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SCHOOL OF ENGINEERING

DEPARTMENT OF GEOSPATIAL AND SPACE TECHNOLOGY

DEVELOPING A WEB MAP FOR CIVIL ENGINEERING APPLICATIONS: A Case study of Laikipa County

BY

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Abstract

Information Communication Technology is one of the greatest technological revolutions of our age and a key driver of economic prosperity among nations. Today information is regarded as a resource and therefore a factor of production. This migration towards an information society is enabled by the internet and most importantly the World Wide Web. The goal of this project was to develop a web map that shares key spatial data consumed in Kenya for Civil engineering applications using Laikipia County as a case study. The idea for this project came from the proposal by the Kenya government to develop the Kenya National Spatial Data Infrastructure (KNSDI) which began in 2001 as part of vision 2030 to allow sharing of spatial information among organizations and the public; however the project was never completed due to lack of support. Potential beneficiaries of such a web map would include: the government by making delivery of spatial data to the public as a service easier and civil engineering practitioners. The most common web maps currently in use world-wide are Google maps, Microsoft Bing maps and OpenStreetMaps; they mainly display information such as streets, hotels, restaurants, banks, bus stops and schools among many others. Some common applications of web maps include: delivery services such as food delivery services, taxi services such as Uber maps, tracking services such as vehicle tracking, defence such as the military. For this project a user needs assessment was done using a questionnaire to determine the relevant datasets used in civil engineering applications in Kenya. The design technologies applied to this web map consisted of a triad of web design languages; they are: HTML, CSS and JavaScript. Web optimization technologies were used to create a more user friendly and cost effective web map that utilizes network and computational resources efficiently, they included AJAX, image tiling, image compression and image file formatting. The result was a web map that displayed data on topography, land parcels, administrative boundaries, forestry, rivers and man-made structures such as roads and railways. The web map was hosted on a website with the URI www.beampositioningsystems.com.

Key words: World Wide Web, web mapping application, civil engineering, spatial, GIS, data, information, Kenya.

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List of Abbreviations

AJAX	Asynchronous JavaScript and XML
API	Application Programming Interface
CSS	Cascaded Style Sheet
DEM	Digital Elevation Model
GeoDRM	Geospatial Digital Rights Management
GI	Geospatial Information
GIS	Geospatial Information Systems
GPS	Global Positioning System
HTML	Hyper Text Markup Language
HTTP	Hyper Text Transfer Protocol
ICT	Information Communication Technology
KNSDI	Kenya National Spatial Data Infrastructure
OGC	Open Geospatial Consortium
PNG	Portable Graphics Format
RIM	Registry Index Map
SDI	Spatial Data Infrastructure
SOA	Service Oriented Architecture
SOK	Survey of Kenya
SRTM	Shuttle Radar Topographic Mission
TIFF	Tagged Image File Format
URI	Universal Resource Identifier
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
VGI	Volunteered Geographic Information
WCS	Web Coverage Service
WFS	Web Feature Service
WMS	Web Map Service
WWW	World Wide Web
XML	Extensible Markup Language

Chapter 1: Introduction

1.1 Background to the study

Kenya is marching towards an information society, its internet speed is high and connectivity is vast. At the same time a paradigm shift from GIS to Geospatial information (GI) service [31] has been experienced world-wide. Web mapping - which is part of GI service - is the process of designing, implementing, generating and delivering maps on the World Wide Web. [53] The first web maps were merely static web pages displaying maps as images with few options on the client side, [53] an example is Xerox PARC map. [14] The introduction of dynamic web capabilities led to development of more interactive web maps where servers could respond to client's requests, [53] an example is Google maps. [11] Collaborative web maps such as OpenStreetMaps and Wikimapia rely on volunteered geographic information by encourage communities to contribute by mapping their locations. Geotagging allowed multimedia capabilities on web maps such as photos, audios and videos to pop up at locations, an example is Google maps. [11] Digital globes such as Google Earth are web maps that provide a global view of spatial data. Mobile web maps provide real time mapping capabilities such as waypoints and routes, this is enabled by kinematic GPS technology built into the mobile devices, examples include handheld GPS, smart phones, tablets and car navigation devices. Web maps with 3D street viewing capabilities such as Google maps [11] enable a 360 degree viewing space that captures the real setting of the location, providing a realistic and life-like view. *Online atlases* and *spatial data infrastructures (SDI)* are also attempts to use the web to disseminate maps to a vast audience. Online atlases are a collection of maps on a website that are used for the study of Geography; an example is the Online Atlas of the British and Irish flora. [32] SDI utilizes the web to disseminate geospatial information as a service using the clearing house concept [31] for example USGS EarthExplorer. [52] Some practical applications of web maps include: taxi services such as Uber maps, delivery services such as food delivery services, logistics services such as road transport, tracking services such as vehicle tracking among many others. Currently the most successful web map in use is Google maps, it is user friendly, detailed in information and is available as both a desktop and mobile application. Table 1.1 lists examples of web mapping applications available online and their countries of origin.

Table 1. 1: Web mapping applications in use. (Compiled by myself from internet URIs)

Coverage	Country	Web mapping application
Global	All countries	Google maps (google.com/maps) Microsoft Bing maps (bing.com/maps) OpenStreetMaps (openstreetmap.org) Wikimapia (wikimapia.org)
Africa	All 54 countries	Africomaps (africomaps.com)
	South Africa	AfriGIS Maps (maps.afrigis.co.za)
Asia	Azerbaijan	GoMapAZ (gomap.az/maps/az)
	China	Baidu maps (map.baidu.com) Tencent maps (map.qq.com)
	Hong Kong	Centamap (hk.centamap.com/gc/home.aspx)
	India	Bhuvan (bhuvan-app1.nrsc.gov.in/bhuvan2d) MapMyIndia (maps.mapmyindia.com)
	Kuwait	Kuwait Finder (gis.paci.gov.kw)
	Malaysia	1Malaysia Map (1malaysiamap.mygeoportal.gov.my)
	Phillipines	Philippine Geoportal (geoportal.gov.ph/viewer)
	Qatar	Qatar Geoportal (geoportal.gisqatar.org.qa/qmap)
	Russia	Yandex.Maps (yandex.com/maps)
	Saudi Arabia	GeoPortal Saudia (geoportal.sa/GCS/WebPages/Map/FundyViewer.aspx)
	Singapore	OneMap (onemap.sg/main/v2)
	South Korea	Daum Map (map.daum.net) Naver Maps (map.naver.com)
	Thailand	Longdo Map (map.longdo.com)
Australia	Australia	The Australian National Map (nationalmap.gov.au)
	New Zealand	NZGB Gazetteer (gazetteer.linz.govt.nz)
Europe	Belgium	Geopunt (geopunt.be) WalonMap (geoportail.wallonie.be/walonmap)
	France	Cartes Geoportal (geoportail.gouv.fr/carte) ViaMichelin (viamichelin.com) Mappy (fr.mappy.com)
	Ukraine	Public cadastral map (map.land.gov.ua/kadastrova-karta)
	Malta	Geoserver map portal (geoserver.pa.org.mt/publicgeoserver)
	Switzerland	Maps of Switzerland (map.geo.admin.ch)
	Turkey	Gezgin Geoportal (gezgin.gov.tr)
	United Kingdom	OS Maps (osmaps.ordnancesurvey.co.uk)
N. America	United States	USGS The National Map (viewer.nationalmap.gov/advanced-viewer)

1.2 Problem Statement

Spatial data sharing has always been a challenge especially in developing countries; this is due to lack of awareness in regards to its benefits, lack of infrastructure and lack of policies to promote it. However with the introduction of the World Wide Web things are beginning to change, today spatial data can be shared to end users easily.[41][18][10]

The main problem was the lack of a shared integrated environment to enable sharing of enterprise spatial data used for civil engineering applications held by various independent organizations in Kenya. This led to poor data discovery where different organizations held useful spatial data that would have benefited stakeholders outside those organizations in civil engineering applications. Another problem is data redundancy where similar spatial datasets were reproduced by multiple organizations. [31]

1.3 Objectives

The overall objective was to develop a web map that demonstrates how spatial data for civil engineering applications can be shared over the World Wide Web in Kenya using Laikipia County as a case study.

Specific Objectives

The specific objectives were to:

1. Carry out a user needs assessment to identify the spatial data/information required for civil engineering applications from various independent organizations in Kenya.

2. Collect the relevant spatial data/information used for civil engineering applications in Kenya according to the assessment.

3. Create a web map that shares the identified spatial data/information.

4. Test the web map.

1.4 Justification of the study

A successful model of this web map for use in Kenya would provide spatial data services for civil engineering applications on the World Wide Web. [10][18] The beneficiaries include: the government for example in physical planning which includes urban, agricultural, industrial and residential developments. Building contractors and consultancy firms for operations management for example computation of volumes, design of roads, drainage systems and building floor levels. Learning institutions for research for example ways to improve spatial data sharing using web mapping. [10][18] The key spatial information available on the web map included: relief, man-made structures and the natural environment.

1.5 Scope of work

The scope of this project covered the creation of a web mapping application, whose web dynamic capabilities were limited to the web browser and web server alone, that means the web mapping application was strictly prepared on an offline desktop and hosted on a web server that was accessible to a web browser using a domain name for display. The scope of this project did not cover the creation of a web mapping application dynamically on the web where the web map server, web feature server and geodatabase were dynamically linked on the web. Geographically the project covered Laikipia County in Kenya, this area was chosen due to its wide range of geographic features and availability of data/information.

1.6 Organization of the report

This project report is organized into five chapters where Chapter 1 contains the background, problem statement, objectives, justification of the study and scope of work. Chapter 2 contains the literature review on web mapping, spatial data/information needs and sharing. Chapter 3 discusses the materials and methods used in the study; this is where the data and the development of the web map are discussed. Chapter 4 discusses the results. Chapter 5 discusses the conclusions and recommendations, lastly is a list of reference materials used in the study and an appendix which contains examples of web maps in use today.

Chapter 2: Literature review

2.1 History of web maps

The evolution of web mapping is a part of the wider evolution of data sharing. [53] Table 2.1 describes a brief evolution of web mapping by era, new technologies, functionalities introduced and examples of applications.

Table 2. 1: Evolution of web mapping (Veenendal, 2017). [53]

Era	Technology	Functionality	Example
Static web maps	Web 1.0 HTML	Web maps were read only HTML static images with capabilities such as zoom, projection changes, display layers, change database and pre-set coordinate were possible. The user could select which predefined static maps to view.	Xerox PARC map.
Dynamic web maps	DHTML, CGI, Java applets, servlets, plugins and ActiveX.	Web maps could be modified dynamically, this allowed interactive customizable web maps where servers could respond to requests.	USGS National Geospatial Data Clearing house.
Service web maps	Web mapping APIs	Development of standards by OGC for users and producers of web maps. Map APIs could access geospatial data from servers and combine them in layers for front-end users.	Open layers
Interactive web maps	AJAX, image tiling	Enabled simultaneously interactions between clients and servers; this capability saved time by enabling real time interaction.	Google maps
Collaborative web maps	Web 2.0	Read–write capabilities; led to VGI where users could participate in both retrieval and creation of web maps.	OpenStreetMap, Wikimapia
Digital Globe web maps	3D rendering	The digital globe (virtual globe) offered earth imagery in 2D and 3D; this enabled a more realistic earth view.	Google Earth, NASA World wind
Mobile web maps	Cell phone tower triangulation, kinematic GPS	Real time geographic location of mobile devices was integrated onto a web map; this enabled real time tracking.	Uber maps, Google maps
Cloud based web maps	The Cloud	Offers service-oriented architecture; software, platform and infrastructure services.	Google app engine, Amazon cloud
Intelligent web maps	Web 3.0	Provides knowledge based semantic, context and customization to the information delivered to users and applications.	Google maps

2.2 Why spatial information/data

Spatial data/information needs for individuals and organizations are wide, the most dominant ones include: [28] topographic maps, land cover, transportation data, hydrographic data and satellite imagery. Topographic maps are detailed and accurate illustrations of relief, man-made features and natural features. [26] The distinctive feature of topographic maps is the depiction of topography which is done using contours and spot heights; in Kenya countrywide topographic maps are produced by SoK. Land cover data in a strict sense describes vegetation and man-made features; [44] land cover maps are used to depict existing human activities and the biophysical environment. A series of land cover maps produced over a given period of time are used for change detection. Transportation data incorporates multimodal transportation networks and facilities to include roads, trails, railroads, waterways, airports, bridges and tunnels; [56] transportation data is used to depict infrastructural development of an area. Hydrographic data includes physical and logical components representing the flow and presence of water within the surface water portion of the environment; [9] they include lakes, wetlands, dams, rivers and swamps. Satellite imagery includes images of Earth or other planets collected by imaging satellites operated by governments and businesses around the world; [59] they are produced from remotely sensed data covering a wide range of the electromagnetic spectrum hence they introduce new capabilities beyond the visible spectrum depicted by the human eye.

2.3 Policy/guidelines/legislation on spatial information/data

Spatial data sharing issues include considerations that one has to take into account before sharing spatial data. [10][12] They include: sharing policies, copyright issues, security issues, pricing issues, privacy issues and cultural issues. Sharing policies are rules and protocols set by governments or organizations regarding sharing of spatial data, [16] these policies may encourage or discourage sharing of spatial data. [10] Copyrights issues include intellectual property rights regarding distribution of copies of spatial data and information. [15][40] Geospatial Digital Rights Management (GeoDRM) technology standards given by the Open Geospatial Consortium apply to spatial data to protect copyrights. [36] Security issues involve protecting and authorizing access to spatial data; this is achieved using access control, authentication, auditing, and administration.

[42][43] The introduction of new technologies such as block chain has revolutionized data security. Pricing issues involve valuation of spatial data, [38] should the spatial data be free or on sale and what criteria are used to determine its value. [41] Privacy issues involve confidentiality concerns for people, property, and systems. [4] Techniques for protecting privacy include masking of results, aggregation and "jittering" patient locations through the addition of spatial errors to the coordinates of place of residence. [2] Cultural issues include concerns on how spatial data may impact the lives and belief systems of people. These include religion, politics and social norms. [29]

2.4 Spatial information/data sharing over the web

2.4.1. Advantages

Spatial data sharing over the web has a large clientele, this enables a wide audience to access spatial data/information. [31] Spatial data sharing over the web also enables spatial data marketing due to separation of ownership of spatial data from use. [31] Spatial data sharing over the web leads to data segmentation since data interchange is done by transaction rather than by transfer; this means that only required segments of data are made available to clients. [31] Spatial data sharing over the web leads to user specific maps hence highly customized maps are delivered to clients; [31] this is facilitated by servers.

2.4.2 Challenges in spatial data sharing and possible solutions

The challenges of spatial data sharing are: different standards, spatial data bulkiness, poor data discovery and retrieval, poor cyber infrastructure. De facto standards adopted by individual organizations lead to lack of interoperability between data and systems due to different standards. [1] The different standards include: coordinate reference systems, data models, data formats among many others; OpenGIS standards developed by OGC are being implemented to solve these issues. [61] Spatial data is bulky, this makes them consume huge data storage space and high bandwidth during data transmission; [7] this problem can be solved by optimizing data such that it uses storage space and network resources more efficiently. Poor data discovery and data retrieval is a challenge in spatial data sharing; the need to develop a well-functioning database system that facilitates proper data discovery and data retrieval is paramount. The solution is to have spatial data accompanied by metadata, catalogues and database management systems. Metadata help in data discovery, catalogues help in data organization while database management systems help in data retrieval. [18] Poor cyber Infrastructure is a challenge in some countries especially developing countries; cyber infrastructure comprises of hardware, software, networks and environments that support advanced data acquisition, data storage, data management, data integration, data mining, data visualization and other computing and information processing services. [57] Introduction of new technologies such as the cloud increases storage space and computational power.

2.5 Spatial data/information sharing frameworks and tools

2.5.1 Web mapping service

2.5.1.1 Components

Web mapping service components carry out specific functions, they include: geospatial database, web feature server, web map server, web server and web browser. A geospatial database is a collection of geographic datasets of various types held in a common file system folder, [8] the distinguishing feature of geospatial databases from other databases is that they are spatially enabled. [13] A web feature server is a computer program that accesses spatially referenced data from a geospatial database for publication, [55] it creates published features from this data. A web map server is a computer program that produces maps of spatially referenced data dynamically, [6] it accesses published features from a web feature server and creates a map from them. A web server is a computer where web content is stored, it retrieves websites and sends them as HTTP responses to web browsers. [48] A web browser is a computer program that allows view and access to websites; it sends HTTP requests to web servers and renders HTML code for view. [47]

2.5.1.2 Web map service framework

The web map service information sharing framework consists of hardware, software, protocols, data, networks and messages. [46] Figure 2.1 illustrates web map service framework and components.

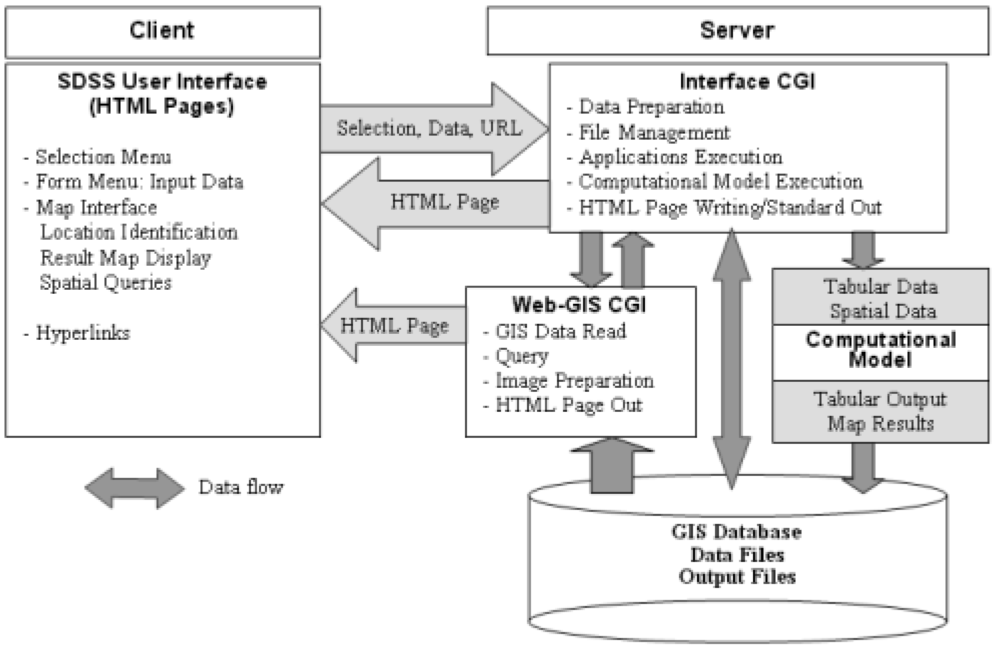

Figure 2. 1: Web map service framework and components. (msu.edu, 2019) [46]

2.5.2 OpenGIS standards for web mapping

Web mapping as a service includes: map services, feature services, coverage services and geoprocessing services. [61][6] Due to the diversity of players involved in web mapping service different ways of serving web maps arose; this created the need for standardization. Standardization is the process of implementing and developing technical procedures based on the consensus of different parties that include firms, users, interest groups, standards organizations and governments. [62] Standardization can help to maximize compatibility, interoperability, safety, and quality; it can also facilitate commoditization of custom processes formerly used. [5] Standards are the key to developing interoperable platforms on the web. [27] The Open Geospatial Consortium (OGC) is an international non-profit organization founded in 1994 committed to making quality OpenGIS standards for the global geospatial community. These OpenGIS standards are made through a consensus process and are freely available for anyone to use to improve sharing of the world's geospatial data. [61] The OpenGIS standards for Web mapping service are protocols, they are: web mapping service, web feature service and web coverage service

Web Map Service (WMS) are OGC standards for production of web maps of spatially referenced data dynamically from geographic information. [33][6][61][19] Web Feature Service (WFS) are OGS standards used to represent a change in the way geographic information is created, modified and exchanged on the Internet. [33][6][61][19] Web Coverage Service (WCS) are OGC standards used in support of electronic retrieval of geospatial data as "coverages." Coverages are digital geospatial information representing space/time varying phenomena, specifically spatio-temporal regular and irregular grids, point clouds, and general meshes. [33][6][61][19][3]

2.5.3 Web mapping service architecture

Service oriented architecture is a style of software design where services are provided to the other components by applications through a communication protocol over a network. The basic principles of service-oriented architecture are independent vendors, products and technologies. [17] A service is a discrete unit of functionality that can be accessed remotely and acted upon and updated independently. There are two types of web mapping service oriented architecture: tightly coupled web mapping service architecture and loosely coupled web mapping service architecture.

Tightly coupled web mapping service architecture is a type of architecture where the geodatabase, web feature server, web map server and web server are collocated. Advantages of a tightly coupled web mapping service architecture include: it reduces data redundancy, it is highly optimized for performance, it requires few protocols between systems. Disadvantages include: it has large number of interdependent systems hence failure in one system could result in failure of the whole system, it is a hard system to maintain due to system interdependence. [24] Figure 2.2 illustrates tightly coupled web mapping service architecture.

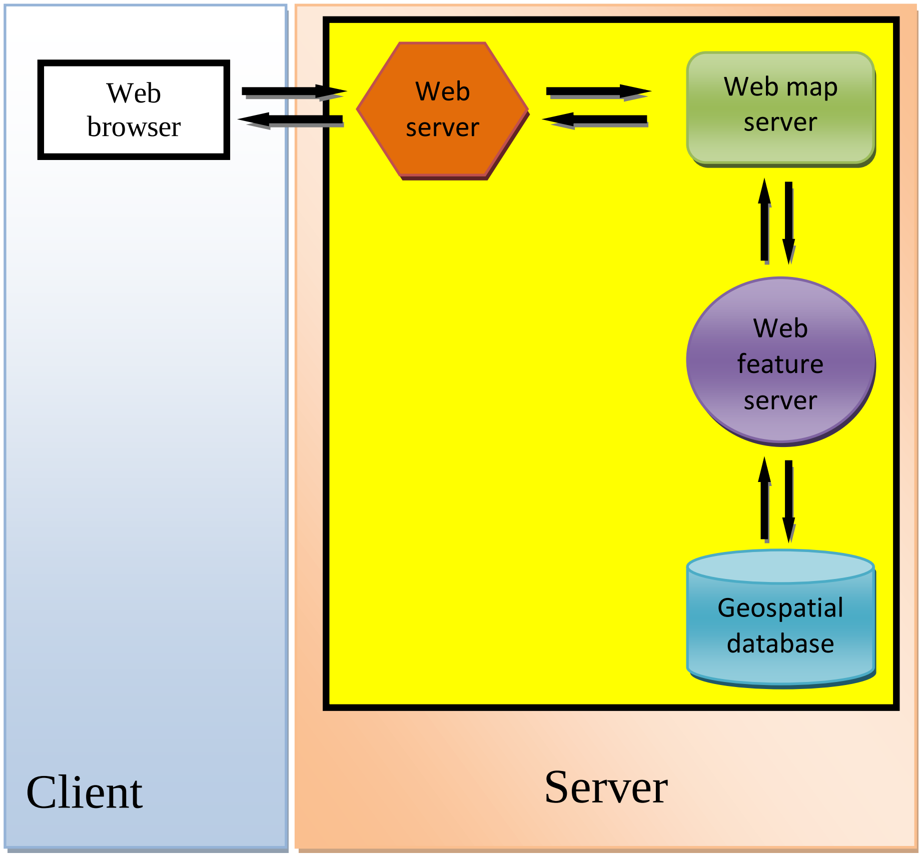

Figure 2. 2: Tightly coupled web mapping service architecture. (Onchaga, (n.d)) [30]

Loosely coupled web mapping service architecture is a type of architecture where the geodatabase and web feature server are separate from the web map server and web server. Advantages of loosely coupled web mapping service architecture include: it has less dependencies hence it is easy to modify and maintain, failure in one system does not affect the whole system, and it is easily scalable. Disadvantages include: it is prone to data redundancy, it has low performance, it requires numerous standards and protocols to make the independent systems work together. [25] Figure 2.3 illustrates loosely coupled web mapping service architecture.

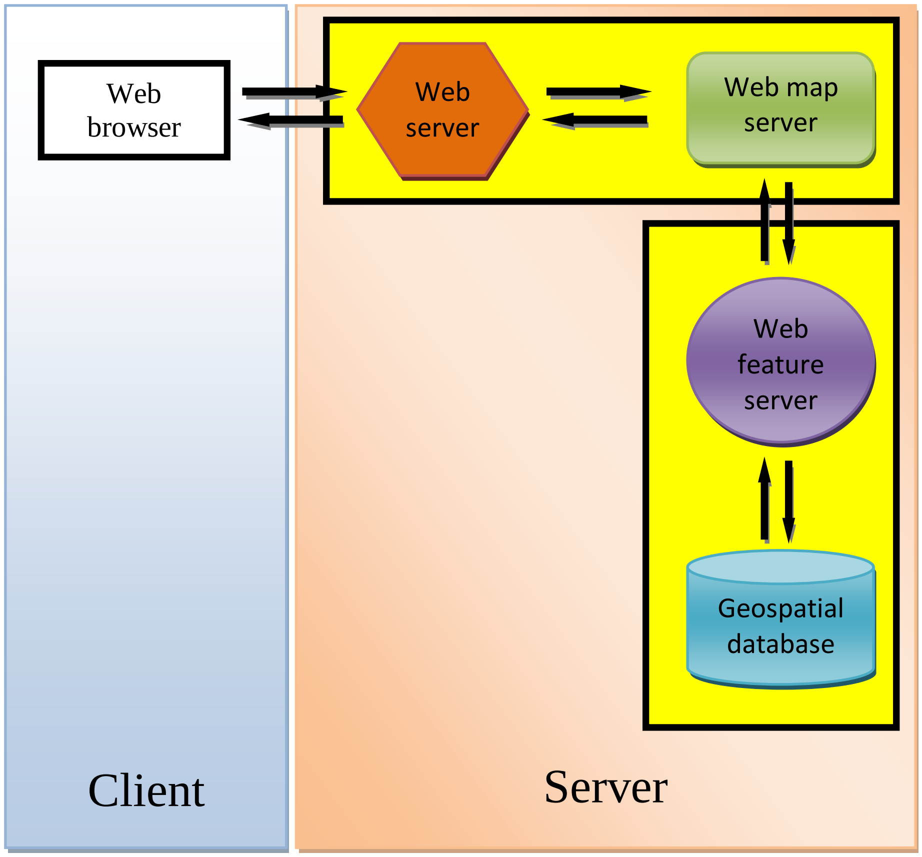

Figure 2. 3: Loosely coupled web mapping service architecture. (Onchaga, (n.d)) [30]

Client approach

Thick client is a client approach where end users only receive the raw data from the server, the logic and presentation are on the client side. [30] Figure 2.4 illustrates a thick client approach

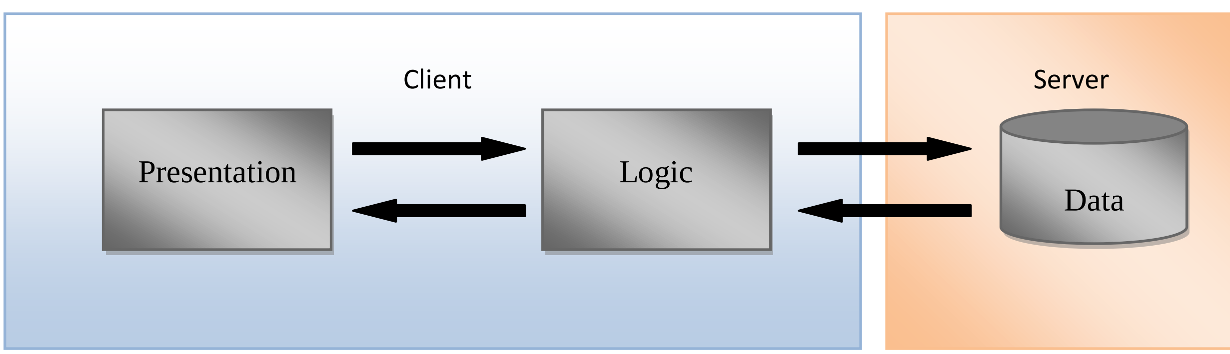

Figure 2. 4: Thick client approach. (Onchaga, (n.d)) [30]

Thin client is a client approach where end users only receive the final presentation on the client side, the logic and data are on the server side. [30] Figure 2.5 illustrates a thin client approach

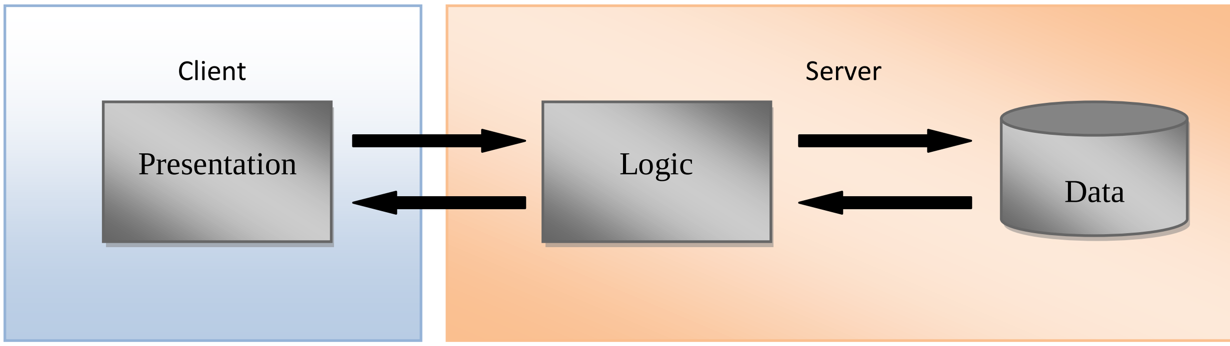

Figure 2. 5: Thin client approach. (Onchaga, (n.d)) [30]

2.6 Technology for spatial data/information sharing

2.6.1 Web mapping design technologies

HTML - Hypertext markup language (HTML) is the standard language used for creating web pages and displaying content on them. [39] Below is an example of a HTML code.

```
<html>
        <head>
                <title>Web mapping application for Kenya</title>
                <style>CSS file   .css</style>
        </head>
        <body>
                <script>JavaScript file   .js</script>
        </body>
</html>
```

CSS - Cascaded style sheet (CSS) is a web design language used for customizing web presentations. [23] Below is an example of a CSS code file.

```
<style>
        Map (orientation, position)
        Border line (height, width)
        Neat line (height, width)
```

```
        Layers dialog box (height, width and colour)
        Background (colour)
</style>
```

JavaScript - JavaScript is a web programming language; [54] it handles programming logic on the web. Below is an example of a JavaScript file.

```
<script>
        Variables, statements
        Conditions, Loops
        Functions, Objects
</script>
```

2.6.2 Web design optimization technologies

Design in web mapping requires optimization which provides a balance between functionality, quality of maps and quantity of information; failure to do so leads to: high payloads, poor image quality and delivery of unnecessary information. Optimization techniques used include: AJAX, image tiling, image compression, image file formats and browser cache memory. Asynchronous JavaScript and XML (AJAX) is a programming language that allows web pages to change content dynamically without the need to reload the entire page; this is made possible by decoupling the data interchange layer from the presentation layer. [50][22] Image tiling is the process of subdividing an image using a regular grid in optical space and rendering each section of the grid or tile separately (frame by frame rendering). The advantage to this design is that the amount of memory and bandwidth used is reduced compared to immediate mode rendering systems that draw the entire frame at once. [21] Image compression reduces the cost of transmission and storage of data in digital images; there are two types: lossless compression and lossy compression. [49] Image file formats are standardized means of organizing and storing digital images; they include JPG, TIFF, PNG, BMP. Issues related to image formats include: quality, storage space, computational power, generational degradation. [58] Browser cache memory is a temporary storage location on your computer for files downloaded by the web browser. [45] Browser cache memories have the advantage of saving bandwidth and reload time but run a risk of providing out-dated data; it is upon the client to manage their browser cache memories.

2.7 Spatial data/information needs for civil engineering applications

Topography is data used to illustrate relief using contours, spot heights and digital elevation models. [26] Hydrography is data representing the flow and presence of water within the surface water portion of the environment. [9] Hydrographic data includes lakes, wetlands, dams, rivers and swamps. Geological data represents rocks, soils and fault lines. Land cover maps are used to depict existing human activities and the biophysical environment. [44]

Chapter 3: Methods and materials

3.1 Introduction

The materials used to implement this project consisted of a set of spatial data, software, hardware and the internet. The methods mainly included web programming.

3.2. Area of Study

Geographically the project covered Laikipia County in Kenya which lies approximately 9969130 mN to 10096211 mN, and 192032 mE to 321321 mE referenced to UTM Arc1960 zone 37S. The area has a wide range of geographic features both natural and man-made; it also has a lot of human activity.

3.2.1 Topography

Laikipia County has varying topography, to the south east the levels rise as one gets close to Mt. Kenya, to the south west the levels are high due to their proximity to the Aberdare ranges. The northern parts of the county are the lowest parts in terms of levels; this is evident from flow analysis of river Euaso Nyiro which drains towards the northern parts of the county.

3.2.2 Land cover

Laikipia County has three major urban centres, Nyahururu to the south west and Nanyuki to the south east and Rumuruti in the mid-west. The southern parts of the county have a fairly good tree cover while the northern parts are open grasslands with lesser tree cover.

3.2.3 Climate

Laikipia County's northern part is semi-arid, the southern part and middle part varies from wet to semi-arid while the western part of the county is cool and wet.

3.2.4 Economic activity

Laikipia County has good soil for agriculture; ranching, pastoralism, green housing and small scale farming are the key agricultural developments. Nyahururu is an agricultural town, major agricultural facilities are Kenya Cooperative Creameries (KCC) dairy processing plant and grain storage facilities. Rumuruti is both an agricultural and an administrative centre; county government offices are being developed there for administrative purposes. Nature and conservancy is another key economic activity in the county, this has led to a thriving tourism economy. Nanyuki is a tourist centre with large hotels; it is also where Kenya's main air force base is located.

Figure 3.1 is a map of Laikipia County.

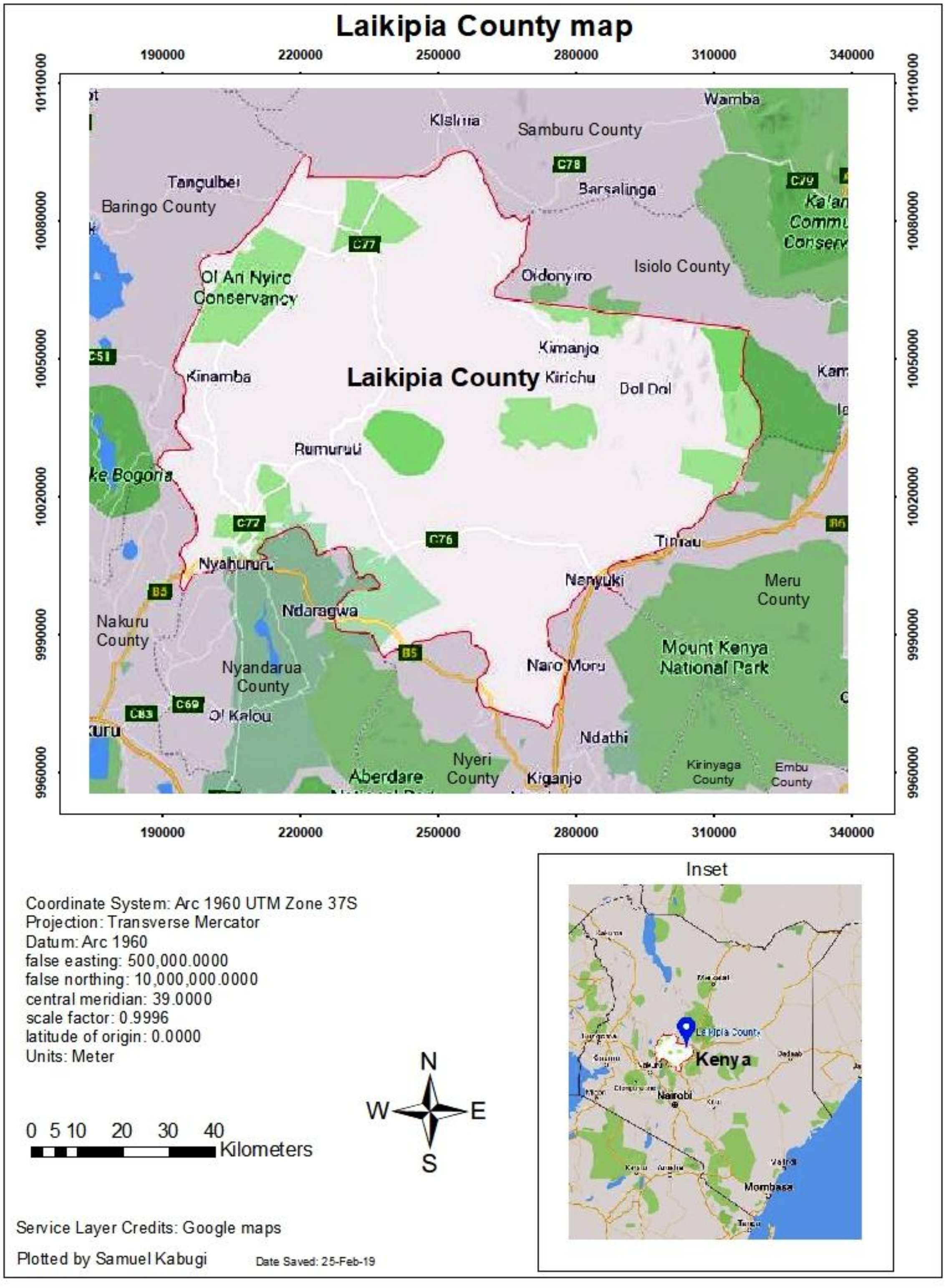

Figure 3. 1: Area of study map (Laikipia County)

3.3 Research instruments

Questionnaires as research instruments were used to identify and assess the spatial data/information relevant for engineering applications; the questionnaires were partly structured and partly unstructured

3.4 Data Sources and tools

3.4.1 Data sources

The datasets used to implement this project consisted of topographic maps, shapefiles, registry index maps and some dummy data.

The datasets used and their sources are as described in table 3.1.

Table 3. 1: Datasets used for study.

Datasets	Description	Activity/Output	Source
Topographic maps	Scanned topographic maps	Elevation data such as spot heights and contours for surface modelling. Man-made structures such as roads, settlements, railways.	Survey of Kenya
Shapefiles	Vector datasets	County boundaries, Land parcels	Digitizing
Registry Index Maps (RIM)	Represents land parcels	Digitizing for land parcel boundaries	Laikipia county survey office
Dummy data	Created datasets	parcel details	Created data

3.4.2 Tools

The tools used to implement this project included hardware, software and networks. They are as described in table 3.2.

Table 3. 2: Tools used for study.

Tools	Description	Activity
Scanner	Creates raster datasets	Scans hardcopy maps
PostGIS & PostgresSQL	Database and database manager	Organizing and retrieving data
QuantumGIS	GIS software	Coordinate systems and projections, georeferencing, digitizing
Leaflet	Web map server	Representing geospatial features
Google Chrome	Web browser	Display map on the Web
Visual studio code	Source code editor	Scripting
Notepad++	Word processor	Scripting
The internet	World Wide Web	Delivery of products to the receiver

3.5 Web-map development

Development of the web mapping application was a process that involved the following stages:

Stage 1: Data preparation

The first step in data preparation involved scanning the topographic maps and RIMs resulting to rasters images in TIFF format; the rasters were then georeferenced on the UTM grid. The next step was to digitize the land parcels from the RIM representing land parcels as vector datasets which were stored in a spatial database as shapefiles. To facilitate rendering on a web browser the datasets were reformatted; for the raster datasets they were converted to PNG format and for the vector datasets they were converted to GeoJSON format. The PNG images and GeoJSON files were organized in a folder

Stage 2: Web programming

The first step in web programming involved creation of a web page that would be used to display the web map's contents as a part of a website, this was done using HTML. The next step involved adding base map elements to the web map; the most important base map element added was the bounding box which conformed to OGC's web map service standards. Other base map elements added were the coordinate reference system, layers, scale and company logo. In addition to that, built in capabilities such as pop-ups, zoom and pan were included. Lastly was the inclusion of the datasets to display on the web map; these are the PNG and GeoJSON files. CSS was used to achieve style sheets on the web map, these determined colours, position and orientation of the map objects. JavaScript was used to objectify the web map using object oriented programming; this enabled the web map as an object to do things through use of built in capabilities as functions for example compute distance and area.

```
<html>
        <head>
                <title>Civil engineering applications map</title>
                <style>CSS file  leaflet .css</style>
        </head>
        <body>
                <script>JavaScript file  leaflet .js</script>
        </body>
</html>
```

```
leaflet.css file
<style>
        Map (orientation, position)
        Border line (height, width)
        Neat line (height, width)
        Layers dialog box (height, width and colour)
        Background (colour)
</style>
```

```
leaflet .js file
<script>
        Variables
        Statements
        Conditions (if, else, else if)
        Loops (for, do while, while)
        Functions
        Objects
</script>
```

Web programming codes

```
<html>
    <head>
        <!--leaflet library-->
        <link rel="stylesheet" href="css/leaflet.css"><link rel="stylesheet"

        <style>#map {width: 100%;height: 100%;}</style>

        <title>Civil engineering applications map</title>
    </head>
    <body>
        <div id="map"></div>

        <script src="js/leaflet.js"></script>
<
        <script>
        //creates the webmap object
        var map = L.map('map')

        //specifies coordinate system by OGC standards
        var crs = new L.Proj.CRS('EPSG:21037');

        //rasters
        var layer_1202_1 = new L.imageOverlay();
        map.addLayer(layer_1202_1);

        //kenya county shapefile
        var layer_kenyacounty_0 = new L.geoJson();
        map.addLayer(layer_kenyacounty_0);

        //parcels layer
        var layer_parcels = new L.geoJson();
        map.addLayer(layer_parcels);

        //title
        var title = new L.Control();
        title.addTo(map);

        //measurement tool
        var measureControl = new L.Control.Measure();
        measureControl.addTo(map);
```

```
        //search
        var osmGeocoder = new L.Control.Geocoder().addTo(map);

        //Layers
        var baseMaps = {};
        L.control.layers(map objects).addTo(map);

        //highlighting layer
        var highlightLayer;
        function highlightFeature(e) {
            highlightLayer = e.target;

            if (codition) {
                statement});
            } else {
                statement});
            }
            highlightLayer.openPopup();
        }
        </script>
    </body>
</html>
```

Stage 3: Web optimization

Web optimization involved reduction of demands on computational and network resources. Payload reduction was used to reduce the quantity of material load to be transported over the internet; compression and resampling were used for the PNG images. The GeoJSON vector data was extremely small hence payload reduction was not necessary. Overhead reduction was done by reorganizing the web programming codes such that minimum code was used without affecting functionality. Image tiling (tile rendering) was used to organize the raster data (PNG) as individual tiles that could be rendered separately frame by frame on the web browser. AJAX was used to reload sections of the web page without loading the whole web page, this reduced demand on the network. Web browser caches were used to temporarily store data on the client side memory; this helped to reduce load time from the internet.

Below are examples of AJAX and image tiling techniques used respectively.

```
// AJAX
function loadDoc(url) {
    var xhttp = new XMLHttpRequest();

    xhttp.open("GET", url, true);
    xhttp.send();
  }
```

```
//image tiling
  function loadDoc() {
  var xhttp = new XMLHttpRequest();
  xhttp.open("GET", true);
  xhttp.send();
}
```

Stage 4: Web hosting

Web hosting involved saving the website containing the web map on a web server and obtaining a URI. In this case the URI was www.beampositioningsystems.com.

Web map development flow chart

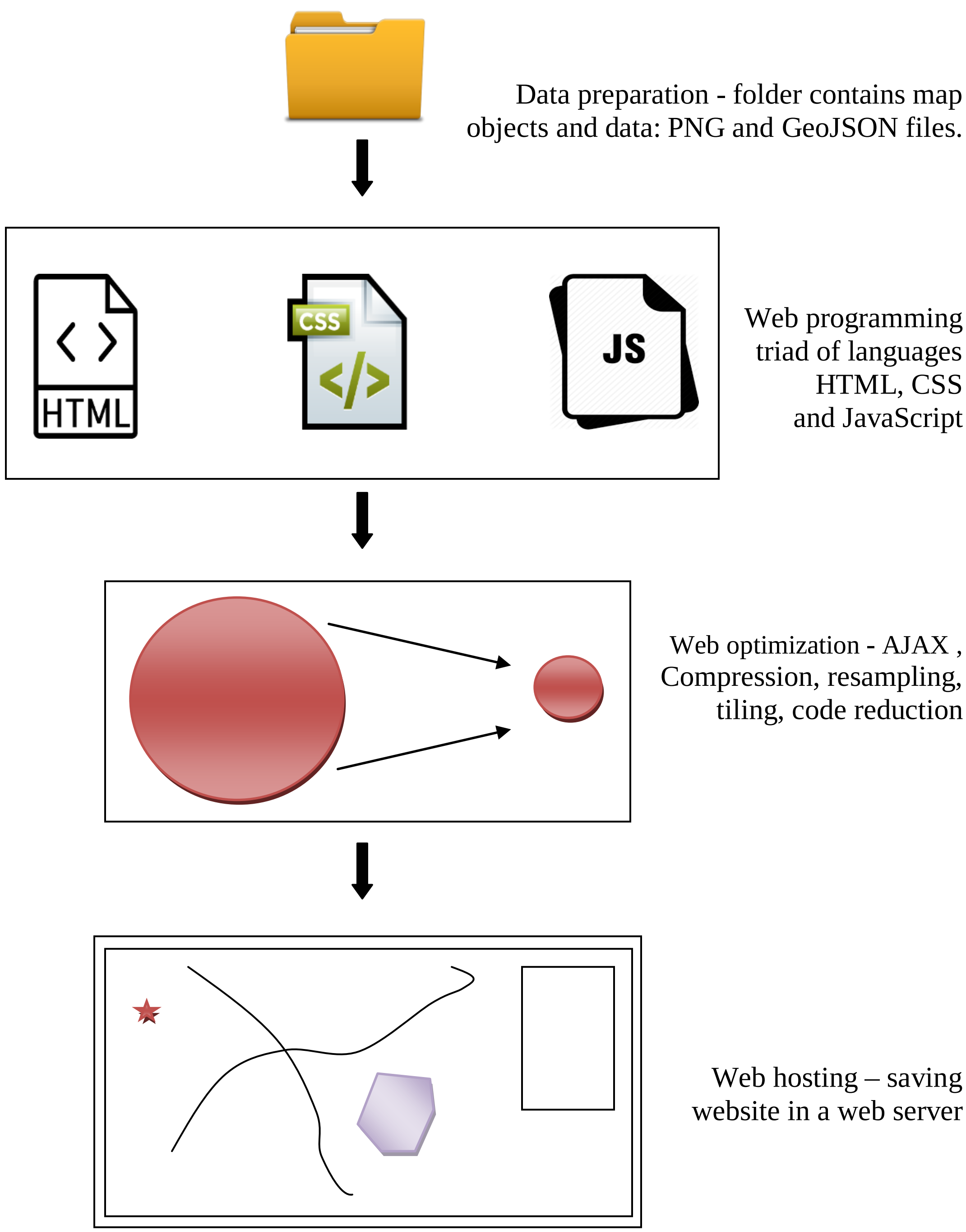

Figure 3. 2: Web map development flow chart

3.6 Testing of the web map

The web map was tested in terms of accessibility, data displayed and built in functional capabilities. The following aspects of the web map were tested: accessibility of the web map on the World Wide Web, organization of the data displayed in terms of layers that can be switched on and off and functions such as zoom, pan, pop-ups, distance, area, search and location.

Chapter 4: Results and discussions

4.1 Datasets and functionalities recommended

The results from the user needs assessment on datasets reccommended for civil engineering applications are laid down in table 4.1 while the geoprocessing functionalities are laid down in table 4.2.

Table 4. 1: Datasets recommended.

Datasets	Use	Source	Professionals	Accuracy/ Resolution	Scale	Temporal resolution
Contours and spot heights	Elevation, surface modelling, topography	Topographic maps, DEM	Civil engineers, Land surveyors, Quantity surveyors, Architects, physical planners	0.1m-0.5m for small extent 5m-20m for large extent	1:500 for large scale 1:100,000 for small scale	1-100 days for large scale 1-5 years for small scale
Land Parcels	Position measurements(coordinates, distance and area), ownership	Registry Index Maps(RIMs), Cadastral maps	Civil engineers, Land surveyors, Quantity surveyors, Architects, Physical planners	3m-5m for general boundaries 0.02m-0.03m for fixed boundaries	1:500	1 month-12 months
Land use	Buildings, developments, planning	Topographic maps, aerial photos, satellite photos	Civil engineers, Land surveyors, Quantity surveyors, Architects, Physical planners	0.03m-0.05m for large scale 30m-100m for small scale	1:100	1 month-12 months
Hydrography	Water resources	Topographic maps, aerial photos, satellite photos	Civil engineers, Land surveyors, Quantity surveyors, Physical planners	0.1m-0.5m for small extent 5m-20m for large extent	1:500 for large scale 1:100,000 for small scale	1-100 days for large scale 1-5 years for small scale
Counties	Administration	County shapefile	Civil engineers, Land surveyors, Quantity surveyors,	1m-5m	1:100,000	1 year-10 years

			Physical planners			
Roads	Planning, visualization, access	Topographic maps, aerial photos	Civil engineers, Land surveyors, Quantity surveyors, Architects	0.03m-0.3m	1:500 for large scale 1:100,000 for small scale	1 month-12 months
Rivers	Planning, visualization, surface water design	Topographic maps, aerial photos	Civil engineers, Land surveyors, Quantity surveyors, Architects, Physical planners	0.03m-0.3m for all purpose	1:500 for large scale 1:100,000 for small scale	1 year-10 years
Forestry	Planning, visualization, protection	Topographic maps, aerial photos, forestry maps	Civil engineers, Land surveyors, Quantity surveyors, Architects, Physical planners	1m-30m	1:100,000	1 year-10 years
Water, storm and sewer lines	Planning, drainage, structural design	Water, storm and sewer lines design maps	Civil engineers, Land surveyors, Quantity surveyors, Architects, Physical planners	0.03m-0.05m	1:1,000	1 month-12 months
Power lines	Planning, structural design	Power line design maps	Civil engineers, Land surveyors, Quantity surveyors, Architects, Physical planners	0.03m-0.05m	1:500 for large scale 1:100,000 for small scale	1 month-12 months
Geological data	Fault lines, rocks, soils	Geological maps	Civil engineers, Land surveyors, Quantity surveyors, Architects	0.03m-30m	1:1,000	1 year-10 years

Table 4. 2: Geoprocessing functionalities.

Functionality	**Use**	**details**
Coordinates	Geospatial positioning	0.003m-0.005m for construction drawings 0.03m-0.05m for land parcels 1m-5m for small scale maps e.g. forestry
Distance	Determining dimensions	0.003m-0.005m for large scale fine distances 0.03m-0.05m for medium scale

		1m-5m for large scale coarse distances
Area	Determining 2D extent	0.003m-0.005m for large scale fine distances 0.03m-0.05m for medium scale 1m-5m for large scale coarse distances
Query/search	Identifying and retrieving data	As much details as can be queried
Dynamic scale (Zoom)	Allows dynamic change of scale	According to standard scales
Pan	Allows the map to move within the bounding box	Allows more details to be viewed
Pop-ups	Allows labelling of map symbols	Describes map symbols
Layers	Grouping related data together in a common class	All data should be layered

4.2 Datasets collected for the study

The datasets collected for the study are laid down in table 4.3.

Table 4. 3: Datasets collected for the study.

Datasets	**Data displayed**	**Use**
Topographic maps	Map symbols – contours and spot heights, roads, rivers, land use	Elevation, positioning, planning, visualization
Land Parcels	Position measurements(coordinates, distance and area), ownership	Property survey, position, planning
Counties	Administration	Planning

4.3 The designed web map

The web map is available on www.beampositioningsystems.com

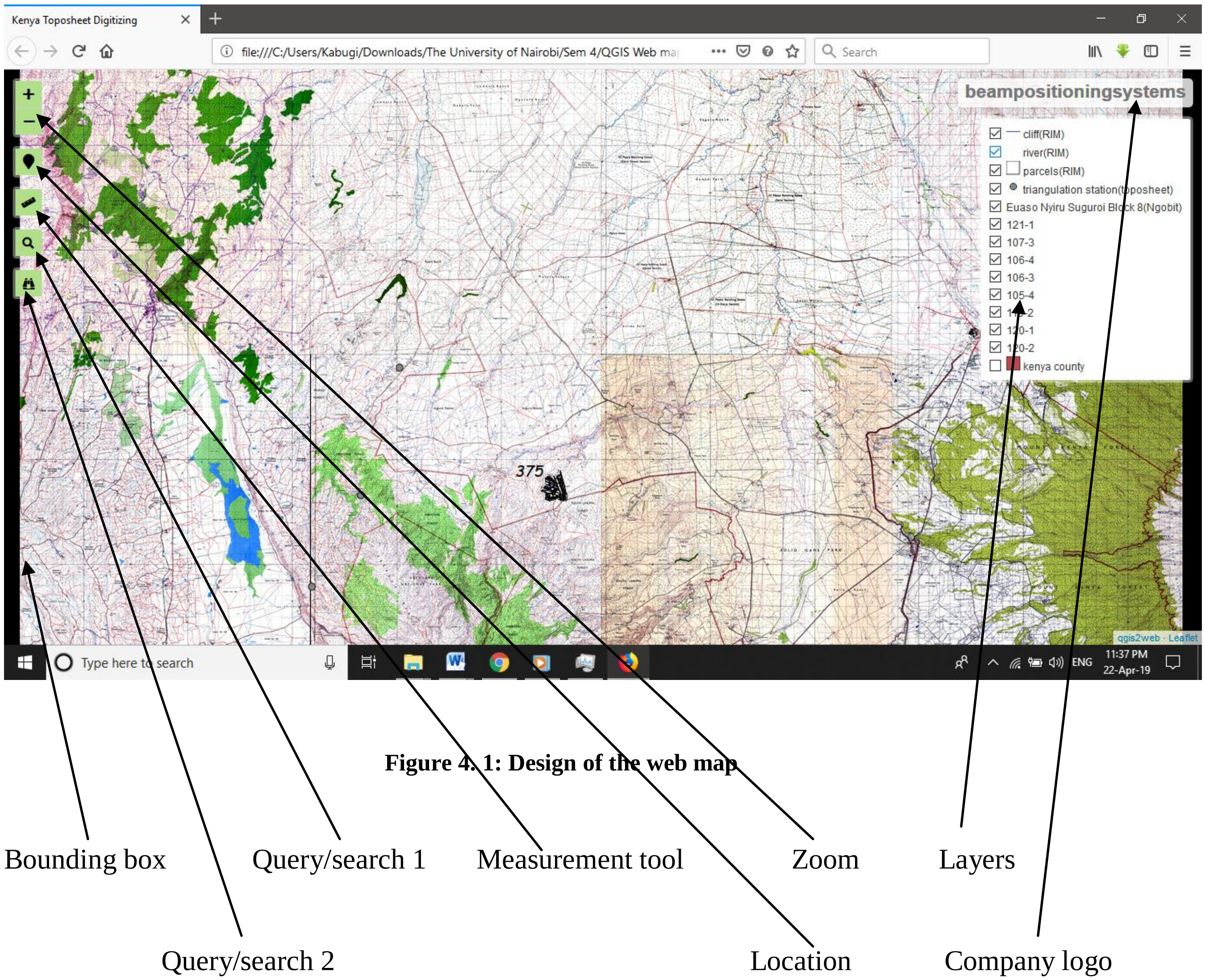

Figure 4. 1: Design of the web map

Based on the design of the web map as shown in figure 4.1, the parts of the web map were: The bounding box which contained the web map objects, it occupied the full screen to maximize the view. The zoom which was a dynamic scale that changed by rolling the mouse wheel, it allowed one to magnify the contents of the web map. The location function was used to coordinate points on the web map while the measurement tool was used for computation of distance and area on the web map. The search tool was used to query data from the web map while the layers panel was used to switch layers on and off.

4.4 Possible applications of the web map

4.4.1 Road and railway construction

Topography would be the most important data in road and railway construction, it would be used for computation of volumes for earthworks, plotting profiles and cross sections. Contours and spot heights are the datasets used to represent topography. Hydrography would also be important to consider, this helps in designing roads and railways that avoid water bodies and also locate areas that require building bridges. Land parcels would be used to identify owners that require compensation for their land to pave way for construction. Topographic and hydrographic information is represented on topographic maps while land parcels are represented on cadastral maps. Figure 4.2 shows how topography was represented on the web map using a contour and its label.

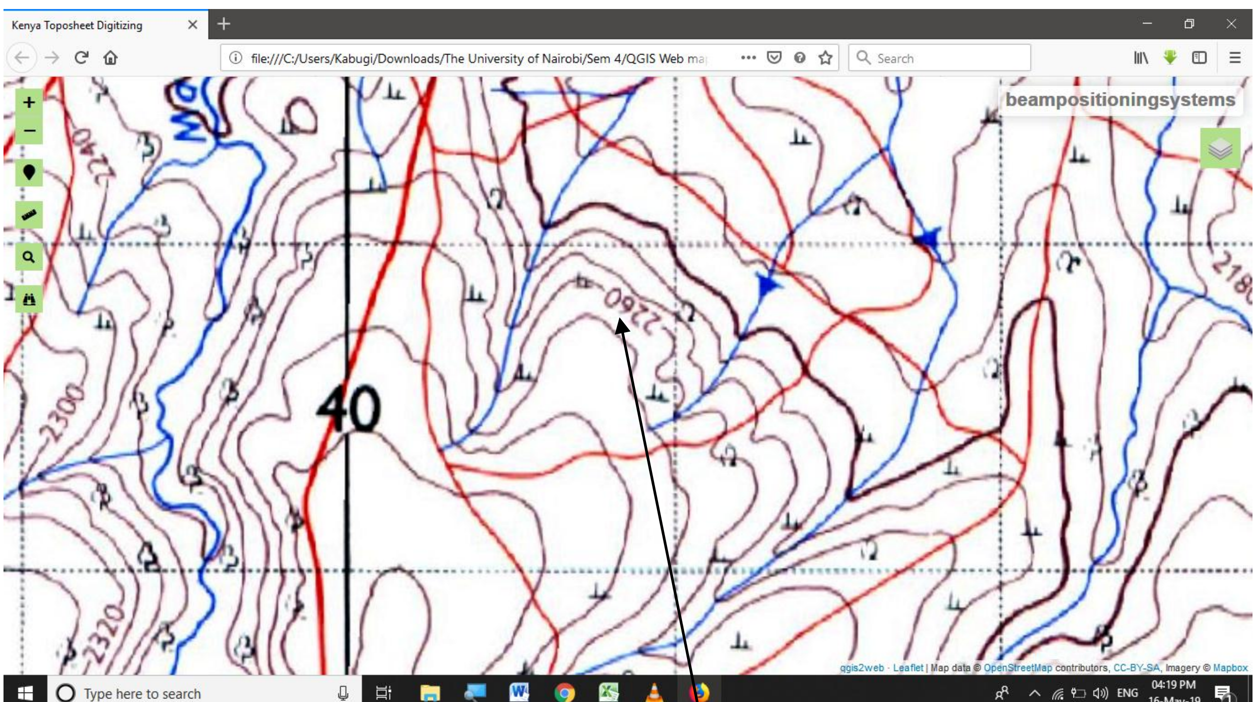

Figure 4. 2: Topographic map representing contours

Contour label for elevation modeling

4.4.2 Visualization

Visualization involves interpretation of map symbols that represent a geographic space. Topography, land use/cover, hydrography and geology represented on the web map abstracted the real world where one could choose what to display by using the layers panel to switch features on and off. Figure 4.3 shows how the web map represented Lake Olbolosat to the west and Mt.Kenya forest to the east.

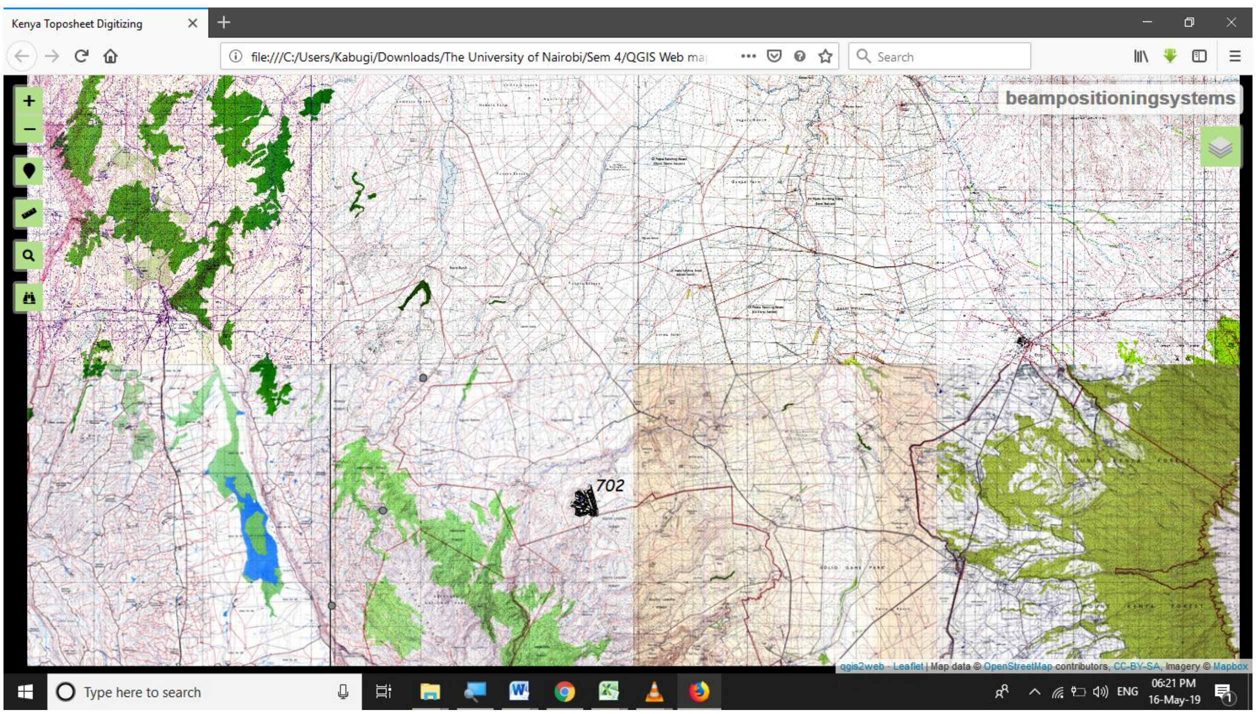

Figure 4. 3: Topographic map showing map symbols.

4.4.3 Land parcels

Land parcels are important for planning, they are used to represent developments on land using zones; for example zones of agricultural developments, urban settlements, commercial, residential and industrial developments. The web map represented land parcels as a layer where parcel details popped up to give more information on a specific parcel. Figure 4.4 shows how the web map represented land parcels which were overlaid on a topographic map.

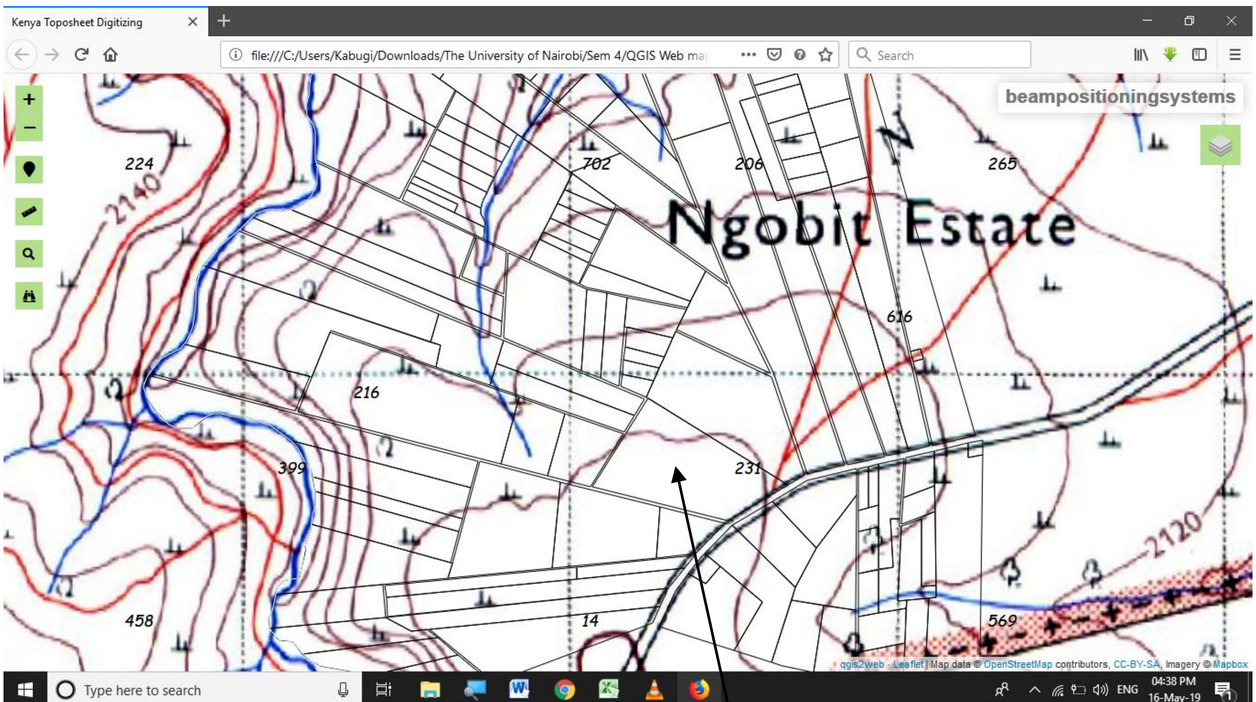

Figure 4. 4: Land parcels overlaid on a topographic map.

Land parcel

4.4.4 Administrative county boundaries

Administrative county boundaries are important for legal requirements in civil engineering projects; these include signing contracts, acquiring approvals, attending stakeholder meetings. In this web map administrative boundaries were drawn from the Kenya county shapefile, they were one of the layers contained in the web map. Figure 4.5 shows how the web map represented counties with a pop-up to give details.

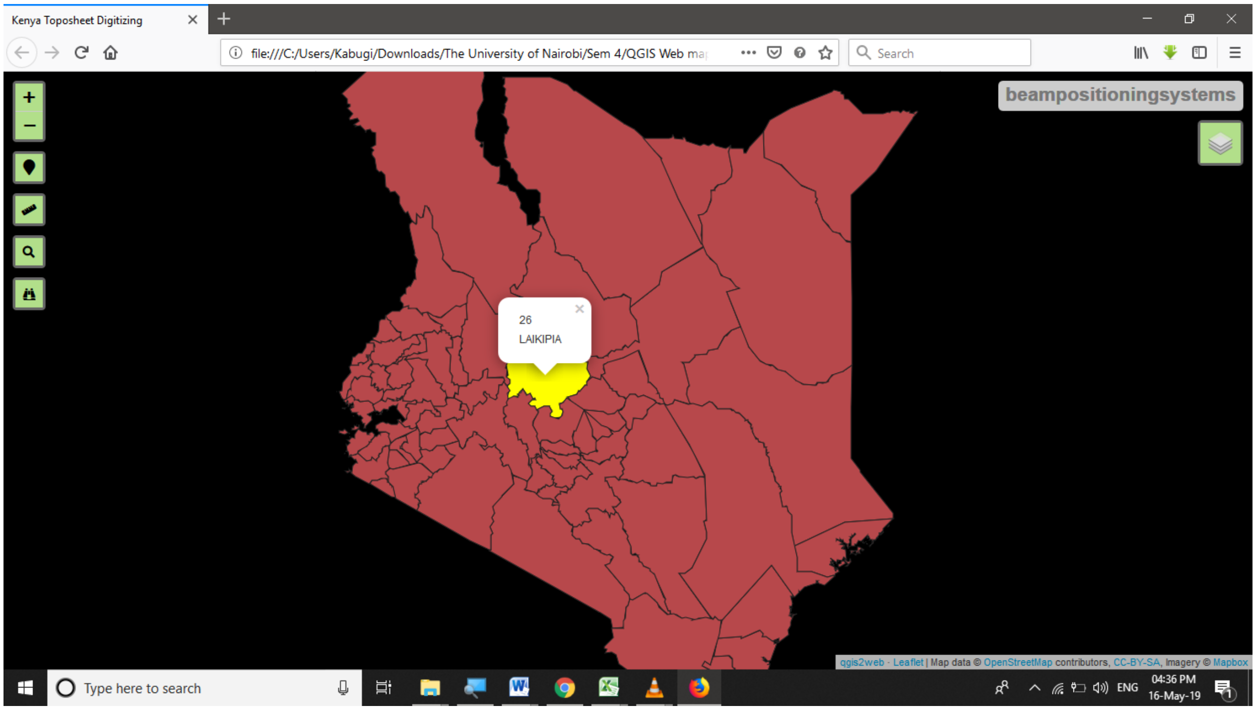

Figure 4. 5: Administrative and county boundaries

4.5 Discussions

4.5.1 Datasets

Topography is important to Civil engineers, Physical planners, Land surveyors and Quantity surveyors, hydrography for Land surveyors and Civil engineers, geology for Civil engineers, land use/cover for Civil engineers and Land surveyors. For this study the source of data for topography, hydrography and land use/cover was topographic maps produced by SOK; the source of data for geology was geological maps while the source of data for land parcels was cadastral maps. The scale required for each data depended on the extent the data covers on the ground, the accuracy/resolution of the data depended on the method of observation done to produce the data. Topography represents surface elevations modeled from contours and spot heights. Land use/cover represents vegetation and human activities over a geographic space. Man-made structures represent airports, roads, railways, power lines and sewer lines among many others. Geology represents rocks, soils data and fault lines while hydrography represents water bodies and water resources. Topographic data is used for determination of profiles, determination of gradients and computation of volumes. Land use/cover is used for forestry, settlements, economic activities such as Agriculture and other regional developments. Man-made structures are used for relating positions of facilities such as airports, roads and railways while geology is used to determine suitability of soils for foundations, rocks for buildings and positions of fault lines and crustal movements. Hydrology is used for water resources mapping hence it is used to determine sources of water for human activities.

4.5.2 Geoprocessing Functionalities

The key geoprocessing functionalities included on the web map were: Coordinate inquiry, calculation of distance, calculation of area, dynamic scaling (zoom), pan, pop-ups, search query and layers. Coordinate inquiry was used to describe positions on the web map based on a coordinate reference system, these positions were unique to every point. Distance gave the range between two points, it was calculated from coordinates while area was calculated from distances. Dynamic scales were used to change the size of the web map within the bounding box. Pan allowed moving of the web map within the bounding box while pop-ups allowed labeling of map symbols. Search query was used to request features on the web map while layers allow on and off switching of data for view.

Chapter 5: Conclusions and recommendations

5.1 Conclusions

In this study the use of web maps for civil engineering applications proved to be very important.

The study found out that the important datasets used for Civil engineering applications were: topography, land use/cover, man-made structures, geology and hydrography. Therefore provision of these datasets as a web mapping application would be resourceful for the Civil engineering discipline. The basic functional requirements of a web mapping application are: coordinates, distance, area, zoom, pan, pop-ups, search and layers.

The main advantage of web mapping is that it provides fast and easy access to spatial data, this is because the World Wide Web is available to anyone who can access the internet. The second most important advantage is service of maps to a very large clientele, this is because the World Wide Web is accessible globally. The third most important advantage is collaborative mapping where as many people in different locations can contribute to generation of spatial data for web mapping. Other advantages of accessing maps on the web include: saving time taken to access maps; this is in contrast to earlier methods which required visiting map custodian offices. Web mapping also eliminates the need for printing hardcopy maps that use large printers which are bulky, expensive and require high maintenance; this greatly reduces the cost of serving maps. The main disadvantage of web mapping is its dependence on the internet which is only available to countries with the necessary infrastructure. The disadvantage of collaborative web mapping is poor data integrity, this is because anyone is allowed to upload spatial data to a web mapping application and hence it’s difficult to prove its integrity.

Collaborative web mapping shares a lot in common with the web video platform called YouTube where today videos are easily accessible and served to a large clientele where anyone can participate in creating as well as viewing videos.

5.2 Recommendations

I would recommend this research study to be used as a model to demonstrate how web mapping can be used to share data on the web for civil engineering applications. A practical application of such a web map can be used during site visits for reconnaissance surveys, for presentations of civil engineering projects, for research purposes in learning institutions, for data sharing to end users of Civil engineering data including the public.

It is important to note that the process of updating, editing and uploading new data to a web mapping application is a continuous process hence I would recommend that the existing data provided by the web map be updated, edited or replaced to ensure data currency. I would also recommend further optimization of the web mapping application to ensure its efficient use of network and computational resources. I would also recommend the incorporation of an SDI to the web mapping application to enable it function like a geoportal, this enables end users to access the data by downloading it rather than just viewing it.

References

1. Arshad, N.H. & Hanifah, F.A. (2010, October). *Issues and challenges in NSDI implementation.* Retrieved February 21, 2019, from researchgate.net.

2. Association of American Geographers. (2013). Geospatial Data Confidentiality: Collection, Sharing, and Use .

3. Baumann, P. (2010, October). *The OGC web coverage processing service (WCPS) standard.* Retrieved March 01, 2019, from researchgate.net.

4. Bertino, E. (2008). Security and Privacy for Geospatial Data: Concepts and Research Directions.

5. Blind, K. (2004). *The Economics of Standards Theory, Evidence, Policy.* Retrieved February 25, 2019, from e-elgar.com: https://www.e-elgar.com/shop/the-economics-of-standards

6. Blois, M. (2016). Web Map Servers.

7. Bratt, S. (2017). Big data, Big Metadata, and Quantitative study of science: A Workflow Model for Big Scientometrics.

8. ESRI. (2018). *What is a geodatabase?* Retrieved February 25, 2019, from arcgis.com: http://desktop.arcgis.com/en/arcmap/10.3/manage-data/geodatabases/what-is-a-geodatabase.htm

9. Federal Geographic Data Committee . (2008). Geographic Information Framework Data Content Standard Hydrography.

10. Gelagay, H. S. (n.d.). Geospatial Data Sharing Barriers Across Organizations and the Possible Solution for Ethiopia.

11. Google. (n.d.). *google.com/maps*. (Google) Retrieved January 17, 2019, from google maps: https://www.google.com/maps

12. Hamzah, A.H. (et al). (2005). *DATA SHARING ISSUES IN SDI IMPLEMENTATION*. Retrieved March 13, 2019, from academia.edu.

13. Idowu, T. & Zemba, A. (2016, July). *GIS DATABASE DESIGN AND IMPLEMENTATION*. Retrieved March 01, 2019, from researchgate.net.

14. inwap. (n.d.). *Xerox PARC Map Viewer*. Retrieved January 16, 2019, from inwap.com: http://www.inwap.com/inwap/chez/parc-map.html

15. Jothimani, P. (2002). GIS Data Dissemination and Intellectual Property Rights.

16. Kok, B. (2007). Spatial Enablement of Government and NSDI - policy implications.

17. Linthicum, D. (2006, December). *Chapter 1: Service Oriented Architecture (SOA)*. Retrieved March 18, 2019, from archive.org.

18. Marie, C. (2007). DEVELOPING A SPATIAL DATA INFRASTRUCTURE FOR RWANDA: Case Study of Land Administration Sector.

19. Michaelis, D. (2008, January). *Web Feature Service (WFS) and Web Map Service (WMS)*. Retrieved March 01, 2019, from researchgate.net.

20. Microsoft. (n.d.). *bing.com/maps*. (Microsoft) Retrieved January 20, 2019, from bing maps: https://www.bing.com/maps

21. Molnar, S. (1994). A Sorting Classification of Parallel Rendering.

22. mozilla. (2019, February 25). *XMLHttpRequest*. Retrieved March 01, 2019, from developer.mozilla.org.

23. Mozilla. (n.d.). *Learn to style HTML using CSS*. Retrieved February 15, 2019, from developer.mozilla.org/en-US/docs/Learn/CSS.

24. Myerson, J.M. (2008, January 24). *Tight-coupling Web services in the SOA*. Retrieved February 24, 2019, from ibm.com.

25. Nassar, E. (2015). Loose Coupling between Cloud Computing Applications and Databases A Challenge to be hit. *II*(3).

26. Natural Resources Canada. (2014). Topographic maps: The basics.

27. Noucher, M. (2017). Spatial Data Sharing: A Pilot Study of French SDIs.

28. Oguchi, T. & Wasklewicz, T. (2011). *Spatial Data*. Retrieved March 13, 2019, from sciencedirect.com.

29. Omran, E. (2007). Spatial Data Sharing: From Theory to Practice.

30. Onchaga, R. (n.d.). Web Mapping Service (WMS).

31. Onchaga, R. (n.d.). Web Mapping-An Introduction.

32. *Online Atlas of the British and Irish Flora*. (n.d.). Retrieved February 14, 2019, from brc.ac.uk: https://www.brc.ac.uk/plantatlas

33. Open Geospatial Consortium. (2006). OpenGIS® Web Map Server Implementation Specification.

34. Open Geospatial Consortium. (2014). OpenGIS Web Feature Service 2.0 Interface Standard.

35. Open Geospatial Consortium. (2018). OGC Web Coverage Service (WCS) 2.1 Interface Standard.

36. Open Geospatial Consortium Inc. (2006). Topic 18: Geospatial Digital Rights Management Reference Model (GeoDRM RM).

37. openstreetmap.org. (n.d.). *openstreetmap*. Retrieved January 14, 2019, from openstreetmap.org: www.openstreetmap.org

38. Ozmus, L. (n.d.). SPATIAL DATA WEB SERVICES PRICING MODEL INRASTRUCTURE.

39. Quackit. (n.d.). *HTML*. Retrieved February 15, 2019, from quackit.com/html/: https://www.quackit.com/html/

40. Rados, S. (2002). Legal Issues Regarding Spatial Data.

41. Rwanyiziri, G.& Uwayezu, E. (2016, September). *Available Spatial Data and Data Sharing Habits in East Africa: The Rwandan Experience.* Retrieved February 21, 2019, from researchgate.net.

42. Sangita, Z. (2012). PROTECTION OF GEOSPATIAL DATA: PRESENT APPROACHES AND RESEARCH NEEDS.

43. Sangita, Z. (2013). CONCEPTUAL FRAMEWORK FOR GEOSPATIAL DATA SECURITY. *V*(5).

44. Schmullius, C. (n.d.). Earth system monitoring and modelling.

45. Sieber, T. (2012, April 10). *Browsers.* Retrieved February 17, 2019, from makeuseof.com: https://www.makeuseof.com/tag/browser-cache-makeuseof-explains/

46. *Spatial Decision Support* . (n.d.). Retrieved March 18, 2019, from msu.edu: http://www.iwr.msu.edu/mwdssp/about-sdss.asp

47. techterms.com. (2014, February 28). *Web browser*. Retrieved February 25, 2019, from techterms.com: https://techterms.com/definition/web_browser

48. tutorialspoint. (n.d.). *Web Server*. Retrieved February 25, 2019, from tutorialspoint.com: http://www.tutorialspoint.com/internet_technologies/web_servers.htm

49. uiowa.edu. (2000, October 25). *Image Data Compression.* Retrieved February 16, 2019, from user.engineering.uiowa.edu.

50. Ullman, C. (2007). *Beginning AJAX*. Retrieved February 16, 2019, from wrox.com: http://www.wrox.com/WileyCDA/Section/id-303217.html

51. USGS. (2019). *USGS science for a changing world*. Retrieved January 16, 2019, from usgs.gov: www.usgs.gov

52. USGS. (n.d.). *USGS EarthExplorer*. (USGS) Retrieved January 20, 2019, from earthexplorer.usgs.gov: https://earthexplorer.usgs.gov/

53. Veenendal, B. (2017). Review of Web Mapping: Eras, Trends and Directions.

54. w3schools. (n.d.). *JavaScript Tutorial*. Retrieved February 15, 2019, from w3schools.com: https://www.w3schools.com/js/default.asp

55. Wenjue, J. (n.d.). WEB SERVICE BASED WEB FEATURE SERVICE.

56. West Virginia GIS Technical Center. (2002). GIS-Transportation Study for WV DOT .

57. wikipedia. (2019, February 12). *Cyberinfrastructure.* Retrieved February 22, 2019, from wikipedia.org: https://en.wikipedia.org/wiki/Cyberinfrastructure

58. wikipedia. (2019, February 5). *Image file formats.* Retrieved February 16, 2019, from wikipedia.org: https://en.wikipedia.org/wiki/Image_file_formats

59. wikipedia. (2019). *wikipedia.org/wiki/Satellite_imagery*. Retrieved from wikipedia.org/wiki/Satellite_imagery: https://en.wikipedia.org/wiki/Satellite_imagery

60. wikipedia. (n.d.). *Distributed_GIS.* Retrieved February 15, 2019, from wikipedia.org: https://en.wikipedia.org/wiki/Distributed_GIS

61. www.opengeospatial.org. (n.d.). *www.opengeospatial.org*. Retrieved January 15, 2019, from www.opengeospatial.org: www.opengeospatial.org

62. Zongjie, X. (2015). Standardization efforts: The relationship between knowledge dimensions, search processes and innovation outcomes.

Appendix

Web mapping applications in use

Coverage	Country	Web mapping application
Global	All countries	Yahoo maps (yahoo.com/search/?p=maps)
N. America	United States	MapQuest (mapquest.com)