

GIS Approach for a Common Geothermal Database for East African Rift System Region (EARS)

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Keywords:

ABSTRACT

Research activities on GIS application for mapping geothermal energy sources in the East African Rift System region (EARS) were performed. This compilation is a result of a fellowship awarded by the International Council for Science and High Technology and the United Nations Industrial Development Organisation (ICS-UNIDO) Trieste Italy to do GIS work related to geothermal sources in the East African Rift System region, (EARS). The project covered eleven countries which include; Eritrea, Djibouti, Ethiopia, Kenya, Uganda, Tanzania, Comoros, DR Congo, Zambia, Burundi and Rwanda. The whole project was to use a GIS approach to map and build a common geothermal geo-database for the EARS countries so that data could be availed for identification of gaps, project formulation for geothermal development, resource assessment, risk analysis and multi-criteria decision supporting tools at regional and country levels. Both geographic spatial data and non-spatial (ancillary) data were captured. The end result was a geo-database organised in an orderly manner with data that can be used for formulation of geothermal project proposals, multi-criteria decision supporting tools (SDSS and DSS), assessment of resources and risk analysis at both country and regional levels. Schemas for data that has not been availed from member states are already prepared and waits for data to be filled in. The geo-database as it now can be used to provide a lot of information through queries and selections in Arc GIS. The database also contains information that may directly or indirectly affect geothermal development, for example location of geothermal potential in relation to conservation areas, major power lines, other powerhouses and potential market. There is also room for improvement if we join hands with all member states and stakeholders.

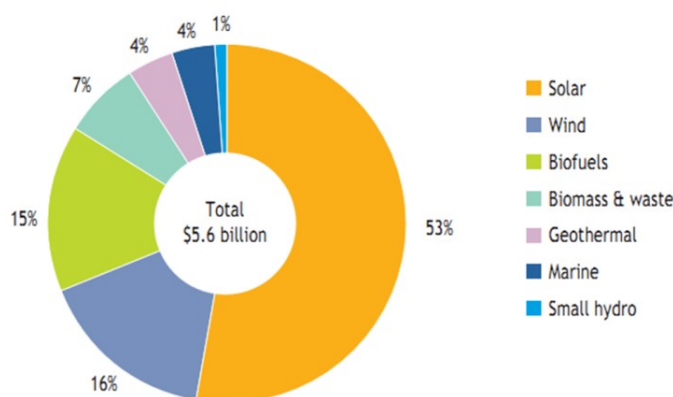
1. INTRODUCTION

1.1 Energy outlook.

The population of the world has been growing in the history of mankind. Throughout time the rural population has been greater than urban till the year 2009 according to the World Energy Outlook 2010. With an ever increasing population, which is projected to double by the year 2100 coupled by the projected urbanisation, the demand for energy is also expected to rise. The world population is expected to increase overwhelmingly in the countries which are not part of the Organisation for Economic Co-operation and Development (non-OECD).

Africa being non-OECD, the population of this continent is expected to almost double by the year 2035. With such increase in population, Africa should also expect an energy demand increase of about the same fold. There is therefore a need for strategy for energy sources which are clean and renewable, geothermal being one of them. For a country to develop there must be an increase in power demand and Africa is at its infancy stage of development which explains why there must be increase in energy demand on the African continent in the years to come.

The rising demand for fossil fuels continues to drive up energy related carbon dioxide emissions. Even additional governments' policies that are assumed to be adopted (including Copenhagen accord) to reduce greenhouse gas emissions can only help to slow down the rate but not to stop the increase (World Energy Outlook 2010). According to the same report, little (4%) has been put into scientific research for geothermal compared to other renewable sources of energy (Fig. 1)



Source: Bloomberg New Energy Finance databases.

Figure 1 Global spending on research and development in renewable energy by technology, 2009

1.2 Mapping geothermal energy sources.

Geothermal is a clean, renewable and environmentally benign source of energy based on heat from within the earth's surface. It is always important to do proper mapping of the resources because a lot of information is required before projects can be proposed or investments made. At times, the resources are Trans-boundary which requires a common databank for proper monitoring so as to avoid overexploitation to ensure longer lives of reservoirs.

The mapping exercises range from reconnaissance for a large area to map the lateral extent of areas likely to be good geothermal energy sources to a more detailed one such as aiming at estimating the depth and size of reservoir. Depth is one of the key parameters that needs to be clearly understood because it takes the largest share of the total investment in geothermal development projects. Too shallow reservoirs are not sustainable whereas too deep reservoirs are not economically viable for development.

The member states of the East African Rift System region are at different stages of exploration, some at reconnaissance stages and others are already producing electricity from geothermal. The GIS-based geothermal mapping aims at bringing all the available data together for comparisons to be made and also to identify where there are gaps. At no one point can investment decisions on geothermal be made based on GIS-based maps produced at regional scale more so if remotely sensed data has been used. A detailed exploration and mapping is always required. However, GIS can be used to store, organise and process data so as to serve as decision supporting tool. Other supporting information such as lineaments or faults can be mapped exactly using remotely sensed data. With data available in the geo-database, specific maps can be produced to give an answer to specific questions.

1.3 Area of study and its location on African continent.

The area of study is on the African continent (Fig. 2). It covers eleven countries which include Burundi, Comoros, Djibouti, Congo DRC, Eritrea, Ethiopia, Kenya, Rwanda, Tanzania, Uganda and Zambia. These are the countries which signed the Addis Ababa declaration on geothermal energy in June 2009, and being traversed by the African Rift. Malawi which is another state crossed by the rift had not yet signed the declaration and was not included in this project.

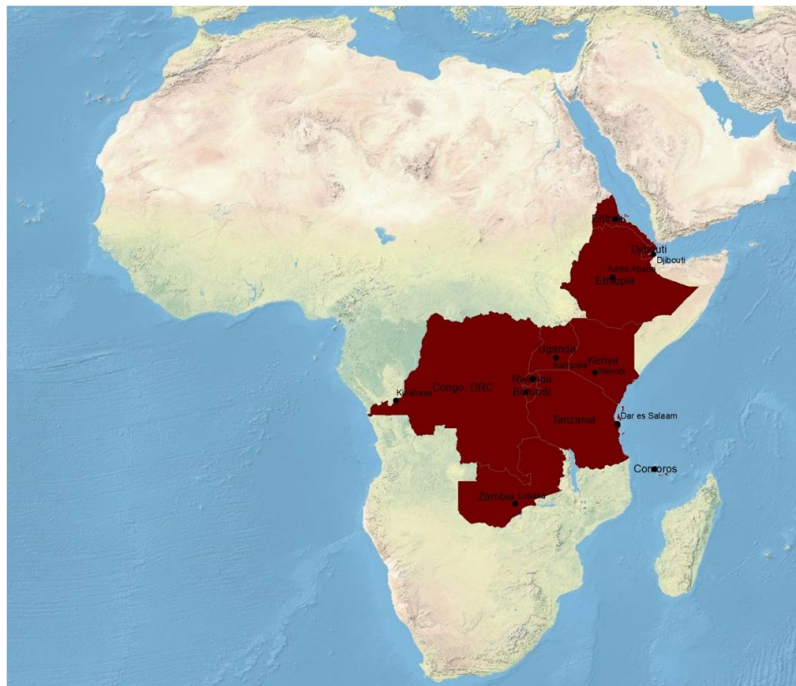


Figure 2 Map of Africa showing the location of eleven countries under coverage by the project.

1.4 Tectonic Setting – The East African Rift

The East African Rift formed as a result of three plates; the Arabian plate, the African plate and the Somali sub plate. The rift extends from Red Sea at the Gulf of Aden up to Malawi in the south. It is known to be seismically active (Saemundsson 2008).

EARS development was initiated in the Gulf of Aden at about 30Ma, over a large temperature anomaly region in the mantle (mantle plume). During the Miocene, the border faults of the Afar and Main Ethiopian rifts started developing, crust oceanization concentrating along distinct tectonic and magmatic zones during the Pliocene and Quaternary. Rifting propagated successively in central Kenya and western Uganda later during the mid-Miocene, in the Panafrican crust in the former and dominantly in the older Kibaran terrain in the later.

The Aswa structure which traverses northeast Uganda in the NW-SE direction dates from Panafrican times (Fig. 3). It was activated during the Miocene and served as a mechanism for the transmission of extensional stress from the eastern branch of the EARS which had failed to propagate further south across the thick and rigid Tanzanian craton at about 12-10 ma. Sinistral shear along the Aswa is thus believed to have initiated and driven Western Rift development. Later, during the late Miocene, this direction of stress transfer was reversed far in the south, along the lakes Tanganyika-Rukwa-Malawi fault zone, in the southwestern outskirts of the Tanzanian craton. The reversal reinstated the locus of EARS propagation preferred by the stress field installed in the region by the

thermal uplift and stretching of the crust. The development of the Western Rift can thus be viewed as a consequence of the failure of the Eastern Rift to effectively continue its southward propagation across Tanzania. Thus, in contrast with the active Eastern Rift, the Western Rift is a passive rift having no internal stress field which drives its opening.

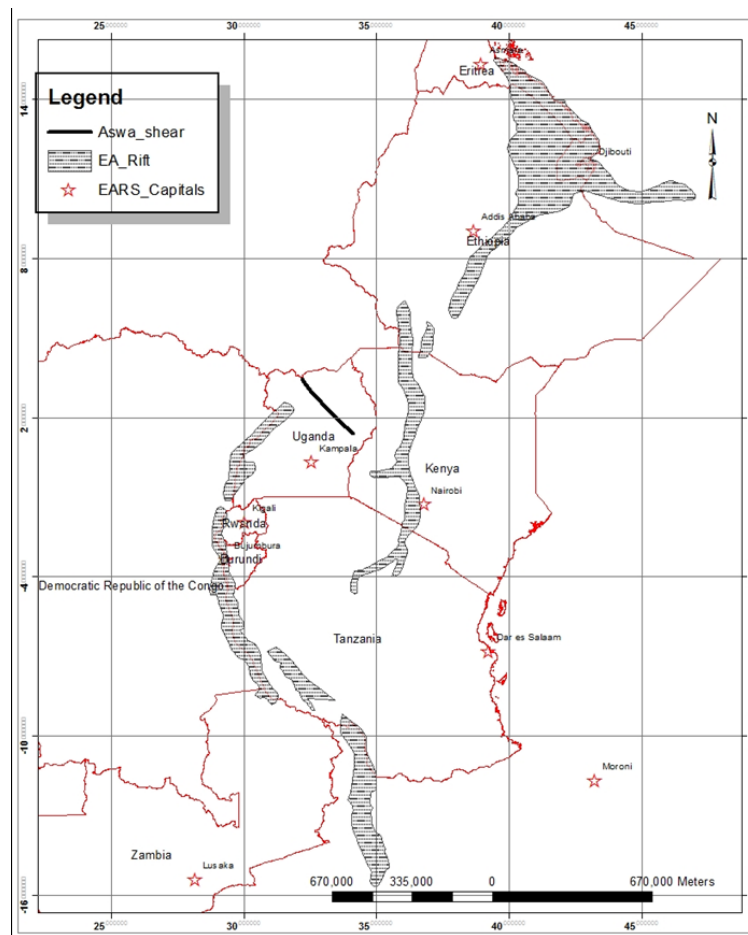


Figure 3 Map showing EARS member states, their capitals and East and West arms of the East African Rift. Note the Aswa in relation to the two arms.

2. THE FELLOWSHIP

This is a report which was produced as a result of a fellowship awarded by the International Centre for Science and High Technology (ICS - UNIDO). The fellowship was under the programme title: Renewable energies (RE) – Supporting developing countries to exploit renewable energy sources for energy production – GIS for mapping geothermal energy sources in East African countries.

2.1 Objectives

According to the terms of reference of the fellowship, the objective was to perform research activities on GIS applications for mapping geothermal energy sources in the East African Rift Valley region.

In practical terms, the objective of the whole project was to use a GIS approach to build a common geothermal geo-database for the EARS countries so that data could be availed for identification of gaps, project formulation for geothermal development, resource assessment, risk analysis and multi-criteria decision supporting tools at country and regional level.

2.2 Geographical Information Systems (GIS) technology and remote sensing

GIS in simple terms can be defined as a computer – aided system designed to capture, store, manipulate, analyse and present geographical spatial data and it should allow such data to be queried in a user friendly manner (Fig. 4).

GIS consist of a number of elements which include personnel (people), software, hardware and procedures (methodology). From this point of view, GIS can then be defined as: A system consisting of people, computer software and hardware, and procedures that can be used to capture, manipulate, analyse, present and query data. Sometimes GIS is referred to as geographical information science or geospatial information studies.

Within the context of this project, remote sensing refers to the gathering of information about the earth without being in direct contact with it. To be more specific, remote sensing is the gathering of information about the earth by using images acquired by satellites or aeroplanes by using electromagnetic radiations or any other forms of energy emitted or reflected by the earth. Other forms of remote sensing include airborne geophysics which measures the magnetic and radiometric properties of the earth or rocks.

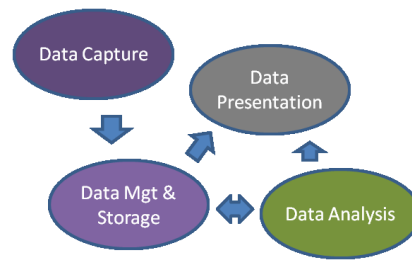


Figure 4 The four major components of a GIS system

In remote sensing, usually the incident ray interacts with the earth and the reflected ray or energy is sensed and recorded. This is processed and analysed to be able to use it to study the differences on the earth's surface. If the source of incident ray of path is the sun, then it is called passive remote sensing, but if the source is artificial such as radar, then it is called active remote sensing. Now days there are several platforms from which imaging of the planet earth is being done such as, Land Sat Aster, MODIS, AISA Eagle, IKONOS, Rapid eye, Quick bird, and world viewer.

2.3 Geothermal energy

Geothermal is a clean, renewable and environmentally benign source of energy based on heat from within the earth's surface. Prospect areas for geothermal heat are only those ones where the depth of the heat and reservoir permit extraction of such heat at a profit by man. The heat is extracted in the form of hot water or steam for power generation or for direct utilisation (Fig. 5).

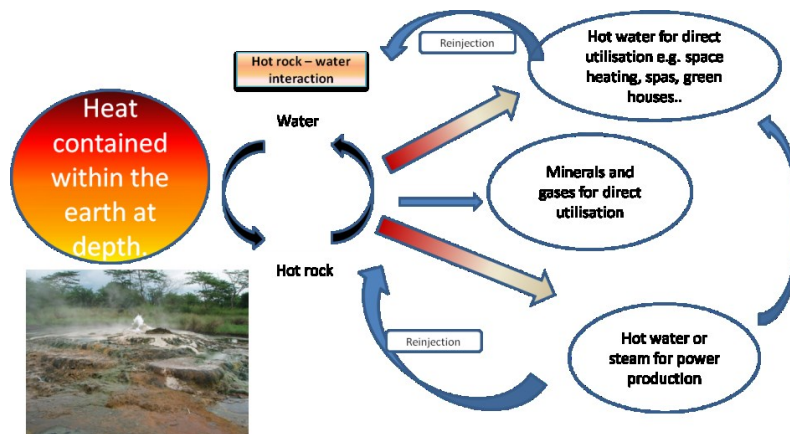


Figure 5 Cycle of Geothermal system

Power generation is only possible in high temperature geothermal fields. Geothermal fields may produce dry steam only, two phase fluids or hot water only. When all conditions of pressure, chemistry and discharge of wells permit, the dry steam can be used directly to turn the turbines (flash power plants). Sometimes the hot water is used to heat another solvent of low boiling point (higher vapour pressure) which is in turn used to turn the turbines (binary power plants.)

Low temperature geothermal fields find direct utilisation application, and this will vary from one country to the other within the region, for example we cannot talk of heating of houses in a hot country like Djibouti. Possible direct use applications within the region may include; heating greenhouses, providing hot water to local communities, drying of agricultural products, spas or balneological uses, and refrigeration.

High temperature gradients for geothermal utilisation and extraction are found in tectonically active zones known as plate boundaries. The EARS region is located on an active divergent zone of the African plate, Arabian plate and the Somalia sub-plate. Because of spreading, the crust thins out leading to an upward movement of heat in the form of volcanism, fumaroles and hot springs found along the rift.

The EARS is said to store a remarkable geothermal energy potential. It is estimated that using today's technologies, the EARS has a potential to generate more than 15,000 MWe of power from geothermal energy (African Union Group report, 2010). There are a number of reasons why the EARS should consider geothermal as one of the major renewable energy sources:

- Geothermal is a clean and renewable form of energy. If Africa is to control the accelerated production of greenhouse gases especially carbon dioxide, it has to resort to carbon free renewable energies. Geothermal is one of them and is available in the region.
- In terms of generating costs of renewables-based electricity generation by technology and learning rates in new energy policy scenarios, geothermal is the cheapest, (World Energy Outlook 2010).

- Geothermal reservoirs and power plants when managed well (monitored), can have long life spans of up to a century. A very good example is the Larderello geothermal field of Italy which has been operating since 1904.
- Geothermal energy systems are not affected by climatic conditions like hydro.
- The region should prepare for the projected population increase as well as increased energy demands which will almost double by the year 2035.

3. DATA TYPES AND SOURCES

The countries that make up the area of study are at different stages of geothermal development and utilisation. This means they have different sources of data to contribute to the regional geo-database. Some countries for sure have less or no geothermal related data to contribute to the geo-database since they are just starting to do their reconnaissance studies for geothermal potential. However, whether there is data related to geothermal or not, other datasets for forming the base map had to be put together during this exercise of mapping the geothermal sources. Layers like rivers and streams, water bodies, roads and railways were all mapped. Water is very important in geothermal systems because it is required to mine the heat from hot rocks and also during drilling. Roads and railways are needed for planning of geothermal development activities in terms of accessibility. Tectonically and volcanically active areas were also mapped because they are the potential sources of heat.

The data that is required to construct the geo-database should throw some light on the spatial distribution of geothermal potential areas, political and administrative boundaries and areas, main power grids, existing power plants and wells, hydrology (lakes and rivers), transport facilities, conservation areas, geo-hazards and terrain (for slope and altitude related analysis). With all this kind of information, multi-criteria analysis can be done during formulation and implementation of projects.

3.1 Datasets

The datasets that were used in this exercise were from different sources. The data types were either geographic spatial data or non-spatial datasets sometimes referred to as ancillary data.

3.1.1 Geographic spatial data

Spatial data is one which was obtained already with geographic coordinates and could easily be integrated into the GIS directly, with or without coordinate transformations. Some of the data was obtained from the member states, from ESRI data sets and also from different web sites (online data). Spatial data used may be categorised as raster, vector remotely-sensed and so on.

The data that was acquired in raster format involved satellite images, aerial photographs and digital terrain models (SRTM). Satellite images were downloaded from different sites as well as those provided by some member states of the EARS. Now days there are several sites from which satellite images can be downloaded. The SRTM was obtained from ESRI data provided on CD's. Data in the form of shape files were also obtained from different sources including online sources. Some of the important sites from which data was obtained include; <http://databasin.org/>, www.diva-gis.org, <http://glovis.usgs.gov> and <http://glcf.umiaccs.edu/index.shtml>.

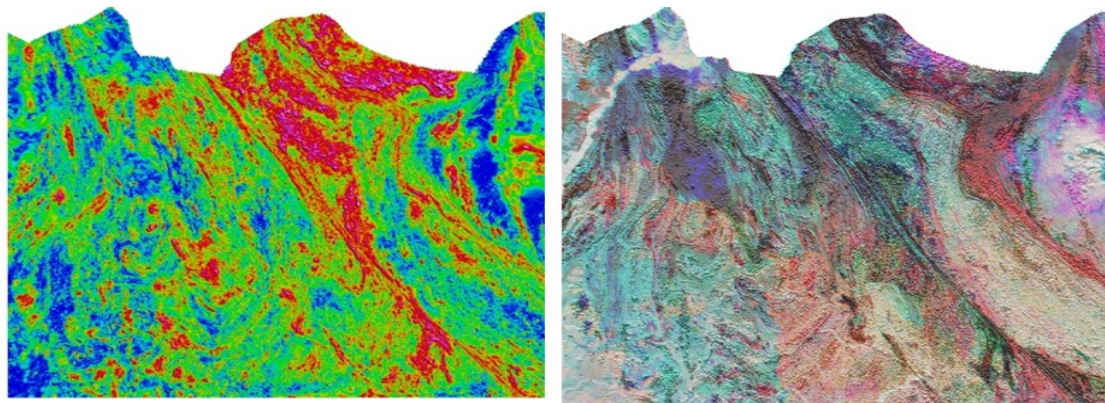


Figure 6 Portions of airborne magnetic data (left) and Radiometric data from Uganda that clearly define the Aswa shear zone trending NW-SE

For some countries such as Uganda, airborne geophysical data such as magnetic and radiometric data was used (Fig. 6). Magnetic data for example can be used to delineate all structural features. The tilt derivative of total magnetic intensity for example, is very useful when mapping faults and shear zones. In the future, we would need all such data if available to be used to improve on this geo-database.

3.1.2 Ancillary Data (Non-spatial data)

Over the years, a lot of work related to geothermal exploration and development has been done in the EARS region and some reasonable amounts of data have been collected. Unfortunately, there has been no common geo-database to store such information or data. Even at the country level there are countries whose geothermal data has not been managed properly. Worse still, most of the data has not been GIS based and it is usually stored as written reports and printed maps. In some cases there is no organised way of storing such important information. During this exercise, it was demonstrated that data contained within reports maybe

transformed into GIS formats and stored in an organised manner. Data was obtained from previous reports, printed maps or legacy maps, tables and so on.

Some excel templates were sent to the member states to acquire data concerning geothermal fields, institutions in charge of geothermal development as well as geothermal power plants and wells. In these templates several fields were included to give information about the status of exploration, availability of laboratories and equipment related to geothermal exploration and development.

3.2 Previous work and strategies.

Throughout the whole region of the EARS, work related to geothermal exploration has been done over the years. In some countries, reports show that this kind of work started as early as 1889, but through the years no organised geo-database for the region has ever been established. It is also absurd that although exploration works for geothermal started long ago; hitherto only two countries (Kenya and Ethiopia) are generating electricity from geothermal. This has rendered all the geothermal potential untapped which is estimated to be up to 15,000 MWe. In the following few paragraphs a summary of geothermal exploration has been highlighted for some of the countries whose information was accessed. Through reviewing old information, data was extracted and stored in the regional geo-data base.

An African Union (AU) group report that was compiled in connection with the regional geothermal stakeholders' workshop, held March 2010, contains some important information. The report summarised the status of geothermal exploration and development and also highlighted a five year strategy beginning from the year 2010 for eleven countries. It also looks at the energy policies of different countries to see if geothermal is given a priority, personnel and equipment. Such info has been extracted and included in the database.

3.2.1 Djibouti

The historical aspects of geothermal development in Djibouti were not accessed because of limited time. Currently, a pre-feasibility study was done at the Lac Abhe project. Phase two which involves the feasibility studies and deep drilling is still pending (Ainan 2010). The licence to this project was awarded to an India-based company and according to Ainan (2010), environmental assessments and logistic settings were completed. The project may produce up to 150 MWe utilising reservoirs of medium depth (400-600 m deep). Binary power plant technology will be used in this project.

They plan to utilise a number of low temperature prospects using binary. Djibouti being a volcanically active point, previous drillings made for the search of water showed that there is heat almost everywhere. It was common to intercept water at temperatures of 40-60°C at a depth of 100 metres. The five year strategy was to produce 50 MWe at Assal.

3.2.2 Eritrea

In Eritrea, assessment of geothermal resources started as early as 1902 at Alid by Angelo Marini from the Italian Institute for Military Geography, (Yohannes 2011). In 1973, a reconnaissance survey sponsored by UNDP was carried out to map geothermal potential areas. Prof. Giorgio Marinelli in 1992 made studies and recommended detailed studies to be carried out at Alid geothermal prospect. Studies at Alid were carried out by different teams and times; 1994 by Mikhail from Geological Survey of Israel and 1996 by the Geological Survey of USA. In 2004, geochemical re-interpretation of all geothermal water and gases was carried out (Yohannes 2004). According to the AU report, the five year strategy for Eritrea is to establish a pilot power plant at Alid.

3.2.3 Ethiopia

In Ethiopia, geothermal exploration started as early as 1969 and findings show the existence of both low and high temperature geothermal areas, sixteen of which may be utilised for electricity generation. In 1980, eight deep wells were drilled at a depth of about 2,500 metres at Aluto Langano. Four of these wells were productive (Meseret et al 2005).

Later in 1990, exploration drilling was also made at Tendaho and showed existence of high temperature and pressure fluids. Three of these wells were deep (2,100 m) and three were shallow. The first pilot power plant at Aluto Langano was commissioned in 1998 with a net capacity of 7.2 MWe. Studies have also been done at other prospects which include Corbetti, Tulu Moye-Gedemesa, Abaya, Dofan, Fantale and Meteka. The strategy of Ethiopia by the year 2014 is to increase production up to 125 MWe from Aluto Langano and Tendaho (AU Group report 2010).

3.2.4 Kenya

Exploration for geothermal resources in Kenya started far back in the 1960's with surface exploration leading to drilling of wells at Olkaria. Exploration continued in the 70's between Lake Bogoria and Olkaria and by 1973 deep exploration well drilling was done and was funded by UNDP (Simiyu 2008). The first 15 MWe power plant was commissioned in 1981 at Olkaria, followed by two other units each producing 15 MWe in 1982 and 1985.

In 2003, two units of 35 MWe each were commissioned at Olkaria 2 (Mwangi 2005). There is a private producer generating 12 MWe at Olkaria III. In addition to KenGen and the government of Kenya, other companies that are doing exploration work in Kenya include British Geological Survey (BGS) and Geotermica Italiana Srl.

From such studies above, the geothermal potential for Kenya has been estimated at 4,000 MWe and from such production, only a very small fraction is being utilised and only at Olkaria. The government has undertaken studies at Olkaria, Lakes Bogoria and Baringo, Korosi and Paka volcanic fields. The future plan of Kenya is to install an additional 1,260 MWe by the year 2018. This requires an investment for 300 production wells and 60 reinjection wells (Simiyu 2008). The strategy by the year 2014 is 880 MWe according to AU group report.

3.2.5 Uganda

In Uganda, mapping hot springs started in 1921 by the Geological Survey of Uganda. Serious exploration work for geothermal resources started in 1993 and several prospects were identified. Detailed studies focused on three prospects; Katwe – Kikolongo, Buranga and Kibiro. The potential for geothermal energy in Uganda is estimated to be around 450 MWe (Bahati 2009). Surface geology, geophysics and geochemical exploration have been done on the three prospects.

Shallow drilling for temperature gradient measurements was done at Katwe and Kibiro and according to the results there is need to study the details of the structures and to expand the area of study for surface mapping. Currently geothermal only finds a few applications in direct utilisation. The five year strategy is to drill at Katwe, Buranga and Kibiro.

3.2.6 Tanzania

Several reconnaissance surveys and a few detailed studies of hot springs and geothermal sites have been carried out in Tanzania since 1949. In 1979, a geothermal reconnaissance exploration programme was carried out by SWECO – a Swedish consultation group in cooperation with VIRKIR Iceland (Mnjokava 2008). The study investigated 50 hot springs mainly in northern Tanzania and in the Mbeya region and high temperature areas were reported at Lakes Manyara and Natron, Ngorongoro crater and Mbeya, while Lake Eyasi and Musoma areas indicated low temperature prospects. Strategy is to drill at Mbeya.

In 1995 and 2004-2005, further studies were made by Hochstein et al. and Deutsche Energie-consult Ingenieurgesellschaft mbH (DECON, a Germany company) respectively. Geothermal surface exploration in the Mbeya area of Tanzania was carried out between 2006 and 2009 within the framework of GEOTHERM Technical Cooperation, implemented by the Geological Survey of Germany (BGR). The studies involved structural, volcanological and travertine investigations.

3.2.7 Zambia

Hot springs in Zambia have been utilised for a long time. In 1889, Wallace visited and described the springs at Lakes Mweru, Chisi and Wantipa. He found natives producing salt from the hot springs. In 1902, Ferguson did chemical analysis on springs in Zambezi valley when he was trying to relate their chemistry with mineralisation in the area and as an exploration tool (Musonda et al 2005). The Geological Survey of Zambia started exploration work on geothermal since 1950 but no utilisation has taken place.

There are several hot springs in Zambia and according to Musonda, 80% of them have been recorded. Some of the springs and their temperature are shown in the table below.

Prospect	Spring temperature °C
Kapisya	85
Lupiamanzi	73
Lubigu	77
Chongo	87
Chickowa	64
Chinyunyu	73
Kasho	72

In 1986, a pilot power plant was established at Kapisya by Zambian Geological Survey together with DAL SPA of Italy using funding provided by the Italian government. The power plant of 200 KWe was utilising 15 shallow exploratory and production wells and was a binary power plant. Later temperatures were found to be too low and the project never became operational. The government is now working out ways of refurbishing and commissioning the power plant after 15 years of being idle.

4.0 METHODOLOGY

The methodology for mapping geothermal sources and developing a geo-database for the EARS region was divided into four categories which represent a typical GIS. The steps involve data capture and preparation, data management (storage and maintenance), data manipulation or analysis and data presentation or dissemination.

4.1 Data capture and preparation

The methodology for data capture involved several approaches and processes depending on the type of dataset being dealt with. It was at this stage that pre-processing, verification and validation of data was done. Data such as satellite images and shape files were downloaded from various sites (or provided by member states) and projections and coordinate transformation done where necessary. The datum and projection used for all data sets was UTM WGS 84. Enhancements for raster data was done such as multiband displays (composites), ternary images, clipping and subsets. For shape files, verification and validation was done followed by topology.

SRTM covering the whole region was prepared according to UTM zones. The UTM zones that cover the countries of interest were selected, dissolved and buffered to ensure overlap. The SRTM was clipped using the respective buffered UTM zones and each slice of SRTM was projected and hill shade applied to it to assign it a 3D feeling.

For non-spatial data, a lot of literature review was done so that data could be extracted out of the different reports and pdf files. Tabulation of information was done with or without coordinates. The resultant table were integrated into GIS; those with coordinates were added as XY data and converted into shape files. Tables that were lacking coordinates were either joined and related, with other tables within ArcGis or stored as standalone tables.

Available paper maps and those contained within the reports were scanned and converted either to jpeg or tiff and geometric correction done to them. Excel tables were designed (for information about geothermal fields, geothermal institutions and power plants) and sent to respective countries to collect information about geothermal exploration and development. The data that was received was verified and validated, and of course some of the data had wrong coordinates. Editing was done and columns standardised according to ESRI or geo-database formats and exported to GIS.

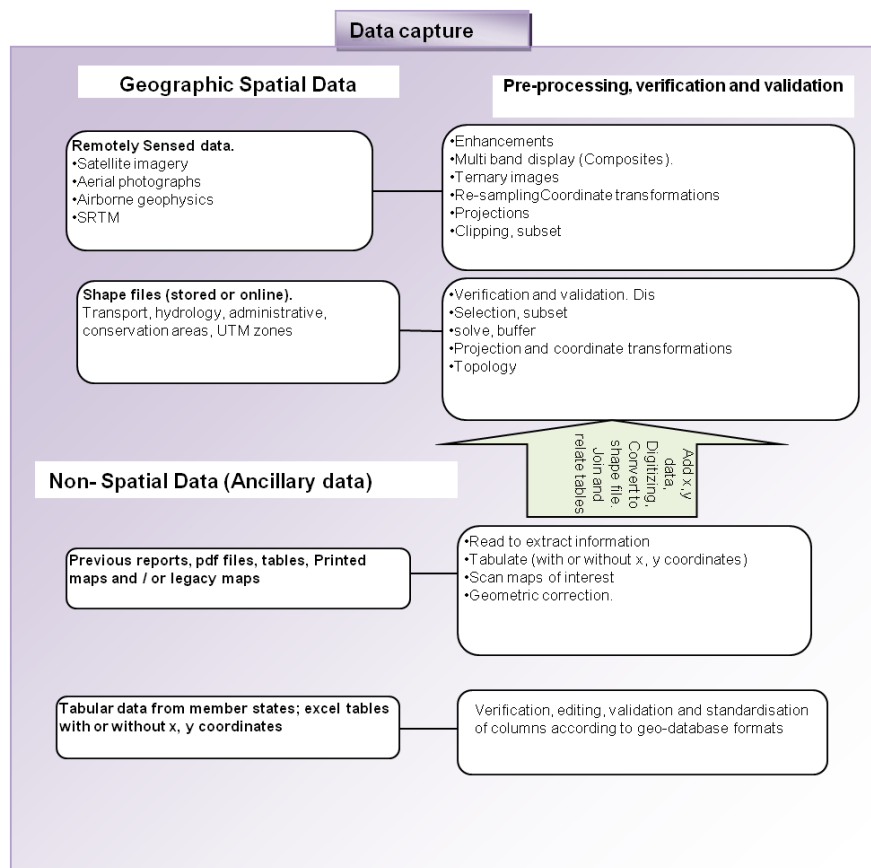


Figure 7 Methodological steps taken in the data capture phase.

4.2 Data Management – storage and maintenance

For purposes of data storage and management, a geo-database was developed. The geo-database stores raster data, vector data (shape files) as well as tabular data. For vector data eleven (11) feature classes were developed to house different feature datasets (Fig. 8). The feature classes that were developed were just to start with and were based on the data that was available, but this geo-database will be revised from time to time as new data comes in. New feature classes may be added from time to time based on prevailing scenarios and needs. There is still more work that needs to be done even on the data stored in the GDB, therefore working on it continues and there is a need for all stakeholders to provide contribution.

4.3 Data manipulation and Analysis

The manipulation and analysis of data involved several processes such as layer overlays, classifications, map algebra, band ratios, principle component analysis, operational geographical units, spatial joins, buffers, Euclidian distances, clipping and grid analysis (Fig. 8). For this project, some of this analysis was not done because some of the data was still lacking. The spatial resolution of the images that were provided could not allow the small features such as surface manifestations, which are tiny at regional scale. As more data gets filled into the geo-database, much more analysis will be done including multi-criteria evaluation. The kind of analysis that is done will depend on the kind of question whose answer is being looked for, and from area to area and data that is readily available. Some of the analysis and processing was done using models that were built using the model builders' tools within ArcGis.

4.4 Data presentation and dissemination

This stage can also be called data modelling and end product. Here data and information is availed to stakeholders and end users. Cartographic presentation will be used to prepare maps at different scales and of different layers depending on end user's needs. Web-based presentation is also possible, for example some of the map and layers were converted to kml (kmz) files that can be published on Google Earth.

Information will also be availed in the form of hardcopies such as printed maps, atlas and compiled reports. ICS-UNIDO was to publish this kind of information if and when it is ready and logically arranged and organised, but before this, stakeholders' workshops and meetings were necessary for more inputs and paving the way for more data to be gathered and added to the geo-database.

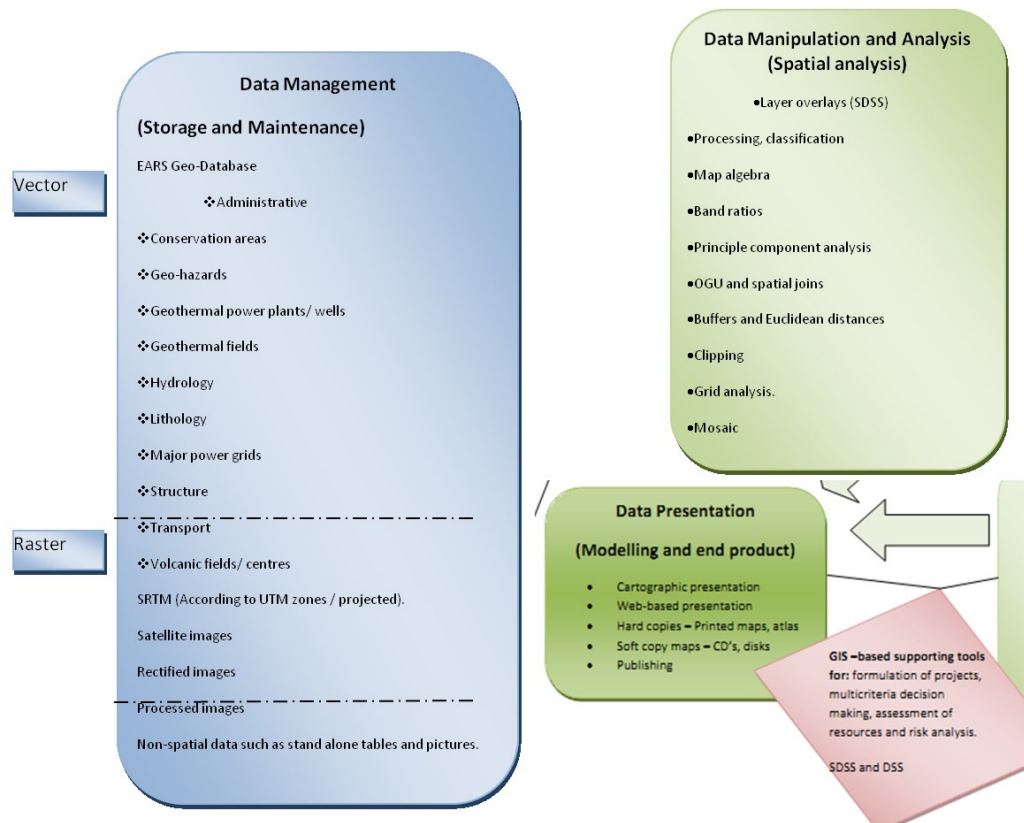


Figure 8 Methodological approaches in the Data management, manipulation, analysis and presentation phases

5.0 END PRODUCT, CONCLUSIONS AND RECOMMENDATIONS

The end result was a geo-database organised in an orderly manner with data that can be used for formulation of geothermal project proposals, multi-criteria decision supporting tools (SDSS and DSS), assessment of resources and risk analysis at both country and regional levels. The database is made up of eleven feature classes, raster data sets and tabular data (both GIS based and stand alone). Many types of analysis cannot be done because the database lacks a lot of data which is to be availed by the member states. Schemas for data that has not been availed are already prepared and waits for data to be filled in.

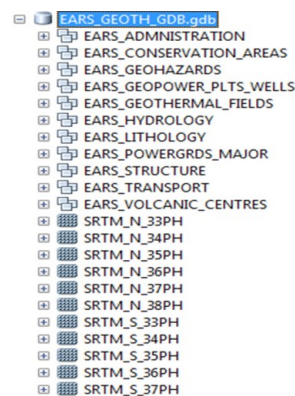


Figure 9 Part of the East African Rift system database. More data is still required in the data base.

The geo-database as it now can be used to provide a lot of information through queries and selections in ArcGIS. The kind of end products such as maps and analyses can be prepared according to the end user, for example from SRTM slope angles analysis may be made so as to get slopes which are most likely to permit for land slides, slope analysis for optimum solar energy utilisation, volcanic centres can be queried so as to get what kind of magmatic flows, eruptions and status in terms of volcanic activity.

With the complete database:

- Maps can be produced based on the needs of end user. The maps and overlays are Spatial Decision Supporting Systems (SDSS).
- It will be easy to develop GIS-based decision supporting systems (SDSS and DSS).

- With data, gaps can be identified and formulation of projects related to geothermal development and utilisation possible.
- The same database can be used to do other studies in the region such as solar energy studies and any other sites investigations.
- Resource assessments can be done at a regional level.
- Risk analysis such as those related to geo-hazards can be done e.g. earthquake and landslide high risk areas.

5.1 Conclusions and recommendations

- ✓ Data acquisition was a big constraint in this project. There is need for ICS in collaboration with the EARS region and Fellowship to get means of getting the required data. Now that ICS suspended its activities, the region or another partner should take on the project so that it becomes beneficial to the region. Since ARGeo has a similar vision of a regional database which it is building, probably the two projects can be married.
- ✓ Some countries do not have data to provide. Some data requires one to go on ground. There are times when some countries feel insecure to provide data for regional database.
- ✓ More data is needed before the GDB can be used for certain types of multi-criteria evaluation.
- ✓ The EARS member states did not respond satisfactorily in terms of availing data to the GDB.
- ✓ There is need for ICS and EARS member states (or any other partner) to organise a forum where the little achievements can be disseminated and bring every stakeholder on board. This will allow ideas to be exchanged and create awareness for more data to be acquired and to see how member states can access and make use of the database when need arises.
- ✓ At a regional scale (1: 18000000), remotely sensed images may not allow analysis for studies on geothermal manifestations.

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