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The use of Time Domain Electromagnetic method and Continuous Vertical Electrical Sounding to map groundwater salinity in the Barotse sub-basin, Zambia

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ABSTRACT

This paper describes the results from the application of two geophysical exploration techniques, Time Domain Electromagnetic (TDEM) and Continuous Vertical Electrical Sounding (CVES) that have proved effective in mapping groundwater salinity variations within the sedimentary formations of the Barotse sub basin in the Western Province of Zambia. TDEM was used to map groundwater salinity variations on a regional scale, whereas CVES was used at the local scale to investigate freshwater–saltwater distribution in an ephemeral river valley. On a regional scale, salt water occurrence was shown to be present mainly on the south-eastern portions of the basin, which are situated in a rift that forms a tripe junction with the East African Rift Valley. The general geophysical model indicates an aquifer with saline water with a thickness of about 40 m with resistivity variations less than 35 Ωm (more than 500 mg/l of Cl^- based on a formation factor of 5), overlain by an unconfined freshwater aquifer of about 10 m thickness with resistivities in excess of 70 Ωm (i.e. less than 250 mg/l of Cl^- based on a formation factor of 5). The origin of the saline water is hypothesized to be related to the evapo-concentration of salts in interdune deposits, which were subsequently buried due to dune migration about 32 to 4 thousands of years ago or kilo annums (ka). The occurrence of saline groundwater could also possibly be linked to evaporation of a former Lake Paleo Makgadikgadi, an extensive endorheic lake system that once covered large parts of Southern Africa. Locally, a thin freshwater aquifer was observed in an ephemeral river valley, indicating recent recharge of river water into a pre-existing saline environment.

1. Introduction

The Kalahari Basin (McCarthy and Haddon, 2005) comprising mostly of sedimentary units has a high potential for groundwater yields albeit for the occurrence of saline groundwater which can prove a limiting factor for water supply interventions for the rural population in an area that is described as semi arid (hence water stressed). The Western Province of Zambia lies within the Kalahari Basin and it has been reported that elevated levels of groundwater salinity occur within this region (UNZA/GEUS/DTU, 2008). *Salty* groundwater has neither been adequately mapped nor documented in the part of the Kalahari Basin that extends into Zambia. It thus became necessary that a study be conducted to understand the nature of the salty groundwater problem and its spatial extent within the context of the application of appropriate geophysical field methods.

A case study was therefore conducted in the Sesheke Area of the Western Province of Zambia, whose objective was to develop an understanding of salty groundwater distribution in the Barotse Basin (as a subset of the Kalahari Basin) by way of a case study in the Sesheke Area in the Western Province of Zambia using geophysical field methods. The study sought to determine the groundwater salinity variations in the Sesheke Area and how these were affected by the geological regime that controls the groundwater including the extent to which the groundwater salinity variations occurred spatially.

The study area was in the Barotse sub basin of the Zambezi River Catchment, however the focus area for the study was Sesheke District located in the south-western part of Zambia between 15°27′–17°28′ S and 23°06′ –025°33′ E. The relief varies from about 850 m above mean seal level (AMSL) to about 1200 m AMSL.

The geology is that of a basin floored by Basement and Katanga rocks in filled with a variety of sediments ranging from Lower Palaezoic to Quartenary. However, it was only the Kalahari Supergroup formations that were of interest to this research and these are described as continental sequence of post Cretaceous rocks which comprise the sandstones and quartzites of the Barotse Formation and the unconsolidated sands of the overlying Zambezi Formation (Money, 1972).

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2. Materials and methods

2.1. Geological modelling

A geological model of the study area was prepared using GEOSCENE 3D (I.GIS, 2010). GEOSCENE 3D is a software for visualising, interpreting, editing and publishing geological data and is perfectly suited for both groundwater and environmental use (I.GIS, 2010). A total of 39 boreholes comprised the database upon which the geological model of the study area was based. They constituted the only available geo-referenced lithologic borehole profiles for the study area at the time of study and were drilled between March 2002 and February 2003 (Kameyama, 2003).

The distribution of most boreholes in the study area was somewhat unidirectional along a south-west to north-east stretch from Lunga (near Sesheke Town) to Mulobezi. This resulted in data gaps (e.g. between Namwinga and Munyeula) that made the geo-modelling rather difficult. To overcome this difficulty, pseudo boreholes were created with lithological profiles identical to those of the nearest boreholes with known lithology. The assumption was that the change in geology was slow horizontally. The basis of this assumption is the vast expanse of the Kalahari Supergroup sedimentary rocks that were deposited in a large basin stretching some 2200 km from South Africa in the south, northwards through Botswana and Angola into the Democratic Republic of Congo (McCarthy and Haddon, 2005). The lithology for each borehole was described in terms of depth to the top surface of the different geological units during data entry. In addition, the top most surface was taken as the digital terrain elevation model of the study area based on Shuttle Radar Topography Mission (SRTM) data with 90 m resolution.

2.2. Time Domain Electromagnetics (TDEMs)

Electrical resistivity mapping using TDEM (Kirsch, 2006) was conducted in the Sesheke Area from the 4th of July to the 18th of August 2009. On an average day two soundings would be performed. The locations at which TDEM sounding was conducted are shown in Fig. 1.

2.3. Continuous Vertical Electrical Sounding (CVES)

CVES (Christiansen, 2003) was conducted from the 17th of September to the 8th of October 2009. Its objective was to investigate the surface water–groundwater interaction including the recharge of freshwater lenses by the ephemeral rivers. The field measurements were conducted on a transect that cut across the Machile Stream at a location close to Mangumwi Basic School in the Sesheke Area, Western Province, Zambia. The basic procedure involved setting up a transect about 1.2 km long across the Machile Stream and doing CVES measurements all along and TDEM soundings every 40 m from the start of the transect line up to the end. Fig. 2 shows the field layout which was setup close to Mangumwi Basic School.

2.4. Data analysis

Data from field measurements was analysed, interpreted and presented in digital form using software such as SiTEM SEMDI (Hydrogeophysics-Group-1, 2001) and RES2DINV (Geomoto, 2004) for geophysical data and GEOSCENE3D (I.GIS, 2010) for geological modelling. The main GIS application was ArcGIS 9.3 (ESRI, 2008). This lead to the development of a single hydrogeological model of the study area based on all results showing the spatial distribution of saline and fresh groundwater.

3. Results

3.1. Geological model

The regional geological model of the study area was presented as a 2D cross section along a north–south trending profile line. It was possible to generate profile lines at any location and with any desired orientation within the model area. However, only one north–south trending profile has been reproduced with the vertical scale exaggerated in order to show the vertical variations in the topography and geology. Hence most of the narrow valleys are actually very wide valleys or river channels.

The regional geology is thus characterised by sand underlain by sandstone, which in turn is underlain by rocks ranging from Karoo

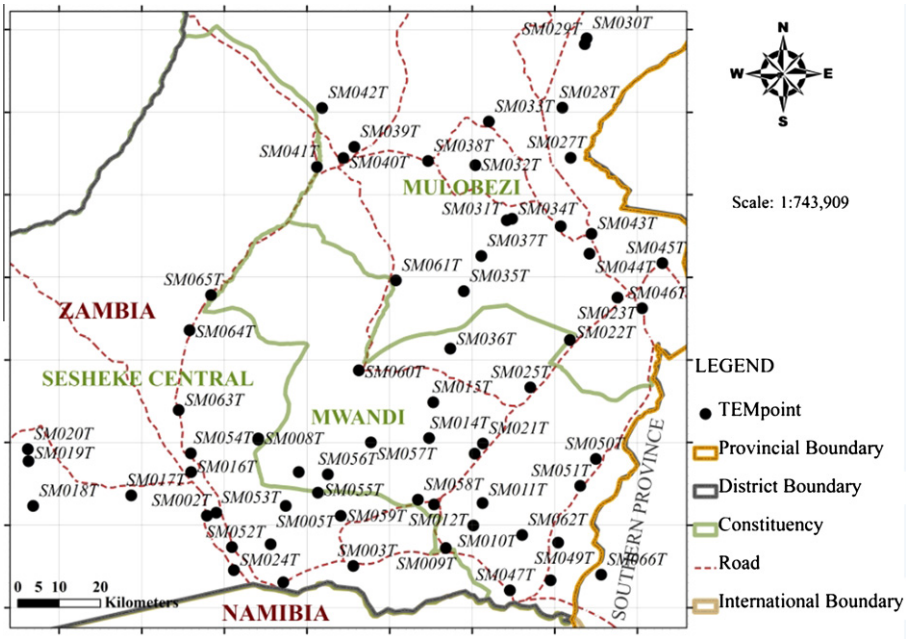

Fig. 1. Location of TDEM sounding sites in Sesheke District, Western Province, Zambia.