To link the developed web enabled DBMS and Geo-Spatial databases to Google Earth for visualization and display of theme wise maps**

Visualization has become a very important aspect of disseminating information and research findings. By using Google earth as an overlay layer in this research, it enhanced the visual quality of the information been communicated. This formed a good background of satellite images to make the user to be attached to the area of study without been there physically and complement the thematic layers used in this study. Even though the prototype does not have the polish of a professional software product, it does provide

many valuable contributions for the general public, concerned citizens, and water sector players.

The provision of the user interfaces allowed for ease of interaction, simple enough to be used directly and mastered by local decision makers without the constant support of computer analysts, and present outputs in formats that are easy to interpret

Through using Open Source software's, a cost effective development and deployment process, demanding minimum hardware, software and licensing costs was realized. This can further be used in the identification, adoption and adaption of suitable existing tools, models and routines, with particular emphasis on the usage of non proprietary, inexpensive or widely available industry –standard software tools

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

A review of internet GIS, database systems and software applications, with respect to the web environment and interconnected networks. Database development, data acquisition and analysis, user accessibility, and interfacing, was carried out. Current Web-based GISs and Web technologies were reviewed. Methods for a CGI server-side approach to Web-GIS functions were investigated. A prototype Web-Based Spatial Decision Support System for application in water development and management in Samburu District was designed and implemented.

5.1 Conclusion

Although Samburu Water MIS utilized under desktop GIS enable a wealth of analytical possibilities for users, the systems face several challenges such as interoperability, long learning curves and prohibitive software costs, these challenges can be resolved as demonstrated by the developed Web Based Spatial Decision Support System prototype developed for Samburu District based on the Samburu District Water MIS by taking advantage of modern advances in distributed computing, in particular the Internet and the World Wide Web.

Further, the cost implication of such a system can be further reduced by use of Open Source softwares, database and server application. Accordingly, these services offer an evolutionary framework for delivering data and GIS functionality, that is interoperable and therefore capable of integrating heterogenous GIS as well as enterprise information systems, that is flexible and capable of adapting to market changes and that supports reuse of GI resources while cleanly separating ownership and use of the resources with low learning curves for the service users.

5.2   Shortcomings

Although these types of system have a lot of potential, they also have their inherent pitfalls which were encountered during this research work which need to be addressed to ready the prototype for practical use. Web mapping is facilitated by the Web. As such internet connectivity is a basic requirement. Without Internet connectivity, talk of web mapping is meaningless in spite of its many appealing features.

Samburu District generally has poor internet infrastructure and low band width which need to be upgraded for performance and widespread access of the system to ensure public participation in spatial decision making relating to water resource development in the district. Other issues to be considered though they can be satisfactorily addressed include; internet security, map quality and liability.

5.3   Recommendations

In the arid and semi arid areas, there is a high variability of water quantity, quality and reliability of water sources due to the different seasons. It could be critical for further research in ways of presenting issues touching on seasonal variability of livestock and human water demand in the wet and dry season.

As well pasture variability can be used as a way of tracking migration patterns of pastoralist which can be useful in planning of natural resources and minimizing of water and pasture related conflicts in these areas. Also a versatile query facility can be implemented and appended to the client page for further enhanced analytical capabilities.

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