Evaluation of the Geothermal Potential for Korosi/Chepchuk Prospect, Kenya, Using GIS

Levi Shako and Joseph Mutua
Geothermal Development Company, Nakuru, Kenya
lshako@gdc.co.ke • jmutua@gdc.co.ke

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ABSTRACT
Geographical Information System (GIS) is a technology used to determine the spatial association between geo-scientific data layers with a view to mapping production zones in a geothermal area. Surface observations in Korosi/Chepchuk geothermal prospects in Kenya were used to identify suitable areas to site exploration wells. Areas characterized by high permeability (faults and structures), surface manifestations, and anomalous values in the apparent resistivity surveys were the main targets. Detailed surface exploration survey was done using various scientific methods, mainly: Geophysics (MT, TEM and Gravity), Geology (Structures, eruption centres), Geochemistry (Soil Gas sampling), and Reservoir Science (Heat Loss measurements). Data integration method within GIS was used in determining the spatial relationship between the datasets to assess the geothermal potential and prioritize areas for exploration drilling. ArcMap, geoprocessing and model building tools were used to develop the GIS Model for Priority Areas for Exploration Well (PAEW) project.

Introduction
GIS software applications today have the tools for creating multi-layer spatial databases. Using a variety of data structures, and ensuring the geographic registration between layers, multi-layer analysis can be done to give spatial relationship of multi-themed datasets (Bonham-Carter, 1994). In the current trend of a multi-disciplinary approach in natural resource utilization and management, GIS offers a basis for integrating both data and analysis tools from broad spectra of scientific disciplines. This paper aims to present an understanding of concepts and methodologies involved in the field of GIS. It describes major steps involved in processing spatial information and illustrates the diversity of GIS application in spatially related problems. GIS as a set of computerized tools, also provides an integrated environment for storage, management, retrieval, processing and analysis of spatial information from the applied geosciences. GIS models have been successfully applied in regional exploration studies of mineral resources (Bonham-Carter et al., 1988; Agterberg, 1989; Bonham-Carter, 1991; Bonham-Carter et al., 1994).

In making decisions and plans on geothermal resources, data must be collected, processed and analyzed to describe the resource. There are a set of multi-criteria and multi professional cadres of datasets that should be considered in field during geothermal exploration for eventual weighting in site selection for geothermal exploration drilling. Spatial data collection procedures and/or models must be developed to predict the resultant findings and viability of geothermal resource exploitation and associated environmental, economic effects and their mitigation measures.

Physiography of Geothermal Prospect Area
Korosi and Chepchuk volcanoes are located in the inner trough of the Kenyan rift, which is a NNE-trending zone of Quaternary volcanism and sedimentation. The trough varies in width between 17-35 km in the north and south respectively. It is bounded to the east and west by escarpments that are controlled by faults and monoclinal warps and has a marked northward gradient (Omenda, 2000). Korosi is one of the main volcanoes in the northern rift floor rising about 500 m above the surrounding floor of the trough and covers an area of about 260 km². No caldera or major crater is developed on the volcano. Its landforms are degraded and the shield is broken by a set of prominent NNE trending faults. Chepchuk is the highest point (1380 masl) of a series of prominent N-S trending ridges that rise 220 m above the plains to the NW of Korosi and SW of Paka. The remnants of Chepchuk volcano crop out over an area of about 100 km².

Methodology
GIS technology was used for integrating data and information from the geo-scientific disciplines and development of a conceptualized geothermal model of the area. Surface exploration survey in
Korosi/Chepchuk was done with the aim of determining whether the prospects are suitable for further exploration and drilling.

A GIS was used to carry out a suitability analysis and site selection process because it can handle a large amount of data, is a powerful tool to visualize new and existing data, can help produce new maps while avoiding human errors made during decision-making and allows the effective management of the GIS data (Noorollahi et al., 2007). The main sets of data used for integral interpretation using GIS were captured through various techniques.

**Geology Prospecting**

Detailed geological mapping of the prospect areas was carried out to confirm the reported geological features, surface geology, structures, hydrothermal indicators and their distribution. Interpretation of data collected assisted in development of volcanological model of the areas in order to help in understanding the geothermal system and to establish the heat source, reservoir rocks, hydrogeological controls and possible capping formation.

**Geophysics Prospecting**

Transient-Electromagnetic and Magnetotellurics (MT) measurements were done to infer the depth and extent of the possible heat source and geothermal reservoirs. Magnetic and gravimetric data was conducted to define the location of intrusive bodies and regional faults.

**Geochemistry Prospecting**

This entailed sampling and analyzing fumarole steam discharges, borehole waters, and carbon dioxide and Radon in soil gas. The results have also been used to estimate reservoir temperatures based on geothermometry.

**Surface Heat Loss Measurement**

Surface heat loss measurements were done to estimate the natural conductive and convective heat loss within the prospect areas. Conductive heat loss was estimated by drilling 1 m holes and recording temperatures at surface, 25cm, 50cm, and 1 m depths. Convective heat loss measurements were done by measuring flow rates of fumarole steam. Boreholes were also logged to measure temperatures and pressures. Data obtained were used to estimate total natural heat loss and define the shallow hydraulic gradient.

**GIS Data Integration**

The process followed in carrying out the suitability analysis of the data obtained for the Korosi/Chepchuk geothermal prospects were data combination and merging after initial processing and analysis, weighted distance analysis and finally weighted overlay. The process is outlined in the figure below;

**Evidence Layers (Thematic Maps)**

Five data sets were obtained from the exploration of Korosi/Chepchuk field and integrated in a GIS environment to predict the best areas to locate exploration wells. The data introduced in the model are surface geology (structures), resistivity anomalies, geochemistry (Soil gas sampling) heat loss anomalies and surface manifestations.
Geology Dataset

Digitized data on spatial distribution of geologic structures including major faults on the eastern and western flanks of Korosi geothermal prospect and eruption centres were included in the surface geology map.

From the field geologist’s evaluation, the heat source for the geothermal resource at Korosi is associated with shallow magmatic bodies associated with the Upper Trachytes and to a less extent the intrusive dykes associated with the Young Basaltic magmatisms (Omenda, 2006). The manifestations on Korosi are confined within an area of approximately 33 km$^2$. Surface temperatures in some areas are about 90°C and reach a maximum recorded value of 96°C. Surface activity within all these areas is located upon faults or in close proximity to them (Lucy N, et al., 2011).

Geophysics Dataset

The Geophysical prospecting involved the use of transient electromagnetic (TEM) and magnetotellurics (MT) equipment. The TEM and MT measurements were employed to image the subsurface for the existence of electrically conductive zones that could be geothermal reservoirs. By processing the spatial sample data, electrical resistivity maps at different depths are obtained.

At sea level the low resistivity anomaly on the Western part of the Korosi massif might be as a result of conductive alluvial sediments. On the central part of the prospect a slightly high resistivity anomaly of less than 40 ohm.m sets in probably due to high temperature alterations minerals such as chlorites and epidotes (C. Muturia et al. 2011). The aim of the geophysical work was to examine the reservoir extent and identify structures that could be possible conduits for geothermal fluids and nature of the heat source. Areas with a resistivity between 10Ωm and 50 Ωm were selected as potential sites for geothermal. The trend surface plots and maps for sub surface resistivity was done using WinGLink, and Surfer which was then exported into a GIS for further geoprocessing using spatial analysis tools.

Geochemistry Dataset

Geochemical prospecting entailed spatial sampling of fumaroles discharge, borehole water and soil gas to determine the concentrations of carbon dioxide and radon radioactivity. The main objectives of geochemical prospecting are to infer reservoir temperatures from the composition of geothermal fluids present, define areas with enhanced permeability within the prospect from soil gas survey and to determine the chemical characteristics of the geothermal fluids present and their suitable uses.

From analysis and trend surface maps done in ArcMap for the above geochemical samples information on geothermometry, nature of the reservoir and permeability were derived. High concentrations of radon are more likely to be due to convective movement of gases rather than diffusive processes. This implies that high concentrations of soil radon are related to moving hydrothermal fluids that could also have the capability of altering the rocks (Kanda et al, 2011).

Heat Loss Dataset

Natural heat loss at Korosi and Chepchuk geothermal prospects is mainly by conduction through soil and very little by convection through weak fumaroles or steaming grounds. These features are
located along fault lines in both prospects. At Korosi heat loss features display a NE-SW and NW-SE trend while at Chepchuk the trend is not well defined (Mwawongo, 2005).

Data Integration Modeling

Data integration models application to geothermal exploration requires expertise in the selection of the maps that will provide predictor keys of the resource. Assignment of weights in the Index Overlay model depends on the conceptual model of the system to be under exploration.

To answer the questions where, why and how in siting exploration drilling wells, suitability modeling is a useful approach of weighting different types of data from various professional depicting different cadres of geothermal indicators. The useful of traditional overlay analysis techniques cannot be over emphasized coupled with multi criteria suitability analysis and weighting procedures. Based on the geothermal exploration data for Korosi prospect, processing and analysis was carried out as the initial stage of establishing trends of the various indicators prior to suitability modeling and overlay.

The data sets that were considered in the suitability modeling and overlay analysis for Korosi and Chepchuk prospect included the following:

(i) Geological data – Faults and fractures, eruption centres and fumaroles locations
(ii) Geochemical data – CO2 and Radon222 distribution in soil gas, and the ratio of Radon222 to CO2
(iii) Geophysical data - This composed of resistivity plots at different levels of MT soundings and gravity measurements
(iv) Surface Heat Loss Measurements

The weighting scheme was guided by the following criteria of geothermal favorability of the geo scientific results with regard to geothermal suitability a given area:

a) Near (less than 500m) from volcanic domes/eruption centers, which are presumed to be associated with one or more heat sources;
b) Close (less than 200m) to the more permeable areas of the system as defined by faults and fractures;
c) Areas where the carbon dioxide gas concentration is greater than 0.8%
d) Areas where the radon gas concentration is greater than 80 parts per million
e) Areas where the ration of radon to carbon dioxide gas concentration is greater than 80
f) In the vicinity of surface manifestations (e.g. fumaroles, hot springs and acidic hydrothermal alteration zones (less than 1000m) which may indicate the main fluid upflows in the system;
g) In areas where the apparent electrical resistivity is between $10^2\Omega$m and $50^2\Omega$m at target depth (in this case, sea level) for MT sample measurements
Weights are important in any suitability modeling and spatial autocorrelations. In weighting the different geothermal indicators from the different disciplines the following weights were applied as shown below.

These weights can be varied to create different sets of scenarios for use in supporting decisions as the factors to be considered vary from one field to another. Fig 7 shows geothermal drilling priority areas using geophysics, geochemistry, heat loss and geology datasets.

**Discussion**

In geothermal exploration, the areas to be identified are those in which geothermal fluids can be found at temperatures higher than 200°C, and permeability is high enough to allow the inflow of geothermal fluid from the reservoir to the vicinity of the well. The following table outlines the areas of the different ranges of suitability of the Korosi and Chepchuk prospects for geothermal exploration drilling model.

<table>
<thead>
<tr>
<th>Suitability</th>
<th>Area(sq. Km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>86</td>
</tr>
<tr>
<td>Medium</td>
<td>81</td>
</tr>
<tr>
<td>Low</td>
<td>156</td>
</tr>
</tbody>
</table>

**Conclusion**

To contribute and assist in decision making and siting of exploration wells, a suitability model was developed by weighting data collected by different geo-scientific teams using GIS. Preliminary siting of exploration wells can be achieved via a geographical information system based on surface geology, soil gas sampling, heat loss and resistivity surveys. This system can also be used to identify areas suited to more detailed exploration before drilling an expensive exploration well; for instance, costly detailed geothermal gradient measurements could be performed only in the areas that the Index Overlay model has assigned favorability values higher than 60%, (R.M. Prol-Ledesma, 1998). GIS provides a quick and integrated vision for the prospect areas over various scientific evidence data sets for viability of geothermal resource.

In Korosi/Chepchuk geothermal prospects, zones represented as moderate, high and very high priority, delineated by Index Overlay data analysis models on the basis of available geoscientific data were considered for siting exploration wells.
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References


R.M. Prol-Ledesma, Evaluation of the reconnaissance results in geothermal exploration using GIS.