SZENT ISTVÁN UNIVERSITY
FACULTY OF AGRICULTURAL AND ENVIRONMENTAL SCIENCES
MSC COURSE OF AGRICULTURAL ENGINEERING

Validation and Correlation of Soil Information with International Standards in Central Namibia

Stefanus Niilonga Hashondati Nambambi

Department of Soil Science and Agricultural Chemistry

Institute of Environmental Sciences

Thesis Supervisor:

Prof. Erika Michéli

Co- supervisor:

Vince Láng

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1. Introduction

1.1. Background

Projected continuous rising of the world population has created a great pressure on arable land and other natural resources. Securing food for expected 9.5 billion people by 2050 while maintaining the integrity of the fragile ecosystem is a huge challenge for the coming years. The situation is more confrontational to/in developing countries like Namibia and most of African continent in general, where there is global recognition of hunger and the cycle of poverty being the most significant development challenges that the world faces today. Agriculture has been identified as the most effective driver of growth in the world's poorest countries, whereby increasing agricultural productivity is essential for reducing rural poverty, enhancing food security and stimulating of the broad-based economic growth. With no significant extension of agricultural land area foreseen, agriculture advancing does not only depend on improving the technical, economic, legal and trade conditions under which farmers and agribusinesses must operate but crucially on understanding and knowledge of the existing soil resources, both on supply and quantity. The necessary crop yields increasing activities must however appreciate the environmental problems (Intensive farming, land degradation, overpopulation, deforestation, *etc.*) and their vital global impacts. The phenomena has also increased a need to share and exchange soil data and information within countries, across regions and globally. Timely access to consistent, authoritative and understandable data and information is critical to issues such as policy making, food production and adaptation to climate change, water management, energy production and soil conservation. Soil data and information is managed by numerous organizations using a variety of processes, scales and standards and classification systems. A number of national and international activities and projects are currently dealing with the issues associated with collation and harmonization of disparate data sets.

Despites the importance, the soils of Namibia had not yet been fully and systematically mapped or characterized in appropriate scale and the overall knowledge of the soils is still rather scanty. The legacy data is available from the different projects in variable format and classification systems. Aiming to rectify and improve on this shortcoming among others are projects such as; the Agro-Ecological Zoning and Erosion Hazard Mapping at the Ministry of Agriculture, Water and Forestry as well as international bodies such as the FAO Soil of the World, AfSIS and JRC. This study is aiming (1) to make additional contribution by correlating Namibian soils to the World Reference Base for Soil Resources (WRB Working Group IUSS, 2006) the official international correlation system. The additional aim (2) is to test and evaluate a format that is compatible with international data sets. A third, more specific objective (3) of the presented thesis is to validate a recent 1:1 Million Map to be published by the EU in the new Soil Atlas of Africa (in progress) combining several legacy maps and data in a small, about 51 327 km^2 test area in central of Namibia, roughly between 22° – 23.6° S, 15.8° – 18.2° E, using soil data collected by Coetzee in 2009.

The study was carried out under the requirements of the *Master Degree in Agricultural Sciences study programme*, of which the author is the Student in the Department of Soil Science and Agricultural Chemistry of Szent István University, Gödöllő, Hungary. This programme is under the auspices of UN FAO and Hungarian Ministry of Agriculture and Rural Development being undertaken by students from various developing countries.

1.2. Thesis Justification

Educational and other institutions research and developments are commonly supported and applied in most scientific industries. In further addition to large yields of knowledge, they are also behind everyday success and failure of the economic activities of many business disciplines. They reveal and provide information for planning and decision making. Despites being fundamental pillar of Namibian economic and livelihood, Namibian soils have not been explored and studied; therefore there is a need to build the momentum on this subject. About 70% of Namibian population depends on rainfed subsistence farming, with a country located in Arid regions and a reportedly 1% of about 825 000 km^2 arable land, detail knowledge of the soils is an essential. Eventually, this manuscript will presents applied analysis conducted on wide variety of work done by previous researchers, thus diffuses knowledge. Furthermore, it will highlights a new theoretic concept of methods and techniques of deriving soil maps from secondary data set and argue about it.

2. Literature Review

2.1. Natural Conditions of Namibia

2.1.1. Climate

Climate is important for studies on soil and other ecosystems components because climatological factors such as rainfall and temperature determine geomorphology, weathering and soil formation, transport of material, flora and fauna, and the use of natural resources. Namibia climates vary from arid in the south and central, semi-arid in the west and sub-humid in the north-eastern regions (Internet 1). The central, southern and coastal areas are among the most arid landscapes south of the Sahara. Namibia in relation to other southern Africa states represents a low rainfall extreme and experiences intermediate to warm temperatures and high potential evapotransipiration (Okitsu, 2005) with approximately 300 sunshine days a year (Midgley *et al*, 2005). Overall, the climate in is influenced by two factors; the distance from the humid tropics and the Namib Desert (Bertram and Broman, 1999). The distance from the humid tropics results in a northern-southern gradual change of the climate. The Namib Desert, located near the coast, modifies this zonation, especially regarding the rainfall to south-western and north-eastern regions of the country.

Rainfall is entirely restricted to summer months of October through to April, where it occurs in erratic thunderstorms, about 370mm annual average. The most arid Namib desert and coastal in the west usually receives less than 50mm a year of rainfall whereas central and wettest north-east regions averages are 350 and 700mm respectively (Figure 2.2) (Mendelsohn *et al*., 2002). As a result of low and variable rainfall, droughts are frequent in Namibia. Furthermore, due to the most of the county being desert, Namibia has general low relative humidity at a mean year average of 32.7% despites sometimes reaching 80% during and following summer rains (Internet 1). During winter, May to August, the inland day temperature averages 18 °C and drops below 0 °C at night while summer days' temperatures are normally between 20 – 35 °C but can exceed 40 °C. The coast is usually cooler than inland throughout the year. A worldwide weather website (Internet 2) has it that November, December and January are commonly the warmest at average of maximum 30 °C temperature where June and July are the coldest with an average of 6 °C.

Temperatures, precipitation, sunlight and relative humidity monthly and yearly averages are graphical shown in figure 3 and 4 below.

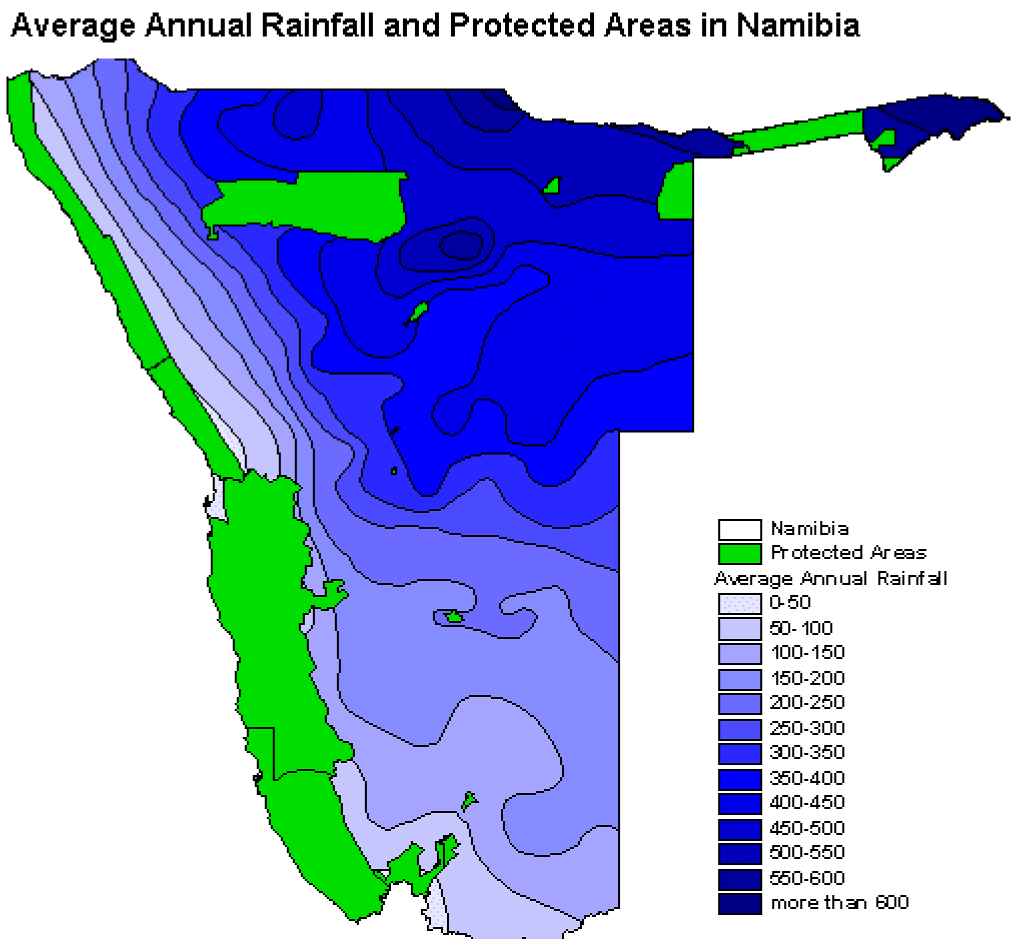
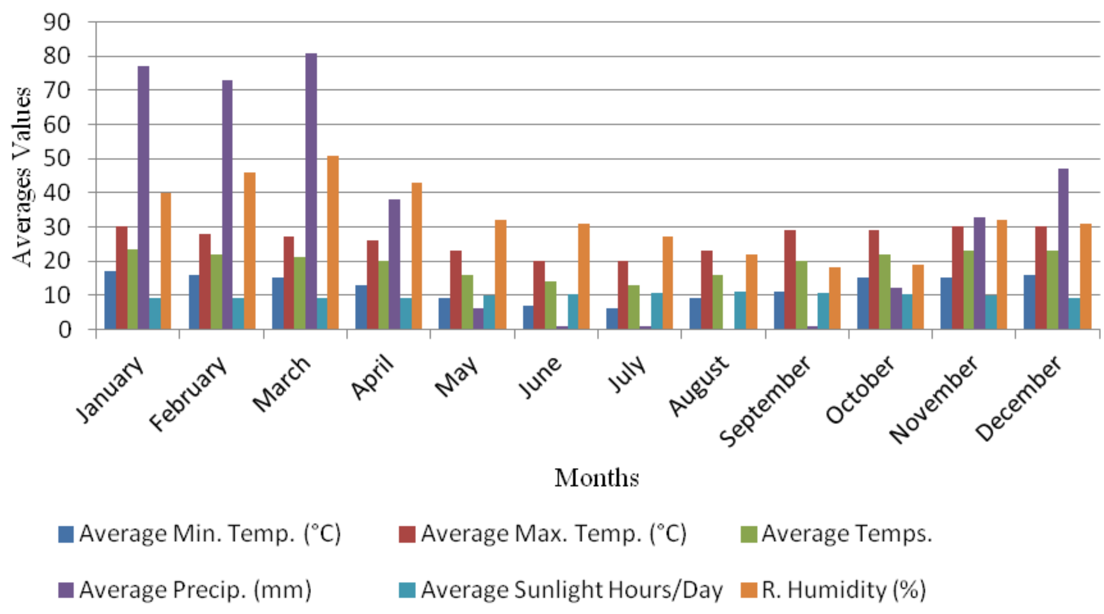


Figure 1. Mean Annual Rainfall Variability in Namibia

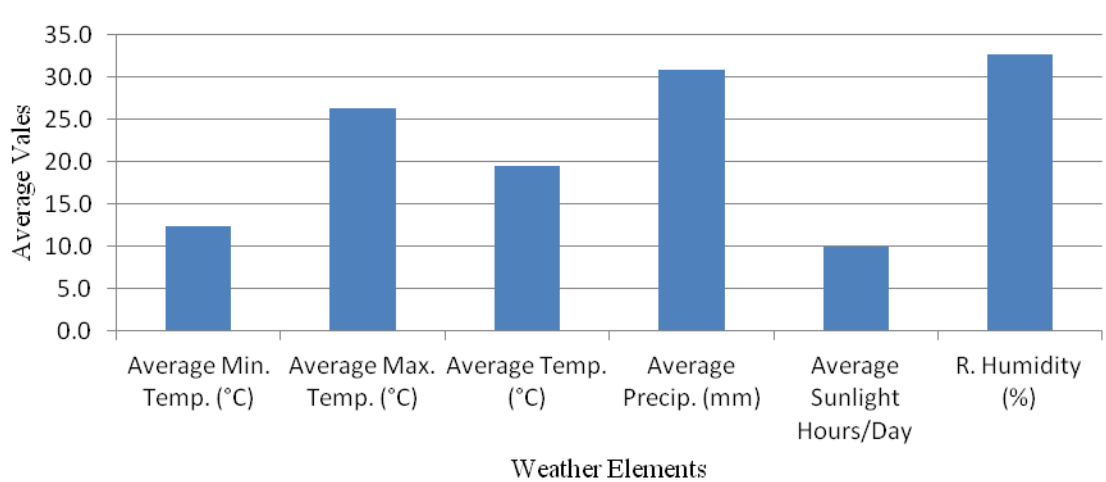
Source: http://www.nnf.org.na/RARESPECIES/InfoSys/IMAGES/GeneralMaps/RainAndParks.gif

Figure 2. Namibian Monthly Weather Averages



Source: http://www.climatetemp.info/namibia/

Figure 3. Namibian Annual Weather Averages



Source: http://www.climatetemp.info/namibia/

2.1.2. Geology

Geology gives insight into the history of the earth by providing evidences of events such as plate tectonics, past climates and processes by which it evolves. The nature of geological (Parental) materials profoundly influences soil characteristics i.e. a coarse-grained, quartz-rich parent material such as granite and sandstones is highly likely to yield a sandy texture soil (Brady and Weil, 1999). Soil texture in turn control water infiltration thus affecting soil particles translocation within a soil profile. Furthermore, parents materials influences chemical and mineralogical composition of the soil, which determines weathering (soil formation rate) and natural vegetations.

Namibian geology encompasses rocks of more than 2600 million years of earth history (Archaea to Phanerozoic age), oldest being Paleoproterozoic Vaalian to lower Mokolian, followed by the Mesoproterozoic middle to upper Mokolian rocks (van Straaten, 2002). A considerable part of Namibia is a bedrock exposure, made up of schist, quartzites, granites, metamorphic limestones, dolomites, conglomerates and other rocks belonging to formations of the Proterozoic Damara Sequence (Internet 3). This northeast-southwest striking belt is folded and metamorphosed with the metamorphic grade progressively increasing towards the axial centre of the fold belt while Granites found in the central part of the belt (van Straaten, 2002). Namibia has two broad geological areas; western and eastern parts (Mendelsohn *et al*, 2002). The western region is rugged valleys, escarpments, mountains and open plains of very old rocks formed in depth of oceans or earth crusts movements and rich in minerals. The eastern part of the country is quite contrast to the western as rocks are covered and buried deep by sands and other sediments of Kalahari origin, thus this region is more uniform. Interspersed is the archaic Mokolian Complex of the Kalahari and Kongo Cratons (gneisses and other highly metamorphic rocks) in the north-west, centre, south-east and south. Karoo-Volcanics occur at intervals in the north-western, central and north-eastern areas (Bertram and Broman, 1999). The reminder is covered by young deposits of the Kalahari and Namib Deserts.

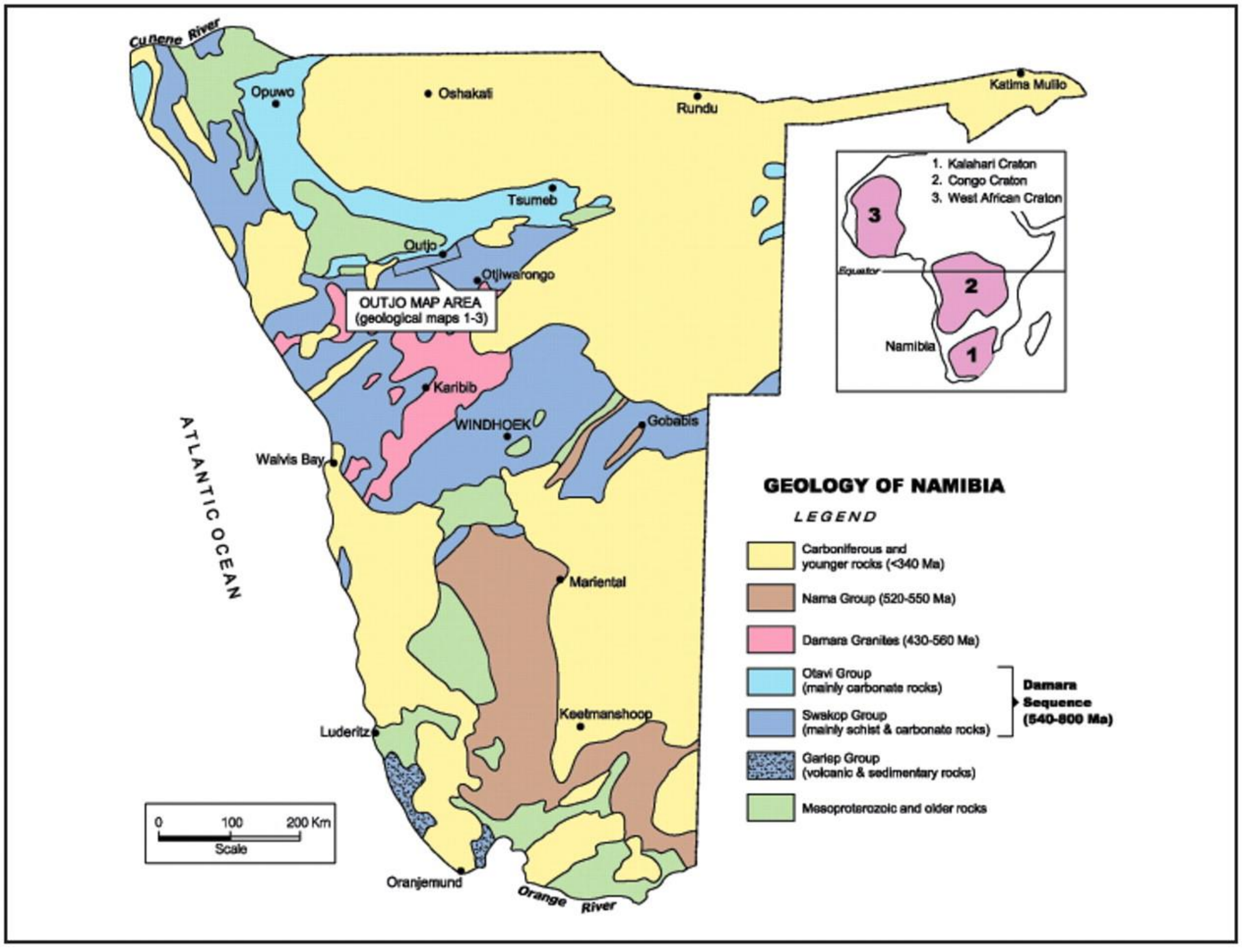


Figure 4. Namibia Geology Map

Source: Schlüter, T: Geological Atlas of Africa (2006)

2.1.3. Geomorphology

The term basically refers to the landforms (topography) and as a scientific study; it seeks to understand the processes that form them and help predict future changes. Breaking up of Gondwanaland and tectonic processes associated with this event is believed to be responsible for the present southern Africa landscape (Bertram and Broman, 1999). Other major contribution factors are; continuous episodes of uplift, rifting, volcanism, warping, and subsequent denudation and erosion due to the creation of new base levels. This combination has yielded unique present features of Africa such as the series of broad upwarps which run parallel to the coastline in several areas and sharp topographic discontinuity in the form of a major escarpment.

Namibia topographic configuration is principally defined by great swaths of rolling country and low coastal plains, separated by rugged frontiers. The excessively ruggedness central plateau is part of the south-west African plateaux that has generated the Khomas highlands at an elevation of 1980 m, constituting the country roof (Mendelsohn *et al*, 2002). The landform gradually sinks into the Namib Desert on the west that border the Atlantic coast. Prevailing winds in the Namib have sculpted its sands into massive dunes; gargantuan, crescent-shaped barchans, with their high windward crests and downwind-sloping wings. The mostly level Namib houses the rough mixture of granite Brandberg, the country highest point at more than 2460m (Königstein) above sea level (Mendelsohn *et al*, 2002). Eastward, the central plateau eases into the flat Kalahari Desert, a massive body of sandy plains, which further spread north of the country as well as South Africa and Botswana.

2.1.4. Soils

The soil is often said to cover the land as the peel covers an Orange. However, while the peel is relatively uniform around the orange, the soil is highly variable from place to place on earth. This is because soil formation and subsequent type is a function of variable factors such as; climate, biota, time, topography and parent material, i.e. bedrock or unconsolidated sediment determined the soil formation, with climates the most influential (Brady and Weil, 1999). Interaction of soil forming factors and processes (weathering, leaching, clay formation)/takes a long time to form soil, thus its vital to take past environmental conditions into consideration as much or more than presents. Mendelsohn (2006) reported that Namibian climates have been generally arid for past millions of years, thus soils are poorly developed and naturally low fertile. This is because the rocks weather more rapidly in wet climates, associated with high rate of soil formation and realizing of more nutrients from the rocks. This is matched by FAO/Unesco Soil Map of the World (1974), scale 1: 5 000 000, which reported that Namibia is dominated by extremely erodible *Leptosols*, *Regosols* and *Arenosols* soils (details definitions provided in section 4.1).

The country's soils can be divided into two soil zones; rock derived and Kalahari sands origin soils (Mendelsohn *et al* 2006): south, central and much of the western regions are rocks-derived soils whereas eastern and northern regions are Kalahari Sands origin soils. The latter include sedimentary sands and clays in the Cuvelai Drainage and the sands of the Namib. The bedrock of Namibia is of high age, deeply weathered and therefore not a good basis for soil development, partly because old bedrock provides limited leaching of minerals (Bertram and Broman, 1999). As a result, coupled with low litter supply (vegetation), Namibian soils generally contain little organic matter (often < 1%), often shallow and skeletic (high content of gravels and other coarser fragments), which leads into decreased water holding capacity. Kalahari Sands, deposits of wind-blown sand dunes during drier periods, are extremely poor in nutrients and very coarser throughout plants roots layers (Mendelsohn *et al*, 2002). Quartz grains make up the bulk of the soil in addition to zones of other sedimentary soils partly formed from water-borne deposits carried down by rivers long ago. Cambisols in the Cuvelai drainage and Fluvisols along the larger river courses in north-eastern Namibia provide comparatively nutrient-rich soils for crop cultivation, and this is where many crops are grown in Caprivi and Kavango (Mendelsohn, 2006). These soil groups have good water retention and relative fertility.

2.1.5. Fauna and Flora

Regardless of climatic constraints i.e. rocky unfertile soils and erratic low rainfall, Namibia is home to amazing biodiversity of plant and animal life. More than 4500 plant taxa have been recorded within the country boundary, of which 690 are endemic species whereas at least 275 species are Namib Desert endemics shared between Kaokoveld and southern Angola (Maggs *et al*. 1998). Variety of plant species in Namibia makes up a broad range of ecosystems types ranging from desert landscapes with sparse plant cover and high succulent dominance (Midgley *et al*, 2005). The arid escarpment is characterized by shrubland and sparse woodland with C4 grasses to tree-grass mixed savannah and woodland vegetation in areas of higher rainfall in the northeastern Kalahari basin (Midgley *et al*, 2005).

The vegetation of Namibia can be divided into three (3) major types: Namib Desert, Savannas and Woodlands (Giess, 1971). Savannas, which occupy 64% of the land area is mostly consisted of taller (15m), scattered and well extended crown savannas in northeastern region of the country. In the central, the dominant form is scattered tall trees and low shrubs tree-shrubs savanna. South and southeastern is predominated by low deciduous shrubs, scattered woods and herbaceous. In northwest, mopane is the dominant savannas. Desert vegetation covers 16% of Namibian territory, the coastal plains where it is consisted of scattered non-wood herbaceous and succulent vegetations except along the riverbeds whereby woody vegetations occur. Woodlands accounts for 20% of the country and occurs in the high rainfall region of Caprivi. They are tall woodlands of continuous crown expansion that almost covers the land.

Namibia is richly endowed with game, albeit poaching has seriously diminished it in parts of the north. Throughout the ranching zone, game (notably antelope and giraffes) coexists with cattle and sheep. The Etosha Pan in the north is a major game area and tourist attraction with Lions, Elephants, Zebras, Lizards and Cheetahs to mention a few (Midgley *et al*, 2005).

2.2. Land use

The predominant land use is agriculture, where people depend directly on natural rangeland resources for their economic well-being and food security. Due to harsh and arid environment, livestock farming is an extremely important activity, as about 70% of the population is directly or indirectly involved in this industry (Mushendami *et al*, 2008). More land is used for agriculture than for any other purpose: mostly for cattle, goat and sheep farming. In the north, farmers keep mostly cattle on farms of 5 000 - 10 000 hectares, while farm size increases southwards (about 15 000 - 20 000 ha) due to decreasing rainfall, and the animal-keeping concentrates on sheep and goats (Mendelsohn *et al*, 2006). Subsistence farming is mainly confined to the "communal lands" of the country populous north regions, where roaming cattle herds are prevalent and the main crops are millet, sorghum, corn, and peanuts. Rainfed cultivation is only possible in the north and north-east of the country, due to relatively high rainfall compared to the rest of the country (Sweet and Burke, 2000).

Namibia has established several parks and reserves to celebrate and protect its rich plant and animal life, occupying up about 18% of Namibia land surface (Internet 4). Some, such as the major tourist attraction Etosha National Park, focus primarily on wildlife, while others like the Namib-Naukluft Park and Fish River Canyon are more landscape oriented, their natural beauty easily upstaging the game. Regardless, these parks represent a network of Namibia's most sought-after tourist destinations and often include a wide-range of adventure, camping, hiking and wilderness activities. Furthermore, Namibia has about 17 mines across the country. Mostly, Diamonds and Uranium are found in south and west regions of Namib Desert, Zinc in central part and Copper in central north. Other minerals are found coexisting with the mentioned major ones (Internet 3).

2.3. Overview and Available Information of Namibian Soils

Very little is known about Namibian soils properties, importantly fertility status. As mentioned in previous section herein, there is no modern map of Namibian soil to this very date, except of the reportedly 1:5 000 000 scaled 1974 FAO/Unesco Soil Map of the World. However, numerous local studies have been carried out across the country. In 2003, Silke Bertram conducted a defining, classifying and systemizing study on late Quaternary sand ramps in south-west of Namibia. The study investigated the formative processes and examined their palaeoenvironmental significance. Two generations of sand ramps were identified, the older generation, represented by a single sand ramp, is characterized by the presence of old basal sediments. The young generation had an arrangement of voluminous ramps in windward positions and low-volume ramps in leeward positions. The last period of deposition, responsible for both generations' shapes has been suggested to have occurred after c. 40 ka BP. The scenario implies a highly dynamic climatic system during that time, with seasonal aridity and low-frequency, but high-intensity rainfall as well as a phase of environmental stability around 25 ka BP, which supported growth of vegetation, stabilization and consolidation of the sediments as well as soil formation.

Heine and Volkel, 2010, conducted a study on soil mineral clays and their significance for the terrestrial and marine past global change research. Seven (7) soil clay minerals provinces were delineated in the process and many clay minerals were found to contain Quartz, Feldspars, Iron oxides (Goethite), Calcite and Dolomite. Provinces findings are as follow:

Clay Mineral Province 1: In northeast Namibia, Kaolinite and Smectite are dominants of good to excellent crystallization.

Clay Mineral Province 2**:** In the northwestern Kalahari, Smectite (55%) is dominant, followed by Illite (20%) and Kaolinite (15%), as well as Illite/Smectite/mixed-layer clay minerals (10%).

Clay Mineral Province 3**:** In the southwestern Kalahari, the clay mineral mainly consists of Illite (10–60%) and Smectite (40–70%), in addition to Palygorskite (15–30%), Chlorite (10%) and mixed-layer clay minerals (5%).

Clay Mineral Province 4: Located Southern of Namib Desert and South of the Orange River. Illite (ca. 40%), Smectite (ca. 40%) and kaolinite (ca. 20%) are characteristic of its clay mineral spectrum.

Clay Mineral Province 5**:** *S*ituated between the Orange and Kuiseb Rivers, clay mineral composition is; Illite (40 - 70%). Chlorite (25%), Smectite (up to 25%), Kaolinite (up to 5%) and up to 10% Palygorskite occurs in the clay minerals of this province.

Clay Mineral Province 6**:** The area between the Kuiseb and Ugab valleys, Illite dominates (20–50%), Smectite (15–30%), Kaolinite (10–15%), Mixed-layer (15%), Palygorskite and Sepiolite (30%).

Clay Mineral Province 7: Northern Namib Desert; well crystallized Illite (30–35%) and Smectite (30–60%) dominate. Kaolinite and Chlorite (10% each), Palygorskite is always present.

Spotlight on Agriculture, Volume No. 65 of March 2003 has mapped numerous soil properties and characteristics under 'Characteristics of Namibia Soils in a Nutshell' heading on a 1: 1 000 000 scale maps. The manual belongs to then Ministry of Agriculture, Water and Rural Development, Directorate of Research and Training. Produced maps are only available in PDF format, they illustrate features such as:

Landform: most of the country (entire eastern region) s depicted medium-gradient hill to high-gradient Mountains. The western/coastal region includes Namib desert is classified as plain and low-gradient footslope toward the north, the agricultural north-east and far north are all valley floors. ***Rooting Depth*** is a very important factor for crops as it refers to the volume of soil available for crops roots to find moisture and nutrients. The entire north, north-east, central western/coast and eastern region have a very deep root depth. This can be attributed to Kalahari sands that cover these regions with an exception of west, which nonetheless covered by Namib Desert sands. Most of the central region through to south is very shallow. These soils are formed from a hard rock and lie in most aridity of the country, thus soil development is slow. The northwest is moderately deep to deep. Rooting depth is a complete opposite of ***Rock Fragments*** presence.

Consistency is a measure of the hardness of the soil that can limit roots penetration thus impeding the crops growth. Nearly the whole country, except a strip in north is consistent. ***Texture*** has a great effect of soil qualities, direct determinant of water and nutrients storage capacity. North, north-eat, east and a part of central west has been classified as coarse whereas central through south is moderately coarse to medium. The second part of western region is moderately coarse to moderately fine. All regions with coarse texture have low ***Cation Exchange Capacity (CEC)*** as well.

Hydraulic Conductivity is a measure of internal drainage and is directly proportion to ***Infiltration Rate,*** which is a measure of water percolation into the soil. North, north-eat, east and a part of central west all have rapid rates and conductivity whereas central through south are moderate to moderately rapid. The two properties are opposite of ***Water Holding Capacity***, areas with rapid rates of infiltration and hydraulic conductivity have low water holding capacity. Only the central Namib Desert soil has ***Gypsum, Salinity and Sodicity*** which is an indication of soluble salts concentration in the soil is low too. A strip in the north has an average content. Most of the country soils are ***Workable***, except central, stretching centrally southward and central northwestern that is poor workability. ***Waterlogging*** is only a problem in far north-east, due to biggest rivers in the country and frequent flooding.

Mendelsohn, Jarvis, Roberts and Robertson (2002) in Atlas of Namibia have also briefly classified the Namibian soils in several maps (1: 1 750 000 scale) on basis dominants soils and relative suitability for crop cultivation on high-medium-low scale. The most of the country is low on crop production suitability, north-east is medium whereas north central and far north classified highly suitable. *Leptosols, Regosols* and *Arenosols* are the most dominant soil groups in addition to *Fluvisols, Cambisols, Calcisols, Gypsisols, Luvisols, Solonchaks* and *Solonetz*. Dune sands, rock outcrops and coastal salts plains do exist as well with *dystric*, *calcaric* and *chromic* suffix dominating.

Coetzee (2009) investigated number of chemical and physical features of Namibian soils in a 22 790 km^2, two degree-square block in eastern central Namibia and established the fertility status.

The investigation concluded that the soils of the study area are very poor in organic matter, nitrogen, phosphorus and sulphur without being neither too alkaline nor too acidity. East part of the study area has deep Kalahari sands with high content of Quartz and variety of vegetation despites the natural low fertility including deep-rooted plants, main medium in bringing nutrients to the surface. Rainfed crop production is unsuitable due to climates but irrigation and carefully managed production is possible.

In 1999, Bertram and Broman conducted an assessment study on Soils and Geomorphology in Central Namibia by collecting a total of 104 soil samples in 56 profiles. Out of 56, 26 profiles were practically impossible to divide the profiles clearly into master horizons (like A, B and C horizons). The case is due to lack of organic matter accumulation and weakly weathered bedrock, which in turn has eliminated any border between soil and parent material. There was hardly any layer fulfilling the criteria of certain diagnostic horizons even after the physical and chemical soil analyses had been conducted. However, in four (4) profiles, Sodic properties were present i.e. saturation in the exchange complex of 15% or more of exchangeable sodium or of 50% or more exchangeable sodium plus magnesium. These profiles were classified as *Leptosols* due to limited in depth by a continuous hard rock within 30cm of the surface and less than 20% of the fine earth over a depth of 75cm from the surface. *Leptosols* group was further divided into soil units; *Lithic Leptosols* (limited in depth within 10 cm from the surface), *Dystric Leptosols* (having a base saturation less than 50% in at least some part of the soil) and Eutric Leptosols (having a base saturation of 50% or more throughout). The rest of the profiles had to be classified as *Regosols* (*Dystric* and/or *Eutric*), coarse textured soils having no diagnostic horizons.

2.4. Harmonization of Soil Information and Database Building Efforts

Bertram and Broman (1999), reported that there is no modern soil map of Namibia apart from the 1974 FAO/Unesco Soil Map of the World (1: 5 000 000). It can be argued that this was the first attempt of soil harmonization in the country, but no more information can be found on the reported map. However, Coetzee (2001) has outlined the compilation of the national-level data into 1:1 000 000 scale NAMSOTER, the country version of SOTER digital database to form part of the World SOTER to be compiled by FAO.

According to the report, the aim is to inventorize, computerize, process and analyze the country agricultural resources with computer databases and geographical information system, and objective that have been pursued since 1993 by the National Agro-Ecological Zoning (AEZ) programme of then Ministry of Agriculture, Water and Rural Development, which has since changed to Ministry of Agriculture, Water and Forestry. One of many other projects encompassed into AEZ programme is National Soil survey, which are all Geographical Information System (GIS) linked into an umbrella body, Namibia Agricultural Resources Information System (NARIS).

The basic concept of this agro-ecological geo-referenced database is to mark out lands with distinctive pattern of landform, surface form, slope, parent materials and soils. The database is to be consisted of field or physical/chemical laboratory analyzed visual quantifiable observations that are described and coded according to FAO Soil Profile Description Guideline and SOTER Manual Procedures. Mappable SOTER units i.e. location and topology of terrain-soil mapping units are stored in GIS software e.g. ArcView whereas the non-mappable units characteristics are stored in Relational Database Management System (RDMS) software e.g. MS Access.

National Soil Survey Phase I was conducted between 1998 and 2000 by Cartographic Institute of Catalonia and AEZ team. Pedo-morphological mapping was among many objectives, of the study and happened at 1: 100 000 scale along Kavango River and North Central, 1: 250 000 scale in North-East and 1 000 000 scale for the rest of the country. Regions were profile pitted and augured as illustrated in table 2 below with samples analyzed at the Agricultural Laboratory of Namibian Agricultural, Water and Rural Development Ministry (MAWRD). Digitizing of the soil map and typing the attribute data in databases allowed the recording of all information in digital format. ArcView 3.2 handled the mappable units whereas associated attributes were dealt with MS Access 2000.

Table 1. Regions Profile Pits and Augering

Survey	Scale	No. of Profiles	No of Augering
Kavango River Area	1:100 000	73	645
Northern Central Namibia	1:100 000	319	0
Northern East Namibia	1:250 000	435	0
Remainder of Namibia	1:1 000 000	828	0
Total		***1655***	***645***

Phase II is expected to improve the accuracy and completeness of NAMSOTER with further larger scales mapping than 1: 1 000 000 and 1: 250 000 scales, which are more of Namibian Soter Database and GIS Coverage establishment tools. Diamond area in the south, Etosha National Park and the Skeleton Coast, which were excluded from initial phase are set to be mapped as well as cross-border mapping for neighboring countries.

2.5. International Classification Systems

As previously stated in the first chapter, the data have to be reclassified and correlated to the latest WRB (2006) version classification system from their original FAO (1998) and Soil Taxonomy (1999). Two systems are briefly summarized below.

2.5.1. WRB

World Reference Base for Soil Resources (WRB) is an international standard soil classification system authorized by International Union of Soil Sciences (IUSS). It was developed through global negotiations synchronized by International Soil References and Information Centres (ISRIC) sponsored by FAO Land and Water department and IUSS (Rossitier, 2001). The system was adopted as the official reference soil classification system for European Commission and by the West and Central Africa Soil Science Association between 1998 and 2006 (WRB, 2006). WRB borrowed greatly from other classification systems; Soil Taxonomy, the legend for the FAO Soil Map of the World 1988, the Référentiel Pédologique and Russian concepts.

Soil classification is on soil morphology basis into 32 Reference Soil Groups (RSGs) and combination of 121 qualifiers (suffixes and prefixes) and it does not take climate into an account

(WRB, 2006). RSGs are assemblage of distinct and general features of similar behavior and implications on ecological function, soil suitability and management strategies. They are determined according to the primary pedogenetic process that has affected the characteristic soil features. Qualifiers on the other hand, reveal more details and specific about soil behaviors, determined according to any secondary soil-forming process that has affected the primary soil features significantly (WRB, 2006).

2.5.2. Soil Taxonomy

Developed by United States Department of Agriculture (USDA) and the National Cooperative Soil Surveys in 1975, Soil Taxonomy is another international adopted soil classification system comprised of 12 soil orders and numerous suborders, groups, families and series (Soil Survey Staff, 1999). The system is commonly used in Latin American countries and also applied in other parts of the world. The system is unique in two ways; firstly, is based on objectively observable and measurable soil properties (color, texture, organic matter, clay, etc.) and secondly, is a nomenclature (Brady and Weil, 1999). The first attribute reduces the controversies of presumed soil formation mechanisms during the soil classification process, whereas the latter gives a definite connotation of the major soil characteristics.

3. Methods and Materials

3.1. JRC Map to be validated

The soil map, prepared by the EU JRC (European Commission, Joint Research Center) for the Soil Atlas of Africa, to be published in the very near future are based on different sources with the overall aim of developing an African soil database (Figure 5). This database contains soil information that can be used for various environmental issues, ranging from modeling the effect of global change on food security, drought and desertification to understanding the dynamics of the carbon cycle. The Namibian part of the map (Figure 6) is primarily derived from the Harmonized World Soil Database (HWSD: FAO/IIASA/ISRIC/ISS-CAS/JRC, 2008) that has been developed by the Land Use Change (LUC), Agriculture Program of IIASA and the FAO in partnership with the ISRIC - World Soil Information and European Soil Bureau Network (ESBN). The HWSD original data combines existing regional and national updates of soil information (SOTER databases) with the information contained within the 1:5 000 000 scale FAO-UNESCO Soil Map of the World (FAO/Unesco, 1971-1981). The spatial resolution represents approximately a 1:1 million map scale. The presented and validated in this thesis includes The SOTER (van Engelen VWP and Wen TT, 1995) physiographic units and their soil associations in the polygons. The map units are given in the WRB 2006 (IUSS WG WRB, 2006), defined by the Reference Soil Group (RSG) and one qualifier.

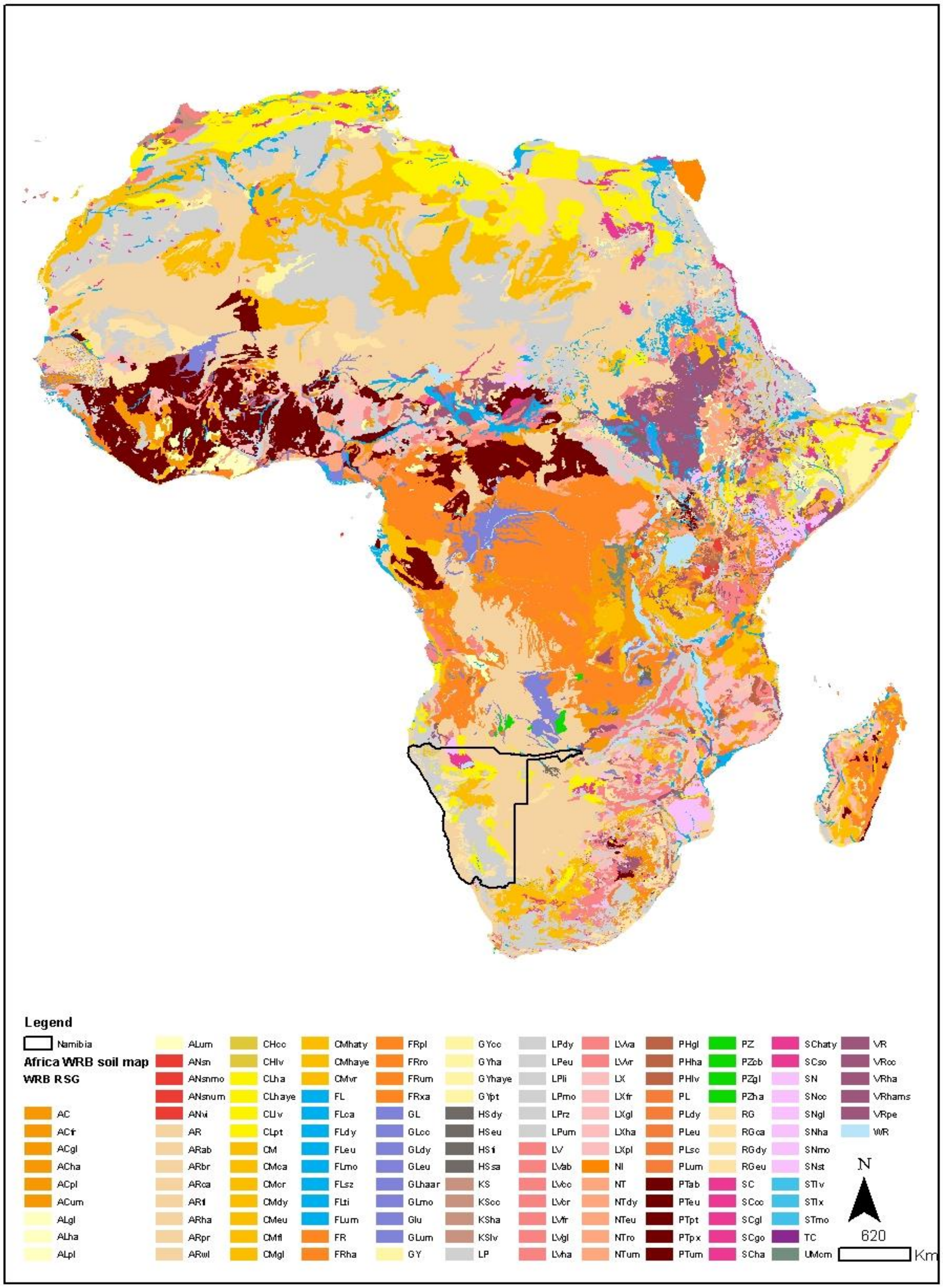


Figure 5: EU JRC African Soil Map to be published in 2013 as part of the Soil Atlas of Africa (personal communication with A.R. Jones, editor of the Atlas)

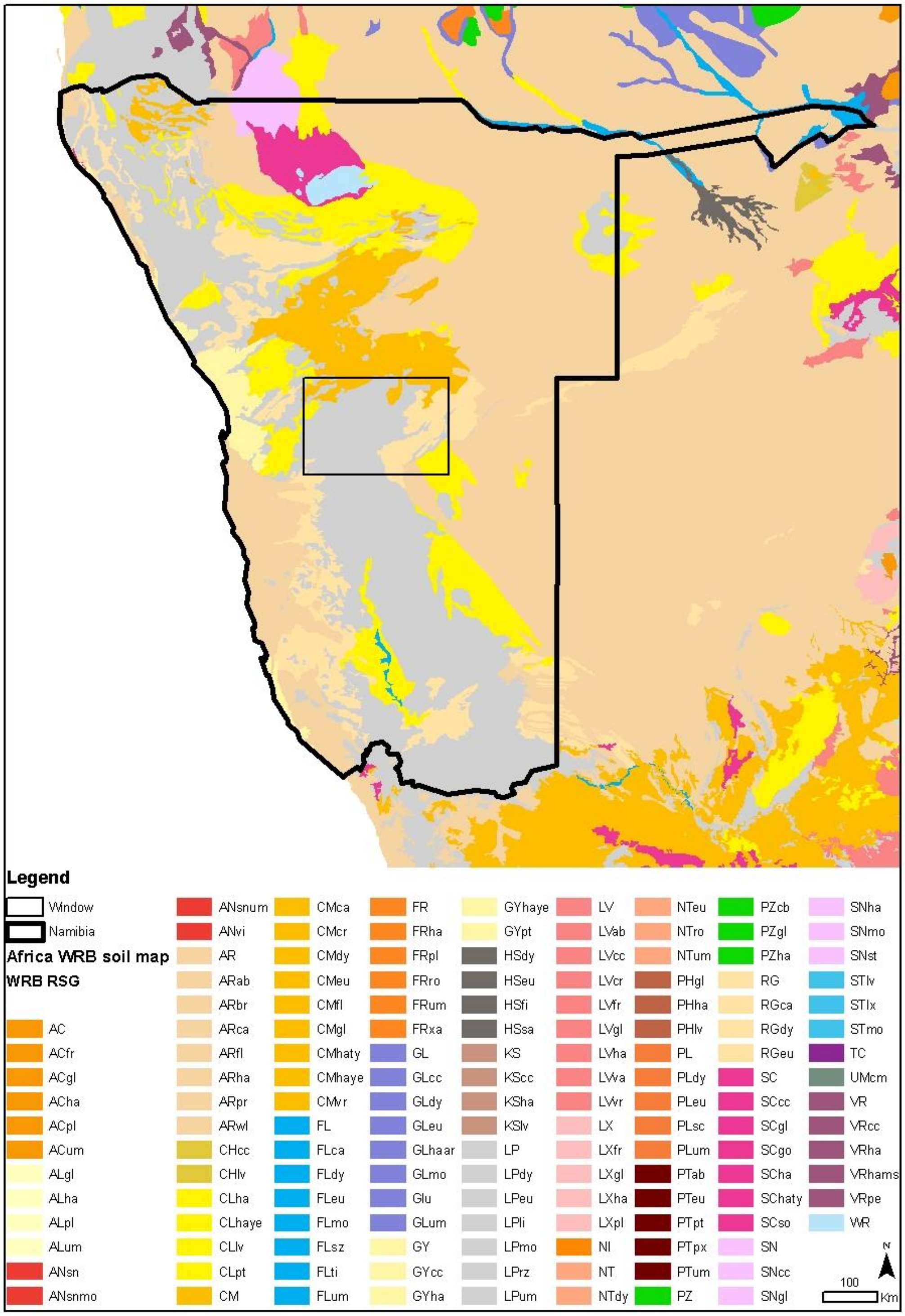


Figure 6. EU JRC Namibian Soil Map and the study area location (personal communication with A.R. Jones, editor of the Atlas)

3.2. Study Area

3.2.1. Location

The JRC map was validated based on the recent soil survey data collected for soil fertility assessment purpose by Coetzee and colleagues (2009). The area of soil fertility status investigation study area extends over Khomas, Omaheke, Hardap and Otjozondjupa administrative regions (Figure 6), covering a total surface area of 51 327 km^2, roughly between 22° – 23.6° S, 15.8° – 18.2° E. furthermore, within the study area boundaries, a subset area of 500 km^2 has been independently undertaken an assessment study on soils and geomomorphology by Bertram and Broman (1999).

3.2.2. Climate

The study area belongs to the semi-arid hot steppe/savannah climatic region (BShw). The area is characterized by high evaporation rates exceeding the average annual rainfall (≈380mm), relatively hot (18 – 19 °C) average annual temperature and dry winter season (Bertram and Broman, 1999). Rainfall is limited to summer months, mostly January to March and increase from 300mm – 410mm northward (Mendelsohn *et al*, 2002). Due to a relative high elevation, temperatures are lower than normally expected, December and January are the hottest contrasted by June and July (Mendelsohn *et al*, 2002). Mean annual evaporation ranges between 1820 – 1920mm, whereas relative humidity soars up to 70 – 80% in March and drops to 20% in September (Coetzee, 2009). Solar radiation is about 5.8 - 6.2 $kWh/m^2/day$ at the average of 8h of sunshine per day whereas east-west wind dominates although almost 40% of the days are wind calm (Mendelsohn *et al*, 2002).

3.2.3. Land Cover and Vegetation

The site is consisted of grasslands, shrubland and woodland of sparse tall trees and shrubs interspersed with grass cover. Namibia central part vegetation is dominated by scattered tall trees and low shrubs, known as tree-shrub savanna (Okitsu, 2005). Savannah is further divided in classes, which Mendelsohn (2002) reported in the study area, namely; Central and Southern Kalahari, Highland and Thornbush Savannah. Bertram and Broman (1999) nearly echoed the same in; highland, thornbush and camelthorn savannah. Sweet and Burke (2006) have merged central and southern Kalahari with camelthorn and trees – shrubs mixed savannah respectively and described the classes in details as follows:

Southern Kalahari **tree-shrub mixed savanna** is dwarf type, suitable for sheep farming. Trees component is comprised of *Acacia haematoxylon* and various *Acacia* and *Boscia* species on deep sand and harder grounds respectively. Perennial grasses include *Centropodia glauca*, *Antephora pubescens, Eragrostis lehmanniana, Stipagrostis uniplumis* and *S. ciliata*.

An open central Kalahari **camelthorn savanna** is dominated by *Acacia erioloba* trees in addition to common shrubs such as *Acacia hebeclada, Ziziphus mucronata, Tarconanthus camphoratus, Grewia flava, Ozoroa paniculosa* and *Rhus ciliata*. Despites the good cover, the grass is coarse and unpalatable *Eragrostis pallens* and *Aristida stipitata.*

The **thornbush savanna** dominates the central part of the country and is associated with troublesome *Acacia mellifera* and *Dichrostachys cinerea* species as far as bush encroachment is concerned. Further *Acacia* species are *reficiens, erubescens* and *fleckii* as well as *Antephora pubescens, Brachiaria nigropedata, Digitaria spp., Stipagrostis uniplumis* and *Schmidtia pappophoroides* common grasses.

The **highland savanna** is characterized by *Combretum apiculatum*, *Acacia hereroensis, A. reficiens* and *A. erubescens* tree species and good fodder grass species such as *Antephora pubescens, Brachiaria nigropedata, Digitaria eriantha* etc.

Bigger trees and other grass species like *Aristida* sp., *Cenchrus ciliaris*, *Aristida meridionalis* and *Fingerhuthia africana* are very observable on the slopes and valley floors (Bertram and Broman, 1999).

3.2.4. Geology and Topography

The study area is situated on the south central of the Precambrian Damara orogen, estimated to be 700 – 1100 years-old and part of tectonostratigraphic Khomas Terrance. The geology is dominated by metamorphic rocks; mica, schist, micaceous quartzite, subordinates calcareous schist and impure marble (Bertram and Broman, 1999). Khomas hochland, a highland is the highest point in the study area at about 2000m above sea level and is strongly dissected (Coetzee, 2009). The topography slopes down towards the Southeast where is almost flat at 1310m above the sea level as shown in figure 3.1.

3.2.5. Soils

According to Sweet and Burke (2006), soils in the study area of typically semi-arid climatic regions; unconsolidated sand (Arenosols) and shallow, weakly developed soils on bedrock (Lithosols, Xerosols, Regosols and Yermosols), very low in organic matter content (<1%). Soil map of the world (FAO-Unesco, 1977) defined these soils as follows. Xerosols (Gr. *Xeros,* Dry) are medium and stony textured Aridic soils with a weak Ochric A horizon and carbonate enrichment within 125 cm of the soil surface. Lithosols (Gr. *Lithos*, Stone) are mountainous areas depth limited soils due to a continuous rock within 10cm of the surface. Regosols have been defined as dunes whereas Yermosols soils are stony, Lithic and petrocalcic soils of salts crust and sometimes shifting dunes. Lithosols soil group has since been renamed Lithic Leptosols whereas Xerosols have been completely deleted since the Soil of the World map (FAO, 1988) legends revision (Bertram and Broman, 1999). Very thin A-horizons are down to coarser silt and fine to medium grained sand that are easily blown and washed away.

Unconsolidated sand corresponds to the Kalahari sands on the western side of the study area. Soils are low in organic matter (<1%), deeply weathered and of high hydraulic conductivity i.e. recharge potential but very poor water storage. They are classified as Arenosols (Luvic, Albic and Cambic) (FAO/Unesco, 1974) and Quartzipsamments in a USDA nomenclature (Coetzee, 2009).

3.2.6. Land Tenure and Use

Approximately 70% of the study area is individually owned, the rest is shared between corporate entities (commercial farms), government (farms and agricultural college), local authorities and organizations (farmers association and churches) (Coetzee, 2009). Most of the area is natural rangeland dominated extensive low pressure cattle farming (>90%), mixed and small stock farming as well as minor game and eco-tourism. Maize, tobacco, cotton, Pearl Millet, Sorghum and cultivated have been tempted but irrigation water has proven a limitation. Invader bushes have been harvested for charcoal production. Ground water is generally of good quality but insufficient.

3.3. Validation Soil Data

Data used were obtained solely from Coetzee (2009) extensive work in the area (Soil Survey and Laboratories Analytical work), further supported by Bertram and Broman (1999) study on soil within the test area (500km^2 area). Apart from being recent and suitable for this purpose on their credibility as accepted research articles, there are no other similar and relevant works previously done in the area or anywhere else in the country in general. The “Coetzee Survey” was carried out by the Agricultural Ministry AEZ program soil technicians in 2006, although remapping the terrains via digital elevation data and satellite images was carried by her, the author. On the other hand, Bertram and Broman (1999) works were prepared and conducted by authors themselves.

The first step in both studies was a field surveys, in a typical "Stewart and Perry (1953) Land System theory". By this theory, land is classified based on recurring physical features such as topography, vegetation and soils. The approach provides a simple technique in dividing an area into morphological regions without detailed investigations while maintaining a high degree of reliability. As a result, the study areas were firstly divided into representative terrain units of uniform features as observed from maps, in the field and air photo interpretations. After representative units’ delineation, soil profiles (GPS coordinates recorded) were opened and described as well as collection of samples and soil classification. Furthermore, construction of terrains and soil units were constructed and data were converted into digital formats. Profile depths depended on hardness of the soil and presence of depth limitation agents i.e. continuous hard rock or a hard pan, in absence profiles were opened as deep as 300cm. Soil colors were determined in accordance with revised Standard Munsell Soil Color Chart and Eijkelkamp (1998) Original Munsell Chart respectively. Auguring, road cuts and mini pits were used to confirm the detailed studied profiles to the rest of the homogeneous area whereas stones portion of the soils was worked out in the field as well. The field operations and profile descriptions were all governed by FAO Guidelines for Soil Description (FAO, 1990) in both studies.

Laboratory analysis were carried out on some but not all samples due to both time and cost constraints, Namibian agricultural ministry and Uppsala University laboratories were both used. Samples drying at room temperature or by mild heat not more than 30°C preceded the analysis sequence, concurrent with light crushing of clods. The samples were then sieved twice; initially with 2mm and 3.5mm lastly, coarser materials were weight and percentaged. The following parameters were determined.

- **Electrical Conductivity** and **pH** (in water and KCl solution), both at 2:5 and 1:4 (soil to fluid ratio) were measured with conductivity and pH meter respectively.
- **Organic Carbon** and/or **Organic Matter** were determined with Spectrophotometer, which measures the absorbance of the green Chromium (III) complex generated as organic matter was oxidized by Potassium Dichromate.
- **Cations** (Ca, Mg, Na and K) via atomic absorbance spectrometers and acidity with titration.
- **Cation Exchange Capacity** (CEC) and **Base Saturation** were calculated from the above results.
- **Extractable Micro Elements** (Iron, Manganese, Sulfate, Zinc, Copper, Nitrate and Nitrite) and plants-available phosphorus were also assessed. Reagents: 0.5M Ammonium Acetate, 0.5M Acetic Acid and 0.02M EDTA were used at pH 4.65, 1:5 soil mass to extractant volume. Iron, Manganese, Copper and Zinc were then established by atomic absorption spectrometer. Nitrate, Nitrite and Sulfate were measured by chromatography while plant available phosphorus was extracted with 0.5M Sodium Bicarbonate and ascorbic acid as reducing agent.

- **Carbonate** was predicted on 1 (none) – 5 (very strong) scale, based on effervescence of 10% hydrochloric acid (HCl). Silt, sand and clay were also analyzed as well as the associated classes; coarse, medium, fine and very fine sand fractions.

Bertram and Broman (1999) data were simple described into the research article whereas Coetzee (2009) were subsequently transferred into digital format and these are data sets used in accomplishment of this document's objectives. Databases were structured according to the FAO SOTER methodology (Van Engelen and Wen, 1995; Coetzee, 2001a, 2001b), making use of *Microsoft® Office Access 2003* and *Microsoft® Office Excel 2003* (Microsoft Corporation, 2003) softwares. Analytical data were not available for all profiles and soils were classified according to FAO system (1998) and US Soil Taxonomy (1999).

3.4. Correlation Methods

The available profile description, the laboratory data and the classification information in the FAO 1998 and US Soil Taxonomy (1999) was the available data to correlate the soils with the WRB 2006. The direct classification or one to one correlations from one system to the other are seldom possible; the same situation was in the presented work. The simple reclassification of profiles was not possible, as several criteria of the WRB classification was not available. Expert judgments and a set of simplified correlation rules and algorithm were developed to determine the diagnostics for the correlation based on the data availability (Table 2 - 5) provides the developed simplified correlation rules and their applicability.

The definition of the Reference Soil Groups (RSG) was based on the simplified algorithms (criteria) in the original sequence of the WRB key. All applying prefix and suffix qualifiers were recorded and ranked for each RSG in order of significance, however when naming the soil, the addition of the qualifiers followed the newly developed Guidelines for Constructing Small-Scale Maps Legends of WRB 2006/7 (2006), because the map to be validated followed the same procedure. Under this method, only two prefixes are applied for maps between 1: 1 000 000 and 1: 5 000 000 scales (herein) in addition to the Reference Soil Group (RSG) name, one or two extra suffixes are used at large scale maps. Recording of all qualifiers has been considered not important. Although some important information on certain soil characteristics may not be revealed, it is still deemed sufficient and informative for a small scale map and in addition, not all information and details can be derived from existing soil information stored in databases or GIS. Qualifiers included relates to human influence (Anthric, Colluvic and Drainic), surface conditions easily alterable by human action (Takyric, Yermic and Aridic, etc.) and texture if not already reflected in the RSG (Skeletic, Siltic and Clayic).

Although WRB system has heavily borrowed from series of FAO soil classification systems compared to others, the two systems (WRB and FAOs) are not 'one-to-one' match but relatively best approximation (Lang *et al*, 2010). Therefore, in order for possible correlation, an interface between the legacy data and WRB needed to be developed. Furthermore, WRB soil classification (2006) is based on soil observable and/or measurable morphology features; correlation efforts have to be focused foremostly on identifying these diagnostic horizons on the described profiles and other details about soil behaviors and pedogenetic processes. This was provided in form of algorithms (Table 2 - 5), in which WRB requirements of the diagnostic features; horizons, materials and properties as well as qualifiers were outlined. Terms 'Not possible' and 'possible' were used to indicate unavailability and availability of information in the database at least sufficient to derive the presence or absence of the particular WRB diagnostic/qualifier respectively. However, it must be emphasized that 'possible' does not necessarily mean a 'one-to-one' match with WRB requirements. Available information refer to likes of colour in determination of *Gleyic* or *stagnic colour pattern*, presence of a *continuous rock* and indication of the depth occurring at to determine *lithic* or *leptic* prefix or change in texture within horizons in derivation of *lithological discontinuity* or *abrupt textural change.* Given the climate of the test area in particular and literatures on Namibian soil, only few of WRB 32 RSGs are very likely (not exclusively) to exist within the area, namely; *Leptosols, Regosols, Cambisols, Arenosols* and *Fluvisols*. These RSGs involve about 30 diagnostics horizons, 13 properties, 6 materials and 38 qualifiers, which most constitute the algorithms.

Table 2: The definition and the applicability of the simplified correlation rules in order to define selected WRB diagnostic horizons

Diagnostic horizons	**WRB Spefics/Requirements**	**Data Applicability**	**Remarks/Comments**
Albic horizon	1. a Munsell colour (dry) with either: a. a value of 7 or 8 and a chroma of 3 or less; or b. a value of 5 or 6 and a chroma of 2 or less; and 2. a Munsell colour (moist) with either: a. a value of 6, 7 or 8 and a chroma of 4 or less; or b. a value of 5 and a chroma of 3 or less; or c. a value of 4 and a chroma of 2 or less; and 3. a thickness of 1 cm or more; and 4. does not part of C; D or H horizon.	Possible: Horizons depth and colours, both; moist (all horizon, all profiles) and dry are given for most profiles.	
Argic horizon	1. if the overlying horizon has < 15% clay, at least 3 percent more clay content increase in the underlying horizon; or 2. if the overlying horizon has a clay content between 15-40%, the ratio of clay in the underlying to that of the overlying horizon must be 1.2 or more; or 3. if the overlying horizon has > 40% or more clay, the underlying horizon must contain at least 8 percent more clay; or 4. morphological evidence of clay illuviation in soil description; and 5. does not part of a natric horizon.	Possible: Percentage values for Sand, Silt and Clay for each horizon, for all profiles available.	Texture particles sizes: Clay: ≤2µm Silt: >2µm **-** ≤20µm Sand: >20µm **-** ≤2000µm Gravels: >2000µm
Calcic horizon	1. a calcium carbonate content of 15% or more; and 2. a thickness > 15cm; and 3. > 5% secondary carbonates or intensive HCl effervescence	Not Possible: No $CaCO_3$ and secondary carbonates values.	$CaCO_3$/ CO_3, concretions and HCl effervescence were given in profil discriptions.Higher pH presumed $CaCO_3$/ CO_3
Cambic horizon	1. has a texture of loamy sand or finer; and 2. has soil structure (exclude rock structure, massive and single grain) in half or more of fine earth voume and 15cm or more thick; and 4. not part of a plough layer, not consist of organic material and not part of: *anthraquic, argic, calcic, duric, ferralic, fragic, gypsic, hortic, hydragric, irragric, mollic, natric, nitic, petrocalcic, petroduric, petrogypsic, petroplinthic, pisoplinthic, plaggic, plinthic, salic, umbric, sombric, spodic, terric, vertic* or *voronic* horizon; and 5. higher Munsell moist chroma or value, or redder Munsell hue, or higher clay content than the underlying or an overlying layer; or 6. lower carbonate content than the underlying horizon.	Possible: Horizons depth, textural classes (sandy loam etc.), percentage values for Sand, Silt and Clay, OM/OC content and colours, both; moist (all horizon, all profiles) and dry are given for most profiles.	No carbonate values but in discription where applicable (in some horizons, of some profiles). High pH was presumed to be an indication of $CaCO_3$/ CO_3 content. Texture particles sizes: Clay: ≤2µm Silt: >2µm **-** ≤20µm Sand: >20µm **-** ≤2000µm Gravels: >2000µm

Ferralic horizon	1. sandy loam or finer particles size and <80% gravel, stones, pisoplinthic nodules or petroplinthic gravel; and 2. CEC < 16$cmol_c$/kg/clay; and ECEC <12 $cmol_c$/kg/clay 3. <10% water-dispersible clay, unless it has one or both: a. geric properties; or b. 1.4% or more organic clay 4. <10% (by grain count) weatherable minerals in the 0.05 – 0.2mm fractions. 5. no Andic or vitric properties 6. thickness of 30cm or more	Possible: Horizons textural classes (sandy loam) and values (silt, sand and clay), skeletal share (gravels) and ECEC all available in quantitative values	No data or further discription on clay and weatherable minerals. Texture particles sizes: Clay: ≤2µm Silt: >2µm - ≤20µm Sand: >20µm - ≤2000µm Gravels: >2000µm
Ferric horizon	1.>15% coarse Fe mottles; or 2. >5% Fe or Mn nodules with a diameter 2mm; and 3. has a thickness of 15cm or more.	Not Possible	
Fulvic horizon	1. *andic* properties; ***and*** 2. one or both of the following: a. Munsell colour value or chroma (moist) of more than 2; ***or*** b. melanic index of 1.70 or more; ***and*** 3. a weighted average of >6% OC, and >4% OC in all parts; ***and*** 4. cumulative thickness of 30cm or more with less than 10 cm non-fulvic material in between.	Possible: Horizons' colours, both; moist (all horizon, all profiles) and dry, OM content are given for most profiles.	No data on Melanic Index
Folic horizon	1. > 20% OC; and 2. has a thickness > 10cm; and 3. does not part of an H horizon.	Possible: OM content	
Fragic horizon	1. evidence of alteration, at least on the faces of structural units; separations between these units, which allow roots to enter; ***and*** 2.<0.5% OC (by mass); ***and*** 3. shows in 50% or more of the volume slaking or fracturing of air-dry clods, 5–10 cm in diameter, within 10 minutes when placed in water; ***and*** 4. does not cement upon repeated wetting and drying; ***and*** 5. 50kPa penetration resistance at field capacity of >90% of the soil volume; ***and*** 6. no 10% HCl effervescence; ***and*** 7. >15cm thickness	Possible: Colour, horizons textural classes (sandy loam) and percentage values (silt, sand and clay) and OC content.	No data on structure and penetration resistance as well as HCl effervescence. Texture particles sizes: Clay: ≤2µm Silt: >2µm - ≤20µm Sand: >20µm - ≤2000µm Gravels: >2000µm
Histic horizon	1. saturated with water for >30 days in most years (unless drained) 2. >10cm thickness . 2. If <20cm, the top 20cm soil after mixing, or the	Possible: OC content and horizons depth (indication of	

	entire soil above a continuous rock within 20cm depth must contain > 20% OC.	continuous rock).	
Hortic horizon	1. a Munsell colour value and chroma (moist) of 3 or less; and 2. a weighted average OC > 1%; and 3. Extractable P_2O_5 content > 100mg/kg fine earth in upper 25cm[2], and 4. BS > 50; or 5. >25% soil animal activities 5. >20cm thickness	Possible: Colour, OC content and BS	No data on animal activities and extractable P_2O_5 content, rather exchangeable P.
Hydragic horizon	1. one of the following: a. Fe or Mn coatings or concretions, or b. dithionite-citrate extractable Fe 2 times or, dithionite-citrate extractable Mn 4 times or more than the surface horizon; or c. redox depleted zones with a Munsell colour value 4 or more and a chroma of 2 or less (moist). 2. >10cm thickness	Not Possible	
Gypsic horizon	1. > 5% gypsum and > 1% visible secondary gypsum; and 2. a product of thickness (cm) times gypsum content (%) >150. 3. >15cm thickness	Not Possible	
Irragric horizon	1. a higher clay content, particularly fine clay, than the underlying original soil; ***and*** 2. relative differences among medium, fine and very fine sand, clay and carbonates <20% among parts within the horizon; ***and*** 3. >0.5% OC weighted average, decreasing with depth but remaining >0.3% at the lower limit of the irragric horizon; ***and*** 5. >25% (by volume) soil animal activity; ***and*** 6. >20cm thickness	Possible: Horizons textural classes (sandy loam), percentage values (silt, sand and clay) and OC content values	No data values on carbonates and animal activities. High pH used as $CaCO_3$/ CO_3 content. Texture particles sizes: Clay: ≤2µm Silt: >2µm - ≤20µm Sand: >20µm - ≤2000µm Gravels: >2000µm
Mollic horizon	1. OC > 0,6%; and 2. a Munsell value (moist) of 3 and a moist chroma <3; and 3. BS% > 50; and 4. a thickness > 25cm; or 5. a thickness > 10cm if directly overlying continuous rock; and 6. surface horizon.	Possible: OC content, colour and BS.	No data on soil animals activities.
Natric horizon	1. satisfy the criterias of argic horizon; and 2. ESP (exchangeable Na percentage) >15.	Possible: Texture (Sand, Silt and Clay) and exchangeable bases values	Texture particles sizes: Clay: ≤2µm Silt: >2µm - ≤20µm Sand: >20µm - ≤2000µm Gravels: >2000µm

Nitic horizon	1. < 20% change in clay content over 12cm to layers immediately above and below; ***and*** 2. all of the following: a. 30 percent or more clay; ***and*** b. < 0.10 water-dispersible clay to total clay ratio; ***and*** c. < 0.40 silt to clay ratio; ***and*** 3. moderate to strong, angular blocky structure breaking to flat-edged or nutshaped elements with shiny ped faces (not, or are only partially, associated with clay coatings); ***and*** 4. all of the following: a. > 4.0% citrate-dithionite extractable Fe (*free* iron) in the fine earth fraction; ***and*** b. > 0.20% acid oxalate (pH 3) extractable Fe (*active* iron) in the fine earth fraction; ***and*** c. > 0.05 ratio between *active* and *free* iron; ***and*** 5. > 30cm thickness	Possible: Horizons textural classes (sandy loam) and percentage values (silt, sand and clay)	Texture particles sizes: Clay: ≤2µm Silt: >2µm - ≤20µm Sand: >20µm - ≤2000µm Gravels: >2000µm No data on extractable Iron (Fe).
Petrocalcic horizon	1. very strong effervescence after adding a 1 M HCl solution; and 2. induration or cementation, extremely hard consistence when dry; and 3. > 10cm thickness.	Not Possible	
Pisoplinthic horizon	1. >40% volume occupied by discrete, strongly cemented to indurated, reddish to blackish nodules with a diameter >2 mm; ***and*** 2. > 15cm thickness	Not Possible	
Plaggic horizon	1. sand, loamy sand, sandy loam or loam, or a combination of them; ***and*** 2. <20% *artefacts*, or has spade marks below 30 cm depth; ***and*** 3. Munsell colours with a moist value < 4, and < 5 dry and a moist chroma < 2; ***and*** 4. >0.6% OC; ***and*** 5. occurs in locally raised land surfaces; ***and*** 6. > 20cm thickness	Possible: Horizons textural classes (sandy loam), percentage values (silt, sand and clay), colour and OC content.	No Data on *Artefacts*
Plinthic horizon	1. >15% of the volume single or in combination: a. firm to weakly cemented discrete nodules, with a redder hue or stronger chroma than the surrounding material, change irreversibly to strongly cemented or indurated nodules on exposure to repeated wetting and drying with free access of oxygen; ***or*** b. mottles in platy, polygonal or reticulate patterns that are firm to weakly cemented, with a redder hue or stronger chroma than the surrounding material, and which change irreversibly to strongly	Not Impossible	

	cemented or indurated mottles on exposure to repeated wetting and drying with free access of oxygen; ***and*** c. <40% of the volume strongly cemented or indurated nodules and no continuous, fractured or broken sheets; ***and*** 2. both: a. >2.5% (by mass) citrate-dithionite extractable Fe in the fine earth fraction or >10% in the nodules or mottles; ***and*** b. < 0.101 ratio between acid oxalate (pH 3) extractable Fe and citrate-dithionite extractable Fe; ***and*** >15cm thickness		
Salic horizon	1. > 15 dS m-1 EC (electrical conductivity of the saturation extract); or 2. > 8 dS m-1 EC if pH > 8,5; 3. >15cm thickness	Possible: EC, pH (water and KCl, 1: 4 Soil to Solution)	
Terric horizon	1. colour related to the source material; ***and*** 2. <20% artefacts (by volume); and > 50% BS; ***and*** 4. occurs in locally raised land surfaces; ***and*** 5. no stratification but irregular textural differentiation; ***and*** 6. lithological discontinuity at its base; **and** 7. >20cm thickness	Possible: Textural classes and values, BS and colour	No data on *Artefacts*
Umbric horizon	1. > 0,6% OC; and 2. a Munsell moist value of 3 and a moist chroma < 3; and 3. < 50% BS; and 4. >25cm thickness; or 5. >10cm thickness if directly overlying continuous rock; and 6. surface horizon.	Possible: OC content, colour, BS and horizon depth	
Vertic horizon	1. > 40% clay content; and 2. > 25cm thickness.	Possible: Textural values (silt, sand and clay)	
Voronic horizon	1. > 1,5% OC; and 2. a Munsell moist value of 2 and a moist chroma < 2; and 3. a Munsell dry value of 3 and a dry chroma < 3; and 4. > 80% BS; and 5. > 35cm thickness; and 6. surface horizon.	Possible: OC content, colour, BS and horizon depth	

Table 3: The definition and the applicability of the simplified correlation rules in order to define selected WRB diagnostic properties

Diagnostic properties	WRB Spefics/Requirements	Database Available Parameters	Remarks/Comments
Abrupt textural change	1. if the overlying horizon has < 20% clay, doubling of the clay content; or 2. if the overlying horizon has > 20% clay, 20% increase in clay content; and 3. distinctness of horizon transition is abrupt or clear.	Possible: Horizons textural (clay, silt and sand) content percentage values	
Andic	1. an $Al_{ox} + Fe_{ox}$ value >2.0%; ***and*** 2. <0.90 kg/dm^3 bulk density; ***and*** 3. >85% phosphate retention; ***and*** 4. <25% OC (by mass).	Not Possible:	No enough data apart from OC content.
Aridic Properties	1. <0.6% OC if the texture is sandy loam or finer; or 2. <0.2% OC if the texture is coarser than sandy loam, as a weighted average in the upper 20 cm of the soil or to *continuous rock*; ***and*** 2. both broken and crushed samples with a Munsell colour value of 3 or more when moist and 4.5 or more when dry, and a chroma of 2 or more when moist; ***and*** 4. >75% BS (by 1 *M* NH4OAc)	Possible: Horizons textural classes (sandy loam) and percentage values (silt, sand and clay) OC content, colour and BS.	
Continuous rock	1. shallow profile (lower horizon boundary of the deppest horizon < 1m); or 2. >80% coarse framents.	Possible: Horizon depth and skeletal values.	Continuous rock where exist is indicated in the profile model.
Ferralic Properties	1. < 24cmolc kg^{-1} $clay^2$ CEC (by 1 *M* NH4OAc); ***or*** 2. <4 $cmolc.kg^{-1}$ soil CEC (by 1 *M* NH4OAc) and a Munsell moist chroma >5.	Not Possible	Only ECEC (sum of bases and acidity)
Geric Properties	1. < 1.5$cmol_c$/kg/clay ECEC (sum of exchangeable bases plus exchangeable acidity in 1 *M* KCl); *or* 2. >0.1 delta pH (pH_{KCl} minus pH_{water}) value.	Possible: ECEC and pH; water and KCl.	
Gleyic colour pattern	1. >90% reductimorphic colours with Munsell hue N1/ to N8/ or 2.5 Y, 5 Y, 5 G, 5 B; or 2. >2.5% mottles of oximorphic colours, which comprise any colour, excluding reductimorphic colours and < 1m depth to groundwater.	Possible: Colour and profile general description information	
Lithological discontinuity	1. The difference in sand or coarse fragment content between the underlying to that of the overlying horizon must be >10; or 2. abrupt change in colour not resulting from pedogenesis.	Possible: Textural classes, skeletal share and colour.	

Reducing conditions	1. < 20 hydrogen partial pressure (rH) negative logarithm value; ***or*** 2. the presence of free Fe^{2+}, as shown by strong red colour after wetting it with a 0.2% **a,a,** dipyridyl solution in 10% acetic acid; ***or*** 3. the presence of iron sulphide or methane.	Not Possible	Little information profile/horizon description
Secondary carbonates	1. masses, nodules, concretions or spheroidal aggregates (*white eyes*) that are soft and powdery when dry, occupy >5% soil volume; or 2. soft coatings in pores, on structural faces or on the undersides of rock or cemented fragments, cover >50% of the structural faces visible when moist.	Not Possible	Little information profile/horizon description
Stagnic colour pattern	1.mottling; and 2.lighter (at least one Munsell value unit more) and paler (at least one chroma unit less) peds (or parts of the soil matrix); and 3. peds interiors (or parts of the soil matrix) are more reddish (at least one hue unit) and brighter (at least one chroma unit more) than the non-redoximorphic parts of the layer, or than the mixed average of the interior and surface parts.	Possible: Colour and profile general description information	
Vertic properties	1. >30% clay content; and 2. >10cm thickness.	Possible: Textural content percentage values (silt, sand and clay)	
Vitric properties	1. >5% (by grain count) volcanic glass, glassy aggregates and other glass-coated primary minerals, in the fraction between 0.05 and 2 mm, ***or*** in the fraction between 0.02 and 0.25 mm; ***and*** 2. an Al_{ox} + .Fe_{ox} value >0.4%; ***and*** 3. >25% phosphate retention; ***and*** 4. < 25% OC.	Not Possible	Only OC content

Table 4: The definition and the applicability of the simplified correlation rules in order to define selected WRB diagnostic materials

Diagnostic Materials	**WRB Spefics/Requirements**	**Database Available Parameters**	**Remarks/Comments**
Calcaric material	1. CaCO3 content > 2%; and 2. does not part of a calcic horizon.	Not Possible	High pH has been presumed to imply $CaCO_3$.
Colluvic material	1. Sedimentation through human-induced erosion normally in foot slope positions, in depressions or above hedge walls. 2. Having characteristics (texture, colour, pH and organic carbon content) similar to the surface layer of the source in the neighbourhood. 3. Have artefacts such as pieces of bricks, ceramics and glass and a lithological discontinuity at the base.	Not Possible	
Fluvic material	1. Presence of *lithological discontinuity*; and 2. More OC than the overlying horizon, decreasing with depth but keep >0.2%.	Possible: Horizons textural classes (sandy loam) and percentage values (silt, sand and clay), colour, and OC content	
Gypsiric Material	>5% gypsum (by volume).	Not Possible	
Organic material	> 20% OC in fine earth (by mass)	Possible: OC content values	

Table 5: The definition and the applicability of the simplified correlation rules in order to define selected WRB diagnostic qualifiers

Qualifiers	**WRB Spefics/Requirements**	**Remarks/Comments**
Abruptic ap	having an *abrupt textural change* within 10cm of the soil surface.	Possible:
Albic ab	having an albic horizon starting within 100cm of the soil surface.	Possible: *Hyper*-: starting within 50cm of the soil surface through to 100cm or deeper. *Gloss*-: showing tonguing of an *albic* into an *argic* or *natric* horizon
Arenic ar	having a texture of loamy sand or coarser in a layer, 30cm or more thick, within 100cm of the soil surface.	Possible: *Epi*-: *Arenic* within 50cm of the surface *Endo*-: *Arenic* within 100cm.
Aridic ad	Having an *arici* properties without a *takyric* or *yermic* horizon.	Possible:

Calcaric ca	Calcaric material between 20 and 50cm from the surface or between 20cm and and continuous rock or any other hard agent.	Partially possible: High pH (>8)
Calcic cc	Calcic horizon or concentrations of secondary carbonates within 100cm of the soil surface	Possible: Concretions and secondary CO_3.
Cambic cm	having a cambic horizon starting within 50cm of the soil surface	Possible
Chromic cr	>30cm thick subsurface layer within 150cm having a Munsell hue redder than than 7.5YR or both a hue of 7.5YR and a moist chroma of >4.	Possible
Clayic ce	having a texture of clay in a layer, 30cm or more thick, within 100cm of the soil surface.	Possible: *Epi*-: *Clayic* within 50cm of the surface *Endo*-: *Clayic* within 100cm.
Colluvic	Having a >20cm thick colluvic material layer created by human lateral movement.	Not Possible
Cutanic cu	Clay coatings in some parts of an *argic* horizon either within 100cm or 200cm of the surface if the *argic* is overlain by loamy sand or coarser.	Not Possible
Dystric dy	having a BS% < 50% between 20 and 100cm from the soil surface or between 20 cm and continuous rock	Possible: *Epi*-: BS<50% from 50cm – 100cm *Endo*-: BS<50% from 20cm – 50cm
Eutric eu	having a B% > 50% between 20 and 100cm from the soil surface or between 20 cm and continuous rock	Possible: *Epi*-: BS>50% from 50cm – 100cm *Endo*-: BS>50% from 20cm – 50cm *Hyper*-: BS>50% throught 20cm – 100cm or BS>80% within 100cm *Ortho*-: BS>50% throught 20cm – 100cm
Ferralic fl	In *Arenosols*: *ferralic* horizon within 200cm. In other soils: *ferralic* properties within 100cm	Possible: *Hyper*-: ferralic properties and a CEC <16cmol$_c$/kg clay within 100cm *Hypo*-: >30cm thick layer within 100cm CEC <4 cmol$_c$/kg fine earth and a Munsell moist chroma of >5 or hue redder than 10YR (*Arenosols* only).
Fluvic fv	having fluvic material in a layer, 25cm or more thick, within 100cm of the soil surface.	Possible: *Endo*-: between 50cm and 100cm
Fulvic fu	Having fluvic material in a layer, 25cm or more thick, within 100 cm of the soil surface.	Possible
Gleyic gl	Reducing conditions within in some parts within 100cm and in >25% of the soil volume, a *gleyic colour pattern*.	Possible: *Endo*-: between 50cm and 100cm
Haplic ha	Having a typical feature of certain features, such that no other meaningful characterization is fitting or none of other qualifiers apply.	Possible
Humic hu	Following weighted average OC contents in fine earth 1. In Leptosols: weighted average of > 2% OC to a depth of 25 cm from the mineral soil surface; or 2. *Ferralsols* and *Nitisols*, >1.4% OC to 100cm	Possible: *Hyper*-: >5% weighted average OC content , to 50cm.

	2. In other soils: weighted average of OC > 1% to a depth of 50 cm from the mineral soil surface.	
Leptic le	*Continuous rock* starting within 100cm of the soil surface	Possible: *Endo*-: between 50 and 100cm *Epi*-: within 50cm
Lithic li	*Continuous rock* starting within 10cm of the soil surface (in *Leptosols* only)	Possible: *Nudi*-: *continuous rock* at soil surface.
Luvic lv	1. having an argic horizon that has a CEC < 24 cmolc kg-1 clay; and 2. > 50% BS between 50 and 100cm from the soil surface.	Not Possible
Mollic mo	having a mollic horizon	Possible
Natric na	having a natric horizon starting within 100cm of the soil surface	Not possible
Protic	showing no soil horizon development - just C horizon(s) in the profile (in *Arenosols* only).	Possible
Rhodic ro	>30cm subsurface layer within 150cm with a Munsell hue redder than 5 YR, moist value < 3.5 and dry value of no more than one unit higher than the moist value.	Possible
Rubic	>30cm subsurface layer within 100cm with a Munsell hue redder than 10YR or a moist chroma of >5.	Possible: In *Arenosols* only
Ruptic rp	Having a lithological discontinuity within 100cm.	Possible
Salic sz	having a salic horizon starting within 100cm of the soil surface.	Possible: *Endo*-: between 50 and 100cm *Epi*-: within 50cm *Hyper*-: >30 dS/m EC_e at 25°C within 100cm. *Hypo*-: >4 dS/m EC_e at 25°C within 100cm.
Siltic sl	having a texture of silt, silt loam, silty clay loam or silty clay in a layer, 30cm or more thick, within 100cm of the soil surface.	Possible: *Endo*-: between 50 and 100cm *Epi*-: within 50cm
Skeletic sk	having > 40% gravel or other coarse fragments averaged over a depth of 100cm from the soil surface or to continuous rock, whichever is shallower.	Possible: *Endo*-: between 50 and 100cm *Epi*-: within 50cm
Sodic so	having exchangeable Na plus Mg > 15% within 50cm of the soil surface	Possible: *Endo*-: between 50 and 100cm *Hypo*-: >6% of Excang. Na, >20cm thick within 100cm
Stagnic st	having stagnic colour pattern within 100cm of the soil surface.	Possible: *Endo*-: between 50 and 100cm *Epi*-: within 50cm
Umbric um	having an umbric horizon.	Possible:
Vertic vr	vertic horizon starting within 100cm of the surface.	Possible:

NB: OC = Organic Carbon, BS = Base Saturation, CEC = Cation Exchange Capacity, ECEC = Effective Cation Exchange Capacity, $CaCO_3$ = Calcium Carbonate, CO_3 = Carbonate, HCl = Hydrochloric Acid, > greater/more than and < less than.

These crucial characteristics in soil classification and correlation were rerecorded into a simple algorithm spreadsheet of *Microsoft® Office Excel and Word 2007* (Microsoft Corporation, 2007) software and were subsequently used to correlate and reclassify the profiles into the WRB 2006 key. An example is FAO (1998) *Lithic Leptosols, rupic phase* Profile KH_21 (Appendix 1), which was reclassified into WRB (2006) *Epieutric Lithic Leptosols*. Both *Epieutric* and *Lithic* are formative elements for second-level units of the WRB. *Epieutric* represents the recorded base saturation of more than 50% (*Eutric*) occurring between the soil surface and 50cm (*Epi-*) depth mark, whereas *Lithic* corresponds to the presence of the continuous rock (occurred at 10cm depth mark in the profile) within 10cm of the soil surface, which is applicable only to *Leptosols* RSG (WRB, 2006). *Leptosols* by definitions are other soils having a limitation of depth by continuous rock within 25cm of the soil surface; or less than 20% by volume of fine earth averaged over a depth of 75cm from the soil surface or to a continuous rock, whichever is a shallower; and no calcic, gypsic or spodic horizon (WRB, 2006).

Since profiles locations coordinates are known, polygon shapes were created, thus generating a map of the test area, by ArcGIS 9.3 Software (ISRI, 2006). GPS coordinates were also converted to decimal format before spatially inserted to the test area. For example profile 21 (Appendix 3.1.) coordinates are; 16°43'11" E and 22°29'55" N. Conversion formula is; 16°+((43*60)+11)/3600 = 16+0.7197 = 16.7197 E and 22+((29*60)+55)/3600 = 22+0.4986 = 22.4986 N. The map unit and point data in the map unit were then matched for the validation purposes. In the original JRC map, the map unit information includes the physiographic units and association of the RSGs with one qualifier and their proportion of the spatial coverage within the physiographic units. The point data (in the physiographic units) included the RSGs and all recorded qualifiers in the order following the Guidelines for Constructing Small-Scale Maps Legends of WRB 2006/7 (2006). The matching of the RSGs the qualifiers and their proportions were determined.

3.5. Evaluation of the Applied Systems

The evaluation of the WRB was based on the carried information content of the taxonomic units, if they provide the necessary and useful information on soil functions and for land use possibilities. The data base was evaluated in terms of applicability, structure and content for classification and other purposes.

4. Results and Discussion

In this chapter, the research results are presented together with associated analysis performed. Results are additionally compared to previous research findings and argued about. Overview of the results: correlation of the soil profiles from FAO (1998) to WRB (2006) classification system, validation of the JRC 1: 1 000 000-scaled Namibia Soil Map and the variance analysis.

4.1. Soil Reclassification and Correlation

The first step toward the correlation process was determination of the database applicability and suitability to the process i.e. to find out if there was enough information within the database to derive the presence or absence of the particular WRB diagnostic feature. This was done via simplified algorithms (Table 2 - 5) for the diagnostic horizons, properties, materials and qualifiers associated with WRB RSGs anticipated to be in the area as a function of climate and soils background of the study area. The algorithms yielded 73% applicability (sufficient information to derive WRB diagnostic features) of the database for the 26 diagnostic horizons, 65% for 13 diagnostic properties, 40% out of 5 diagnostic materials and 85% of the 34 qualifiers. Despites diagnostic materials scoring lowly, it must be emphasized that *Calcaric* one of the three (3) who were unable to be derived straightforward from the data was sometimes able to be detected via alternative paths such as profiles summaries and indirectly represented in high pH (>7.5, water) while the other qualifier; *Colluvic* deemed to have little effect on soil classification for a small scale map.

Correlation process carried out on 55 profiles resulted in *Leptosols* and *Cambisols* being the dominant RSGs, with 21 profiles (38%) each. Six (6) profiles (11%) met the requirements of the *Regosols* soils whereas *Fluvisols* and *Calcisols* claimed 3 (5%) and 2 (4%) profiles respectively with the remaining two profiles shared by *Arenosols* and *Planosols*. With exception to *Planosols* and *Fluvisols*, which to a great extent are associated with surface water, the rest of the RSGs were expected and are acceptable in this particular test area (Table …). They all generally share quite similar parent materials in wide range of weathering rocks (Siliceous and/or Calcareous), heavily linked to arid and semi-arid, mountainous and hilly terrains, commonly coarse-textured and little to moderately developed profile. *Planosols* are associated with impeded downward percolation of the water, causing occasionally *reducing conditions*; higher clay accumulation is subsurface than surface horizon and *abrupt textural change* (WRB, 2006). *Fluvisols* on the other hand, are usually genetically young azonal illuvial lacustrine and marine deposits. The existence of these particular RSGs (*Planosols* and *Fluvisols*) is justified in their location within catchments areas and numerous ephemeral rivers within the study area.

Table 6: Full Profiles Correlation Results

Profile ID	**Latitude**	**Longitude**	**WRB RSGs**	**WRB Qualifiers**	**Soil Unit ID**
Nam1	-22.688600	16.980800	Leptosols	Eutric Hyperskeletic	2
Nam14	-23.116700	16.431400	Arenosols	Eutric	2
Nam15	-22.965300	16.474700	Leptosols	Dystric Hyperepiskeletic	2
Nam16	-22.490000	16.165800	Regosols	Eutric Skeletic Leptic	2
Nam18	-22.402500	16.544400	Leptosols	Eutric Hyperskeletic	2
Nam19	-22.717200	16.116100	Leptosols	Eutric Skeletic	2
Nam21	-22.498600	16.719700	Leptosols	Eutric Lithic	2
Nam24	-22.960300	16.515600	Leptosols	Eutric Lithic	2
Nam25	-22.722200	16.479700	Leptosols	Eutric Lithic	2
Nam26	-22.546400	16.938300	Fluvisols	Eutric	2
Nam27	-22.705600	17.098100	Cambisols	Eutric Fluvic	2
Nam28	-22.289400	17.097200	Cambisols	Eutric	2
Nam29	-22.576400	17.127800	Cambisols	Rhodic Eutric Skeletic	2
Nam31	-22.641700	17.055800	Cambisols	Eutric Chromic	2
Nam32	-22.644200	17.056100	Cambisols	Eutric Chromic	2
Nam33	-22.577800	17.137500	Fluvisols	Eutric Gleyic	2
Nam34	-22.686400	17.122800	Regosols	Epieutric Leptic	2
Nam36	-22.706900	17.091100	Cambisols	Eutric Fluvic Skeletic	2
Nam38	-22.621400	16.689700	Regosols	Eutric Colluvic	2
Nam41	-22.294200	17.074700	Leptosols	Dystric , Hyperskeletic	2
Nam43	-22.541700	16.933100	Leptosols	Eutric, Lithic	2
Nam45	-22.531700	16.928900	Regosols	Dystric Skeletic	2
Nam47	-22.531700	16.928300	Cambisols	Eutric Leptic Skeletic	2
Nam48	-22.558100	16.936100	Regosols	Arenic Leptic	2
Nam49	-22.535800	16.930800	Leptosols	Dystric Hyperskeletic	2
Nam5	-22.889200	16.677800	Cambisols	Eutric Chromic Skeletic	2
Nam50	-23.263300	16.319400	Leptosols	Eutric Lithic	2
Nam51	-22.499700	16.676900	Cambisols	Eutric, Leptic, Skeletic	2
Nam55	-23.597800	16.382800	Cambisols	Rhodic, Calcaric, Leptic	2
Nam56	-22.573300	17.121100	Leptosols	Eutric, Hyperskeletic	2
Nam7	-22.592200	16.850300	Calcisols	Petric	2
Nam8	-22.608100	16.798600	Cambisols	Eutric Skeletic	2
Nam44	-22.533100	15.927800	Leptosols	Eutric, Hyperskeletic	43
Nam10	-23.312200	16.467800	Cambisols	Calcaric Skeletic	51
Nam12	-23.291100	16.330800	Cambisols	Eutric Leptic	51
Nam13	-23.290300	16.328900	Fluvisols	Eutric	51
Nam2	-23.000800	16.819400	Leptosols	Eutric Hyperskeletic	51
Nam20	-22.872500	16.774700	Cambisols	Eutric Chromic Leptic	51
Nam22	-22.768300	17.243100	Regosols	Dystric Leptic	51
Nam23	-22.780600	17.231400	Leptosols	Eutric Lithic	51
Nam3	-23.000000	16.820000	Leptosols	Eutric Hyperskeletic	51
Nam30	-22.770800	16.912200	Cambisols	Rhodic Calcaric	51
Nam37	-22.972500	16.869400	Leptosols	Eutric Lithic	51
Nam39	-23.134200	16.899400	Calcisols	Petric	51

Nam4	-22.980600	16.847500	Cambisols	Eutric Skeletic	51
Nam40	-22.911400	16.843600	Cambisols	Dystric Leptic	51
Nam53	-23.295600	16.361900	Leptosols	Eutric, Hyperskeletic	51
Nam6	-23.010300	16.815800	Cambisols	Eutric Leptic	51
Nam9	-23.249400	16.557800	Cambisols	Calcaric	51
Nam35	-22.276400	17.049200	Cambisols	Chromic Eutric	52
Nam11	-23.358300	16.507800	Planosols	Calcic	52
Nam52	-23.522500	16.759700	Leptosols	Eutric, Hyperskeletic	52
Nam54	-23.403300	16.512800	Leptosols	Eutric, Hyperskeletic	52
Nam42	-22.545600	17.935000	Leptosols	Eutric, Lithic	53
Nam17	-22.093100	16.354700	Cambisols	Rhodic Eutric	55

By definitions (WRB, 2006):

- *Leptosols*: depth limited soils by continuous rock within 25 cm of the soil surface or soils of less than 20% (by volume) fine earth averaged over a depth of 75 cm from the soil surface or to continuous rock, whichever is shallower and in all cases lacking *calcic*, *gypsic* or *spodic* horizon.
- *Cambisols*: soils having; *(i)*. *cambic* horizon starting within 50 cm of the soil surface and having its base 25 cm or more below the soil surface or 15 cm or more below any plough layer; *or (ii)* an *anthraquic*, *hortic*, *hydragric*, *irragric*, *plaggic* or *terric* horizon; *or (iii)* a *fragic*, *petroplinthic*, *pisoplinthic*, *plinthic*, *salic* or *vertic* horizon starting within 100 cm of the soil surface; *or (iv)*one or more layers with *andic or vitric* properties with a combined thickness of 15 cm or more within 100 cm of the soil surface.
- *Regosols*: coarser-textured soils having no diagnostic horizons thus not fitting in any other RSG.
- *Fluvisols*: soils having *fluvic* material starting within 25 cm of the soil surface or starting immediately below a plough layer of any depth and continuing to a depth of 50 cm or more without layers with *andic or vitric* properties with a combined thickness of 30 cm or more within 100 cm of the soil surface and starting within 25 cm of the soil surface.
- *Arenosols*: soils with weighted average texture of loamy sand or coarser and less than 40 percent (by volume) of gravels or coarser fragments in all layers within 100 cm of the soil surface or to a *petroplinthic*, *pisoplinthic*, *plinthic* or *salic* horizon starting between 50 and 100 cm from the soil surface. Further requirements are absence of *fragic*, *irragric*, *hortic, plaggic, terric* horizon or layers with *andic or vitric* properties with a combined thickness of 15 cm.

- *Planosols*: Soils having an *abrupt textural change* within 100 cm of the soil surface and directly above or below, a layer 5cm or more thick that has in some parts they possesses *reducing conditions* for some time during the year and in half or more of the soil volume, single or in combination; a *stagnic colour pattern* or an *albic* horizon; and no *albeluvic tonguing* starting within 100 cm of the soil surface.
- *Calcisols*: soils having either *Petrocalcic* or *Calcic* horizon within 100cm of the soil and a calcaric matrix between 50cm of the surface and a calcic horizon. *Argic* is only present when permeated with calcium carbonate.

As per WRB 2006/7 (2006) small scale maps constructing guidelines, the RSGs were dominated by qualifiers and eventually qualified as follows:

i. Leptosols:

- *Lithic*: having continuous rock starting within 10 cm of the soil surface.
- *Eutric*: having a base saturation of 50% or more throughout.
- *Hyperskeletic*: having 80% or more of stones or other coarser fragment.
- *Dystric*: having a base saturation of less than 50% throughout.

ii. Cambisols

- *Eutric*: having a base saturation of 50% or more throughout.
- *Skeletic:* at least 40% gravel or other coarse fragments averaged over a depth of 100 cm from the soil surface or to *continuous rock*.
- *Calcaric:* contains 2% or more calcium carbonate equivalent.
- *Chromic:* hue redder than 7.5YR or both 7.5YR hue and a moist chroma higher than 4 within 150cm of the soil surface, 30cm or more thick.
- *Rhodic:* hue redder than 5YR and a moist value less than 3.5 and a dry value not more than one unit higher than moist value within 150cm of the soil surface, 30cm or more thick.
- *Leptic*: having continuous rock starting within 100 cm of the soil surface.

iii. Regosols

- *Leptic*: having continuous rock starting within 100 cm of the soil surface.
- *Arenic*: loamy fine sand or coarser texture in a layer, 30 cm or more thick, within 100 cm of the soil surface.
- *Eutric*: having a base saturation of 50% or more throughout.
- *Skeletic*: at least 40% gravel or other coarse fragments averaged over a depth of 100 cm from the soil surface or to *continuous rock*).

iv. Fluvisols

- *Eutric*: having a base saturation of 50% or more throughout.
- *Gleyic*: reducing conditions and 25% or more *gleyic* colour pattern within 100cm of the soil surface.
- *Arenic:* loamy fine sand or coarser texture in a layer, 30 cm or more thick, within 100 cm of the soil surface.

v. Arenosols

- *Eutric*: having a base saturation of 50% or more throughout.
- *Protic*: showing no soil horizon development.

vi. Planosols

- C*alcic:* concentrations of secondary carbonates within 100cm of the surface.

vii. Calcisols

- *Petric*: having a strongly cemented or indurated layer within the soil surface.
- *Skeletic*: having at least 40% gravel or other coarse fragments averaged over a depth of 100 cm from the soil surface or to *continuous rock*.

Except of *protic*, *arenic*, *lithic*, *calcaric* and *protic*, all qualifiers had specifiers prefix, which indicate either a depth of occurrence or an intensity of the soil characteristics (WRB, 2006). They are added single or double to give a double or triple combination e.g. *Endoskeletic* or *Epihyperskeletic*. The first example signifies more than 40% of gravel or other coarser fragments

(*Skeletic*) between the depths of 50 – 100cm (*Endo*-) while the latter indicating 80% or more (*Hyper*-) of gravel or other coarser fragments (*Skeletic*) between the soil surface and the depth of 50 cm (*Epi*-). The full correlation and qualifications results are fully tabulated in table 6.

As above mentioned, most profiles fulfilled requirements for *Cambisols* and *Leptosols* RSGs with others as given. However, these outcomes do not necessarily mean the test area is dominated in this order, due to physically location of the profiles relative to each other within the test area. There are areas where profiles are very close to each other whereas some are isolated and few over a large area. Variation in topographic and other physical features is presumed to have caused a need of many profiles close to each other while the isolated profiles have been attributed to probable extensive homogeneity of the surface that can sufficiently represented by a single or two profiles.

4.2. Soil Map Validation

According to the map, the correlated profiles have fallen into six (6) different soil units also known as polygons (Figure 7). Soil units or land systems as defined in section 3.3; represent land morphological areas of recurring features such as topography, vegetations and soils. Five (5) soils types, namely; *Leptosols (Eutric* and *Lithic*), *Calcisols* (*Haplic* and *Petric*), *Regosols (Eutric*), *Cambisols (Eutric*) and Rock in different combinations and proportions are accommodated in these soil units (IDs: 2, 43, 51, 52, 53 and 55), with only one qualifier given per RSG (excluding Rock). By Proportion, *Leptosols* dominate the soil units combined by 40% almost double of each *Calcisols* and *Regosols* at second and third respectively whereas *Cambisols* and Rock are equal on 7% each. *Cambisols* and rock each appears only in one of the six soil units, while the rest occur in five soil units each as shown in comparison to the correlation outcomes in a table 7.

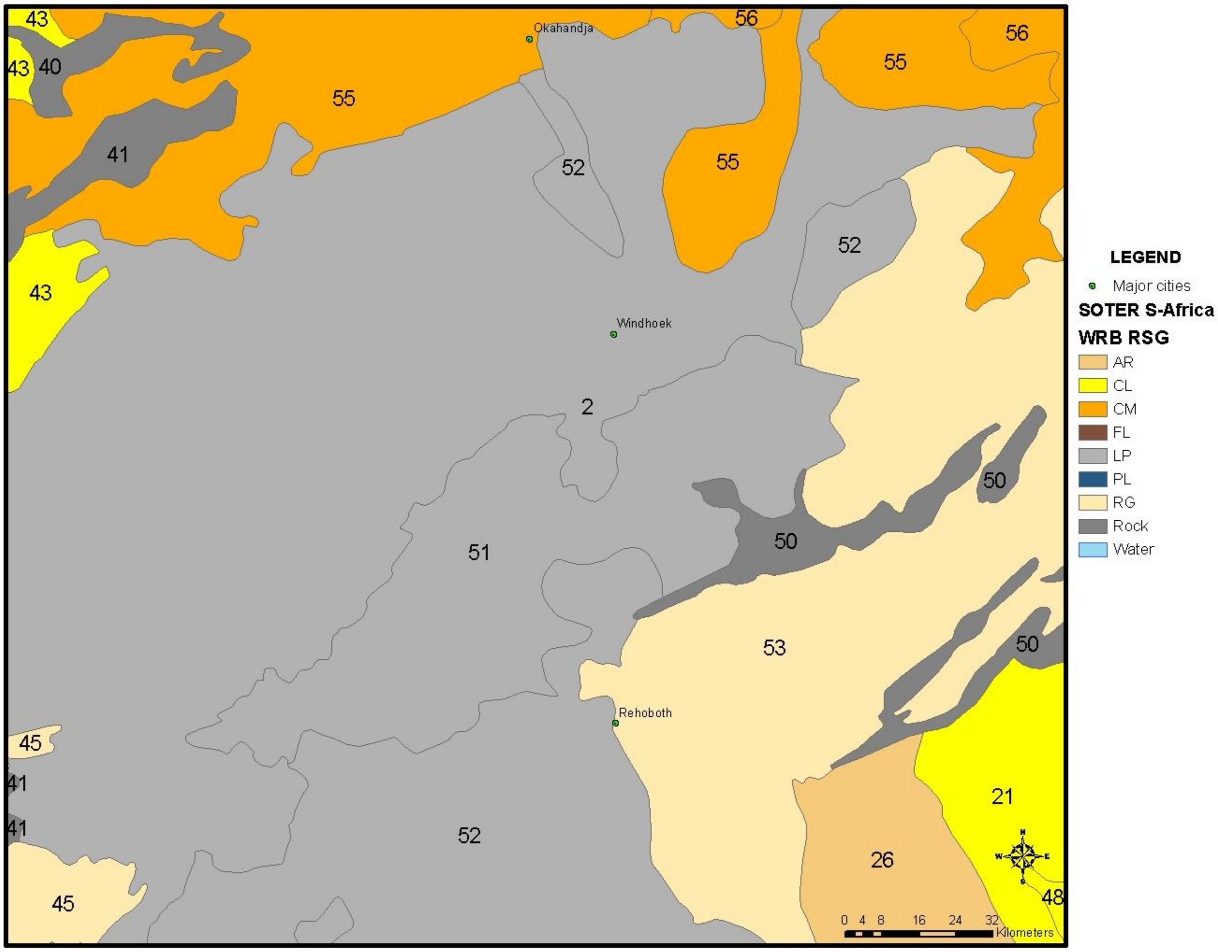


Figure 7: EU JRC Namibian Soil Map Soil Units IDs and Dominant RSGs in the study area (personal communication with A.R. Jones, editor of the Atlas)

Table 7: Comparisons of the Map Soil units and Correlation Results

Soil units IDs	***Map Legends***			***Correlation Outcomes***		
	WRB RSGs	***Qualifiers***	***Prop. (%)***	***WRB RSGs***	***Qualifiers***	***Prop. (%)***
2	Leptosols	Eutric	60	Leptosols	Eutric, Hyperskeletic, Dystric, Skeletic, Lithic	38
	Rock		40	Cambisols	Eutric, Fluvic, Rhodic, Chromic, Skeletic, Leptic	34
				Fluvisols	Eutric, Gleyic	6
				Regosols	Eutric, Leptic, Colluvic, Dystric, Skeletic, Arenic, Hyperskeletic.	16
				Calcisols	Eutric, Petric	3
				Arenosols	Eutric	3
43	Calcisols	Petric	60			
	Leptosols	Lithic	30	Leptosols	Eutric, Hyperskeletic	100
	Regosols	Eutric	10			
51	Leptosols	Eutric	60	Leptosols	Eutric, Hyperskeletic, Lithic	32
	Regosols	Eutric	30	Regosols	Dystric, Leptic,	6
	Calcisols	Petric	10	Calcisols	Eutric, Petric	6
				Fluvisols	Eutric	6
				Cambisols	Calcaric, Eutric, Hyperskeletic, Leptic, Chromic, Skeletic, Dystric	50
52	Leptosols	Eutric	60	Leptosols	Eutric, Hyperskeletic,	50
	Regosols	Eutric	30	Cambisols	Chromic, Eutric	25
	Calcisols	Petric	10	Planosols	Eutric Calcic	25
53	Regosols	Eutric	50			
	Leptosols	Eutric	30	Leptosols	Eutric, Lithic	100
	Calcisols	Haplic, Petric	20			
55	Cambisols	Eutric	40	Cambisols	Rhodic, Eutric	100
	Regosols	Eutric	25			
	Calcisols	Haplic, Petric	35			

According to the map and by definition, soil units are constant legends representing lands with identical attributes in terms of landform characteristics, parent materials and soils (SoterManual, 2009), therefore RSGs falling into units of same ID, are expected to be similar or close thereabout. If this is always going to be true, then this investigation would have been regarded as a failure. The comparison of the findings as shown in ***table 7*** has shown a significant difference in soil unit 2, 51 and 52. The correlation process has either added/found new RSGs or has changed the proportion in relation to the map legends. Proportion unlike RSGs, does not bear much significance, given the sample of profiles used in the correlation process and a fact that many profiles in close proximity of each other will increase the proportion of one RSG relatively to others, if they all happen to belong to a single RSG. Unit 2 is made up of Leptosols (60%) and rock (40%) in the map legends, the latter can be classified as *Nudilithic Leptosols*, making it 100% Leptosols unit. *Nudilithic* qualifier indicates a presence of a continuous rock at the soil surface (*Nudi*-) (WRB, 2006).

Emergence of new RSGs to the units (2, 51 and 52) as shown in table 6 is quite complex to justify as soil formation and development of diagnostic horizons, properties and material is usually very slow in arid and semi-arid needed for change or conversion of one RSG to another. On the other hand however, the fact that part of the data used in compilation of the map dates back to 1960s and the study area being a mixture of landforms; plateau, plain, low-gradient footslope, medium and high-gradient hill and mountains (SOTER, 2009), there might be a possibility of changes in soil development. These landforms are associated with active cycle of soil development involve both deposition and erosion areas where new soils form after matured ones have eroded away, an almost common genesis route of all involved RSGs: *Cambisols, Fluvisols, Regosols, Calcisols* and *Arenosols* (FAO, 2001). *Planosols* occurrence is catered for by any possibility of periodic above ground stagnation water, which to a great extent has also an influence on *Fluvisols*. Both unit 43 and 53 being *Leptosols* and unit 55 being *Cambisols* only compared to additional *Regosols* and *Calcisols* on the map in all units has been accepted on grounds that only a single profile fell into these polygons (Figure 8).

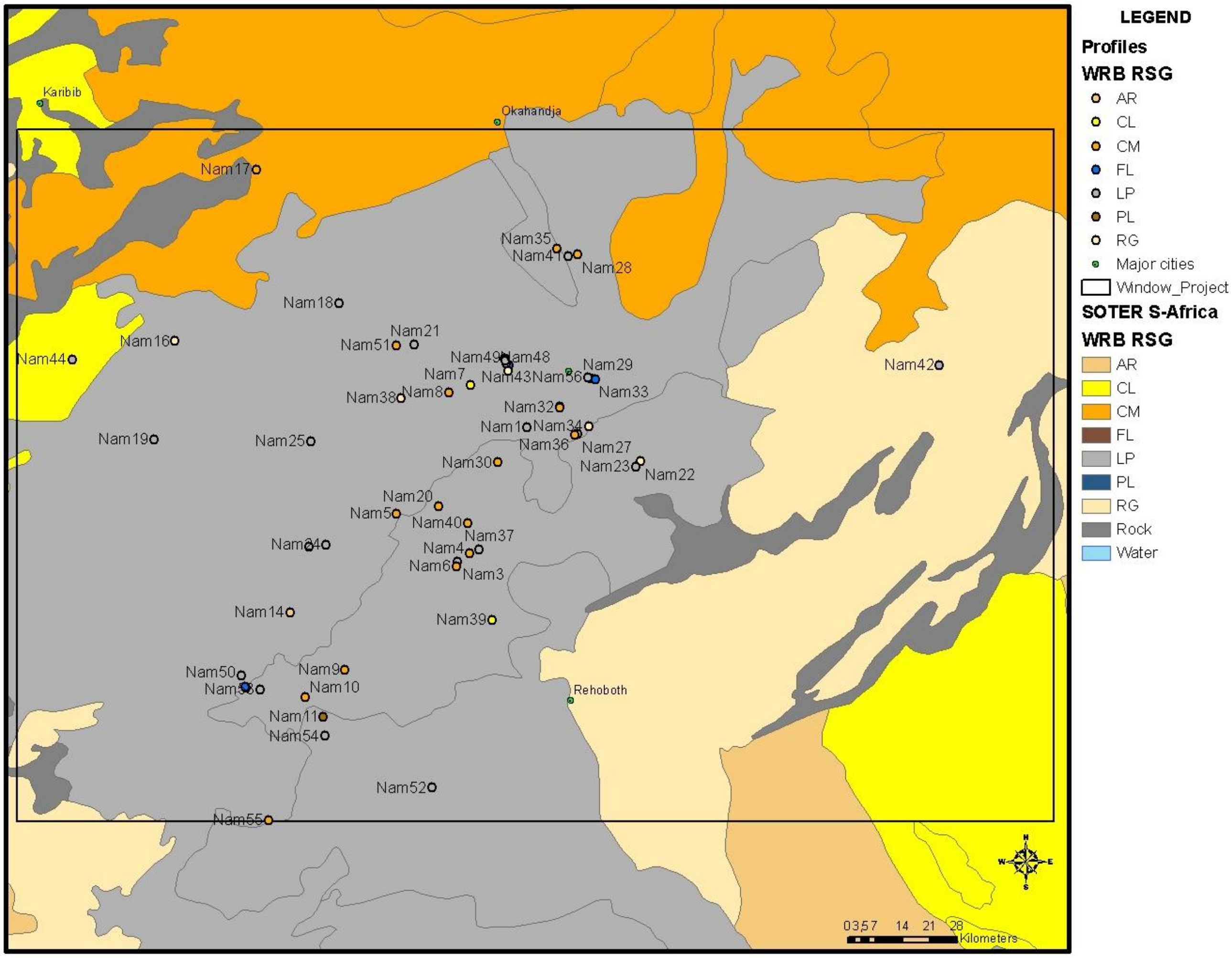


Figure 8: Correlated Profiles Results and location in the study area on the EU JRC Namibian Soil Map (personal communication with A.R. Jones, editor of the Atlas).

The margin in similarity and differences among RSGs and soil classification in general is very thin, further compounded by profiles physical position and a fact that soils (RSGs) exist in associates or alongside each other i.e. one RSG at the highest point of the landscape to the different one in the bottomland. Examples include *Fluvisols*, which occur alongside other 'typical' aqueous sedimentary soils such as *Arenosols*, *Cambisols*, *Gleysols* and *Solonchaks* as well as weakly developed in *Leptosols* and *Regosols* (FAO, 2001). Also Calcisols range from shallow *Leptosols* on the hill to Vertisols at the lower end of the slope. Another justification for new RSGs exists in a fact that many diagnostic horizons, materials and/or properties used in deriving of an RSG can also occur in other RSGs without being decisive because other properties have high priorities. This implies that one RSG includes soils, which may have been correctly other RSGs but just missed out on one or two requirements (e.g. 2cm on horizon thickness to fulfill a diagnostic horizon, material or property). For example *Cambic Leptosols* cease into *Cambisols* the moment a cambic horizon reaches a thickness of 15cm and a base deeper than 25cm (FAO, 2001), on the same talk, Bertram and Broman (1999) claimed *Leptosols* and *Regosols* in the study area are only separated by depth and Regosols being soils that could not fulfill other major soil criterion.

RSGs are roughly based on telling identifiers indicating unique conditions of soil formation as derived from diagnostic horizons, materials and/or properties which are reflection of widespread and common results of the soil formation processes (WRB, 2006). This suggests RSGs can be obtained from climate (soil formation factor) e.g. permafrost and soil formation processes e.g. human influence, parent material (Volcanic materials) and physiology of topography (lowlands/elevated). The testimony exists in WRB (2006) RSGs broad definitions, whereby *Regosols* is regarded to be soils with no significant profile development; *Cambisols* are moderately developed soils while Arenosols are relatively young soils with little or no profile development. These definitions are hard to separate between the three (3) RSGs thus not sufficient without second-level analytical supplement. Second-level information is called qualifiers (suffix and prefixes), which outline secondary soil-forming processes that have significantly affected the primary soil features (WRB, 2006). Comparing the two outcomes (table 6), there are many similarities in qualifiers, despite a map carrying only one qualifier per RSG, except the rock group. This signifies consistent and offers another angle to argue about the variation between the two findings regarding RSGs.

All qualifiers in the map have been matched by corresponding RSGs from the correlation process in spite of additional qualifiers to the latter. This as previously mentioned indicates similarities in analytical properties (chemical and physical) of the soils within the test area. This scenario adds to the arguments offered with RSGs as case in point. For instance *Leptic Skeletic Cambisols* and/or *Leptic Hyperskeletic Regosols* discovery in soil unit 2 from correlation process compared to only *Leptosols* (rock has been converted to *Nudilithic Leptosols*) can be related to or very close to Leptosols, given they commonly further share eutric qualifier. *Leptic Skeletic Cambisols* signifies soils with a 15cm or thicker cambic horizon, with a base deeper than 25cm from the soil surface. However, the same soil has a continuous rock within 100cm of the soil surface (*Leptic*) and more than 40% gravel or other coarser fragment on average through to a continuous rock (*Skeletic*). There is a possibility of a continuous rock just being minimal 2cm deeper, to disqualify this soil from being a *Leptic Leptosols*. The same applies to Leptic Regosols and other RSGs carrying a *leptic*, *skeletic* or *hyperskeletic* qualifier. Conclusively, unlike the RSGs, the qualifiers match to a great degree.

4.4. Evaluation of the Applied Systems

The World reference base for soil resources proved to be applicable for the correlation. The information content of the RSGs allow correlation on global and regional level, however the application of the qualifiers makes possible to indicate most important soil property governing soil functions and land use options. The data structure applied was easy to use and contains most the attributes that are necessary for policy making, land use, classification or correlation purposes. Unfortunately several of the attribute data were not available in the data base, but on long term they can be completed. The standard structure allows also the data exchange and harmonization with other data bases.

5. Conclusions

The following conclusion can be drawn from the present study that ranges from the correlation of both Soil Taxonomy and FAO 1998 soil profiles to WRB 2006 soil classification system and eventually the validation of the recent 1:1 Million Map to be published by the EU in the new Soil Atlas of Africa. The data used is from the local soil survey in a small, about 51 327 km^2 test area in east central Namibia, roughly between 22° – 23.6° S, 15.8° – 18.2° E, carried out by the Agro-Ecological Zone program of the Namibian Ministry of Agriculture, Water and Forestry in 2009. The local data contained adequate details and information to allow the correlation of the above-mentioned systems, as it was possible to identify key WRB 2006 diagnostic features that led to the establishment of the RSGs name and qualifiers as per both WRB 2006 requirements and Guidelines for Constructing Small-Scale Maps Legends of WRB 2006/7 (2006). As often is the case, the 'one-to-one' match was not possible between the classification systems, as a result, an interface was created in the form of simplified logarithms to act as best approximation medium for the correlation process. Seven (7) RSGs were diagnosed by the correlation process, and all fit in the area function of climate and topographic features. *Leptosols* and *Cambisols* were equally dominant with 38% of profiles studied each, followed by *Regosols, Fluvisols, Calcisols, Arenosols and Planosols*. Feeding these profiles to the map according to their respective GPS coordinates yielded soil unit composition relatively different from the map's in terms of RSGs and their proportion but there was a great deal of homogeneity at the second classification level, i.e. the qualifiers.

The significance of the difference between the map soil unit composition and the local data was dismissed by the argument t that all RSGs diagnosed fit the climate and other properties of the area; topography and parent materials. It was secondly argued that these RSGs are very close to each other, as they all almost point at poorly developed profiles status and a degree of sandy to coarser texture. The fine margin exists for example between a *Cambisols* and Cambic *Leptosols*, which may just be an extra 'cm' thickness in the Cambic horizon. The topography complexion of the area, which is a mixture of hills, mountains, ephemeral rivers and flat plains made it possible for many RSGs to coexist i.e. one RSG at the highest point of the landscape to the different one in the bottomland.

This concluded map validity of the map supports the theory of Mendelsohn (2006) that Namibian soil develops little over a very long time due to dry and arid climate compared to the state if it were wetter. However, constant surveys are necessary for the continuous update of national database, which, at the moment, is far behind. At 1:1 000 000 scale the Atlas of African Soils will still be small for planning purposes for a country that largely depends on Agriculture and busy conducting processes such as Land reform, which needs land and soil evaluation and suitability classifications. These are the areas for future but urgent research.

Summary

Providing the foundation of every agrarian economy, soil is the most important resource in Namibia, as about 70% of the population depends directly on subsistence mixed farming for livelihood, mostly food production. The country's soils consists of 46% pastures, 1% arable, 22% desert and 31% woodlands and a wide range of diverse biodiversity of vegetation; desert, savannas and dry woodlands. It is worth mentioning that despite its importance, Namibian soil has not extensively been studied and there is not a modern soil map apart from the 1: 5 000 000 scale FAO/UNESCO Soil Map of the World, which is too far small for any planning purposes. The present study is aimed at evaluating the approaches of compiling soil maps from the national legacy data, maps and air photographs. This was achieved by validating the recent 1:1 Million Map to be published by the EU in the new Soil Atlas of Africa (in progress) by using 2009 soil survey data on a small, about 51 327 km^2 test area in east central Namibia, roughly between 22° – 23.6° S, 15.8° – 18.2° E. Literature review, studying data , classification systems correlations (FAO 1998/US Taxonomy to WRB 2006), analysis and evaluation of the obtained results as well as spatially insertions of profiles studied and correlated onto the map as per their GPS coordinates given in the database were all carried out to achieve g the objectives.

The results obtained indicated that there was sufficient information to enable the derivation of key WRB 2006 diagnostic features as to establish the RSGs name and qualifiers per Guidelines for Constructing Small-Scale Maps Legends of WRB 2006/7 (2006). Accordingly, correlation or reclassification of profiles from FAO 1998 and US Soil Taxonomy to WRB 2006 was possible. It must however be emphasized that this was not 'one-to-one' match but best approximation after making all efforts possible. All WRB 2006 RSGs found fitted in the area given the climate and topographic properties. There was a difference in soil units in RSGs composition and proportion once profiles were spatially mapped i.e. some new RSGs were added and removed in same soil units when compared to the map, or the RSGs dominance proportion was altered. However, there was homogeneity at qualifier level of classification, which, in conjunction with RSG and their relation to each other found the map valid.

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*"This work is dedicated to my late father **KALIMBO** (1949-1989) and beloved cousin **TULINANE (1987 – 2008)".***

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Declaration

Signed below, ***Stefanus Niilonga Hashondati Nambambi***, student of the Faculty of Agriculture and Environmental Sciences, Gödöllő Szent István University, at the MSc Course of Agricultural Engineering declare that I have used the cited and quoted literature in accordance with the relevant legal and ethical rules. I understand that the one-page-summary of my thesis will be uploaded on the website of the Faculty/Institute/Course.

Confidential data are presented in the thesis: yes no

Gödöllő, …….day…………………..month………year

…………………………….

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As primary thesis adviser of the author of this thesis, I hereby declare that review of the thesis was done thoroughly; literature sources cited in the dissertation were used in accordance with the relevant legal and ethical rules. I hereby, approve the thesis for oral defense on Final Examination.

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