

GEODATABASE DESIGN AND WEBGIS FOR LAND INFORMATION MANAGEMENT: A CASE STUDY OF THE MINISTRY OF LANDS AND RURAL RESETTLEMENT, ZIMBABWE

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Abstract:

Land administration is dynamic in nature as it depicts the people–land relationship. Therefore, there is need for development of a system which can be used to integrate all farm beneficiaries' spatial and non-spatial data. The research's objectives were to review the current system of administrating land related data at the Ministry of Lands and Rural Resettlement, create a relational geodatabase which incorporates all relevant data, and development of website to allow remote access to the data. The website was configured in such a way that it can handle spatial data, using the concepts of WebGis. PostgreSQL was used as a geodatabase. QGis, PgAdmin and ArcGIS 10.3 were used to connect to the geodatabase. Data security was enforced through usage of login credentials, users and roles. The website was hosted locally using XAMPP server. Publishing of geospatial data was online was done using GeoServer. The results showed that effective land administration can be achieved using the combination of geodatabases and WebGis. The data is centrally located, and easy to retrieve as long as the user is authorized to do so. The results also show that the geodatabase can be used as a cost-effective basis for the creation of a digital, up-to-date national cadaster. This geodatabase can be used for geoprocessing functions such as segmenting a farm into several equal sections, segmenting basing on other features such as roads and rivers as well as determining the optimum farm which meet requirements (proximity to road network, an area with certain vegetation and soil type or a certain natural ecological region) of the applicant.

Keywords: *Geodatabase, GeoServer, Land Administration, WebGis*

1.0 INTRODUCTION

Land administration is dynamic in nature as it depicts the people–land relationship. Therefore, governments need to carefully manage the resource for it to be properly used (Dale and McLaughlin, 1988). They require accurate and current land records for mapping the location and extent of landholdings, establishing the ownership of rights in real property, and determining the value of those rights. There is need for promotion of Geographic Information Systems (GIS) in developing countries in form of data accessibility and availability through creation of policies which are conducive for GIS implementation. The availability of an online, digital, up-to-date and easily accessible cadastral database is a primary requirement for undertaking efficient land administration and/or spatial planning decisions across relevant government departments for any country. This can be achieved through implementing a seamless, web-based geo-database based in a GIS.

Due to the fact that the data is centralized on a server, this will improve efficiency because it reduces chances of data lost and any authorized user can access data processed by another. There is also high security on the issue of assessing the data since it is confidential. The system is cost effective since it uses freely available software and can be incorporated to existing software which is ArcGIS 10.1. Open source software used are PostgreSQL coupled with a spatial extension- PostGIS and QGIS. PostGIS follows Simple Feature Specification for SQL as OGC Standard; an Open Source Spatial Data Base that was released under GNU General Public Licence (De Filippis et al, 2012). GeoServer, another open source software is a server written in Java programming language which allows users to share and edit geospatial data online Babawuro (2010), aiding in interoperability.

Mapping of the land parcels is a continuous job as it must be constantly updated to keep pace with the subdivision, consolidation or mutation of land boundaries (such as during the Fast track land reform program). The Ministry of Lands and Rural Resettlement has statutory rights to monitor and administer all rural land information in Zimbabwe. It is responsible for all resettlement, especially the exercise which was carried out nationally, of the land reform program (Moyo and Chambati, 2013). Therefore, a digital cadaster which is synchronous with the current situation on the ground as far as farmers' information is concerned, is needed. Hence this study seeks to demonstrate how the system can be implemented in Zimbabwe.

Several researches have been done to understand the use of geodatabases and WebGis in various fields. Studies were done on the use of geodatabases for managing archaeology data and resources (Tennant, 2007). Another geodatabase model was developed to aid the Missoula Field Office BLM to adequately fulfil their land management data responsibilities, and assist their GIS demands as a federal agency (English, 2008). However, the system was developed using Esri's ArcGIS 10.1 (ArcGIS, 2012) which is expensive for LEDC's in terms of buying and license renewal. It was also not internet based, making it impossible for remote access. Hence study seek to use open source software which is affordable perform the same functions without compromising quality as well as being remotely accessed. There is currently only a limited amount of spatially referenced data readily available to support analysts and decision makers working in LEDCs (Mennecke and Jr, 2002).

Currently, at the Ministry of Lands and Rural Resettlement, there is no linkage between the latest spatial data collected after land reform (from Resettlement and Planning Development department) and non-spatial data (from LIMS, Valuation and other departments). Each

department stores only a fractional part of the whole information about land which gives rise to the problem of duplication and redundancy of the data in custody. This linkage can be done through modeling of spatial data and its integration into a geo-database management system (Aref and Samet, 1991).

Little research was done on the use of relational geodatabases and WebGis in management of farmers' spatial and non-spatial information as well as cadaster creation through the process of integrating several surveyed farms' spatial and non-spatial data. This research focuses on relational geodatabase and WebGis development for effective land management using open source software and without compromising quality.

The hypothesis is that there is increased effectiveness in land information management due to the implementation of geodatabases. The effectiveness is going to be tested by comparing the current system and the proposed system in terms of the following issues; data integrity, data security, time taken to retrieve spatial and no-spatial information of the farmer, information sharing and integration across all approved users

2.0 Study Area

Since the system is a prototype and due to time restrictions, two provinces were used: Mashonaland East and Manicaland. In each province, 3 districts were studied. In Mashonaland East; Murewa, Mutoko and Seke, in Manicaland; Chipinge, Makoni and Mutasa districts were used.

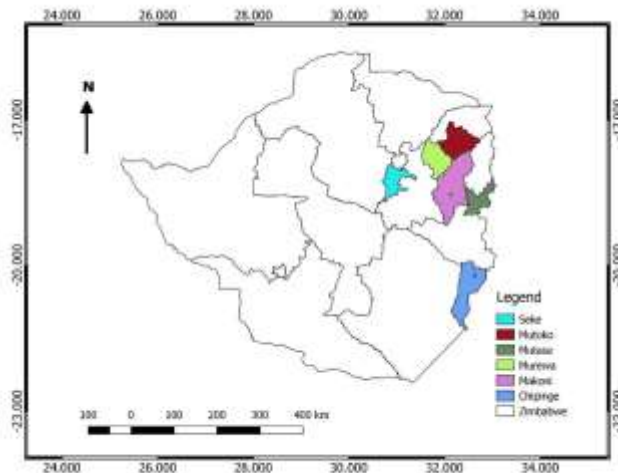


Figure 1: The study area

3.0 Materials and Methods

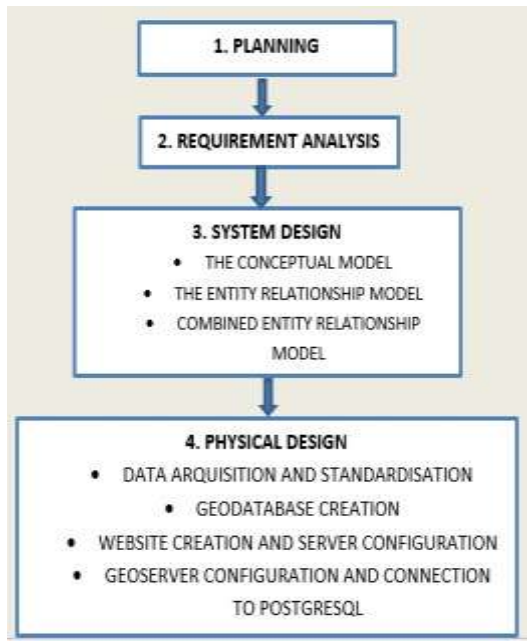
For the geodatabase to function, several materials were used. PostgreSQL coupled with PostGIS extension was used as the relational geodatabase for storing all spatial and non-spatial data (Güting, 2014). Another software used was PgAdmin which is a General User Interface for making queries to the geodatabase and retrieve the data stored. QGIS with a DB Manager plugin and ArcGIS were used for retrieving data from the geodatabase. XAMPP, a lightweight Apache distribution (Walia and Gill, 2013) was used to create a local host for the MLRR website. GeoServer, an open source software server written in Java programming language Babawuro (2010) was used to allow users to share and edit geospatial data online.

The data for the research was sourced mainly from the Ministry of Lands and Rural Resettlement (MLRR) – Head office and online. Spatial data for surveyed sub-divided and whole farms was

collected from the Planning department at the MLRR Head Office and also from MLRR Seke District. Beneficiaries' and previous white farmers' data were collected from Resettlement department at the MLRR head office. The LIMMS department at the MLRR head office provided the researcher with Farm ID's and District Codes. Road network data was downloaded from an online source (www.openstreet.com). Settlements, river network and vegetation cover datasets were downloaded from an online source (www.divagis.com).

3.1 System Development

To successfully develop the system, a set of steps in Figure 2 were followed.



The first stage is the planning stage which is concerned with conceptual understanding of the organization and is obtained through a review of existing system(s). The current status is assessed so as to determine its strengths and weakness. Potential applications of the system in respect to the Ministry goals are identified. Finally, in this stage, the direction of system development is determined by developing a system implementation plan which meet the organization's business objective.

The second stage is requirement analysis. In this stage user and functional needs analysis is carried out through the use of a combination of data collection tools such as questionnaire, interviews and literature review so as to determine the data, information, system components and data processing

Figure 2: Flowchart of the system development.

required by There is also software to evaluates

the organization to meet its objectives. need to determine hardware and be used in the system. The researcher existing hardware and software and also determine another necessary open-source software to include.

The third stage is system design. This stage demonstrates how the system will address the requirements and which is specific to the needs of the client. System design is composed of several stages which are; a) the conceptual model, b) entity relationship model, c) combined entity relationship model and d) data dictionary.

The fourth stage is the physical design. This stage comprises of a) data acquisition and standardization and b) geodatabase creation c) Website creation and server configuration, and d) GeoServer configuration and connection to PostgreSQL.

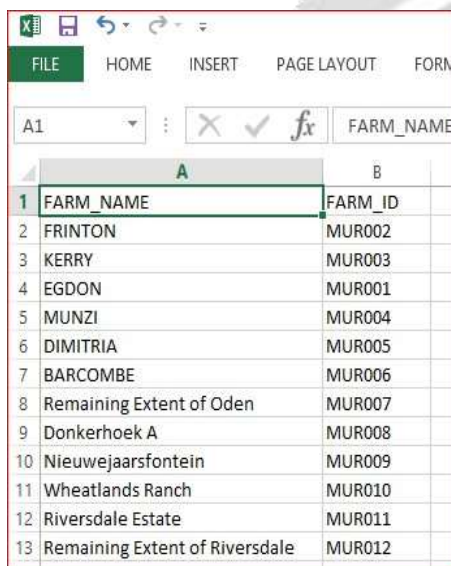
a) In data acquisition and standardization, data was acquired from several sources. The sources were GPS coordinates from GPS receivers, excel sheets, images of digital map layouts and word documents. The data was processed and standardized so as to be of the required format and meet requirements stated in the data dictionary. Spatial data was reprojected to the same coordinate reference system to enable geoprocessing of the dataset.

- b) The next step was geodatabase creation. After installing the geodatabase, schemas were created with respect to departments of the Ministry. Data for each department was loaded into respective schemas. Relationship between datasets was enforced through use of primary and foreign keys. Login credentials through the creation of users and roles were implemented. Views were created to restrict access within a table and for quick retrieval of data. Inheritance was implemented for grouping data of the same area or representation.
- c) In website creation, web pages were created using html5 and CSS. The server, XAMPP, was used to host website.
- d) GeoServer was configured and embedded into the website. It was also connected to the spatial database, PostgreSQL so that it retrieves, spatial data.

4.0 RESULTS

4.1 The current system at the MLRR.

The LIMMS department across all districts, provinces and the head office, store district and farm codes/ID for each district and farm respectively. There is no data sharing between the department and others which depend on their data. The data is stored in the excel format on a computer. This makes data insecure since anyone with access to the excel files can alter or delete without trace. It is possible to have one farm ID for several farms since enforcing primary key integrity is not practical with excel.



FARM_NAME	FARM_ID
FRINTON	MUR002
KERRY	MUR003
EGDON	MUR001
MUNZI	MUR004
DIMITRIA	MUR005
BARCOMBE	MUR006
Remaining Extent of Oden	MUR007
Donkerhoek A	MUR008
Nieuwejaarsfontein	MUR009
Wheatlands Ranch	MUR010
Riversdale Estate	MUR011
Remaining Extent of Riversdale	MUR012

Figure 3: Excel file for farm codes

notebooks and used to create a then printed as an image and stored image cannot be used in the data since it is incompatible for The planning department has an Figure 4 which has pre-Land It also fails to represent the ground since some farms were subdivided into several



Figure 4: Spatial dataset at the planning department.

After surveying a farm, spatial data is sometimes captured physically in farm layout which is stored digitally. The geoprocessing of the integration in GIS. outdated cadaster in reform information. situation at the displayed as whole divisions.

4.2 The new geodatabase structures.

The relational geodatabase created has data for all relevant departments which is accessible to any user within the respective department and other departments which may need to use it.

The ALLOCATION_REFERENCE schema is administered by the planning department. It stores other spatial data for use in determining the area of a selected district which meet the conditions specified by an applicant for a farm. An applicant may wish to do market gardening therefore need a farm which is close to a tarred road. The resettlement department can then identify possible a number of possible farms closest to road network.

The BENEFICIARIES schema is administered by resettlement department and contains all beneficiaries' data on several levels. Inheritance technique has been used to group districts which are within the same province so as to show provincial beneficiaries. The same technique has been used to create the national beneficiaries table which contain all current beneficiaries. The primary key is the beneficiary's National ID. The foreign key, Farm/Sub-division_ID relates to the specific land parcel in the planning department.

The REMAINING_WHITE_FARMERS schema in Figure 5 contains all remaining white farmers' details. The schema data is created and resettlement department. The data is in form of updatable views from the respective BENEFICIARIES tables. There is sharing of the data among authorized users on different levels, (district, province and head office).

The LIMMS_REFERENCE schema contains two tables; District_codes which contain codes for

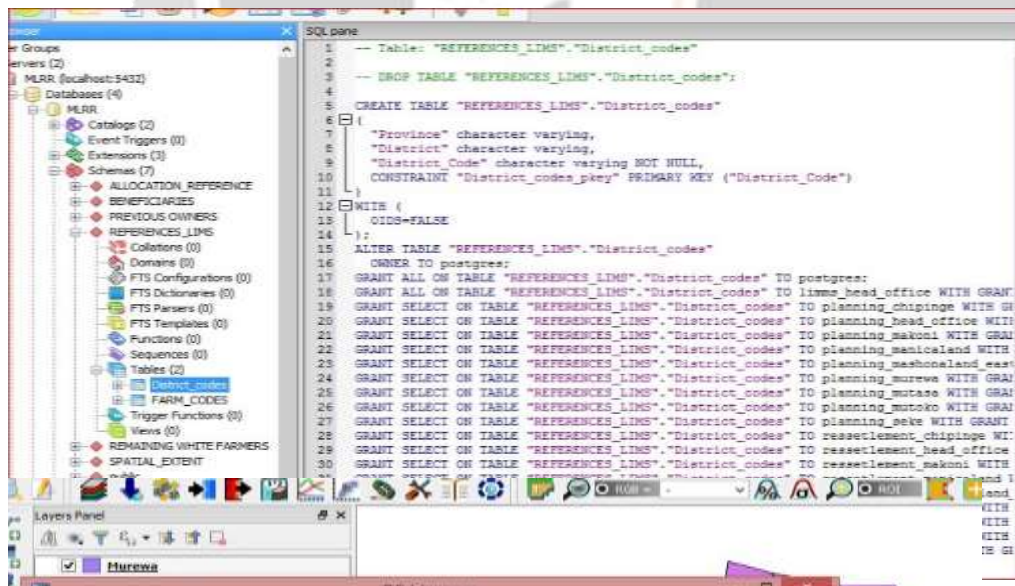


Figure 5: BENEFICIARIES schema



Figure 6: SPATIAL_EXTENT schema.

all districts and FARM_CODES which contain codes for all the farms.

The SPATIAL_EXTENT schema in Figure 6 contains spatial data for the surveyed land parcels on different levels (district, province and head office). Aggregating data from district to province and head office tables is through inheritance using child tables from respective lower levels. Generation of farm/sub-division_ID was basing on the farm’s code in the Farms_Codes table stored in REFERENCE_LIMMS table.

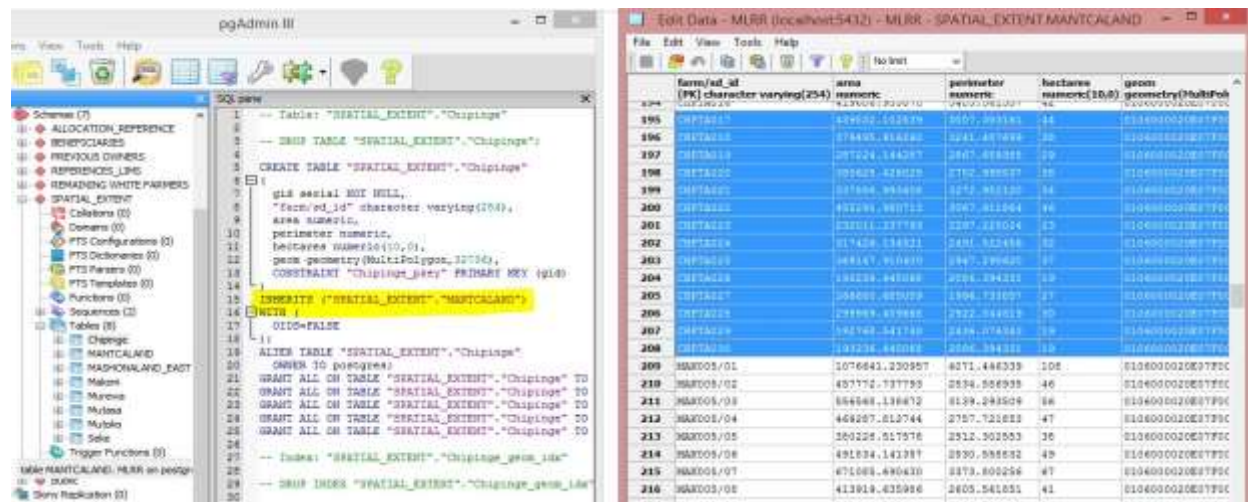


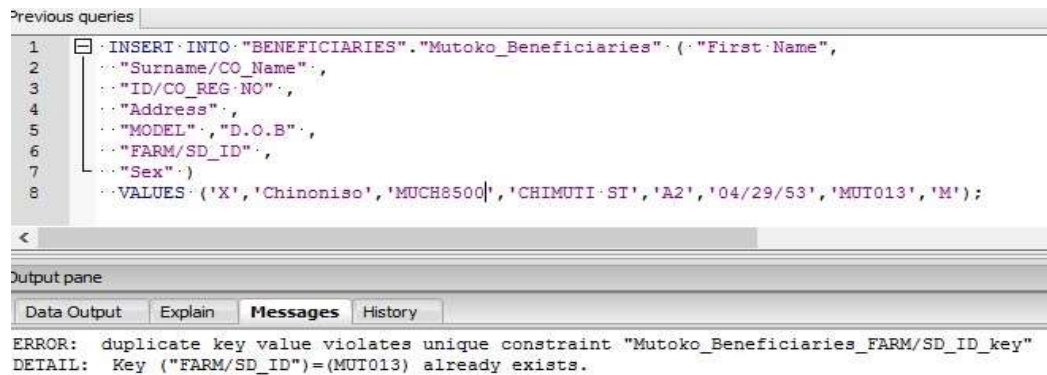
Figure 7: Inheritance. The table to the left shows that Chipinge inherits Manicaland province (highlighted text). The table to the right shows inherited Chipinge (highlighted) Makoni which also fall under Manicaland.

4.3 Access Restrictions through authentication

The users and roles created has enabled restricted access to certain parts of the database. A user with login credentials is only able to access allocated schemas and/or tables as per the Ministry regulations. A user PLANNINGMRE, who is from the planning department of Murewa District, has full privilege to Murewa spatial data only. However, the same user has no privileges to other tables and/or schemas such as REMAINING WHITE FARMERS.

4.4 Prevention of double allocation

If the farm/subdivision has been already allocated to a beneficiary it is impossible to allocate to another beneficiary without taking it back from the current beneficiary.



```

Previous queries
1  INSERT INTO "BENEFICIARIES"."Mutoko_Beneficiaries" ("First_Name",
2  "Surname/CO_Name",
3  "ID/CO_REG_NO",
4  "Address",
5  "MODEL", "D.O.B",
6  "FARM/SD_ID",
7  "Sex")
8  VALUES ('X', 'Chinoniso', 'MUCH8500', 'CHIMUTI-ST', 'A2', '04/29/53', 'MUT013', 'M');

Output pane
Data Output  Explain  Messages  History
ERROR:  duplicate key value violates unique constraint "Mutoko_Beneficiaries_FARM/SD_ID_key"
DETAIL:  Key ("FARM/SD_ID")=(MUT013) already exists.

```

Figure 8: Error message indicating that the farm or sub-division entered was already allocated to a beneficiary.

4.5 One farm per beneficiary

Since every person has a unique ID, trying to register a beneficiary with an ID already in the geodatabase will create an error. One has to check with the National Beneficiaries table which is an inheritance of all beneficiaries' tables whether the applicant has a farm already, and if it is true, all the details are shown.

4.6 Data retrieval

Since all the data is centrally located, related and easily accessible to approved users, retrieval or exporting of data for any purpose such as report writing, map or layout creation and lease document generation can be done.

4.7 WebGis

By typing localhost at the address bar, the user is directed to the homepage of the online geodatabase. The user clicks any part of the province at the Zimbabwe map and is directed to the districts of the respective province. A user highlights the preferred district and a drop-down menu appears where the department is selected.

After selecting the PLANNING department, the user is directed to the GeoServer which need log in in order to access it. When logged as admin (Head Office Planning), the user has all the rights to the spatial datasets of the whole country. The user can make all necessary changes to the server (the left panel of the interface). Encryption is used to restrict hacking. When logged in as another user, only data relevant to the user is retrieved from the geodatabase. The user does not have the rights to the server, besides viewing and exporting relevant data.

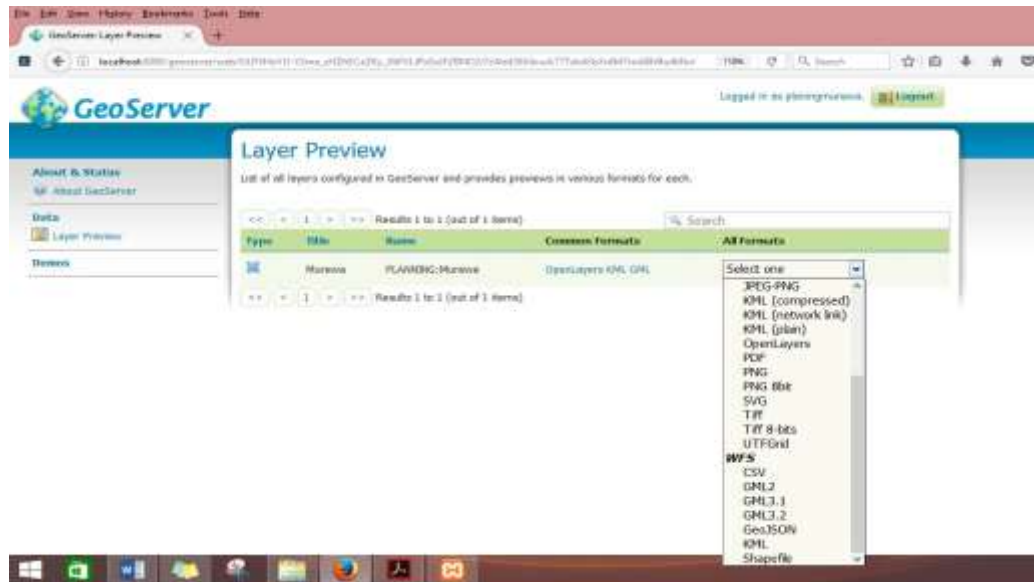


Figure 9: GeoServer interface when logged in as planning Murewa and several export formats.



Figure 10: Shows online previewing of the spatial data.

The user can preview the data in Figure 9 prior to exporting. Functions such as zooming to a preferred level and highlighting a farm to view its attributes are supported.

Geoserver supports spatial data exports in several formats. One can export in WMS formats such as JPEG, GIF, PDF, PNG and SVG. The user can also export in WFS formats such as shapefile, GeoJSON, GML, kml, and csv.

5.0 Discussion

The research showed that the current system of data handling at the Ministry needs improvement. The current system has many drawbacks which makes land management ineffective since there is no proper storing and sharing of data among the users. With the data scattered along the departments, retrieval of specific information is not an easy task. On the other hand, the new system of relational geodatabase and WebGIS has shown how GIS can be used to effectively manage land information.

Data standardization and cleaning enabled data from different sources or providers (such data captures from different districts) to be of the same format before it is exported to the database. In land management, there is information which is critical and has to be included in the database.

Ability to differentiate between critical and optional information in geodatabase design leads to the integrity of the database.

Since the geodatabase contains confidential information, access to it has been through encrypted login credentials which are passwords and usernames. No unauthorized person can access it. The results have shown that the database administrator has powers to make changes to passwords. To increase security, the passwords can be created to function for a period of time and then they expire.

Applying inheritance in a database enables automatic update of related tables. When the function is implemented to district level data, this enables automatic update to provincial and national data. This also allows all levels to have the same data. In an event of a system failure to a part of the geodatabase, it is easy to reconstruct the database again since most of the tables are dependencies of each other. The use of updatable views which depend on other tables enabled quick access to specific data. This also leads to access restrictions where a user is allowed access to a certain part of the whole table.

The use of WebGis enabled remote access of data in the database. This means that any user, be it from the district, province or head office can access the data online, everywhere, provided that (s)he has login credentials to the website. The website has security through use of encryption as demonstrated so as to prevent hacking.

6.0 Conclusion and Recommendations

Since land ownership and land parcel spatial extent change with time, the use of a centralized geodatabase to record every change for management purposes is essential. It avoids several departments or administration levels (districts, provinces and head office) from having different information about the same land parcel. The use of a combination of relational and hierarchical geodatabase design leads to cost-effective land management. Relational geodatabase enables connection of several datasets which have common attribute(s). By enforcing referential and foreign key integrity constrains, data redundancy is reduced since attributes are stored once and business rules are upfolded since one cannot change data in one department which is dependent on other department without following proper procedures. One cannot allocate a sub-division of a farm an ID which is not related to the parent farm. Hierarchical geodatabase design enables inheritance between parent and child tables. This increases efficiency since all manipulations are done on the child tables and parent tables are updated accordingly. A geodatabase can be used as a basis for creation of a digital, up-to-date cadaster of the whole country. Every surveyed farm's spatial and non-spatial details are appended to the geodatabase and related. Changes to already surveyed farms, such as change in farm size and ownership can be updated to the geodatabase. Conflict resolution can be used with the geodatabase since all the up to-date details will be in the geodatabase. Referential and foreign key integrity restricts double farm allocation as well as one beneficiary having more than one farm. Further studies can be done on incorporating spatial data on GeoServer with other WMS services such as Open Street Map and Google Earth prior to exporting so that the user can drop or view the dataset overlaid on top of these WMS and have an appreciation of the satellite view of the area.

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