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TOWARDS A DIGITAL MINE: A SPATIAL DATABASE FOR ACCESSING HISTORICAL GEOSPATIAL DATA ON MINING AND RELATED ACTIVITIES

Samkelisiwe Ntandoyenkosi Khanyile

A Research Report submitted to the Faculty of Science, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Science.

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DECLARATION

I declare that this research report is my own, unaided work. It is being submitted in completion of a Master of Science in GIS and Remote Sensing to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.

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 (Signature of candidate)

Signed on the ___18th___ day of __August___ year __2016_

at _University of the Witwatersrand, Johannesburg___

ABSTRACT

Countries around the world are recognising the importance of geospatial data in answering questions related to spatially varying industries such as mining activities (ongoing and discontinued). This is becoming increasingly evident with countries such as Canada, Australia, and the United Kingdom working towards establishing Abandoned Mine Lands (AML) inventories. However, the increasing need for data on mining activities is not paralleled by an increase in the availability of such data. The aim of this research therefore is to design a database for accessing historical and current geospatial data that can be used to support research, environmental management efforts as well as support decision making at all levels.

A user needs survey was conducted. Two sampling methods were employed, convenient sampling and snowball sampling method. The convenient sampling method was used mostly with all the WDMP group members and the latter was employed with the respondents from institutions and organisations outside of the university respectively. The data were then categorised so as to make analysis easier and data could be evaluated on the same basis. An evaluation of the data collected showed that although the WDMP required different types of data (spatial and non- spatial) the data feed into each other and as such it is important that there is a central repository in which to store them. Furthermore investigation also shows that there is a wealth of data on current mining activities, but not so much on historical mining activities. Although data on mining activities exists, accessibility to these data is hindered by various factors such as copyright infringements, data costs, discrepancies in the data request process.

The outcome of this research has been that of a physical database PostgreSQL database (PostGIS) and one mounted on an online platform (GeoServer). The databases can be visualised on PostgreSQL using select statements or visualisation through establishing a connection with QGIS, alternatively the database may be accessed on GeoServer.

The database is expected to be of use to at least all members of the Wits Digital Mine Project (WDMP) and stakeholders involved in the project. The database can be used for baseline studies and also as a basis for the framework used to analyse, remedy as well as predict future challenges in the mining industry. Moreover, the database can act as a central repository for all data produced from the WDMP.

ACKNOWLEDGEMENTS

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LIST OF ACRONYMS

CD: NGI	Chief Directorate National GeoSpatial Information
CER	Centre for Environmental Rights
D/O mines	Derelict and Ownerless mines
DBMS	Database Management System
DMR	Department of Mineral Resources
GDARD	Gauteng Department of Agriculture and Rural Development
GIS	Geographical Information Systems
GISc	Geographical Information Science
MRAs	Mine Residue Areas
MPRDA	Mineral and Petroleum Resources Development Act of 2002
NEMA	National Environmental Management Act of 1998
NWA	National Water Act of 1998
PAIA	Promotion of Access to Information Act of 2000
SASDI	South African Spatial Data Infrastructure Act
SDBMS	Spatial Database Management System
SDIA	Spatial Data Infrastructure Act No. 54 of 2003
SDIs	Spatial Data Infrastructures
USGS	United States Geological Survey
WDMP	Wits Digital Mine Project
Wits	University of the Witwatersrand

CHAPTER ONE   INTRODUCTION

1.1 Background

Mining and related activities, in particular subsurface mining practices, are characterized by the contamination of surrounding soils and water bodies, biodiversity loss, high tailings volumes (Martin et al., 2014), changes in land used for agricultural purposes (Moncur et al., 2014) and frequent geological incidents, i.e. the formation of sinkholes as a result of the dissolution of bedrock material or collapse thereof (Pretorius, 2012) and last but not least, mining induced seismic events and rockbursts. These remain one of the most important issues facing deep mining operations as they tend to claim the lives of thousands of mine workers countrywide annually (Durrheim et al., 2010, 3).

Consequently, mine safety is of paramount importance to the mining industry. As such, the mining industry is working towards introducing innovative modern technologies and a diversity of professionals with various skills to alleviate these issues. This however is not a straight forward task, since it requires the integration of a vast amount of information collected and stored in a variety of formats (analogue and digital) which may utilize different scales. Significant advances in data collection and storage methods require the adoption of software for use in different phases from the prospecting to exploitation and they include visualization and for the modeling of data (Kopec et al., 2005). Thus the use of computer software has become inherent in mining and related activities (Katakwa et al., 2013), and is used to aid the understanding of complex issues surrounding mining and related activities (Laes et al., 2008). However, varying mandates and discrepancies in the resultant quality of work and spatial information product deliverables tends to pose a management challenge. Data often is 'hidden' in organizations or institutions that do not have a centralized database of all information on a server (Main, 2013), invariably resulting in the redundancy of spatial data, varying quality and unclear protocol for obtaining or acquiring geospatial data (Landrau, 2012).

A number of studies (Kopec et al., 2015 and Katakwa, 2013) have investigated the use of database management systems to aid design, production planning, simulation of proposed mining activities and the use of GIS techniques for the analysis of ancient and archival data (Carrion et al., 2016 and Milner, 1997), but more especially the use of databases for the storage of information about mine workings and other facilities (Kopec et al., 2015 and Carrion et al., 2016). This data can either be current or historical, as spatial database management systems have the ability to handle spatial data with a spatial and temporal component (Siyuan et al., 2009). Moreover, recently there has been an increased effort in the establishment of historical and/or abandoned mine inventories internationally such as the BLM's Abandoned Mine lands (AML) Cleanup program, USGS Abandoned Mine Lands, the Abandoned Mines database of Iran (Cal Data Limited, 2005), Michigan underground mine inventory project (Johnson and Gere 1998) and similar databases have been developed for countries such as Canada, United States, United Kingdom and Australia. Nevertheless, very little has been done in South Africa. In fact although

some records of mining activities exist, the efforts have been fragmented due to discrepancies between responsible organisations (IIED and WBCSD, 2002).

1.2. Problem statement and motivation

Historical gold mining activities in the Witwatersrand basin have left behind a legacy of mine scars, some of which are easily identifiable, whereas some have been re- integrated into the City of Johannesburg and neighbouring municipalities. The identification of these mining legacies can be achieved through the use of spatial data and is essential for the investigation of the development of mining activities over time, urban and rural planning, policy and decision- making at all levels as well as environmental management purposes; thus the growing need of historical geospatial data (past information on mining activities). However, the increasing need of geospatial data (current and historical) is not paralleled by an increase in the availability of data. This remains an issue in South Africa especially since data access is coverd by at least four forms of legislation and a number of initiatives on the availability of spatial data exist and the topic has been tirelessly investigated (Cooper and Gavin, 2005).

In South Africa, the mining industry is under the jurisdiction of the Department of Mineral Resources (DMR) and governed by the Mineral and Petroleum Development Act (MPRDA of 2002) and the Mine Health and Safety Act (No. 29 of 1996). However, mining activities are further broken down into active, abandoned and derelict and ownerless (D/O) mines which are governed by the Fanie Botha Accord of 1989 and the Water Amendment Act of 1997 (IIED and WBCSD, 2002). This implies that DMR and Department of Water Affairs (DWA) are the rightful custodians of natural resources related technical data. Moreover, these are governmental departments and the data has been collected using public funds and should therefore be publically available. Data on mining related activities is hard to acquire from mining companies as mining staff and contractors are legally bound not to make the data available as it could jeopardise mining investments (Main, 2013).

The Wits Digital Mine Project (WDMP) is an initiative hosted by the school of Mining Engineering at the University of the Witwatersrand. The project is multidisciplinary as it consists of a range of individuals from different scientific fields within the university itself and stakeholders from various organisations; most of whom have provided funding which has made the project a possibility. The WDMP is aimed at working towards the introduction and integrated use of different technologies from a wide sphere of scientific fields to improve subsurface communication systems. By so doing the WDMP will facilitate the necessary steps towards improving not only the mine working conditions but also economic benefits within the mining industry in the long run (Cawood, 2015). The solution presented by the research at hand is focussed on designing a spatial database using open source software so as to make historical spatial data and supporting data on mining and related activities easily accessible to a wide range of users and clients. Spatial databases are designed to store, query and manipulate spatial data (Harrington, 2009).

Using the database, users of geospatial data should have a better understanding of the available data as well as the nature of past mining activities and their impact. The intended beneficiaries of the spatial database under study will be the WDMP, Sibanye Gold (as a sponsor), other mining organisations and

stakeholders involved in the project. The database also forms a basis for a framework which may be used in order to analyse, remedy and predict future challenges of the mining industry. The WDMP can use the data to further studies in the region, mining companies and governmental organisations such as the DMR can use this data to monitor environmental health and use it for decision making and in the urban planning context.

1.3. Research question

What data exists on historical mining and related activities and how can it be made available for the support of research, monitoring, environmental management, mine safety and integrated into urban and rural planning?

1.4. Research aim

To design a spatial database for accessing historical and current geospatial data on mining activities in the wider Sterkfontein and Carletonville areas to support research, monitoring and environmental management efforts.

1.5. Specific objectives

- To conduct a user needs assessment to identify spatial data required by the Digital Mine Project;
- To identify the geospatial data available on mining and related activities for Carletonville and Sterkfontein in both digital and analogue formats, the latter will be converted into digital format through scanning geo- referencing and digitization if necessary;
- To design a database for storing and accessing the spatial data mining activities (historical and current data) using the available data as a guidelines for the system functionalities. Current data were used to describe more recent data on mining related activities within this research report;
- To implement and test the database to check whether it meets the user requirements and the main objective of the research which is to design a spatial database for accessing historical geospatial data on mining activities in the wider Sterkfontein and Carletonville areas to support research, monitoring and environmental management efforts.

1.6. Study area

1.6.1. Description of study area

The study region of interest is located between Johannesburg and the West Rand municipal district (Figure 1) in Gauteng province. This area falls within the summer rainfall region and is characterised by typical Highveld climatic conditions with hot summers of temperatures averaging at 15.9 ^{0}C and generally colder winters with an average rainfall of 678 mm, with a topographic landscape ranging between 1220 and 1840m above mean sea level. The geology of the area is characterised by the Pretoria Group (quartzites and the dolomites). The study area also includes Carletonville and Sterkfontein areas. On the one hand, Carletonville falls within the Merafong City municipality and is a part of the Central Rand land type (Litthauer, 2009) which is known for its gold bearing conglomerate units (Gibson et al.,

2000, 175). The Sterkfontein area on the other hand, falls within the Mogale City Municipality and is famous for the vast majority of hominid discovery (Partridge and Watt, 1991). Sterkfontein area is characterised by breccia deposits and Karst formations (The South African Karst Working Group, 2010) with some parts underlain by dolomite of the Transvaal sequence (Partridge and Watt, 1991). The study region is also associated with the first notable appearances of sinkholes assumed to be associated with gold mining activities in the Far West Rand (De Bruyn and Bell, 2001). Most of the projects under the WDMP are in the wider Sterkfontein and Carletonville areas; however most of the mining activities occur in the Carletonville area, thus Sibanye Gold was used as the pilot study.
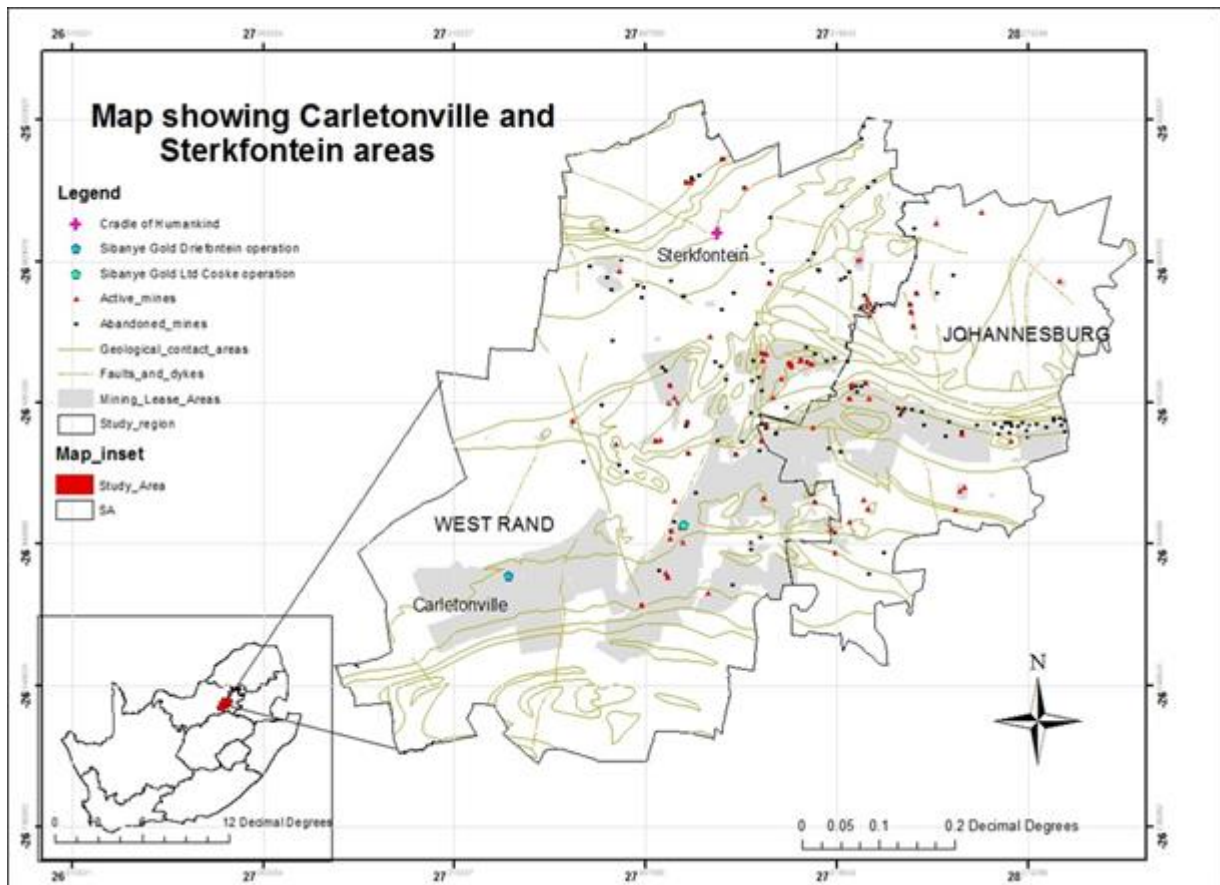
Figure 1: Map showing the study region between Car

1.6.2. Mining activities in the West Rand

The Witwatersrand basin was one of the oldest and first large scale mining areas following the discovery of gold in 1886, in one of the conglomerate reefs in Langlaagte in the Central Rand (Reimer and Durrheim, 2011); mining activities soon spread and have become increasingly beneficial to the South African economy. Gold prospecting in the region has led to the production of a 100 km elongated belt which is now commonly referred to as the Witwatersrand mining belt (Heath, 2009, 1). Records of gold production indicate an increase in gold production, from less than 400 tonnes in 1952 to well over 950 tonnes in 1965 (Hartnady, 2009), with a cumulative average of over 47000 tonnes of gold mined within this region (Robb and Meyer, 1995). The depths of the gold bearing reefs within this region range between 800 and 4500 m, as a consequence of low thermal gradients in South Africa (Manzi et al., 2014).

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1.7. Structure of the research report

This research report has five chapters that concentrate on how to make spatial data on historical mining activities available through the implementation of a database system. Chapter 1 has introduced the reader to this research report by giving some background to the research at hand. It reviews the problems associated with the accessibility of data related to mining and related activities and previous studies. This chapter also introduces the study area.

Chapter 2 is dedicated to a comprehensive literature review about the stated problem as well as the provided technological solutions to the identified problem. Namely: the applications of GIS and other digital technologies in the mining sector, previous and related studies, access to information with regards to geospatial information and DBMSs are discussed chronologically. This chapter also discusses the applications used for the purpose of the study.

Chapter 3 discusses the research methodology employed as well as the identified data requirements. This chapter is divided into two sections, the first section discusses the methodology that was employed and the second section outlines the requirements of the database and introduces the data collection plan. In Chapter 4, the DBMS chosen for the study at hand is discussed and evaluated. In this chapter, the design of the database for the WDMP project will be discussed and the provided data characteristics will be described. This section will also give information on how the database can be accessed.

A discussion with the concluding remarks and recommendations for future studies completes the research report in Chapter 5. It highlights what has been achieved by this research, assesses the limitations that constrain the research problem and suggests future directions for future research.

CHAPTER TWO   LITERATURE REVIEW

2.1. Applications of GIS and other digital technologies in the Mining sector

Geographic Information Systems (GIS) are computer- based systems comprised of software and hardware which allow for the use, storage, management, manipulation, visualisation and the analysis of information on geographic phenomena (Burrough and McDonnell, 1998). The nature of a GIS provides a basis for the association of attributes with a geographic location, provision of tools and methods for the conversion of large amounts of data, integration of various forms of information and the evaluation of relationships between types of information using a two dimensional (2D) or three dimensional (3D) visualisation model (Salap, 2008). This makes GIS a suitable tool for the analysis and management of natural or anthropogenic hazards change assessments and performing predictions based on current and previously employed practices (Al-Shuhail, 2002). GIS also offers a mechanism for the support of decisions regarding the remediation of environmental issues related to mining and related activities (Duzgan et al., 2011). Moreover the generation of a GIS which can administrate all the relevant spatial information accompanied by all the necessary metadata of underground data is critical to mine safety regulation (Salap, 2008).

GIS is becoming increasingly important for handling spatially varying activities such as mining and related activities as it can be used not only to provide answers about ongoing benefits of mining activities but also to provide indications as to where and when mining activities are most beneficial across space and time (Swetnam et al., 2011). As such, there has been an increase in the use of various digital technologies such as spatial mapping and electronic data collection tools for modelling the prospectivity of minerals since the 1980s with the availability of GIS software. Computers and related software have been utilized in the mining industry as tools for information dissemination, learning as well as collation, strategic planning, networking, storage, the analysis of mining data as well as facilitating in the design of mining operations.

Commonly used computer programs in the mining industry are Vulcan, SURPAC, MineScape and RockWare, which are accompanied by different software for the visualisation of data such as AutoCAD and ArcGIS (Kopec et al., 2015). The combination of GIS software with statistical methods could be used for the production of geologically consistent maps of mineral systems and thus a better understanding of the geological setting of a region targeted for both future mining practices and urbanization (Porwan and Carranza, 2015). Recently, numerous GIS applications have been modified from a desktop based GIS to a web-based GIS (Chang and Park, 2004). With the expansion of world wide web (www) services, GIS functionalities can be browsed on popular internet mediums which facilitates the sharing of data amongst various user groups (Salap, 2008); thus making GIS accessible to the general public with very limited knowledge on existing spatial data (Chen et al., 2005). Web- based GIS is also advantageous for a number of other reasons as it: usually has a simple to use user interface (Kim and Kim, 2002), reduces performance and reliability related problems (Chang and Park, 2005) and also has the capacity to create intelligent maps which make it possible to perform various analyses (Salap, 2008).

2.2. Previous and related studies

In recent years there has been a growing consensus amongst countries with long mining histories to establish ways of capturing and delivering mining legacy data for public use (Riganti et al., 2015). As such, some countries such as Australia, United States (US), United Kingdom (UK) and Canada have made strong strides towards the establishment of nation scale and state scale abandoned mine inventories these studies have been used as case studies to inform the project at hand and are summarized below.

Although Australia lacks a nation-wide inventory of abandoned mines, it has taken significant steps towards establishing state scale inventories which are the responsibility of the state governments (Cal Data, 2005); this can be seen with the Geological Survey of Western Australia (GSWA). The GSWA started working towards capturing legacy data from the late 1990s to the early 2000s, which resulted in a comprehensive database online which contains information such as photographs of surface and subsurface abandoned mining activities as well as rehabilitation features which have been put into place (Riganti et al., 2015).

The US initialised the Abandoned Mine Lands (AML) Cleanup program hosted by the Bureau of Land Management in the 1990s (Bureau of Land Management, 2013) inventorying efforts to capture tangible and accurate information on abandoned mines were carried out from 1993 to 1995. The result of which has been compiled to form the Abandoned Mine Lands Inventory System (AMLIS) (Cal Data Limited, 2005). AMLIS is a comprehensive online database system which contains pertinent information on abandoned mines such as the proximity of the abandoned mine to human settlements, health and safety hazards which have then been extended to a GIS (Bureau of Land Management, 2013). The database can be accessed by the general public and the user can perform basic queries and obtain reports derived from the data within the database (Cal Data Limited, 2005). Although the US has a nationwide abandoned mine lands inventory, there are also state scale inventories such as those from the Kentucky Mine Mapping Initiative and the Michigan Underground Mine Inventory Project. On the one hand the Kentucky Mine Mapping Initiative worked closely with ESRI to digitize abandoned coal mine maps and make them readily available to the public (ESRI, 2008). On the other hand the Michigan Underground Mine Mapping was carried out by the Michigan University of Technology in 1995 and was aimed at compiling an inventory and then and mapping of subsurface mining activities (Johnston and Gere, 1998).

As of 1870 it is mandatory for all abandoned mines to be documented in England and Wales. However irrespective of the early realisation of the importance of the documentation of legacy data, the UK is still very far from having a full inventory of abandoned mines (Cal Data Limited, 2005). The gaps in the inventory are attributed to the changes in ownership of mine leases along with the loss of mine records. Canada has also seen a rise in concern over the documentation of orphaned mine sites (Natural Resources Canada, 2013). According to Cal Data Limited (2005) all Canadian provinces are responsible for their own abandoned mine inventories, this can be seen with the Alberta database which was acquired from the Alberta Geological Survey, Manitoba database which contains information on all mineral deposits and the British Colombia database. However, a majority of these databases only contain information on

abandoned mines which pose health and safety risks. Nevertheless the National Orphaned or Abandoned Mines Initiative was established in 2002 as a joint initiative between mining organisations and environmental agencies to create a national inventory and encourage community involvement (Natural Resources Canada, 2013).

In Ireland, all data on abandoned mines and related activities are derived from two databases, namely: Abandoned Mines Database of Northern Ireland and BRITPITS. Where the former is comprised of information on mine shaft locations, voids, associated collapses as recorded by the Geological Survey of Ireland, while the latter contains information on mining and related activities and their operational status (European Commission, 2006). Furthermore, data on abandoned mines and their impact on the surrounding environment can be acquired from the Environmental Protection Agency (Cal Data Limited, 2005).

Moreover, smaller studies can be seen in the work of Milner (1997) and Carrion et al. (2016). Milner (1997) conducted a study tracing the progress of mining activities in Victoria during the 19th Century using source materials such as newspaper articles, photographs, reports from mine surveyors and transcripts on the status of mining in a particular period in time. Carrion et al. (2016) conducted a study which entailed the digitization of medieval maps obtained from libraries and other historical archives and mounting the digital data derived from them onto a Web - GIS platform. However, such studies, be it an attempt to create a national inventory, provincial inventory or a localised project aimed at creating an inventory of abandoned mines have not been carried out in South Africa.

South Africa has some of the oldest mines and is one of the most productive gold mining industries in the world, however, this is not reflected in the availability of data on mining and related activities, as few records exist and are made available to the public. According to the Department of Minerals and Energy (1998) Section 19 of the Mineral Rights Act stipulates that it is mandatory for the holder of a prospecting or mining right to provide information on prospecting in no later than a year of excavation; which will be kept confidential, unless no prospecting occurs 15 years after submission of this information, in which case the state may disclose such information. In 2011 the Department of Resources introduced SAMRAD (South African Mineral Resources Administration System); a system aimed primarily at enabling the general public to view all pending and granted applications for mining rights (DMR, 2011). Nevertheless, this system does not include any environmental GIS data which could be used to inform decisions around the granting of mining right applications. Presently some data on mining (operational mines to be exact) can be obtained from the Department of Mineral Resources website, in excel spreadsheet format; however this data is not accompanied by any coordinates; which therefore means that the researcher or any other individual interested in this data may have to geocode this data- which introduces a wide range of other uncertainties.

2.3. Applications for enabling access to information

GIS among other digital technologies is becoming increasingly amalgamated with community participation for urban planning purposes (Mansourian et al., 2011). In recent years, nations have invested a multitude of resources in the creation and dissemination of spatial data (Nogueras- Iso et al., 2005). As such, spatial and attribute data on mining and related activities is spread across various organizations and institutions in various formats and sizes. The spread of data across various institutions is primarily an issue of concern as it contributes to the data accessibility or lack thereof. As a way of alleviating the issues presented by this, it would be favourable to have a central repository for storing all data on mining and related activities. It is therefore imperative to assess the different technologies/ software available to remedy the issues presented by the storage of data in different data housing entities.

Löfberg and Molin (2005) contrast between standalone and web - based applications as suitable technologies for the dissemination of information. Standalone applications or otherwise known as thick clients are built on client/ server models where the user executes a command and the client retrieves the required data from the database on behalf of the user (Figure 2). This implies that the system is dependent on the client; who communicates directly with the database and there is no intermediary, which may serve to limit the response time.

Client   Database
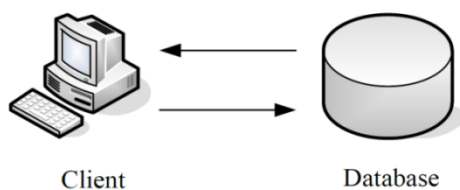
Figure 2: Standalone client/server application (Löfberg and Molin, 2005; 7).

The locality of standalone applications also enables the user to have some control over when the application can be used. Standalone applications are also fully operational offline enabling them to control what is released to the internet and the data that are shared with other users. The system is advantageous as processing and computing is carried out on one computer and all software is on an individual computer thus making the software management easier. The main drawbacks of such applications, however, are related to application performance - because all processing occurs on one computer which may lead to a system overload (Harrington, 2009). Moreover, in circumstances where applications are mounted on multiple compters; the management, maintenance and communication between all computers may become tedious (Cheng et al., 2001).

Although web – based applications are also based on a client / server model, they operate differently in that the user sends requests through the client, which are then processed and extracted by the server and the requested data is returned to the user (Figure 3). At most, Web GIS is characterised by a server and a client; where the server is a web application and the client on the other hand is a browser, desktop or mobile platform application (Fu and Sun, 2011). The user utilizes resources through a database driver which acts as a mode of communication between the client, web server and the actual database (Löfberg

and Molin, 2005). Web - based applications are either connected to internet or an intranet connection, which enables the computer to communicate with other computers using HTTP (Hypertext Transfer Protocol), SMTP (Simple Mail Transfer Protocol), FTP (File Transfer Protocol) or Instant Messaging (Fu and Sun, 2011). Access to the internet enables the system to become centralized; thus making the upgrade and deployment of such applications easy.
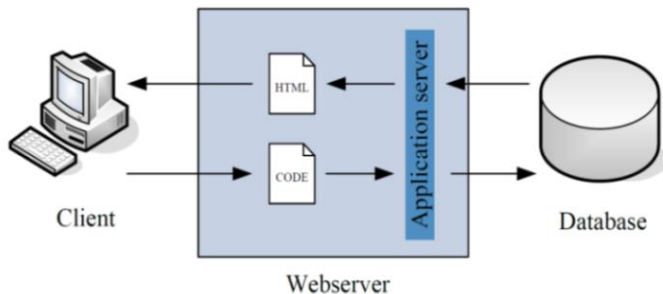
Figure 3: A Web - based client/ server application (Löfberg and Molin, 2005; 8).

However, web - based applications are not without flaws either. Since such applications are centralized, this requires a computer with a high processing capacity. Although the network traffic is reduced as processing is not conducted on the computer but rather on the server (Harrington, 2009), the connection to the internet or intranet connection makes these applications susceptible to security risks and makes the performance of the application connections dependent on the quality of the internet connection (Katakwa, 2012).

Access to information in South Africa is becoming increasingly easier through the development and the growing popularity of the internet and government initiatives aimed at making connectivity in the cities easier. Environmental data are generally easier to obtain, a number of government and parastatal agencies make some spatial data available to the general public using web - based platforms that require very basic administrative commitments, such as: SANBI, CD:NGI, Council for Geosciences (CGS) and Statistics South Africa (Main, 2013). However, data on mining activities are not readily available from a single repository; the researcher might have to contact more than one organization to get an idea of what data exist and are available. Therefore, it was more favourable to develop a web – based application for the purpose of the project.

2.3.1. Database Management Systems (DBMSs)

We have recently entered what is now being referred to as the 'big data' era, which is characterised by high data volumes; data are created at high rates and in a variety of data formats (Colombo and Ferrari, 2015). DBMSs and GIS are crucial tools for the storage, integration, visualization and analysis of large collections of data (Plewe, 2002). DBMSs have a system for synthesizing data sources, documenting metadata accompanying the data in the database as well as data creation standards to be employed in the creation of the data (Gregory and Healey, 2007). DBMSs use a systematic method to structure data in the form of sets of records so that the relations between the data can be easily identified (Salap, 2008); the database is then used to translate queries from the user to the physical database content and can be used by multiple users concurrently (Harrington, 2009).

DBMS are not only essential for the storage, management, and the retrieval of spatial data. They are also essential for the translation of data needs between the user and data inventory (Harrington, 2009). Traditionally, databases were stored on computers; the computer file based management enabled the efficient sharing of data which was static and independent of space (Worboys, 1994). However, there has been growing attention towards the improvement of these systems in the computer sciences and a shift towards the development of databases that have the capacity to hold complex data, i.e. data which is constantly evolving and is of different formats (Karoimi, 2013). Although non- standard database applications such as those found in GIS platforms withstand these challenges; these applications are mostly platform dependent and are mainly concerned with the analysis and visualization of geographic data. GIS technologies are limited in that they are stand- alone applications which require the use of a platform. Thus the extension of commercial and open- source DBMS software to accommodate spatial data.

Spatial Database Management Systems (SDBMS) perform all the essential tasks conducted by DBMS. Moreover they contain numerous files on the relationships and proximity between data entities and how they are organized and stored within the computer (Burrough and McDonnell, 1998). They also consider the temporal aspect of data (Sarda, 1990). But most importantly they provide the capacity to store and query data which is linked to objects with a geographical location including, but not limited to: points, lines and polygons (Westin, 2012).

Although a number of spatial DBMSs have been developed, the most commonly employed are: ArcSDE, Oracle, MySQL, SQL Server and PostgreSQL. Where ArcSDE is a product developed by ESRI and popular for its capability to use middleware technology for the storage and management of spatial data in commercial databases such as Oracle and SQL Server (Yingcheng and Ling, 2012), Oracle (Spatial) is the leading commercial DBMS, it is characterized by an object relational schema and has the capacity to integrate information into a single database (Oracle, 2010), Microsoft SQL Server is a relational database which supports spatial data, and lastly PostgreSQL (PostGIS), is the first prototype of an extensible DBMS which allows users to extend its capabilities with new modules, it is characterized by an object-relational schema which has the capacity to store geometric data in various formats (Westin, 2012), it provides full support for spatial data as well as provides full processing capacity (Crestaz, 2011); which makes it the most commonly used open - source DBMS software. PostgreSQL was chosen for its cost effectiveness, extensibility and more important because it is conversant with other open – source and commercial GIS software.

Irrespective of the DBMS software employed, the SDBMS should provide a platform for the creation of the structure of the database, tools for the modification of the database, mechanisms for data retrieval (Harrington, 2009), an easy to use user interface (Paredaens, 2005), privacy and security mechanisms (Karoimi et al., 2013). It should be independent so that it is conversant with all DBMSs, have the functionality for specifying queries (Orenstein, 1989), and the framework of the spatial database should allow the integration and matching of geometric and thematic data migrated from a variety of sources in a consistent manner (Albdelmoty and Jones, 1997). Nevertheless in the GISc (Geographical Information

Science) community, GIS users are faced with the challenge of finding ways of combining all the available data and reducing any inconsistencies that may arise due to the combination of data retrieved from different databases and sources and the employment of different standards and data creation techniques (Sheeren et al., 2009).

2.3.2. Choice of web – based application

A major consideration of the research at hand was the inaccessibility of data on mining related activities and lack of a centralized platform for making such data available; therefore it was logical to propose the use of open source software in creating the web application. Open source software was the first choice mainly because of its cost effectiveness, extensibility, moderate stability and security (Xia and Xie, 2009). A Web - based application is connected to a web - browser which then communicates with the dataset on behalf of the user. Web - servers utilize a number of scripting languages to write programs, send commands and combine processing tools. Furthermore scripting also enables advanced development tools required for the rapid creation of Graphical User Interfaces (GUIs), searching and manipulating data, managing data directories, customizing visualisation and image processing (Langtangen, 2009).

Interactive and dynamic web pages require high - level coding which is usually in the form of Python which has gained popularity for its clean syntax and good support for numerical computing (Langtangen, 2009) and Javascript which is an object - oriented scripting language which is utilized for the creation of features within webpages (Kovac, 2006). Consequently, GeoServer was chosen as the web server as it supports both languages.

GeoServer is an open source online server with a full transactional Java implementation for web feature services (WFS) and web coverage services, with an integrated web map service (WMS) as specified by the Open Geospatial Consortium (Open Source Geospatial Foundation, 2014). GeoServer is deployed on an Apache Tomcat server, which serves as a web interface which can be used for basic administrative tasks (Iacovella and Youngblood, 2013). As a web - based application, GeoServer allows users to share and modify spatial data, perform server side spatial analysis (Henderson, 2014), and provides conversion and data transformation tools (Fu and Sun, 2011). Moreover, GeoServer was designed for interoperability and is conversant with PostGIS and desktop GIS software such as QGIS (Xia and Xie, 2009). Figure 4 shows a diagrammatic representation of how GeoServer processes requests and data.
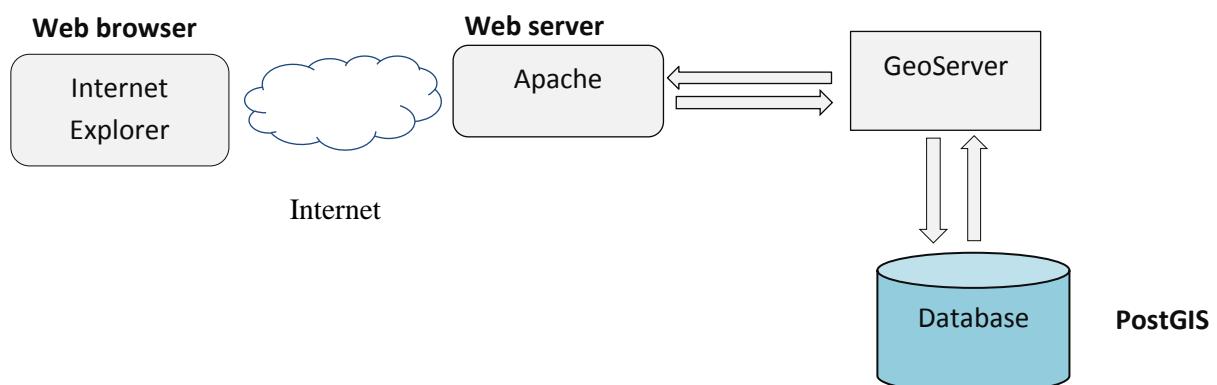
Figure 4: Diagrammatic representation of how GeoServer works (adapted from Xia and Xie, 2009).

2.4. Application design cycle

A formal method is employed in the design of a database to capture the semantics of user requirements and for modelling the foundation of the database (Healey, 1991). The design process required for the development of the information system is referred to as the structured design life cycle (Harrington, 2009) and can be portrayed in a cyclical sequence (Figure 5), which shows eight tasks that need to be undertaken in designing a database. However this method works best where the requirements of the system are known prior to the development of the system.
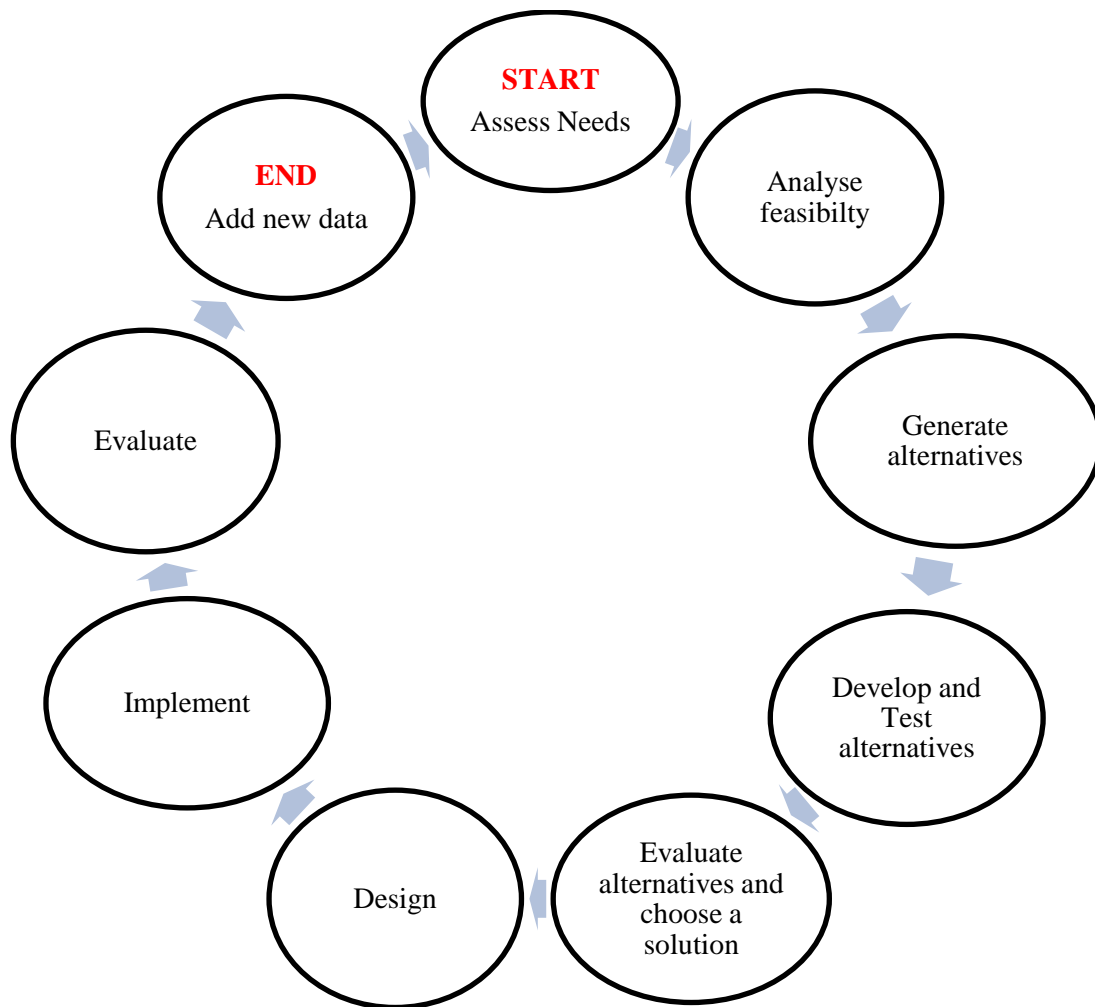
Figure 5: Structured design cycle of a database has been adopted from Harrington (2009). This design cycle does not include a stage for the maintenance of the database.

The optimal method (Figure 5) employed for designing an information system would start by assessing the current systems and recommendations from users, identify all possible alternatives to cure the problems of the currents system, work towards designing the system and end by testing the efficiency of the new system. Lightstone et al. (2007) also shows that the same result can be achieved through simplifying the design process, where the design process only entails the most basic steps which are involved in the designing of the database; starting from the modelling of the conceptual model using the data obtained from the user requirements analysis, the development of a logical deign, the development of an indexed physical schema of the database- which is important for its optimization of instructions

used by the storage device to carry out basic operations and queries on the spatial data in the database (Shekar et al., 1999) and continues to the database implementation as well as the maintenance of the database. Although this design process does not place an emphasis on some parts or sections of the design life cycle portrayed by Harrington (2009), both design structures place a great amount of emphasis on the requirements analysis - which is essential for the identification of all the data which are to be contained in the database and how they will relate to each other (Singh and Singh, 2014), the design of the storage system and its implementation as well as the testing of the storage systems.

2. 5. Summary

This chapter presented the findings of a survey of literature on topics relevant to the study at hand in order to gain an overview of the research initiatives in GIS and DBMS and their applications in the mining industry and data accessibility as a whole. It started by looking at the use of GIS and other digital technologies to the mining sector; followed by the discussion of previous studies on the subject matter; this was done to establish a context and highlight gaps for the subject covered by this research report. Current software and platforms for making data accessible and their advantages and disadvantages were discussed. The chapter is concluded with a discussion outlining the platforms and/or technologies available to address the problem and provides an introduction of the chosen platform.

The next chapter starts off by introducing the design process followed to meet or answer the research questions, followed by the conduction of a user requirements assessment; whose results were used to inform the system and data requirements. The last section outlines the system requirements, as per the user needs requirements results.

CHAPTER THREE   DATA REQUIREMENTS AND NEEDS ASSESSMENT

3.1. Database design process

The method adopted for the purpose of the study follows a basic workflow which is comprised of four core tasks (Figure 6):

Requirements → Data requirements analysis → Database Design → Implementation and evaluation
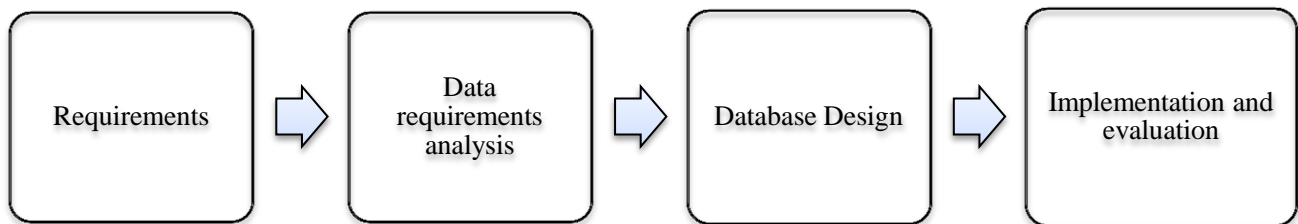
Figure 6: diagram showing the workflow employed for the purpose of the study. The diagram was adapted from the design life cycle of databases in Harrington (2009).

The first step in the design cycle entails the identification of user requirements (which is achieved through contacting individuals and enquiring about their data needs), secondly the needs of the respondents are analysed and the results are used to inform the design of the physical database structure in the third step, the fourth and final step in database design entail the implementation and the evaluation of the database.

3.1.1. Data requirements analysis

The use of spatial and other forms of digital data is imperative for the growth of the mining industry and environmental monitoring. Accordingly, the primary research goal is to design a mechanism for accessing geospatial data to facilitate production, monitor environmental deterioration and improve the mine working conditions. To identify the potential users of such data and their needs, it was necessary to establish contact with the organizations, institutions and individuals concerned with relevant projects on mining and related activities. The specific objectives of the study are to identify the user needs, what spatial data exists, who possess it, spatial data characteristics, data usage and ways for making the existing data on historical mining activities accessible.

A needs assessment is commonly conducted systematically through observation, interviewing, questionnaires and focus groups or brainstorming sessions (Harrington, 2009). For this particular study, needs were identified first during a discussion with the WDMP group (for project specifications) which highlighted the need for historical data, thus the development of a database containing data on historical mining activities. Two sampling methods were employed: the first, a convenient sampling technique (only the relevant bodies were identified), and secondly a snow ball sampling technique was used in the event that the targeted institution or organization is unable to provide data or there are doubts of the completeness and quality of the data.

All the respondents were based in and around Gauteng province (mostly Johannesburg and Pretoria) and questionnaire guided- interviews were conducted in 2014 as part of a Honours project (Khanyile, 2014) and questionnaires were administered and collected between 9 and 24 August 2015. Historical maps and plans were collected from 2 - 5 December 2015 at the Sibanye Gold Geological basecamp located in Carletonville. Respondents from the following institutions and organizations were approached:

Table 1: Respondents category and organization/institution name.

Category	Organisation/Institution
Academic institutions and science and research Institution	Centre for Applied Legal Studies (CALS) Gauteng City Region Observatory (GCRO) School of Architecture and Planning (University of the Witwatersrand) School of Mining Engineering (University of the Witwatersrand) Wits Digital Mine Project group
National and provincial Government	Department of Mineral Resources (DMR) Gauteng Department of Agriculture and Rural Development GDARD)
Private companies Mining companies	Chamber of Mines (CoM) Council for Geosciences (CGS) Gold Plats East Rand Proprietary Mines Impala Platinum Mogale Gold Sibanye Gold

The study utilized two research instruments: questionnaire guided interviews and questionnaires. Two questionnaires were compiled, one which was intended for the WDMP group and the other for organisations that were contacted to participate in the study (Appendix 1 for full questionnaires).

On the one hand, personal interviews were made with some of the respondents (respondents from GCRO, CALS) last year so as to get more in depth responses and comprehensive information from each respondent. Interview questions where applied followed the form of a written questionnaire. The questionnaire intended for the data housing entity representatives examined the following areas:

- Data availability (What data exists on mining activities in the Witwatersrand basin?)

- Data quantity (How much data exists on mining activities in the Witwatersrand basin?)

- Data quality (Of what quality is the available data on mining activities in the Witwatersrand basin?)

On the other hand, questions were sent to all the WDMP group members (10 respondents, Appendix A shows a list of all respondents and respective roles in the project) via email and followed by personal meetings where clarity was needed. The questionnaire intended for the WDMP group examined the following areas:

- Required data (What data is required?)

- Data repository/ data housing entity (Where can the data be found?)

- Existing data (What data has been collected to date?)

- Data applications (What will the above mentioned data be used for?) This question was mainly for understanding the format of the data.

The responses of the participants were captured and subsequent meetings were logged in order to be able to assess the trustworthiness of the interpretations at a later stage. Summaries of the semi - structured questionnaire responses were given to participants to check and validate the veracity of the researchers' interpretation. An informal inventory of responses was made and stored in an Excel format, prior to its analysis. The responses were then categorised to make the data analysis process more manageable. The information and data gathered was used to identify data needs, assess the amount of data available and determine the use of different spatial data types for the purpose of its applications in the monitoring of the development of mining related activities as well as for infrastructural development and environmental monitoring purposes. The data were analysed using quantitative analysis methods which entailed the generation of frequency charts and tables.

3.1.2. Data requirements results

3.1.2.1. User requirements

Before progressing to the design stage of the database, it is essential to get an overview of the backgrounds of the respondents from the WDMP and the data required by them as well as the corresponding data sources and

the facilities available to accommodate them. Figure 7 illustrates the frequency of the respondents and their association with particular data related to mining and mining related activities. The data identified was divided into the categories below, which for the purpose of the study have been defined as:

- **Production data** - is characterized by data which to do with the mine production plan/actual data, Mine Call Factor (MCF) etc.

- **Sensor data**- is characterized by data retrieved from sensing equipment such as extensometers, seismic, gas sensors, etc. and might consist of data such as temperature, rain level, pH level, airflow, communication etc.

- **Survey data** - is characterized by data derived from apparatus or equipment aimed at determining the terrestrial or three-dimensional position of points and the distances and angles between them.

- **Geological data**- is characterized by rockmass data, subsidence data, stratigraphy data, geological contact areas etc.

- **Topocadastral data**- is characterized by data showing topographical features and zoning information.

- **Satellite images/aerial photographs** - is characterized by data derived using satellites or any photography process using overheard phenomena, also includes 3d meshes derived from drone.

- **Mine points and areal data**- is characterized by data showing the location of mine shafts and the extent of mining activities.

- **Historical plans and maps**- is characterized by archival material showing past mining activities, may also show design of mining operations.

The classifications of the data were made based on the similarities between all of the required data types. In order to understand what data is required by whom, the respondents were divided into two categories: 'GIS users' and 'non- GIS users'. The category 'GIS users' was used to describe respondents with projects related to GIS and 'non- GIS users' was used to describe the respondents whose projects were not related to GIS. The data needs of most the respondents were mostly concerned with sensor data, followed by survey and geological data. The least data required by the WDMP group was data falling within the categories of production, mine points and areal data and historical data. This was the least required data because there were only two individuals requiring such data; with one individual involved in a project which requires production data and another individual involved in a project which requires historical data and mine points and areal data.
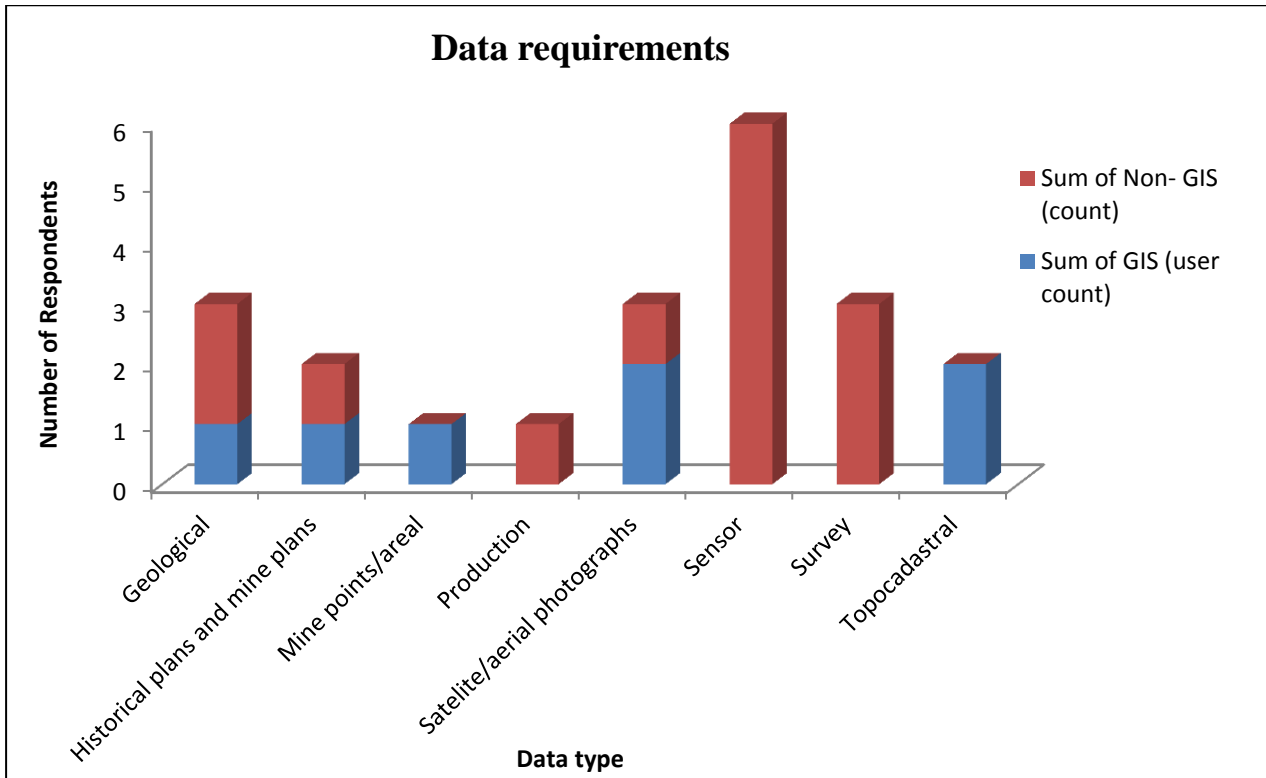
Figure 7: WMDP data needs. Shows the frequency of individuals requiring data falling within the prescribed data categories.

3.1.2.2. Existing data

There were 78 data sets available all together; although more data might have been collected by the other WDMP group members since the questionnaire was administered. All of the data collected to date is spatial data and will be used for GIS purposes. Data required by the WDMP project group will be incorporated later when the data is available. The shortage of data from the other group members is highly influenced by the fact that not all the group members were completing their research in 2015. A majority of the group members are either completing their MSc or PhD studies, and have not yet collected their data. The existing data were categorised into the data types identified earlier on in the study so as to document how much data is available. Table 2 shows the existing data (and data type) and the frequency of each data type. The table shows that most of the data collected was data falling within the category of historical plans and maps, followed by satellite photos/ aerial photos and topocadastral data. The table also shows that some of the identified data types are yet to be collected.

Nevertheless, this is not a true representation of the actual numbers of the historical maps, aerial photographs and topographical data. With regards to the historical maps, folders related to each historical map were created and populated with several photographs taken of the historical map, however only the map folders were considered for evaluating available data as opposed to counting individual photos. Moreover, the aerial photographs/orthophotos and topocadastral data were acquired as folders (the map reference is used as the title of each folder) and each folder is comprised of more than one photo or shapefile. Furthermore, the Mine Residue Areas (MRAs) data were acquired in the form of a geodatabase (gdb.) which contained more than one

shapefile. For the purpose of the research, only the folders and geodatabase were considered- and not the individual photos/shapefiles.

Table 2: Available geospatial data on historical and ongoing mining related activities, although more data may become available with the progression of the WDMP.

Data types	Existing data	Format	Count of data set available
Production	N/A	N/A	0
Sensor	N/A	N/A	0
Geological	Geological contact areas, Lithostratigraphy	Shapefiles	2
Topocadastral	2628, 2528, 2627, 2728, 2527	Shapefiles	5
Satellite/aerial photographs and orthophotos	2628, 2528, 2627, 2728, 2527, Spot 5 imagery and 30 m GDEM	GeoTiff	7
Mine points/areal	Mining licences , MRAs, D/Omines, abandoned mines, active mines	Shapefiles	6
Historical maps and mine plans	Randfontein Estates GMCo Ltd, Luuipaardsvlei Estates GMC co Ltd and West and Consolidated	Hardcopy historical maps PDF document	58
Survey	N/A	N/A	0
	Total		**78**

3.1.2.3. Data sources

Respondents of the WDMP group were expected to provide a list of required data along with the corresponding data sources. Table 3 summarizes the data sources mentioned by the respondents and illustrates the type of data received per data housing entity. Data were acquired from Gauteng City Region Observatory (GCRO), University of the Witwatersrand (School of Geography, Archaeology and Environmental Studies (GAES), DSpace), Department of Mineral Resources (DMR), Council for Geosciences (CGS) and Sibanye Gold. These data sources are coincident with the two projects in the WDMP that are related to GIS. The most dominant data source was Sibanye Gold, followed by Wits University and the least data were acquired from the GCRO, United States Geological Survey (USGS), Gauteng Department of agriculture and Rural Development (GDARD) and CGS. Sibanye Gold was the most dominant data source as it was used as the pilot study.

On the one hand, the large numbers of data acquired from Sibanye Gold and Wits were a misrepresentation of the actual count of the data as some components of some of the data were comprised of more than one file,

which led to the inflation of the numbers of available data. This was especially true for all the historical photographs, orthophotos and topographic data. Sibanye Gold provided 55 of the 58 historical maps and plans (the other 3 maps were obtained from Wits), therefore a sample of the historical maps from Sibanye Gold was pulled and used to create vector historical data. Similarly quite a large number of data (mostly in the form of orthophotos and topographic data) were acquired from Wits as it has a repository for storing archival material and the GAES has an agreement with CD: NGI Chief Directorate: National Geospatial Institute (CD: NGI) to use the data for educational purposes; thus there were no data request procedures to follow in order to obtain the data, which made data accessibility relatively easy. On the other hand, the quantity of some of the other data were reduced. This can be seen with the data acquired from the GCRO (with permission from GDARD); the GCRO provided an entire MRAs geodatabase which contained more than one shapefile. However the different data layers in the geodatabase were not counted as individual entities but were rather combined and regarded as one entity as they all were representative of one theme; the same can be said for the geological data that was acquired from the CGS and USGS. Nevertheless, this is not a true representation of all the data sources for all the data required by the WDMP as not all project group members have conducted their fieldwork or completed their respective courses yet. Furthermore, a significant number of the group members will be using original data.

The DMR is the data custodian for mining data, however Table 3 shows that not only is there a significant number of spatial data available on mining related activities; but the data is also widely spread across various organizations. The spread of data across various organisations is representative of some level of data sharing between organisations. However this may also lead to issues of confusion regarding the relevant data housing entities to contact when in search of data, which may further inhibit data accessibility.

Table 3: Data sources of all data collected.

Data source	Data type	Name of data set	Count of data received
GCRO	Mine points/areal	Mine Residue Areas.gdb	1(with 24 shapefiles)
Wits	Topocadastral and Satellite/aerial photographs	2628, 2528, 2627, 2728, 2527 JeppeSouthernGldfieldsHm73-map-page-001 Witwatersrand-1890-Mendelssohn-GCOOO195004, AtlasRand1CvrMap719-67	6
DMR	Mine points/areal	Active mines, abandoned mines, D/O mines, mining lease areas	5
CGS	Geological	Geological contact areas, Lithostratigraphy	2
GDARD	Mine points/areal	MRAS, Area_mineowners	2

Sibanye Gold	Historical plans and mine plans	Randfontein Estates GMCo Ltd, Luuipaardsvlei Estates GMCo Ltd and West and Consolidated (full inventory available on Appendix B)	55
SANSA	Satellite/aerial photographs	2628, 2528, 2627, 2728, 2527(topographical map rasters), SAC06122014110509	6
USGS	Satellite/aerial photographs	ASTGTM2_S27E027_dem	1

3.1.2.4. Data originators

A wealth of data were collected from various data housing entities (shown in Table 3). However, upon closer analysis of the data sets it was revealed that a majority of the data sets were of differing origins and were not necessarily created by the data sources. Figure 8 shows all the respective data originators. The data originator for most data were 'Sibanye Gold' (this data were from a recently purchased subsidiary of Sibanye Gold, Sibanye Gold had inherited these maps by default), followed by CD: NGI, CGS and GDARD. A significant number of data acquired fell under the 'unknown' category, this data were characterised as such because these data sets were not accompanied by metadata files nor did they contain any information on the origin of the data.
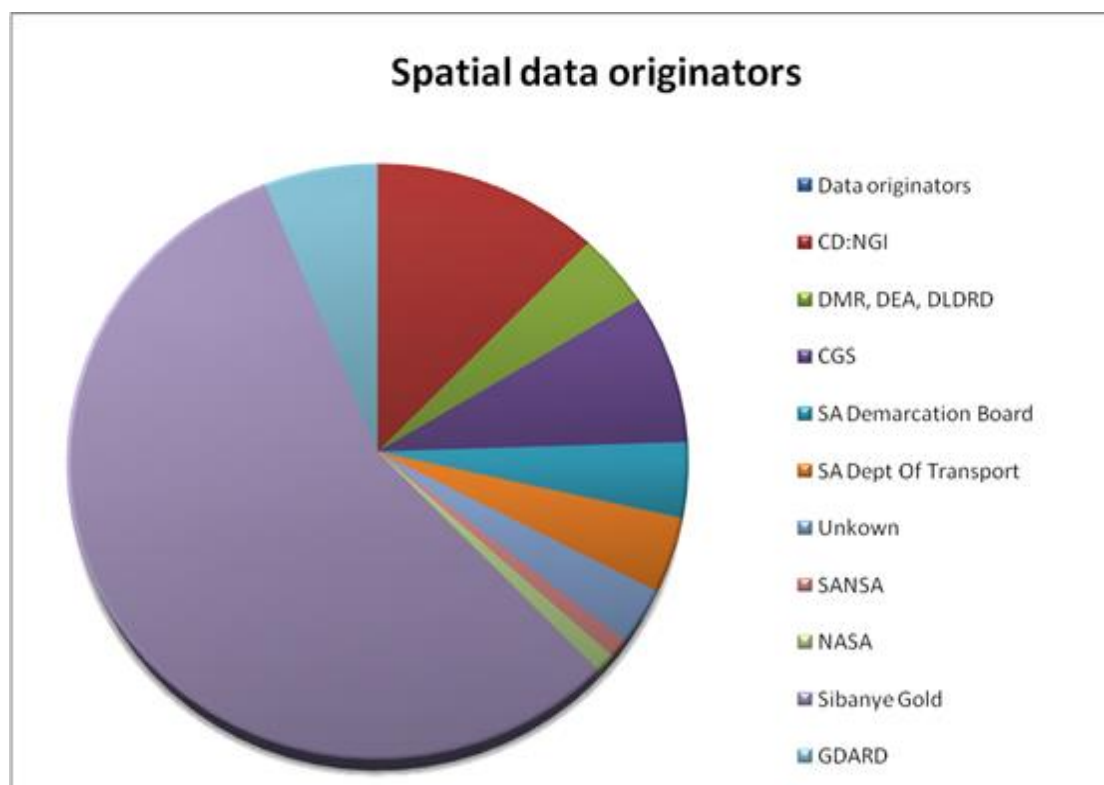
Figure 8: Pie chart representing proportion of data originators.

South African Spatial Data Infrastructure (SASDI Act No.54 of 2003) defines a data custodian as a state worker or individual working for a private entity who has a responsibility to create, maintain, manage,

integrate, distribute and use spatial information and as such is the rightful owner of the spatial information. CD: NGI is the rightful custodian for all imagery and topographic data which was last updated in 2012. Along the same vein DMR is the rightful custodian when it comes to data pertaining mining activities, the DRDLR is in charge of data relating to land distribution and the Department of Environmental Affairs (DEA) is the custodian of all data relating to environmental issues.

Figure 8 shows that the list of data originators is different from the list of data sources. This can be seen where institutions such as GCRO, Wits, and USGS, which were included as part of the list of data sources (shown in Table 3) are now excluded from the list of data originators. This implies that although these establishments were providers of the data required, they are not necessarily the data originators. This is an issue of concern for a number of reasons, namely:

- Confusion over who the rightful data custodian is and whom one should contact when such data is required

- Copyright restrictions, meaning that these data sources may only provide data with the permission of the relevant data custodians; which leads to further obstacles in obtaining the data.

Moreover, this also shows that data is more easily accessible from the data sources listed in Table 3 as opposed to the data originators shown in Figure 8.

3.1.3. User requirements and access to required data analysis

Although the WDMP group is comprised of individuals from various faculties and schools of thought, the data needs / data requirements seemed to share some similarities, thus making it easier to develop themes or categories of all the required data, namely: production, sensor, geological, mine plans, topographic, satellite images/ aerial photographs, mine points and areal and lastly historical plans and maps.

Data most widely required are sensor, geological and survey data. Sensor and survey data were most popular amongst non - GIS users (respondents with projects which are not related to GIS). Moreover, the GIS users or people with GIS related projects appeared to be more aware of exactly what data they required and where it could be obtained. Whereas, the rest of the project members were either still at the proposal stage of their projects or still waiting for the installation of sensors to examine their capabilities and the data that they will be used to capture or record. Although a lot of data were identified as useful for the purpose of the project, there is still a lot more data on mining related activities on which there is very limited knowledge. As such, this research relied on data that is readily available to the general public and that which has been used in previous studies. Nevertheless, all known data sources were contacted and some of the required data were acquired from these sources. However there are still some shortages in some of the data required as some of the required data has not been collected at all. Section 3.1.2.2 *Existing Data* shows that all of the data that has been collected is spatial data and will be used for GIS related studies. Although new data may have been collected or created since the data requirements survey was conducted.

The variation in the existing data obtained from the evaluation of the accessibility of data coincided with other studies (Centre for Environment Rights, 2012 and Khanyile, 2014) as they portrayed variations in data availability and data originators which is indicative of some level of data sharing amongst organizations and institutions. A majority of respondents were willing to share data such as the GCRO, CGS and Wits University (GAES and DSpace). It is important to note that GCRO and CGS were also relatively smaller in size as compared to other contacted organizations and so were supposedly more organized and the availability of the data from these organizations may also speak for competence. GCRO had a simple data request procedure and CGS was willing to give you the data with permissions from the relevant parties. Most of the acquired data were from Sibanye Gold and Wits University (GAES and DSpace); however, the large numbers of data sets were exaggerated and closer observation of the data shows that the data is mostly from NGI and other archival material.

Data were harder to obtain from the DMR, Department of Rural Development and Land Reform (DRDLR) and GDARD - all of which are governmental institutions. Theoretically, in order to gain access to information from the DMR one has to follow the access to information procedure, however, upon repeated approach in search for the permission to derelict and ownerless (D/O) mines data and mine plans there appeared to be a miscommunication between employees (Khanyile, 2014). From this it was deduced that data easier to obtain from smaller and parastatal institutions as compared to government institutions. This suggests a high level of incompetence in governmental institutions, the failure to comply with PAIA regulations; as well as the use of PAIA as a tool for avoiding feedback to concerned members of the public as suggested by CER (2012). PAIA mandates of the different data repositories also have an influence in data availability, as they tend to overlap with PAIA and may in the long run lead to the confusion of members of the public as they are unclear about the relevant authorities to contact (Schutte, 2014). Lastly, high administrative capacities enable private bodies to resist disclosure; this is mostly evident with the mining companies. Five mining companies were contacted overall, two of the five responded, with one expressing their lack of interest and the other was willing to participate in the study.

Resources for the development of a National Spatial Information Framework (NSIF) and the provision of systems to support access to base spatial data sets and corresponding metadata were allocated by the Department of Land Affairs in 1997; however the progress has been rather slow. Further discussions on the improvement of data sharing practices were conducted in 1999 at Earth Information Systems Conference held in South Africa that year, where the discussions on the development of an SDI for Africa were explored (Cooper and Gavin, 2005) and the SDIA was assented by the president in 2004. However, the piece of legislation on the implementation of the SDI was only proclaimed in 2006 and a Committee for Spatial Information (CSI) only established in 2010. Interestingly enough there are still problems with the development and the institutionalization of a SDI for South Africa (Maswanganye, 2015). According to Harvey and Tulloch (2006) problems with the implementation of SDIs are often linked to the failure to consider the symbiotic relationship between local government data sharing and legislated policy and political government activities (Harvey and Tulloch, 2006).

Several studies (Cooper and Gavin, 2005 and Maswangaye, 2015, have been conducted in South Africa surrounding the issue of the lack of access to information and spatial data. The results from the analysis of the user requirements is particularly interesting as it points out the severity of the issue of the lack of access to information and also provides an indication of the state of service delivery where spatial data is concerned. The lack of access to data, in particular spatial data, is an issue of concern primarily because data created by state bodies is created using public funds; therefore in theory data should be accessible. The evaluation of data accessibility suggests that data is more easily obtainable from smaller stand-alone institutions as opposed to government institutions. This suggests a fragmentation of responsibilities amongst the rightful data custodians. For a long time this has been the leading inhibiting factor to data accessibility as there is no clear distinction on the data which should be available from public bodies and that which should be available from private institutions. However, this issue has been considered in the new Geomatics Professional Act (Act no. 19 of 2013) which suggests the rightful custodians of all data and the channels to be followed to acquire data.

3.1.4. Recommendations and suggestions for database design

From the user requirements analysis it is evident that the WDMP group is concerned with different kinds of data which is spatial and non - spatial. Nevertheless upon closer observation it is also evident that the data feeds into each other. This could be seen where respondents required the same kinds of data or where project members required data which had been created or utilized by another individual in the project, as the data derived from one project members research could be used to inform other projects. Therefore it is important thus it is important that the data can be easily accessible to all involved in the WDMP. As such, the requirements for the database are described below:

- Data storage:
    - The optimal database should facilitate data storage (all data related to mining activities). The expected data falls within these categories: production, sensor, geological, topographical, satellite images/ aerial photographs, mine points and areal and lastly historical plans and maps (containing information on the data creation date, source, originator and format where applicable).
    - The database should have a functionality to permit the users to interactively add or remove information in the database.
- Data access:
    - Not everyone involved in the WDMP is familiar with GIS therefore the database should have a simple graphical user interface (GUI) with interactive maps which allow basic queries.
    - The database should have a means of restricting data access depending on the users' involvement in the WDMP.
    - Some data may not be downloadable online such as the mines point and areal data due to copyright restrictions, for that purpose the data custodian is listed to facilitate the data access.

- Database design:
  - The data requirements and acquired information will be used to develop a controlled yet independent spatial database that can handle historical and current records of mining activities and from different data housing entities.
  - The database must have the capability to support desktop and web- based GIS applications.
  - Two databases will be created (one for current data and another smaller one for the storage of historical data) coming together through the identified primary and foreign keys and geometry of the data.
- Management and administration:
  - The database should provide facilities for administration and security implementation.
  - Administrator can store (add) or permanently remove data.

CHAPTER FOUR   DATABASE DESIGN, IMPLEMENTATION AND EVALUATION

4.1. Database Design

4.1.1. Data dictionary

Previous studies (Mitchell et al., 2005 and Federer, 1996) created data dictionaries of the data within each inventory so as to make documentation and maintenance of the database easier, thus a similar approach was adopted for the purpose of the study. With the data needs, collection and prototype requirements already defined and documented. The next task would be to create a data dictionary (Table 4 and database documentation in Appendix I). According to Harrington (2009), a data dictionary is a compiled list of descriptions of data that will be incorporated into the DBMSs. The data dictionary also maintains information about the feature classes and feature data sets. Each entity in the DBMS will be have corresponding attributes and later linked to show the possible relationships.

Table 4 shows that there are two databases: one is the database containing the current data as well as all the other data that will be utilized by the WDMP, the other database will be smaller and contains data created from the photos of the historical mine maps in vector format. The two databases will come together through the primary keys and geometry of the data.

Table 4: Expected data entities. The WDMP is ongoing and new data will be added as they become available. Such data are highlighted in green. The data dictionary also shows that there are two databases, historical database (red) and main database (dark blue).

Entity type	Description	Representation	Data type	Database
Mine reefs (Boulder reef, North reef and Battery reef)	Shows mining reefs within the Luipaardsvlei Estate and GMCo.	Polygon	Spatial	Historical
Turks shaft	Vertical tunnel through which commodities are excavated on the Luipaardsvlei Estate and GMCo. Indicated as a circle in the map.	Line	Spatial	Historical
Ventilation tunnels (cross raises and off reefs)	Transportations systems and airways on the Luipaardsvlei Estate and GMCo.	Line	Spatial	Historical
Historical map photos and plans	Historical maps showing a certain region as well as engineering	Jpeg/tiff	Spatial	Historical

	draw-ings representing the location as well as the structural design of the mine facilities (shafts, admin area, plant etc).			
Gauteng Province	Shows Gauteng province and municipalities within.	Polygon	Spatial	Main Digital Mine Database
Geological contact areas	Geological setting of a certain area, including areas of geological contact and tectonic fault areas.	Point, line, polygon	Spatial	Main Digital Mine Database
Lithostratigraphy	Shows the stratigraphy of the area.	Polygon	Spatial	Main Digital Mine Database
Mining Lease Areas	All mining concessions in the Gauteng province.	Polygon	Spatial	Main Digital Mine Database
Mine shafts	All Active, abandoned and derelict and ownerless mine shafts in Gauteng Province.	Point	Spatial	Main Digital Mine Database
Mine Residue Areas	All mine Residue Areas (tailings dam facilities of mining and related activities) in the Gauteng Province.	Polygon	Spatial	Main Digital Mine Database
Topographic Maps	Map representing topography as well as all geographical features within a region.	Point, line, polygon	Spatial	Main Digital Mine Database
Satellite Images / DEM/ Aerial photographs/ orthophotos	Images of the earth's surface and elevation acquired by satellites. These are collected by sensors aboard a satellite and then relayed to the earth as a series of electronic signals, which are processed by a computer to form an image.	Raster(image)	Spatial	Main Digital Mine Database
Other data from Digital Miners (all individuals involved in the WDMP)	Sensor data (seismic data, subsidence data, airflow data, telecommunications data etc.). Production data Geological data	Various formats	Spatial/ Non-spatial	Main Digital Mine Database

4.1.2. Conceptual data models

The data identified in the data requirements section was used to develop a conceptual model of the database. A conceptual model is a graphical representation and description of how the database is organized and how it will work (Singh and Singh, 2014). Conceptual models are most commonly represented using a formal approach known as Chen's entity- relationship (E-R) model (Burrough and McDonell, 1998), where they show all the entities that are going to be in the database and the relationships between them. Figure 9 and Figure 10 depict a simplified conceptual model of the WDMP database containing current and the historical data. Figure 10 shows the main database that contains data on current mining activities, the diagram also shows that data that is accumulated by the WDMP will be accommodated by the database as the data types are already known.
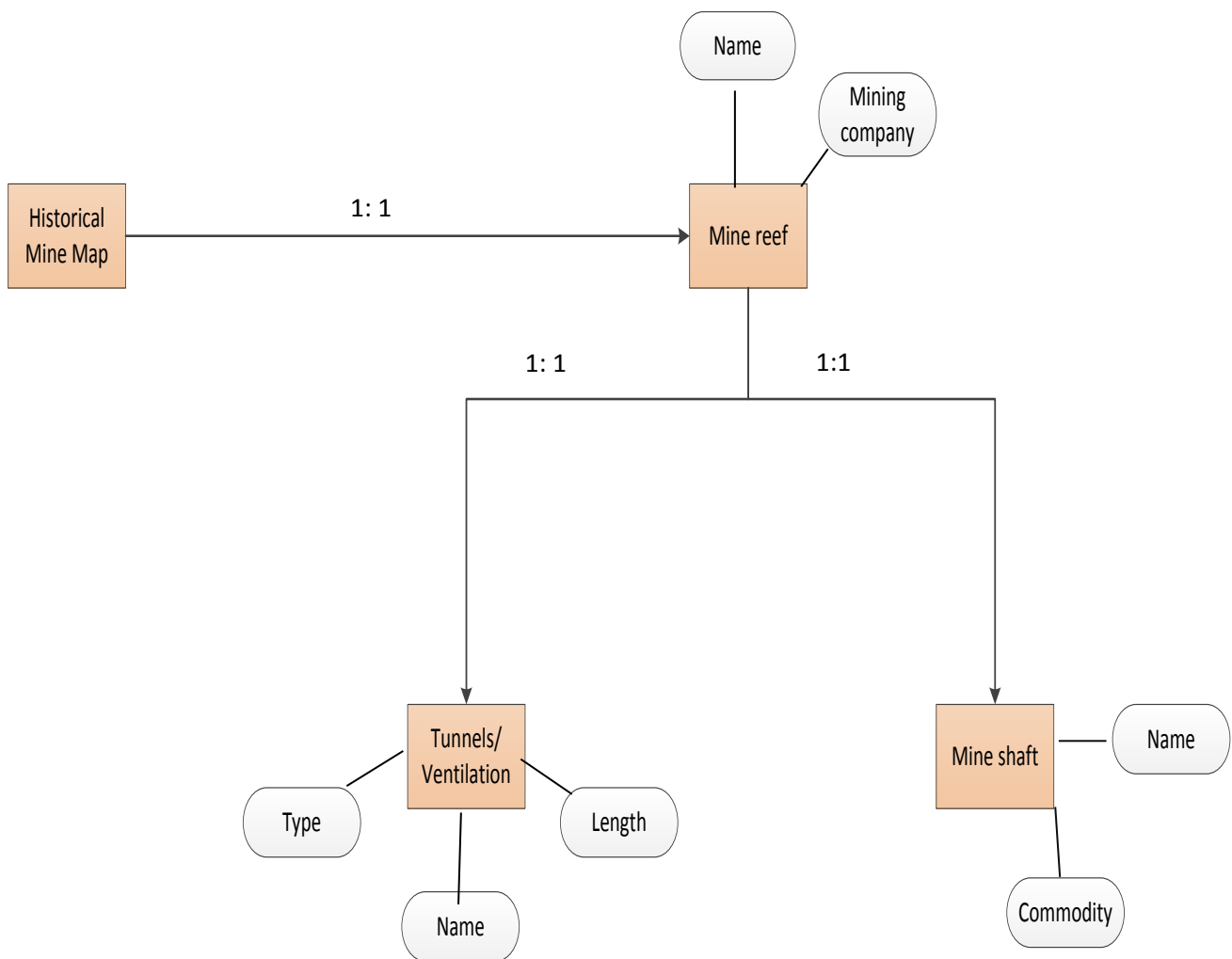
Figure 9: Conceptual model of the historical database as conceived in this research.
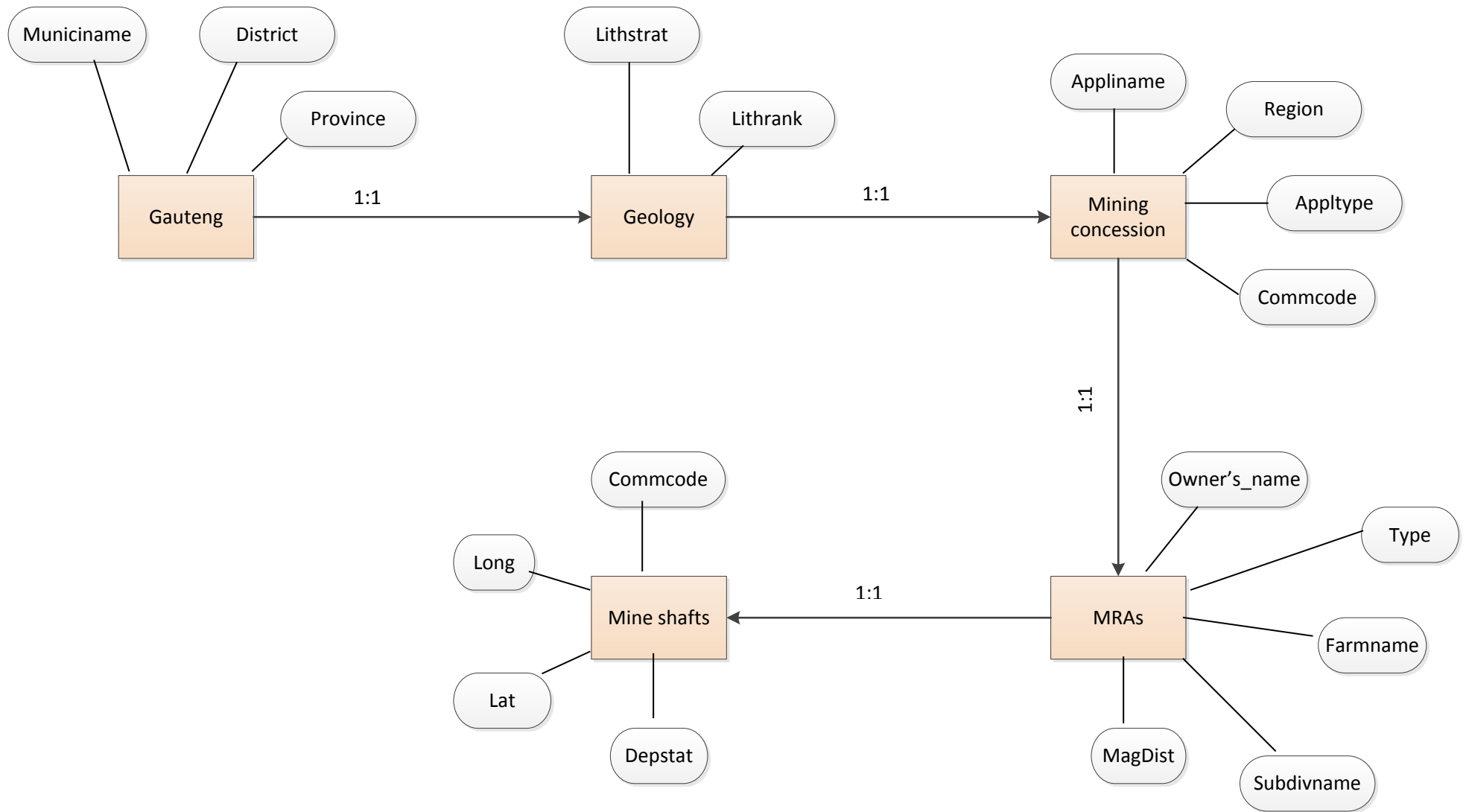
Figure 10: Conceptual model of the main database as conceived in this research.

In the diagrams the entities are represented by a rectangular shape and the data field names are represented by an oval shape. The cardinalities between the data are represented by text. The diagrams do not show attributes of the entities for the purpose of readability.

4.1.3. Logical and physical models

On the one hand, the logical model is a more informative version of the conceptual model as it leads to a more improved understanding of the data entities and their relationships (Laxton and Becken, 1996). It is concerned with all the logical relationships between all the data entities and related objects using a computable data format to express the conceptual model (Singh and Singh, 2014). On the other hand, the physical model is responsible for the allocations of different database components (Healey, 1991). It is a further elaboration of the conceptual and logical models as it tries to describe these models in the real world. This model uses the relationships identified in the conceptual model and the logical models are used as guides for making decisions on data entity attributes, data type lengths, keys and so on. At this stage each entity can be transformed from a simple entity into a database table and each relationship defined (Singh and Singh, 2014). The physical model shows a full list of all the entities in the databases and their attributes (shown in Figures *11* and *12*).

Figure 11: Physical model of the historical database.

GAUTENG PROVINCE
- Gid:serial (PK)
- OBJECTID_1: ObjectID
- OBJECTID: Geometry
- AREA: Float
- PERIMETER: Float
- CAT_B: Text
- TYPE: Text
- PROVINCE:Text
- DISTRICT:Text
- GLOBALID:Text
- NAMECODE:Text
- MUNICNAME:Text
- MAP_TITLE:Text
- SHAPE_LENG:Double
- Shape_Le_1:Double
- Shape_Length:Double
- Shape_Area:Double

Mine history(historical data)
- PhotoID
- Size
- Georeferenced
- Mining concession
- Minename
- Reef
- First_prod
- Last_prod
- Photographer
- Date photos taken
- Data custodian

LITHOSTRATIGRAPHIC STRUCTURES
- Gid:serial (PK)
- FID:ObjectID
- SHAPE: Geometry
- UQ_GEOL:Long Integer
- UQ_SAC_NO:Short Integer
- LITHSTRAT:Text
- LITHRANK:Text
- PARENT1:Text
- RANK1:Text
- PARENT2:Text
- RANK2:Text
- PARENT3:Text
- RANK3:Text
- CHRONSTAT:Text
- CHRONRANK:Text
- LITHO_GRP:Text
- DESCRIPTIO:Text
- COLOR_CODE:Text
- HACHT:Text
- TEXT_LABEL:Text
- SHAPE_area:Double
- SHAPE_len:Double

MINE SHAFTS
- Gid:serial (PK)
- FID:ObjectID
- Shape:Geometry
- OBJECTID:Long Intrger
- UQ_REF:Double
- LONG:Double
- LAT:Double
- DEPNO:Text
- MAPNO:Text
- COM1;Text
- COM2:Text
- COM3:Text
- COM4:Text
- COM5:Text
- COM6:Text
- COM7: Text
- COM8: Text
- DEPSTAT:Text
- MAP_SYMBOL:Text
- ORIENT:Text
- SIZE:Double
- DEPNAME_1:Text
- DEP_CONC:Text
- OR_UNDEF:Tex

MINING LEASE AREAS
- Gid:serial (PK)
- FID:ObjectID
- Shape:Geometry
- BID: Long Integer
- Commcode:Text
- Dtlodgemen:Date
- Tempappid:Text
- Filerefnum:Text
- Region:Text
- Status:Text
- Applname:Text
- Apptype:Text

MINE RESIDUE AREA
- Gid:serial (PK)
- OBJECTID:ObjectID
- SHAPE:Geometry
- FID_AREAMI:Long integer
- ID:Long Integer
- TYPE:Text
- TOPO:Text
- TDF_DAM:Text
- TDF_DUMP:Text
- WRD:Text
- OCAST:Text
- Q:Text
- RWD:Text
- TSS:Text
- OTHERS:Text
- FP:Text
- VISIT:Text
- DOLOMITE:Text
- NEARWETLAN:Text
- F_AREA:Double
- MINE_AREA:Double
- WATERDISQ:text
- BORDER:Text
- FID_FARMSW:Long Integer
- AREA:Double
- GFARM_CL:Double
- GFARM_CL_I:Double
- SG_KEY:Text
- FARMNAME:Text
- FARMNO:Text
- SUBDIVNAME:Text
- SUBDIVNO:text
- MAG_DIST:Text
- PROVINCE:Text
- SG_OFFICE:Text
- MAJOR:Text
- MINOR:Text
- PARCEL:Text
- PORTION_S:Text
- ERF_NUMBER:Text
- TOWN_NAME:Text
- PORTION:Text
- OWNERS_NAM:Text
- TITLE:Text
- SHAPE_LENGTH:Double
- SHAPE_AREA:Double

(Central table)
- MineID/UQ_Ref
- ShapeID
- MapNo/MapID/Topo
- DistrictID
- Region
- Parcel
- Province
- Long/DLong
- Lat/DLat
- Minename
- Farmname
- Owners_nam
- Geology
- Depname
- Depstat
- Comm1- 10
- Commcode
- Status(mining license)
- status(operational)
- First_prod
- Last_prod
- Descript
- Elev
- size
- Scale
- Dolomite:Text
- Nearwetlan:Text
- F_Area:Double
- Mine_Area:Double
- WaterDisq:Text
- Border:Text
- Radiation:Text

GEOLOGICAL CONTACT AREAS
- Gid:serial (PK)
- ObjectID:Object ID
- Shape:Geometry
- Id:Long Integer
- Type:Text
- Topo:Text
- TDF_Dam:Text
- TDF_Dump:Text
- WRD:Text
- Ocast:Text
- Q:Text
- RWD:Text
- TSS:Text
- Others:Text
- FP:Text
- Visit:Text
- Dolomite:Text
- Nearwetlan:Text
- F_Area:Double
- Mine_Area:Double
- WaterDisq:Text
- Border:Text
- Radiation:Text
- Qualificati:Text
- Shape_Length:Double
- Shape_Area:Double

OTHER
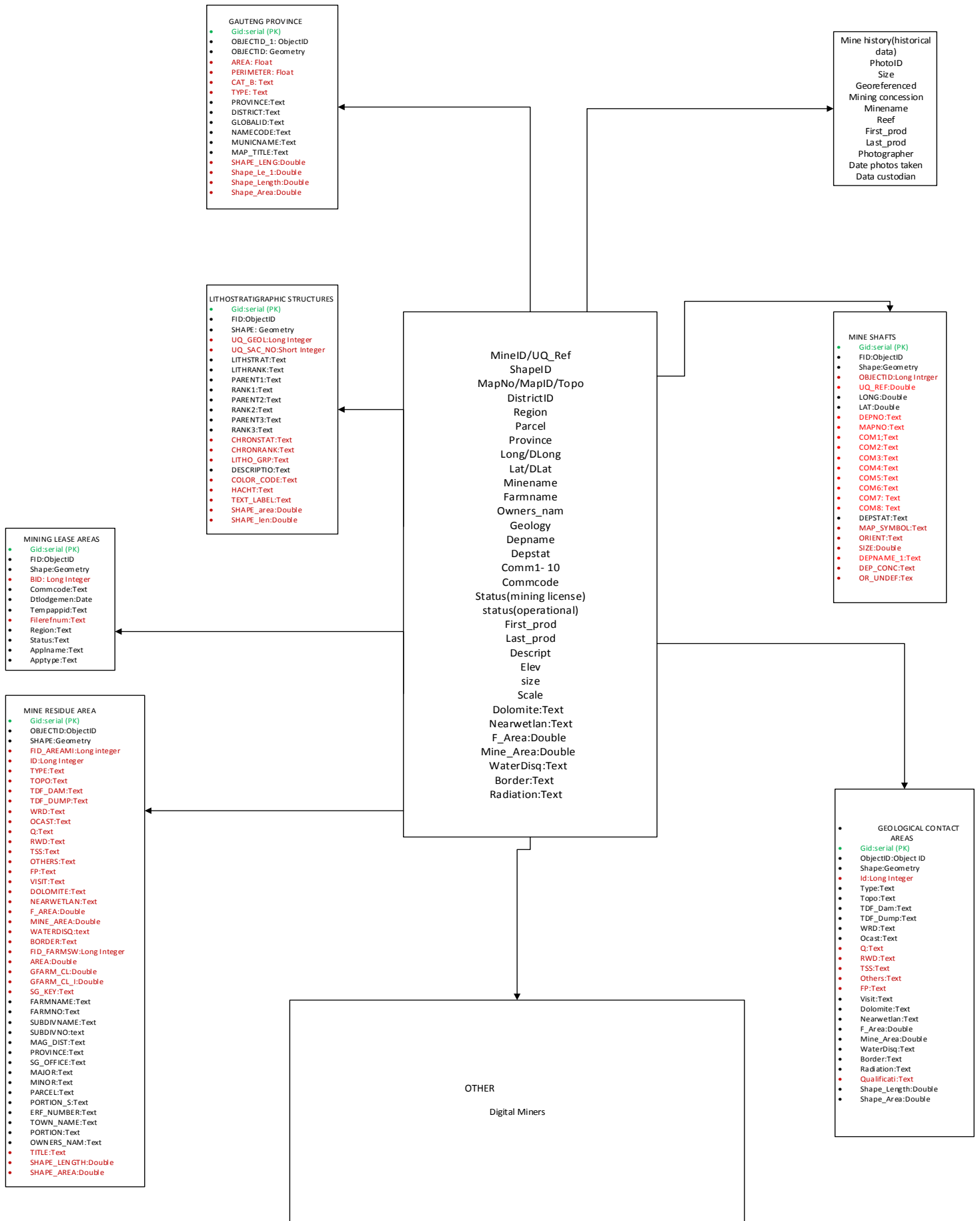
Digital Miners

Figure 12: Physical model for the main database.

The databases shown in Figure *11* and *12* are characterised by a central database which has all the attributes however it is important to note that not all the fields are useful for the study, therefore the fields have been coded using different colours, namely:

- Black is for all the pre-existing attribute fields that will be used in the database.
- Red is for all the attribute fields which are not important for the study at hand.
- Green is for all the newly created fields.

4.2. Implementation

4.2.1. Data creation and conversion of historical data

4.2.1.1. Preparation of historical maps for historical data creation

When studying the progress of mining activities in a particular locality using historical data it is not unusual to have to go through hundreds of records (Milner, 1997). Not only is the sheer volume of the data overwhelming, but also some of the material may have deteriorated with the passage of time and may turn out to be useless for the study being conducted due to the decrease in quality.

The historical maps used for the purpose of the study were held by Sibanye Gold (full inventory of the maps can be found in Appendix B). Sibanye Gold held 55 legible maps, some of the maps were not considered for the purpose of the study due to various reasons, such as: lack of title, poor quality and the lack of scale bar. The maps were in hard copy and could not be used in their current format, thus previous studies (ESRI, 2008 and Carrion et al., 2016) were used to inform on the suitable methodology for the digitization of such data - that could later be used for the digitization of similar data. The methodology employed for the digitization of the historical maps is outlined in the next couple of sections.

Prior to the digitization process, it was necessary to rearrange all the historical maps so as to make the assessment more manageable. The maps were rearranged in the following manner:

- First, the maps were checked for titles, scale bar, legend and an indication of the years through which mining activities commenced.
- The maps were rearranged and put into clusters according to the mining concession, of which three were identified: Randfontein Estates G M Co LTD, Luipaardsvlei Estates G M Co LTD and West Rand Consolidated.
- In each pile the maps were divided according to the mining reefs e.g. Randfontein Estates Main Reef, Randfontein Estates Battery Reef etc. The numbers of maps in each cluster were recorded.

- The maps were rearranged arranged chronologically, and a sample was drawn with which to work with (the oldest and the most recent maps were selected from each pile) and photographed.

4.2.1.1. 1. Georeferencing and mosaicking of historical maps

According to Daniil et al. (2013), both photogrammetry and cartography are applicable for converting historical maps into a digital format. The best methodology to utilize for a particular scenario is determined by a number of factors such as the sensitivity of the drawing, condition of the map and the size of the map. Some of the maps used for the purpose of the study exceeding the AO paper size and were stored haphazardly, thus the use of photography to convert the maps into a vector format. In preparation to take the photographs, the maps were laid flat on the ground. Two types of photographs were taken; those taken at an oblique angle (to show the entire map) and overhead in a row. Some of the photographs taken covered larger areas of the map and some of the photographs taken covered smaller areas on the map; and were taken in such a way that the maps could overlap and could be georectified and mosaicked.

The photographs had to be stitched together in order to produce a continuous map. The following steps were taken towards stitching the photographs together:

- A new project was created on ArcMap and the coordinates for each photograph were identified and used as control points. Each of the maps had coordinates on them using the Goldfields Coordinate System.
- The images were then mosaicked into a single image. However, the image resultant from the mosaicking of photographs covering large areas on the map is clearer and less messy than the image that was resultant using the smaller photograph tiles (Appendix C shows examples of the mosaicked maps using the small and bigger photograph tiles).

4.2.1.1.2. Data Transformation

According to Srivastava (2014) coordinate systems are one of the most difficult concepts to understand in the geosciences, computer sciences and all other fields which utilize geographical data. All the maps were using the Goldfields Coordinate System (GCS), the GCS was a system used in mining operations where the observations were based on the reference beacons of the mining operation (Nel, 1997).

Since the maps were using the Geographic Coordinate System, they had to be projected to another projection in order to establish the location of the mining activities in the real world. However, the conversion of the coordinate system was problematic mostly because ArcGIS does not recognise the Goldfields Coordinate System. Although there is software for transforming Goldfields coordinate System to Cape Datum or WGS84. According to Nel (1997), the transforming from the Goldfields

Coordinates System to Lo or WGS84 can result in deviations of over a metre and do not yield results of acceptable accuracy. The following steps were taken in order to establish the correct location of the mining activities:

- Google Earth was used to identify some of the land parcel names identified on the map. Some land parcels still have the names that are written on the map. Some names may have been changed through time, in which case the mining lease areas shapefile was used to identify boundaries.
- The mining lease areas shapefile was converted to kml/kmz, so that it can be viewed on Google Earth (Figure 13).
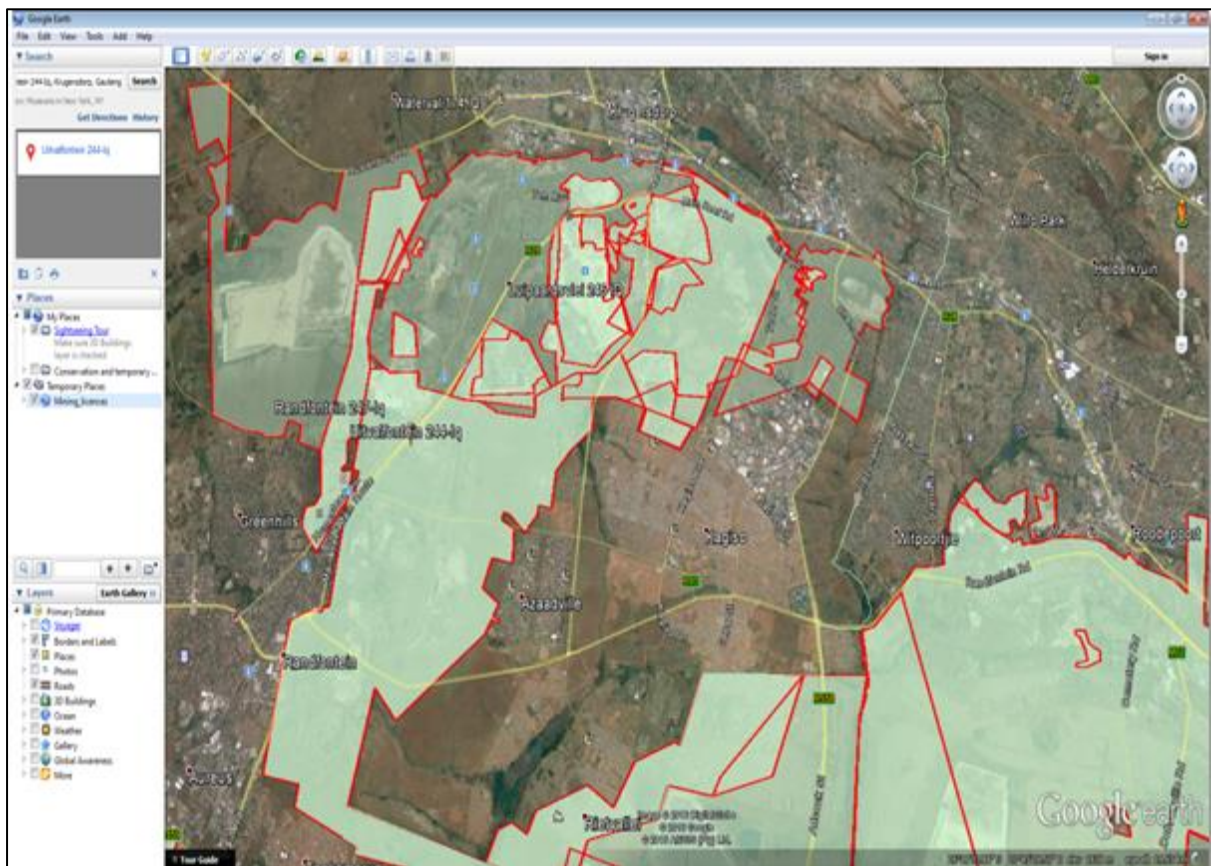
Figure 13: shows land parcels in relation to mining lease areas.

An ArcMap project was created where one of the basemaps and the mining lease areas layer were used to georeference the photo/ tile showing the area covered by overall map. The tile showing the overall extent covered by the maps had mining concessions (marked in green on the photo) which could easily be identified. These similarities between the photo and the mining concessions layer were used to create control points (Figure 14).
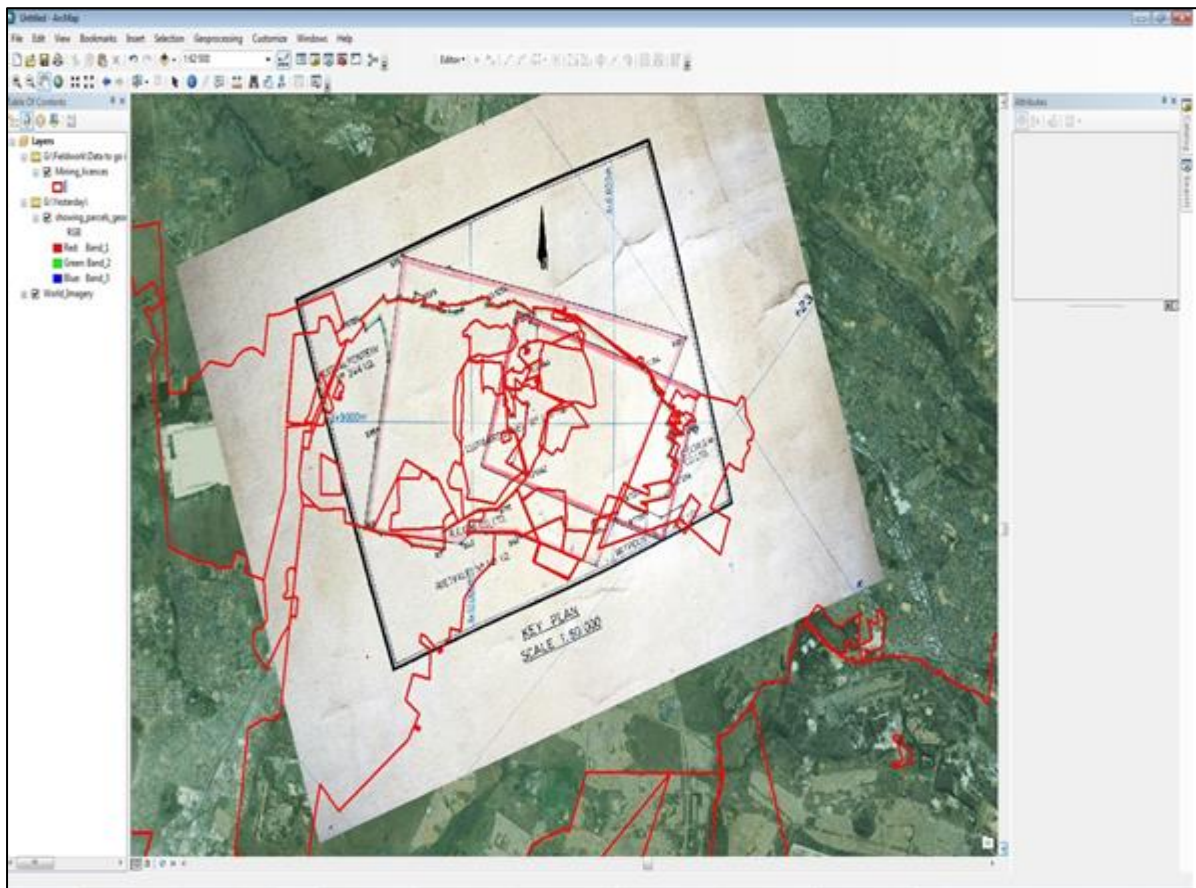
Figure 14: Shows the area covered by the historical map.

In order to georeference the mosaics of the map to the photo showing the extent of the map, a number of steps had to be followed:

- The mosaics were added to the project and had to be dragged to the area representing the map extent which is represented by a small red rectangle (in a south easterly direction inside the black square).

- The map had to be rescaled and rotated so that it not only fit into the outline of the mining activities but also showed the North arrow in the correct place.

- Thereafter control points could be added and the maps rectified (Appendix D).

4.2.1.1.3. Digitizing

Historical vector data were created from the mosaicked maps. This entailed the digitization of a number of features on the maps. The digitization of the maps followed the following process:

- The original photos were opened in order to check the boundaries of the mine reefs and the tunnels, this entailed going back and forth from the ArcMap project and the photos.

- The data were digitized from the map created from the bigger map tiles. Although the boundaries are not clearly visible, this map showed the extent of the mine reefs better than the map created from the smaller images.

- Empty shapefiles were created on ArcCatalog, specifying the expected data (the reefs were expected to be polygons and the tunnels lines and the shaft was made to be a point feature class).

- These empty shapefiles were added onto the ArcMap project and an editing session was started simultaneously for all of the shapefiles.

- The map was used as the base map and the data were traced off it.

- The edits were then saved for each shapefile respectively. Each shapefile had to be re- projected (from WGS84 Web Mercator which had been adopted during the editing session) into the coordinate system utilised by all the other mining data which is GCS_WGS84 (Appendix E).

4.2.2. Data modification and conversion of current data

In ArcMap, all the recent data on mining activities (active mines, abandoned mines, D/O mines, mining licenses, mine residue areas) as well as geological data were projected to use a common coordinate system, GCS_WGS84. An ArcMap map project was started and the mine shaft point data (active mines, abandoned mines and D/O mines) were then merged to create one shapefile containing all the mine shafts. The point data were merged so as to have one shapefile containing all data in hand, and also so that the data could be queried.

4.2.3. Database architecture design

Databases were implemented on two platforms, the physical database on PostgreSQL and again on GeoServer (available on the OpenGeo Suite 4.8. The user interacts with GeoServer (Figure 15). GeoServer is an open source online server is a full transactional Java implementation for web feature service and web coverage service with an integrated web map service (WMS) as specified by the Open Geospatial Consortium (Iacovella and Youngblood, 2013). Data can be imported through a PostGIS connection or through a file directory- both methods were used in this study. The data can be visualised using Openlayers, GeoWeb Cache, GeoExplorer and QGIS. The user can also visualize data by loading the data directly into GeoExplorer or QGIS through a PostGIS connection or from a file directory. The system architecture of the database was deliberately designed to use open source software so as to make it accessible to all interested parties.
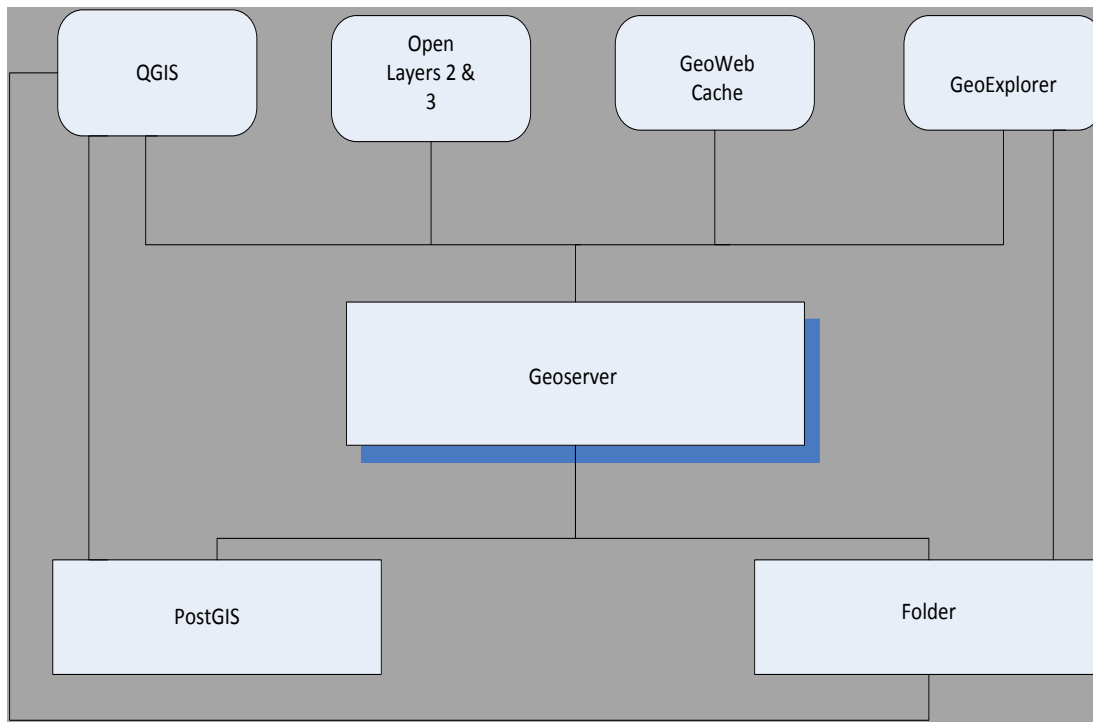
Figure 15: GeoServer web- interface architecture.

4.2.4. Data migration

4.2.4.1. PostgreSQL (PostGIS)

Two databases were created on the graphical user interface of PostgreSQL (pgadmin III) with the PostGIS extension. A new server entitled Digital Mine Project was added and the two databases created, namely: Historical database and Main database.

PostgreSQL supports three methods of migrating data into the database, namely:

- PostgreSQL has a PostGIS Import/ Export Manager which can be accessed through the PostgreSQL GUI, pgadmin III. The PostGIS Import/ Export Manager can be used to batch migrate a number of shapefiles at the same time.
- PostgreSQL SQL console which can be used to load textiles.
- And lastly, the plsql/ copy command line which can be used to import a text file saved as a csv or dbf format.

The first method was used for the purpose of the study, this method was mostly advantageous as it could be used to load multiple files at the same time, it is also very useful as it automatically creates tuples which under normal circumstances one would have to create manually and also defines a default primary key. The two databases can be found in Appendix F.

The following data were imported in the two databases: mine reefs, ventilation tunnels and Turk shaft into the Historical database and mine shafts, MRAs, mining licenses, lithostratigraphic structures, geological contact areas and Gauteng in the Main database.

4.2.4.1.1. Primary (PK) and Foreign keys (FK)

Upon importing the shapefiles into pgadmin III the formulation of constraints on the tables is very important as it enables the user to be able to conduct basic queries. Primary keys are automatically generated in all the tables (gid) and are indicated on the physical schema of the databases. Thereafter foreign keys were not created because the layers are already linked through geometry.

4.2.4.1.2. User roles

After creating the databases, the roles of the users were clearly defined and security measures put in place. Two roles were defined, namely: Admin and Digital miners; the Postgres user role is a default that comes with Postgres. Where on the one hand, 'Admin' is the leading administrative role and has the rights to perform a variety of tasks such as creating, deleting, duplicating databases, creating roles, initiate streaming and can create inherits and on the other hand Digital miners can only view the data and perform necessary queries on it.

4.2.4.2. GeoServer

The OpenGeo suite was used to develop the web map application. A workspace entitled Digital Mine Project was created, which is where all the necessary data were loaded. Data layers were imported using the GeoServer layer importer and alternatively uploaded on the GeoExplorer map composer. The layer importer on GeoServer web interface gives you the option of choosing the data source which can be spatial files from a directory on your computer, PostGIS tables, Oracle tables or SQL Server tables. For the purpose of the project the data source of choice was PostGIS, and all the layers in the database were imported directly onto the GeoServer web interface.

All the layers in the database can be viewed under the layer preview tab. The user can also open the layer or opt to save it as a KML or a shapefile (depending on the access they have). The layer preview also enables the user to perform basic queries when the layers are opened in GeoServer. The user can also get more information on a certain feature by opening the layer in GeoExplorer and clicking on the feature of interest (Appendix G).

4.2.4.2.1. Security and user roles

Two user roles were defined, namely: Admin and Digital miners. Where the user 'Admin' has all the administrator rights in the Digital Mine Project workspace and all the associated layers and the 'Digital

Miners' user only has reading rights to the all the mining data (abandoned mines, active mines, derelict and ownerless mines, MRAs, mining licences) and has full access to the geological data.

4.2.5. PostGIS spatial data delivery and visualisation

Data that is stored in the database can be accessed using various methods; the most basic of these is the PostgreSQL query builder, however the user should at least have basic SQL knowledge in order to be able to execute the correct command line. The user formulates a statement that implies to the required information and in turn that information is translated as a request in SQL language which can then be understood by the database. The basic SELECT statements that can be of use are:

SELECT attribute list, FROM table list, WHERE condition

However, it is somewhat difficult to understand the proper syntax to be used in the statement; therefore the easiest way to get the data is to visualise the data through the use of desktop or web mapping GIS applications. For the purpose of the study this specific database can be connected to desktop GIS applications such as QuantumGIS (QGIS) by creating a PostGIS connection to visualise data on the PostgreSQL database (Figure 16 and Appendix I), and alternatively GeoExplorer has the functionality to save and publish the map which can then be embedded into a webpage or website (Figure 17).
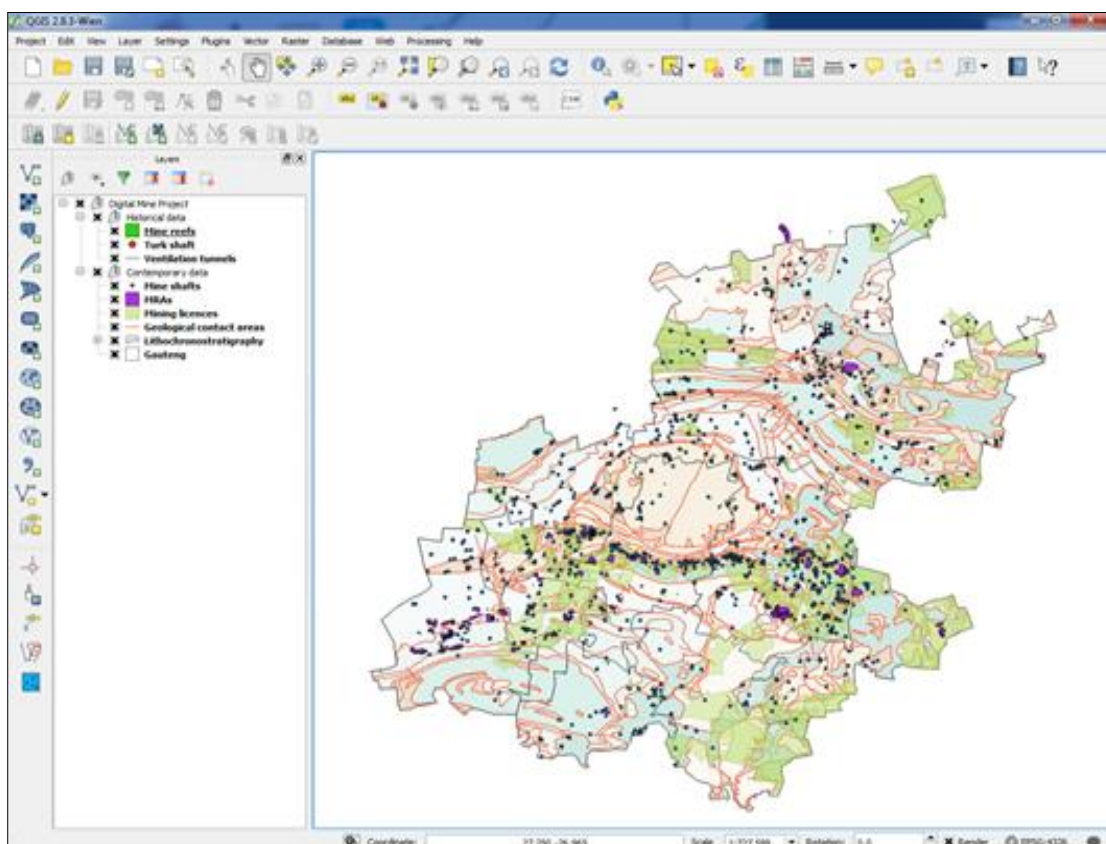
Figure 16: Visualization of all the PostGIS layers in QGIS. The data were grouped according to database it is in PostgreSQL.
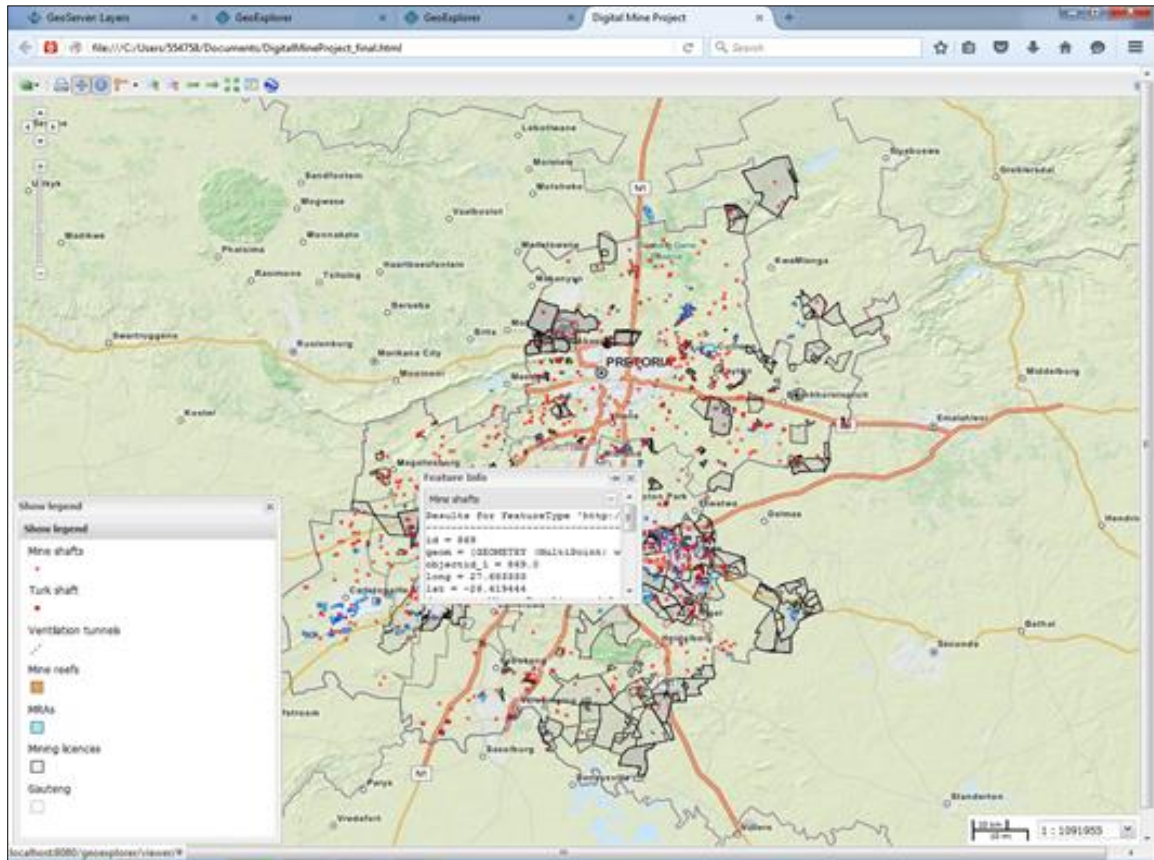
Figure 17: When the map composed on GeoExplorer is published and embedded onto a webpage, the webpage can be viewed by all individuals with the GeoServer on their computers.

4.3. System Evaluation

Before making the database available to the WDMP, it was essential to run performance tests to check the efficiency of the system and identify any apparent inefficiency. Database testing is also important as it evaluates whether the system at hand meets the objectives of the study (in section *1.5. Specific objectives);* similarly, a system evaluation is required to assess whether the system meets the database requirements identified in section *3.1.4. Recommendations and suggestions for database design* and how the system could be improved.

Five data sets were used in the performance tests, namely:

- Mine Residue Areas layer (with 374 features).
- Turks shaft layer, which was digitized from historical map (with 1 feature).
- Mineshafts layer, which combines all active, abandoned, derelict and ownerless mine shafts (with 934 features).
- Mining licenses/ mining concessions layer (with 1268 features).

- All layers and basemaps were also incorporated into some of the performance tests in GeoExplorer.

The Fire Fox (web search engine) Developers Tools were used to evaluate the performance of GeoServer. Performance of the system was evaluated based on the WMS response times. All data were in PostGIS and shapefile format, each data set was spatially indexed and with minimal styling. Each test was run ten times on each layer and the average of the response times was used as the final response time. Additionally, the same set of scenarios were executed for each one of the above datasets, using one layer at a time except for when all layers were used.

4.3.1. Data storage:

4.3.1.1. Test 1: Data formats

GeoServer and Postgres were used for their simplicity, cost effectiveness and the fact that they are conversant with other open source GIS software. The WDMP requires a system which can accommodate graphical, attribute and spatial data. Both environments were evaluated to confirm input data formats and resultant data formats. Appendix I shows that PostgeSQL and GeoServer are conversant with data formats of the data such as shapefiles, raster, excel, csv and kml; however results also show that PostgreSQL is limited in that it requires the installation of further extensions prior to accommodating some data types. This pattern holds when looking at data outputs from each system. Again GeoServer had many resultant data formats (which were WMS and WFS supported), while PostgreSQL outputs were mostly in table format and could only be shapefile or raster data when connected to an appropriate GIS software (Appendix J).

4.3.1.2. Test 2: Adding and removal of data

The evaluation of the response time required to add and remove data from the system showed that the system requires more time to process layers comprised of a lot of features as opposed to those with just one feature (Figure 18). This can be seen where a layer with one feature is loaded into a project in 3041 ms, in contrast it would take 5098 ms to load all layers into the system. Again this pattern holds when investigating the system removal of layers and the associated response time (Figure 19). Removing layers with 1 to 934 features was between 2837 and 3070 ms, while the removal of base maps and all layers simultaneously took relatively longer; with basemaps at 8235 ms and all layers at 22256 ms respectively. These results are therefore indicative that the system admin should have no problem adding data, but should expect a difference in the time taken to load different types of data into the system.
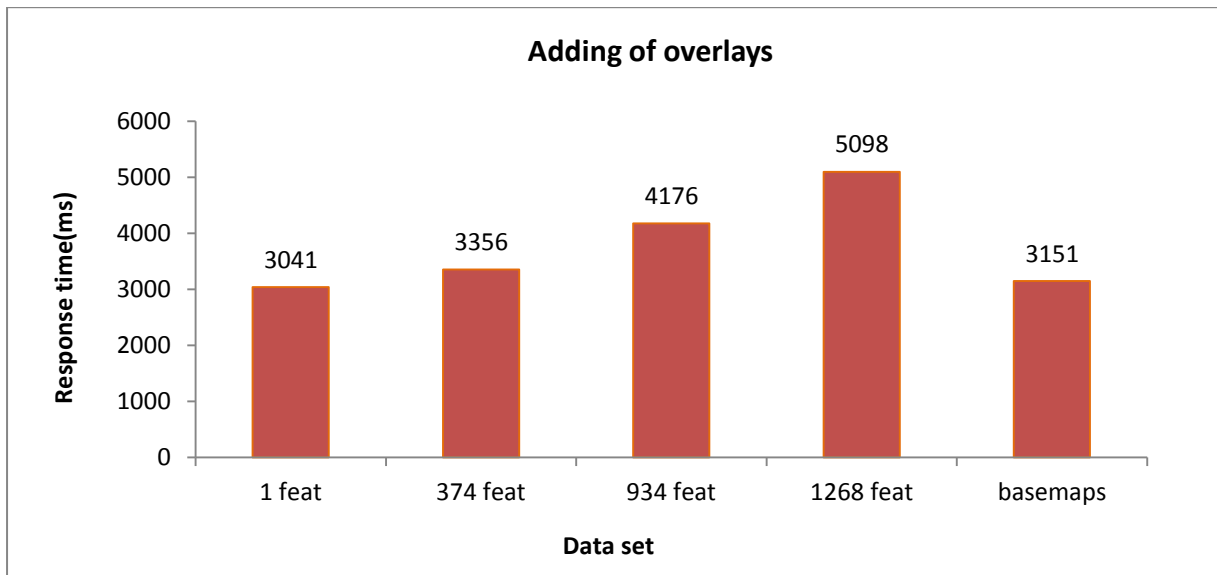
Figure 18: Response time for loading data layers. It takes 3041 ms to load a layer with one feature, while it takes 5098 ms to load all of the layers in the database. These findings indicate the existence of a direct relationship between the number of features in a layer and the resultant response time for loading the data onto a working project
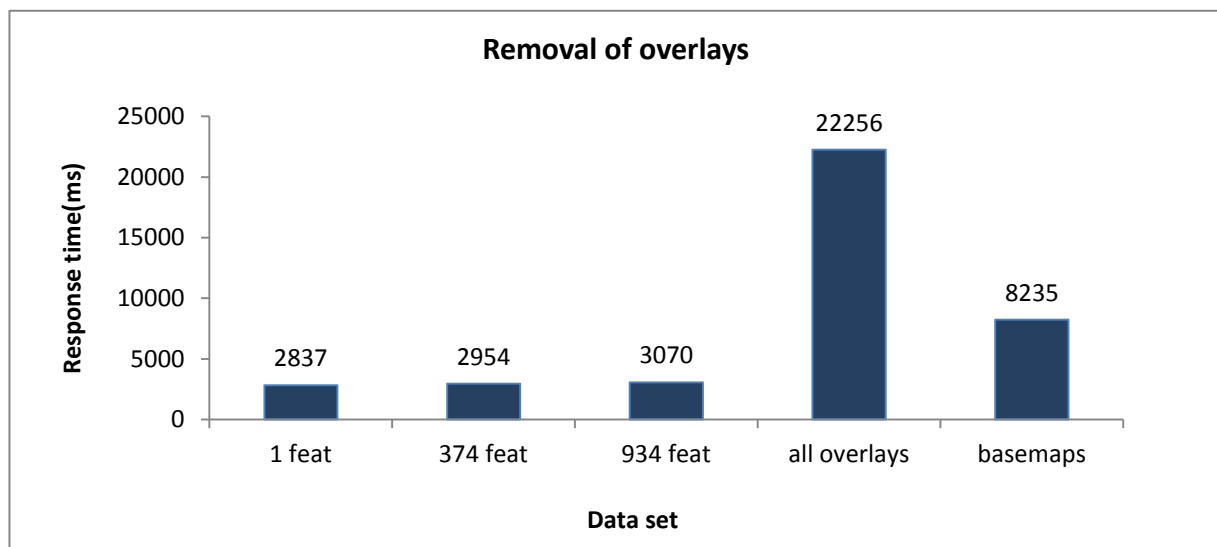
Figure 19: Required response time for removing layers. 2837 ms is required to remove a layer with one feature, whereas 22256 ms are required to remove all layers and 8235 ms are required to remove base maps respectively. The bar graph shows that the system finds it easier to remove layers with fewer features as opposed to those with more features and those that cover a larger geographical extent i.e. the base maps.

4.3.1.3. Data access:

GeoExplorer works efficiently and takes less than 10 000 ms to load, remove or download data. However, raster data require large volumes of memory which could lead to the slowing down of the database platform, thus raster data were not included in the databases but rather a folder was created

containing the satellite and historical maps. The data can be loaded directly onto GeoExplorer or QGIS for visualization purposes. Moreover, GeoExplorer may slow down when conducting advanced queries on layers such as mining licences and MRAs as these layers are comprised of more than one feature.

The database usability was tested on a student from GAES. The student checked the PostgreSQL (PostGIS) database first and then went on to check the database on GeoServer and visualize data from both databases using QGIS and GeoExplorer respectively. The student is not familiar with databases and therefore found using the PostgreSQL database moderately difficult to use. However, the student found the GeoServer database easier to use than the physical database on PostgreSQL. Bearing this in mind, once the database has been migrated to the Wits School of Mining Engineering, a tutorial with guidelines will be prepared for all involved in the WDMP. The database metadata can be found in Appendix K. The database metadata can be studied to gain more insight on the databases and data therein.

4.3.1.4. Management and administration

The security of the system was evaluated to identify the vulnerabilities of the system and evaluate the safety of data in the system. Authentication, authorization, confidentiality, availability, integrity and resilience are the primary objectives of any security test. For the purpose of this study authentication and authorization were tested.

- Authentication: Basic HTTP authentication was utilized. Basic http authentication entails the logging in using individual credentials. As already noted in section *4.2.2.2.1. Security and user roles*, two login roles were created for the WDMP, one for system admin/project coordinator and another for the individuals involved in the WDMP. Appendix L shows the resultant code obtained from the basic http authentication test, which shows that the user requires a username and a password in order to log onto the system.

- Authorization: Authorization within as system is reliant on carefully defined user roles. As such authorization entails the existence of different levels of access to resources for different users using the system. Since the system at hand utilizes data from different repositories, and we do not yet have permission to disseminate such data to the general public; users are only able to perform spatial analysis on the data and visualize the data via OpenLayers as PNG, PDF, JPEG and all other formats that do not provide the raw data itself. Whereas, the admin/ or project coordinator has reading and writing rights for all data in the system.

4.4. Recommendations for future maintenance and management of database

In the creation of the web mapping service, a few issues still need to be resolved:

- The coordinate system utilized by the historical map and the implications of transforming it have to be clearly understood. A majority of the historical maps were using the Goldfields Coordinate System which is not recognized by desktop GIS applications and cannot be easily transformed into commonly used SA coordinate systems. Understanding the implications of transformation on the historical data will spare the data creator a lot of time and avoid unnecessary inaccuracies in the data.

- Higher resolution camera or appropriate scanner is required when dealing with historical maps as most of these maps are stored in poor conditions and their quality may deteriorate over time. In future it would also be advisable to take both small and larger photos. The smaller photos should be taken to capture the desired detail, however, without image matching software the mosaicked maps come out rather messy and the larger photos, although of lower resolution are less messy and are a better option if using a camera of low quality.

- Ideally it would be beneficial to have at least a sample of all the data that will go into the database, it is simply not enough to work on given data types as in some instances it may be necessary to edit the data types in order for the data to be conversant with the database itself. As samples of data become more available, they will be incorporated into the database.

4.4.1. Database maintenance

When it comes to the database maintenance it is essential that users make copies of the data before analysing it on QGIS, GeoExplorer and other desktop GIS applications as any edits to the layers will also be applied to the database on PostgreSQL. Moreover, it is also very important that the data in the database is documented and that the databases (PostgreSQL and GeoServer) are reconciled often. It is also important that the database metadata is updated as needed in order to indicate usability and progress of the WDMP project as a whole.

4.4.2. Security

Security shouldn't be an issue for the server- side applications since there is no programming which is executed directly from the users' machine. However, security may be an issue for client- side applications in the event that users are downloading from the WMS. Nevertheless it is very important to note that internet security is not unique to web mapping applications, therefore with the improvement of overall internet security the security of web mapping applications will also improve.

4.5. Discussion

The resultant databases (PostgreSQL and GeoServer) are important research tools that can be used to access historical and current data on mining and related activities. Having access to historical data and current data on mining activities is not only imperative for the documentation of mining legacies, but it also demonstrates a proactive way of dealing with health and safety hazards posed by these mining legacies on the environment and surrounding communities. Furthermore the databases designed for the WDMP are different from all other inventories that have been designed for similar studies as it not only shows mining activities on the surface, but also activities in the subsurface. This can be further elaborated by Figure 9 which shows that since the cessation (or even during the commencement) of mining activities in the area human settlements have been developed in the area. This is an issue of concern mainly because the map used for the purpose of the study (Luipaardsvlei Estate G.M.Co General Underground Plan Battery Reef) shows the expansion of mining activities on the surface and on the subsurface. Subsurface expansion is indicated by ventilation tunnels underground which may lead to a number of structural problems such as the formation of sinkholes and the pollution of ground water resources. Moreover, access to such data is important as it can be used to study prospecting within a particular region and ensure the optimal usage of all resources in a particular mine.

The databases have basic functionalities such as: edit, query zoom in and out, pan, identify features and measure distance (GeoExplorer) and some others like buffering and network analysis on GeoServer; however, some functionalities are not on PostgreSQL and can only be used when the data is visualised on a desktop or web- based GIS platform. Although the database would be more beneficial if it was a website- which would then be platform independent and accessible from anywhere; at present maps published from the GeoServer web interface only be considered as a webpage. A website will not be created for the web map application in order to restrict access to people involved in the WDMP only and also not to violate any copyright related issues. The databases should be considered as works in progress as they will be improved with the advances in technology and their respective software. Nevertheless, the databases mark a step towards efforts made to make data more accessible for research, monitoring and environmental management efforts. More importantly the databases mark another step closer towards achieving the ultimate goal of the WDMP; which is to work towards a mine that uses various digital technologies and is completely digital.

CHAPTER FIVE   CONCLUSIONS

5.1. Introduction

The design and implementation of a national or regional geodatabase for historical mining and related activities data has not been carried out in South Africa, as shown by the shortage of case studies about the development of abandoned mine lands databases in the country (which are already underway in countries like Canada, Australia, United States and the United Kingdom). This study served to establish a way for addressing this gap. This chapter concludes this research report by highlighting what has been achieved by the study at hand, assessing limitations that constrained the investigation and it ends by suggesting possible future directions for further research on the subject matter.

The objectives of the research are listed below and the outcomes of each are briefly summarised

5.1.1. 1. To identify spatial data required by the Wits Digital Mine Project.

The WDMP is multidisciplinary, and as such requires different data. A user needs survey was conducted where all respondents were asked to provide a list of data that they might require in order to carry out respective projects. The identified data were then categorised into 8 themes, namely: production, sensor, geological, survey, topocadastral, satellite images/ aerial photographs, mine points and areal and lastly historical plans and maps. The respondents were further divided into GIS users and 'non- GIS users' and this was used to evaluate what data is required by whom. The non- GIS users were mostly concerned with data relating to sensor data, survey data and geological data. GIS users on the other hand were concerned with data related to historical maps and plans, geological data, satellite/aerial photographs, topocadastral data, geological data and mine points and areal data.

5.1.2. To identify the geospatial data available on mining and related activities for Carletonville and Sterkfontein in both digital and analogue formats, the latter will be converted into digital format through scanning geo- referencing and digitization if necessary.

A user needs survey was conducted which not only gave an indication of the data, but also the possible data sources. In addition to the data sources identified in the user needs survey, a web search and manual search was conducted to identify data housing entities for data on mining and relate activities. Upon contacting various data sources in search of data it was evident that there is a wealth of current geospatial data on mining and related activities, but not so much on historical mining activities. Spatial data on active mines, abandoned mines, MRAs, mining lease areas, geology and D/O mines can be found from numerous organisations (private and public). However, the researcher had to create historical data in a vector format by digitizing hardcopy historical maps. Mine reefs, ventilation tunnels, mine shafts were traced off maps obtained from Sibanye Gold Mines.

5.1.3. To design a database for storing and accessing the spatial data mining activities (historical and current) using the available data as a guidelines for the system functionalities and technical requirements.

Based on the needs of the WDMP the data base should: facilitate data storage (all data related to mining activities and later the WDMP), have a user friendly GUI with interactive maps to allow basic queries, have security mechanisms and support desktop and web- based GIS applications.

5.1.4. To implement and-test the database to check whether it meets the user requirements and the main objective of the research which is to design a spatial database for accessing historical geospatial data on mining activities in the wider Sterkfontein and Carletonville areas to support research, monitoring and environmental management efforts.

The proposed database for accessing geospatial data on historical and mining related data to facilitate the coordination of research, monitoring and environmental management activities in the wider Carletonville and Sterkfontein areas will help to make sure that all members and stakeholders of the WDMP have quick and easy access to mining related geospatial data. The database uses open source software which can be hard to use for people who are used to utilizing commercial GIS software such as ESRI and even more so for individuals who are not conversant with GIS software. However, the chosen software have user friendly GUIs and should be easy to navigate.

5.2. Contribution of the study at hand

The aim of the study at hand was to design a spatial database for accessing present and historical geospatial data on mining activities in the wider Sterkfontein and Carletonville areas (West Rand District) to support research, monitoring and environmental management efforts. The methodology used for evaluating access to information on historical mining activities involved enquiring on data needs of all involved in the WDMP, designing a database and then deploying it on an online platform. The evaluation of the data collected revealed that there is a wealth of data on mining activities, however this data is fragmented across various organisations which invariably makes it less easy for the public to know the right door to knock on when such data is required.

This database in so many ways presents new opportunities in mining and related fields as it reflects a new and more efficient ways of not only archiving data, but also a way of making this data available to all necessary stakeholders and also makes the work of scientists, stakeholders and decision makers at all levels easier as it provides a way of answering environmental degradation related issues; not only on the surface, but also on the subsurface. This database is also advantageous as it has been developed using open source software (and therefore available to anyone) and also it is extensible, meaning it has the potential to evolve with advances in computer technologies.

In the past, data on historical mining activities (if not lost with the cessation of mining activities) was acquired through the arduous task of ground survey which is not only time consuming but also expensive. This research report takes into consideration that mining data is sensitive and fragmented across a number of organizations and varies with time. Therefore having a database such as this one is an essential step towards the existence of a database with the potential to be updated over time, thus making the archiving of the existing data and providing accurate data to interested parties easier. The idea behind the database then presents an innovative tool to deal with health and safety hazards posed by mining activities remotely.

5.3. Limitations of the study

Although the research report has achieved its aim, there are some limitations and constraints to be considered, namely:

- Access to information

- Time constraints

- Reliability of the data

5.3.1. Access to mining related data

During the data collection phase some of the questionnaires were administered via email, thus lengthening the response time from all the respondents contacted- this was particularly true with the WDMP group members. In some instances respondents were not willing to share data or were only willing to share data to a certain extent. A couple of obstacles were identified as the main factors hindering the accessibility of digital data, namely: rigorous and unclear data request processes, copyright restrictions (which serve to limit data sharing practices without the necessary authorizations and permissions), in other cases the accessibility of data were influenced by the involved costs, however, some institutions had no information on mining related activities- the absence of which is attributable to budget cuts, failure to include the creation of such data in the mandate of the institution or organization and also in the case of the WDMP group respondents, the data had not yet been collected.

5.3.2. Reliability of the data

With regards to the data quality of all the existing data collected from various organizations, data quality assessments were not performed on all data sets (data quality assessments were only performed on the abandoned mines, active mines, MRAs and D/O layers). Most of the point data is in need of further verification. Moreover, there is also the issue of the data quality of the historical data. Should this research be pursued further, appropriate scanning apparatus should be used in order to capture the

finest detail to show the yearly excavation and also show the depth and difference between cross raises and off reefs.

5.3.3. Personal skills of the researcher

This research project was conducted over a couple of months and the fieldwork was conducted over one week; therefore the primary constrain to the project has been that of time. The secondary constraint to the research has been the use of open source software in the development of the databases. Although accessible, open source software is rather hard to use, especially if the user is conversant with commercial software which has technology that is more advanced.

5.4. Future Research

This research report serves to establish a point of reference for the exploration of other research questions within the scope of the WDMP and can be used to support research, monitoring and environmental management efforts. The research report can be used as a framework for advances in the Digital Mine project run by the School of Mining Engineering at the University of the Witwatersrand, Johannesburg. The information in the database may be expanded to include contributions from all individuals involved in the Digital Mine Project in order to have a centralized repository of all the research conducted for the purpose of the Digital Mine Project which is ultimately to guarantee the health and safety of humans involved with and living nearby areas of mining activities.

5.5. Conclusions

A database containing spatial data on current and historical mining activities was developed and implemented as a part of the Digital Mine project run by the School of Mining Engineering. The database is available to all those involved in the Digital Mine project as the necessary software will be installed in the Digital Mine facilities, the database can then be used for study related purposes by the other Digital Mine project group members and be used to answer pertinent questions.

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Appendices

APPENDIX A: Lists all the respondents from the WDMP and their respective roles.

Name of respondent	Year of study	Research topic/ role/ goal
Hamid Ashraf	PhD	Geospatial subsidence hazard model for Sterkfontein caves. Using GIS systems to identify risks. Extension to Sterkfontein caves.
Mpoyi Kanda	PhD	Monitoring geotechnical risk for digital mining. Extension to Sterkfontein caves.
Sarfraz Ali	PhD	Conceptual plan for ground behaviour modelling. Extension to Sterkfontein caves.
Intikhab Hussain	MSc	Underground Communication Systems Engineering. Extension to Sterkfontein caves.
Glenn Stacey	MSc	Towards automated tunnel traversing for the control of deep level mining. Research important at depths where people can no longer mine (Rock temp @ 4km depth ± 70ºC).
Tariq Feroze	PhD	ANSYS Software modelling of airflows underground. Project entails numerical modelling of underground air flows.
Monica Tetteh	PhD	Time and spatial tracking of product and contact. Research presents a digital mining technology to prevent losses.
Stuart Edwards	MSc	Autonomous 3D mapping and surveillance of mines.
Stephen Chabalala	PhD	Cognitive Radio and Wireless Sensor Networks for Digital Underground Mine Communication systems. Research important for reliable underground communication.
Samkelisiwe Khanyile (researcher)	MSc	Towards a digital mine integrated with its environment: a spatial database for accessing spatial data on historical mining and related activities. Designing a web- based GIS on historical mining activities extending to Sterkfontein caves.

APPENDIX B: Map inventory

| Map title	Reef	Title	Scale_and units of the map	Duration
Randfontein Estates G M Co LTD	New and wide Reefs	New and wide reefs Underground plan	1:2500 Ft	1958- 1971
Randfontein Estates G M Co LTD	N/A	No.1 Stubbs- Section on line II	1:500 Ft	1939- 1964
Randfontein Estates G M Co LTD	N/A	Cross section no.7 shaft	1:1000 Ft	
Randfontein Estates G M Co LTD	N/A	Transverse section North Battery incline shaft	1:1000 Ft	1923- 1984
Randfontein Estates G M Co LTD	N/A	Northern division General underground plan		1910- 1920
Randfontein Estates G M Co LTD	RTR and West Reef	South Vertical Shaft Underground plan	1:1000 Ft	1951- 1962
Randfontein Estates G M Co LTD	N/A	No. 32 shaft Cross section on line R-R	1:1000 Ft	1956- 1964
Randfontein Estates G M Co LTD	N/A	Section Flora sub- incline	1:500 Ft	1929- 1939
Randfontein Estates G M Co LTD	N/A	Plan Section North Battery Incline shaft on line T-T	N/A	1923- 1964
Randfontein Estates G M Co LTD	N/A	Cross section south Shaft on line S-S Battery section	1:1000 Ft	1923- 1964
Randfontein Estates G M Co LTD	N/A	Stubb shaft Plan section	1:1000 Ft	
Randfontein Estates G M Co LTD	N/A	South Randfontein Deep Transverse section through main incline shaft	1:1000 Ft	
Randfontein Estates G M Co LTD	N/A	Surface Plan North Eastern area	1:2500 Ft	1958- 1965
Randfontein Estates G M Co LTD	Main Reef	Main Reef Underground Plan	N/A	1935- 1983
Randfontein Estates G M Co LTD	Main Reef	Main Reef Underground Plan	N/A	1938- 1971
Randfontein Estates G M Co LTD	Main Reef and Kimberly Reef series	Main Reef and Kimberly Reef Series Underground Plan	N/A	1937-1983
Randfontein Estates G M Co LTD	Main Reef	Southern Division Main Reef Underground Plan	N/A	1931- 1983
Randfontein Estates G M Co LTD	N/A	Underground Plan Lower Levels	N/A	1934-1938
Randfontein Estates G M Co LTD		South General Workings	N/A	1910
Randfontein Estates G M	Central Reef	Central Sections 6 and 7 Showing	1:1000	1921- 1924

Co LTD		Ventilation pipes	Ft	
Randfontein Estates G M Co LTD	Upper Bird Reef	Upper Bird Reef Underground Plan	N/A	1953- 1960
Randfontein Estates G M Co LTD	Bird Reef	Bird Reef General Underground	N/A	1955-1982
Randfontein Estates G M Co LTD	Upper Bird Reef	Upper Bird Reef Underground Plan	1:1000 Ft	1960- 1983
Randfontein Estates G M Co LTD	Upper Bird Reef	Upper Bird Reef Vertical Projection	1:1000 Ft	1936- 1982
Randfontein Estates G M Co LTD	Kimberly Reef and Bird Reef	North Eastern Kimberly Reef and Bird Reef	N/A	1950-1971
Randfontein Estates G M Co LTD	Upper Bird Reef	Upper Bird Reef Vertical Projection	N/A	1956- 1983
Randfontein Estates G M Co LTD	Leader Reef	Leader Reef Southern division Section 3, 4 &5 Shafts	1:1000 Ft	1914- 1923
Randfontein Estates G M Co LTD	Leader Reef	Leader Reef no.1 Stubbs Shaft Underground Plan	1:1000 Ft	
Randfontein Estates G M Co LTD	Leader Reef	Leader Reef Underground Plan	1:1000 Ft	1940-1956
Randfontein Estates G M Co LTD	Battery Reef	Battery Reef	1:1000 Ft	1923-1933
Randfontein Estates G M Co LTD	Battery Reef	Battery Reef	1:1000 Ft	1933- 1971
Randfontein Estates G M Co LTD	West Reef	West Reef Section 1	1:500 Ft	1911- 1923
Randfontein Estates G M Co LTD	N/A	Plan of the properties belonging to Randfontein Estates Gold Mining Co. Witwatersrand LTD	1:600 Ft	
West Rand Consolidated Mines LTD	N/A	West Shaft Underground plan	1:500 Ft	1910- 1917
West Rand Consolidated Mines LTD	N/A	Transverse Section Flora Shaft	1:500 Ft	1914- 1939
West Rand Consolidated Mines LTD	N/A	Section through No.3 shaft	1:500 Ft	1912- 1937
West Rand Consolidated Mines LTD	N/A	Section through West shaft	1:500 Ft	1915- 1939
West Rand Consolidated Mines LTD	Main and South Reef	No. 2 Shaft	1:500 Ft	1937- 1957
West Rand Consolidated Mines LTD	N/A	Plan of the Randfontein Central and the West Rand Consolidated	N/A	
West Rand Consolidated Mines LTD	N/A	Section Rand Auxillary Shaft	1:500 Ft	1924- 1939
West Rand Consolidated Mines LTD	N/A	Section South Sub- Incline shaft	1500 M	1937- 1990
West Rand Consolidated Mines LTD	N/A	Section through Rand shaft	1:500 Ft	1911- 1929
West Rand Consolidated	Main Reef	Plan showing Main Reef workings	1:500	1950- 1951

|				
Mines LTD		and west shaft section of the railway reserve	Ft	
West Rand Consolidated	N/A	Surface Plan	N/A	1990
West Rand Consolidated	N/A	General surface plan	1:5000 M	1971-1973
West Rand Consolidated	Bird Reef	General Underground Plan	N/A	1942- 1961
West Rand Consolidated	Bird Reef	General Underground Plan	N/A	1953- 1961
Luipaardsvlei Estate and G M Co LTD	Battery Reef	Battery Reef East Incline Shaft	1:1000 Ft	1925- 1937
Luipaardsvlei Estates	Battery Reef	Battery Reef General Underground	1:2500 Ft	1953-1979
Luipaardsvlei Estates	Bird Reef	Bird Reef General Underground	1:2500 Ft	1934- 1938
Untitled	Untitled	Plan No. 3 North Shaft	1:1000 Ft	1954- 1958
Untitled	White Reef	General Underground plan	N/A	
Untitled	Untitled	North East Shaft Cross section	1:1000 Ft	1915-1964
Untitled	Untitled	Plan and Section No. 1 shaft	1:200 Ft	
Untitled	Untitled	Underground Plan No. 1 Stubbs shaft	1:1000 Ft	1936- 1937

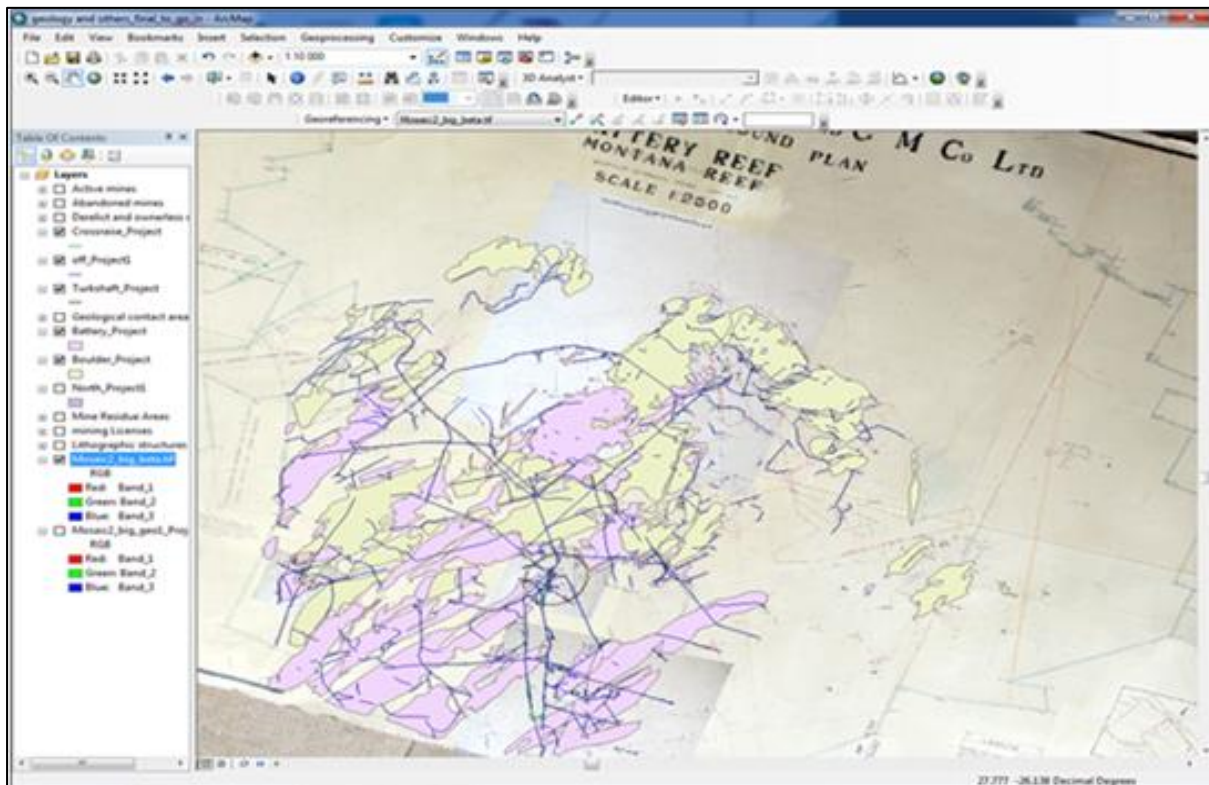**APPENDIX C: Mosaics from small photo tiles (1) and big photo tiles (2)**
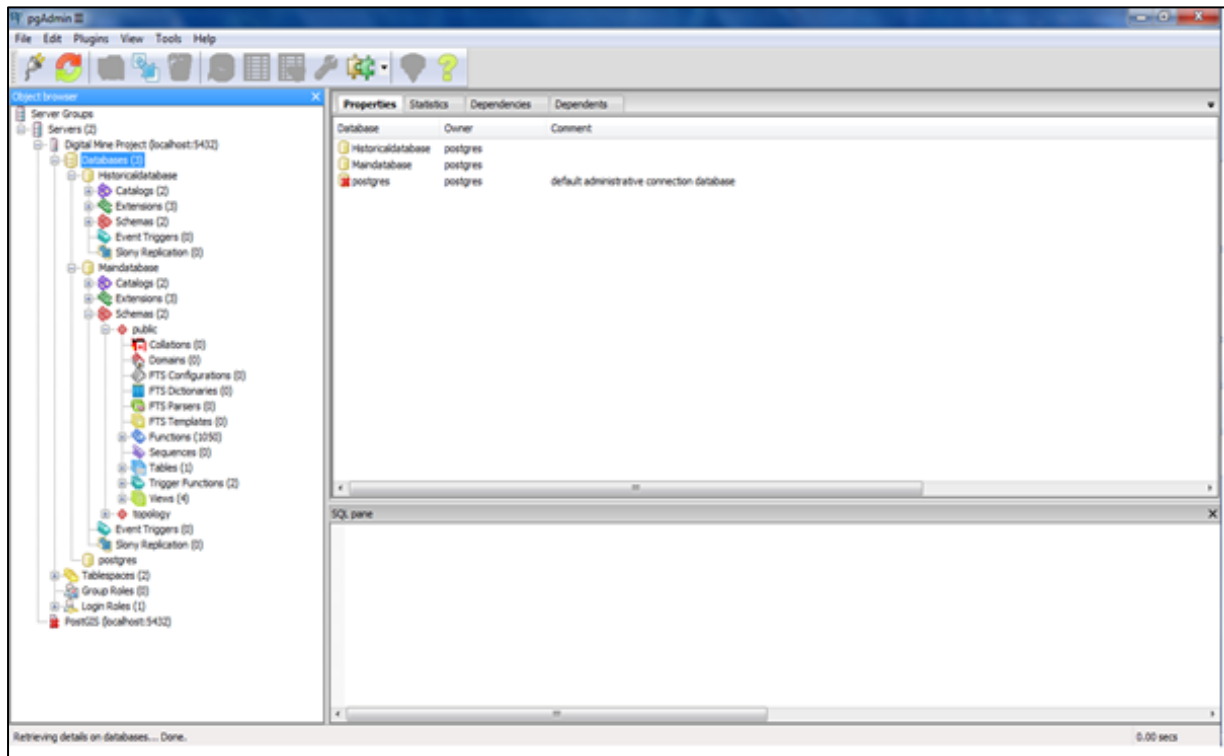
1.)
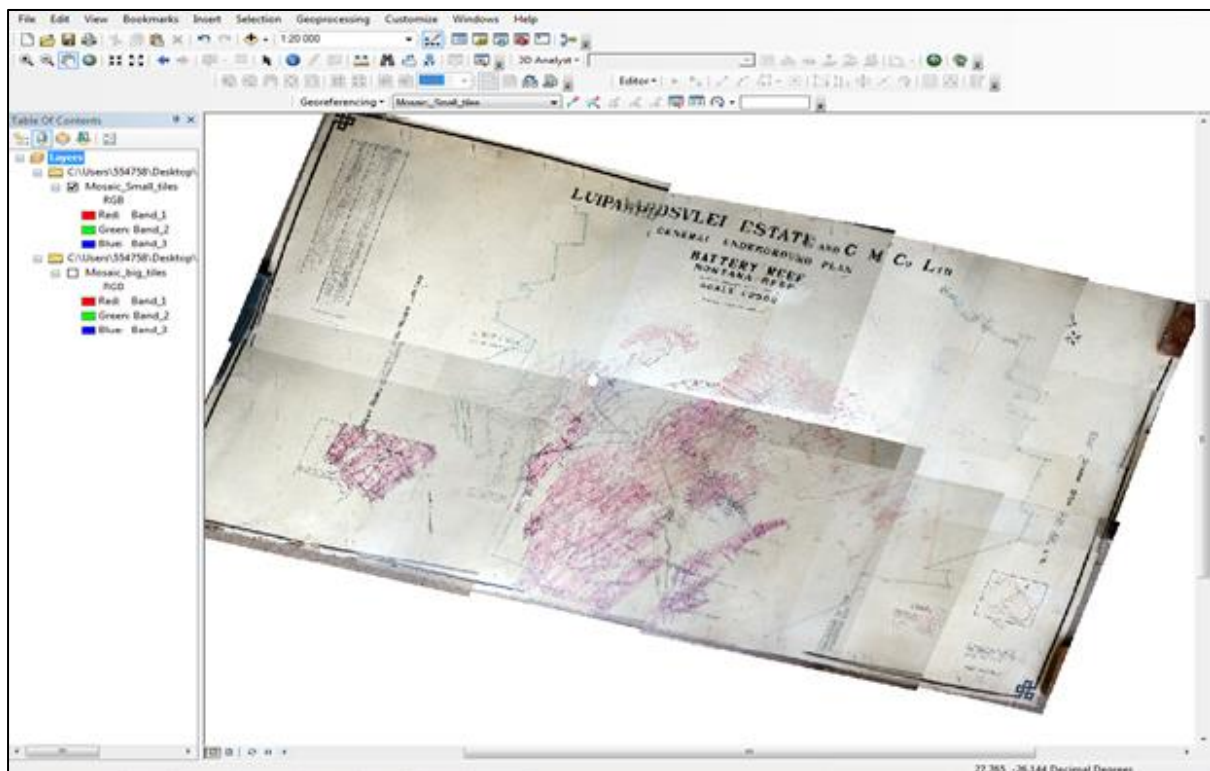
2.)

APPENDIX D: Shows the area covered by the map. The area covered by the map is represented by a red rectangle on the photo tile
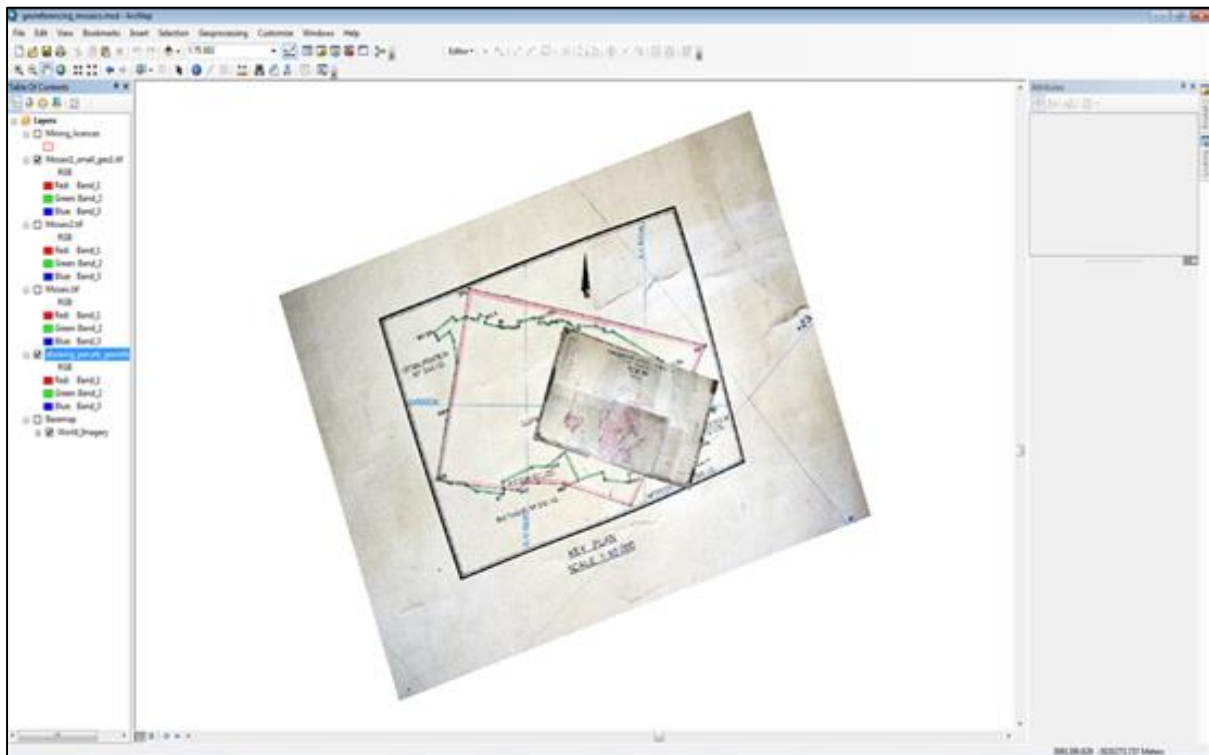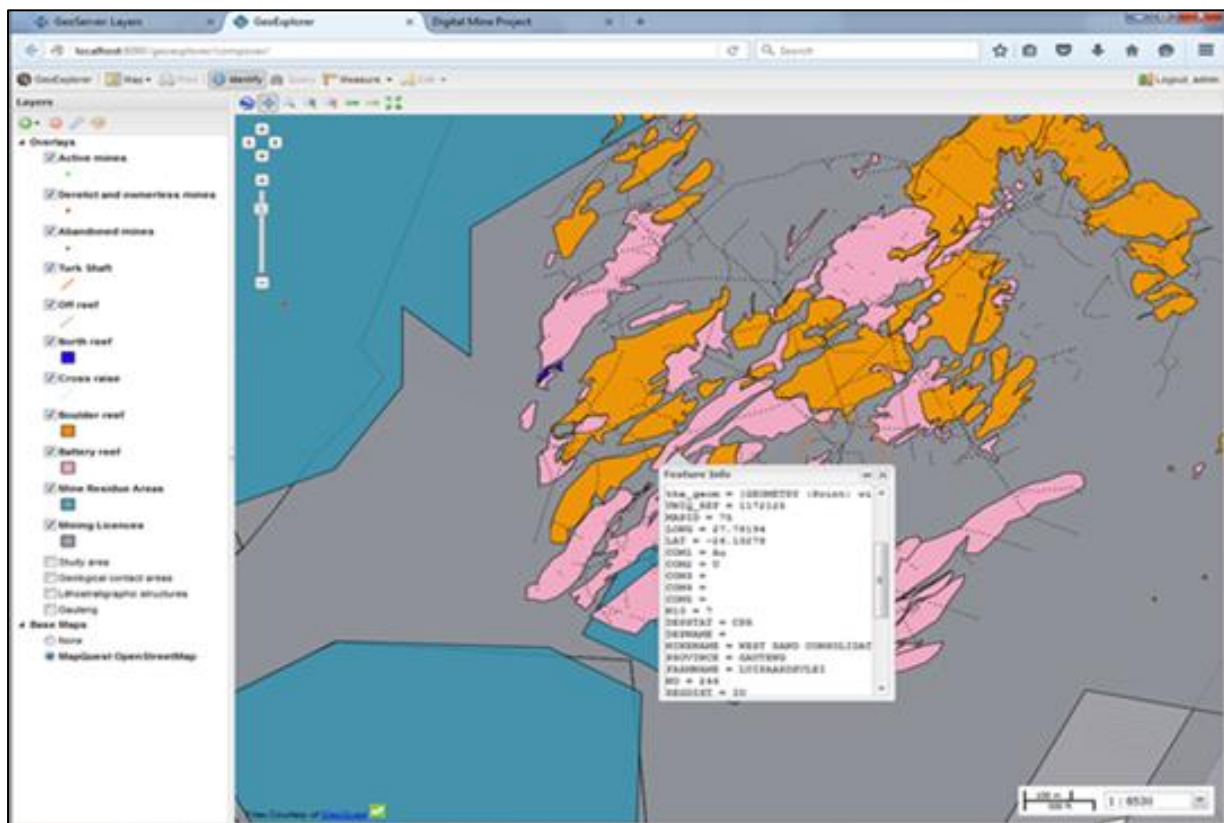

APPENDIX E: Vector format historical data digitized from historical map
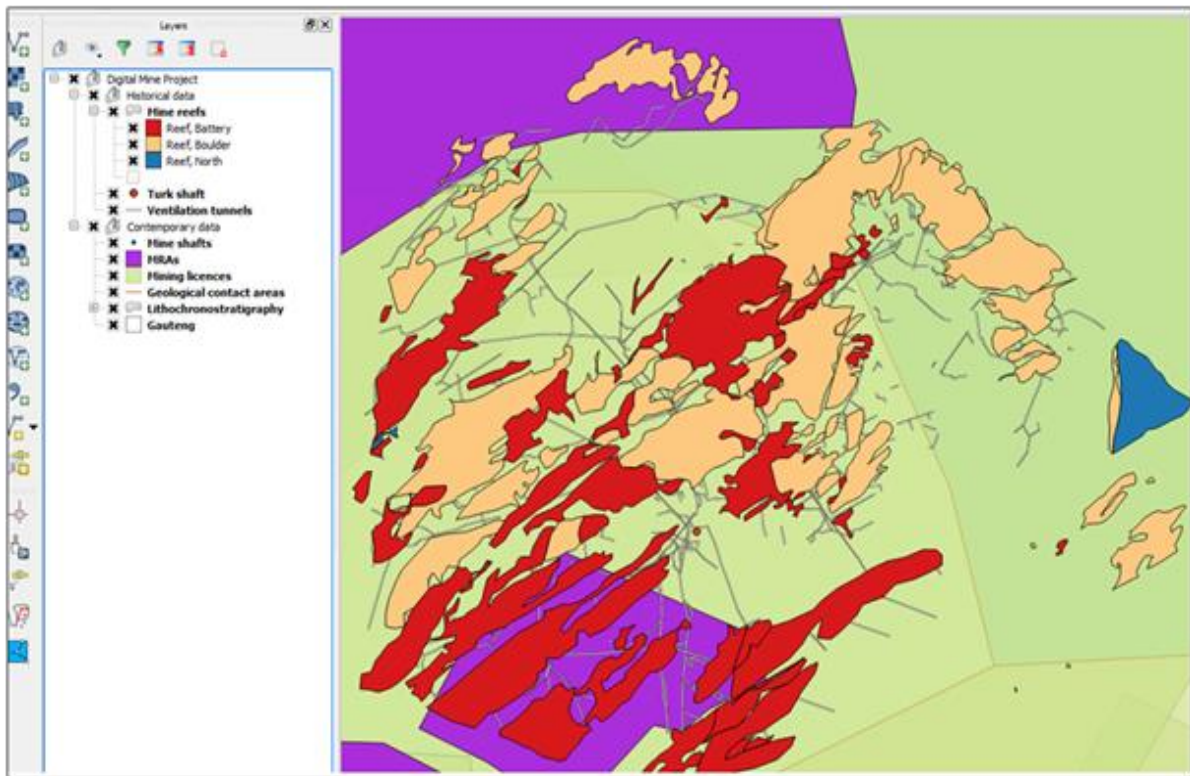
APPENDIX F: Databases created in PostgreSQL

APPENDIX G: Using the Identify tool in GeoExplorer, the user can click on the map and the WMS will return information on all the data found in that area on the map

APPENDIX H: Vector historical data visualised on QGIS

APPENDIX I: Input data formats

Input data format	Geoserver	Postgres
Shape file	X	X (via Postgis shapefile loader)
Raster/ GeoTiff	X	X
Excel spreadsheet		X (bit(size), varbit(size), bitvarying(size),smallint, int, integer, smallserial, serial, bigserial, numeric(m,d), double precision, ral, money, bool, boolean)
CSV	X	
KML	X	
JPEG	X	

APPENDIX J: Output data formats

Platform	Output data format
GeoServer	WMS : AtomHub, GIF, Geopackage, GeoRSS, GeoTIff, Jpeg, KML, MB Tiles, Open Layers, PDF, PNG, SVG, Tiff WFS : CSV, GML, GeoJSON, KML, Shapefile, Application/x-gpkg, geopkg, geopackage, gpkg
Postgres	Shapefiles, Raster (if connected to GIS software), bit(size), varbit(size), bitvarying(size),smallint, int, integer, smallserial, serial, bigserial, numeric(m,d), double precision, real, money, bool, boolean

APPENDIX K: Database documentation

Wits Digital Mine Project database

Data format: Shapefiles and PostgreSQL(PostGIS) object- relational database mounted on GeoServer web platform.

File or table names:

- Mining reefs
- Turk shaft
- Ventilation tunnels
- Gauteng Province
- Geological contact areas
- Lithostratigraphy
- Abandoned mines
- Active mines
- Derelict and ownerless mines
- Mine shafts
- Mine Residue Areas(MRAs)
- Mining Lease Areas

Coordinate system: Geographic (GCS_ WGS84)

Theme keywords: Mining related activities, historical data and geospatial data access.

Abstract: Digital Mine Project database prototype. Two databases were created: one in (Postgresql (PostGIS) and the other is mounted on an online platform (GeoServer). The two databases contain historical and current data on mining and related activities in the Gauteng province (extent is modifiable to show the wider Carletonville and Sterkfontein areas, which is the study area). All known and available and data sources were used to put together the data sets to go into the database including archival material on historical mining activities from Sibanye Gold, the Department of Mineral Resources, Gauteng Department of Agriculture and Rural Development, Council for Geosciences etc. Some data has been modified to suit the purpose of the study i.e. historical data were digitized from hardcopy historical maps to create historical data in a vector format and data on all mine shafts was merged to create a collective shapefile showing all the mineshafts in the area. The databases can be visualised on PostgreSQL by using select statements or through QGIS, alternatively the database may be accessed on GeoServer. GeoServer enables the user to interact with the data. Furthermore data can be visualised on GeoExplorer where the map product can be saved as a WMS. Effort has been made into making the database accurate; however, any additions or corrections should be directed to the Wits Digital Mine Project, University of the Witwatersrand. The database is meant to store data required and used by the Wits Digital Mine Project, however, some group members are yet to acquire their required data, as such, periodic revisions of this database will be issued as new information is made available. This database is a valuable research tool, particularly for accessing historical geospatial data (and current data) on mining and related activities in the wider Sterkfontein and Carletonville areas to support research, monitoring and environmental management efforts.

Identification information

Citation information: Wits Digital Mine Project Database

Title: Wits Digital Mine Project Database

> File or table names: Mining reefs,ventilation tunnels, gauteng province, geological contact areas, lithostratigraphy, abandoned mines, active mines, derelict and ownerless mines, mine shafts , mine residue areas(MRAs) and mining lease areas

> Link: Mining data is very sensitive, so the database is currently only available as a webpage. This was done in order to limit data access to only members of the Digital Mine Project group and necessary stakeholders.

Description:

> Purpose:

> The Wits Digital Mine Project database is a valuable research tool, particularly for accessing
> historical geospatial data (and current data) on mining and related activities in the

wider Sterkfontein and Carletonville for the support research, monitoring and environmental management efforts.

Supplemental Information:

In the Mine shafts layer (where all the mine shafts locations have been considered), each mine is identified by the mine status (abandoned, continuous or derelict and ownerless). To identify the mine shaft by name, the user will have to refer to the individuals shapefiles (active mines, abandoned mines and derelict and ownerless mines respectively). Raster data has not been added to the database to improve response time; however, raster data is available in a folder and can be loaded directly into QGIS or GeoExplorer for visualisation

Language of data sets: English

Time period of content:

Single date/time: Data were collected from various data housing entities; as such, the data has been created on different dates. Dates of creation can be found on layer properties.

Status:

Progress: In work

Maintenance and update frequency: As needed

Spatial domain:

West bounding coordinate: -27.156340 dd
East bounding coordinate: 29.098423 dd
North bounding coordinate: -25.110160 dd
South bounding coordinate: -26.918 397 dd

Key words:

Theme: Wits Digital Mine Project, mining related activities, historical data and geospatial data access.

Place: Gauteng, wider Carletonville and Sterkfontein area.

Access constraints: User should have OpenGeo suite installed on computer.

Use constraints: Locations of mine shafts are indicative of individual shafts unless stated otherwise.

Point of contact:

Contact organization: Wits Digital Mine Project

Primary contact: Samkelisiwe Khanyile, <u>samkelisiwe.khanyile@students.wits.ac.za</u> alternatively ntandoh.khanyile@gmail.com

Data set credit:

- Department of Mineral Resources
- Sibanye Gold (Geological Base Camp)
- Wits University (GAES and Dspace)
- Gauteng Department of Agriculture and Rural Development
- South African National Space Agency
- Council for Geosciences
- United states Geological Survey

Native data set format: Shapefiles, Raster and Jpegs (converted to GeoTiff after georeferencing)

Data quality Information

Quality (positional, attribute, completeness) of some of the current data were evaluated (Khanyile, 2014). The data quality of the data provided by state organisations generally is not accurate. All point and areal data were overlaid on Google Earth imagery and the following observations were made:

- Positional accuracy: A majority of the mine points were not in the areas that are clearly affected by mining activities. There were also some discrepancies with regards to the areal data, which did show the outlines/boundaries of areas affected by mining practices accurately.
- Attribute accuracy: There was a lack of consistency in the attribute fields used to describe features.
- Completeness: The data also did not come with any metadata or lineage information, which makes the interpretation of the attributes rather difficult due to the lack of a dictionary explaining all the abbreviations. According to SASDI all spatial data should be accompanied by the necessary metadata and lineage information, however, most of the data does not come with such data. As a result the data is incomplete.

Spatial Data Organization and attribute and entity information

Spatial reference method: Vector

Name of table	Feature type	Feature	Attribute fields

		Geometry	
Turk shaft	Simple	Point	Objected_1,OBJECTID, Shape-Leng, Orid_fid
Mining reefs	Simple	Polygon	FID, Shape, OBJECTID, Id,Shape_Leng, Shape_Area
Ventilation tunnels	Simple	Line	FID, Shape, OBJECT, Id, Shape_Leng, Name
Gauteng Province	Simple	Polygon	Objectid_1, Objectid_2, Objectid, Category, Cat_b, Muniname, Namecode, Map_title, District, Province, Area, Shape_leng, Shape_le_1, Area_ha, Total_pop_, Area_sqkm, Shape_area
Geological contact areas	Simple	Line	OBJECTID, Shape, LNTYPE, LYNTYPET, DESCRIPTIO, Shape_Length
Lithostratigraphy	Simple	Polygon	OBJECTID, Shape, UQ_GEOL, UQ_SACS_NO, LITHSTRAT, LITHRANK, PARENT1, RANK1, PARENT2,RANK2, RANK3, CHRONOSTRAT, CHRONORANK, LITHO_GRP, DESCRIPTIO, COLO_CODE, HACH, HACHT, TEXT_LABEL, Shape_Length, Shape_Area
Abandoned mines	Simple	Point	FID, Shape, OBJECTID, UQ_REF, LONG, LAT, DEPNO, MAPNO, COM1-8, DEPSTAT, MAP_SYMBOL, ORIENT, SIZE, DEPNAME_1, DEP_CONC, OE_UNDEF
Active mines	Simple	Point	FID, Shape, OBJECTID, UNIQ_REF, MAPID LONG, LAT, DEPNO, MAPNO, COM1-5, N10,DEPSTAT,

				DEPNAME, MINENAME, PROVINCE, FARMNAME, NO, REGDIST
Derelict and ownerless mines	Simple	Point		FIS, Shape, Name, FolderPath, SymbolID, AltMode, Base, Snippet, PopUpInfo,HasLabel, LabelID
Mine shafts	Simple	Point		Objectid_1, Long, Lat, Depstat
Mine Residue Areas(MRAs)	Simple	Polygon		OBJECTID,Shape,FID_Area mi, Id, TYPE, Topo, TDF_dam, TDF_dump, WRD, Ocast, Q, RWD, TSS, Others, FP, Visit, dolomite, Nearwetlan, Riverinter, Nearwetla, F_Area,Mine_Area, WaterDisq, Border, FID_farmsw, Area, GFARD_CL_, GFARM_CL_I, SGKEY, FARMNAME, FARMNO, SUBDIVNAME< SUBDIVNO, MAG_DIST, PROVINCE, SG_OFFICE, MAJOR, MINOR, PARCEL, PORTION_S, ERF_NUMBER, TOWN_NAME, PORTION, OWNERS_NAM, TITLE, Shape_Length, Shape_Area
Mining Lease Areas	Simple	Polygon		FID,Shape,BID,commcode, dtlodgemen,tempappid, filerefnum,region,appliname, apptype,

Distribution Information

Contact organization: Wits Digital Mine Project, School of <Mining Engineering, University of the Witwatersrand

Contact person/position: Samkelisiwe Khanyile (Digital Miner, student)

Contact details: ntandoh.khanyile@gmail.com

Resource description: Downloadable data (download privileges depend on user role)

APPENDIX L: HTTP Authentication script

```
</head>
<body>
  <div id="header">
    <div class="wrap">
      <h2><a class="pngfix" href="./"><span>GeoServer 2.8-
SNAPSHOT</span></a></h2>
      <div class="button-group selfclear">
      <form method="post" action="../j_spring_security_check">
        <label class="noshow" for="username">Username</label>
        <input id="username" type="text" name="username"
value="" title="Username"/>
        <label class="noshow" for="password">Password</label>
        <input id="password" type="password" name="password"
value="" title="Password"/>
        <label class="shown"
for="_spring_security_remember_me">Remember me</label>
        <input id="_spring_security_remember_me"
type="checkbox" name="_spring_security_remember_me" />
        <button class="button-login positive icon"
type="submit"><div>Login</div></button>
        <script type="text/javascript">
        //<![CDATA[
        jQuery(document).ready(function() {$('#username,
#password').inlineInfoTextify();});
        //]]>
        </script>
      </form>
```