Proceedings of the 4th African Rift Geothermal Conference 2012
Nairobi, Kenya, 21-23 November 2012

Geo-scientific Data Integration to Evaluate Geothermal Potential Using GIS (A Case for Korosi-Chepchuk Geothermal Prospects, Kenya)

Levi Shako and Joseph Mutua

Geothermal Development Company, P. O. Box 17700-20100, Nakuru, KENYA

lshako@gdc.co.ke, jmutua@gdc.co.ke

Keywords: GIS, Models, Geothermal, Exploration Drilling, Korosi, Chepchuk

ABSTRACT

Geographical Information System (GIS) is a technology used to present the spatial association between geo-scientific data layers with a view to mapping production zones in a geothermal area. Surface observations in Korosi and Chepchuk were used to identify suitable areas to site exploration wells. Areas characterized by high permeability (faults and fractures), surface geothermal 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 a Geographical Information System was used to determine 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.

1.0 INTRODUCTION

GIS software today has 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-thematic 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 map and describe the resources. There are a set of multi-criteria and multi professional cadres of datasets that should be considered in the 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, the associated environmental and economic effects as well as their mitigation measures.

2.0 PHYSIOGRAPHY OF GEOTHERMAL PROSPECT AREA

Korosi and Chepchuk volcanoes are located in the inner trough of the rift, which is a NNE-trending zone of Quaternary volcanism and sedimentation. The trough varies in width between 17-35km 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 and Kizito, 2000). Korosi is one of the main volcanoes in the northern rift floor rising about 500m above the surrounding floor of the trough and covers an area of about 260km^2. 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 220m above the plains to the NW of Korosi and SW of Paka. The remnants of Chepchuk volcano crop out over an area of about 100km^2.

3.0. 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 surveys in Korosi and 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 (Yousef et al., 2007). The main sets of data used for integral interpretation using GIS were captured through various techniques.

3.1 Geological 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 the development of volcanological model for 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.

3.2 Geophysical Prospecting
Transient-Electromagnetic (TEM) 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 collected and interpreted to define the location of intrusive bodies and regional faults.

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

3.4. 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 1m 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 was used to estimate total natural heat loss and to define the shallow hydraulic gradient.

4.0 GIS DATA INTEGRATION
The process followed in carrying out the suitability analysis of the data obtained for the Korosi and 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 1 below:

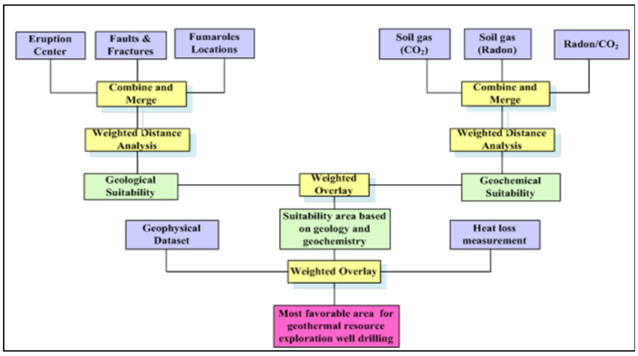

Figure 54: Suitability model schematic.

4.1 Evidence Layers (Thematic Maps)
Five data sets were obtained from the exploration of Korosi and Chepchuk fields and integrated in a GIS environment to predict the best areas to locate exploration wells. The data introduced in the model includes surface geology (structures), resistivity anomalies, geochemistry (Soil gas sampling) heat loss anomalies and geothermal surface manifestations.

<u>4.1.1 Geology Dataset</u>
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 (Figure 2). 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 (Ofwona et al, 2006). The manifestations at Korosi are confined within an area of approximately 33km^2. Surface temperatures in some areas are about 90^{o}C and reach a maximum recorded value of 96^{o}C. Geothermal activity within all these areas is located upon faults or in close proximity to them (Lagat et al, 2011). Faults and fractures were related to strong stresses at depths related with vigorous hydrothermal activity and could indicate productive reservoir zones. Figure 3 displays proximity distances to these structures as one of input data for suitability model for Korosi and Chepchuk prospects.

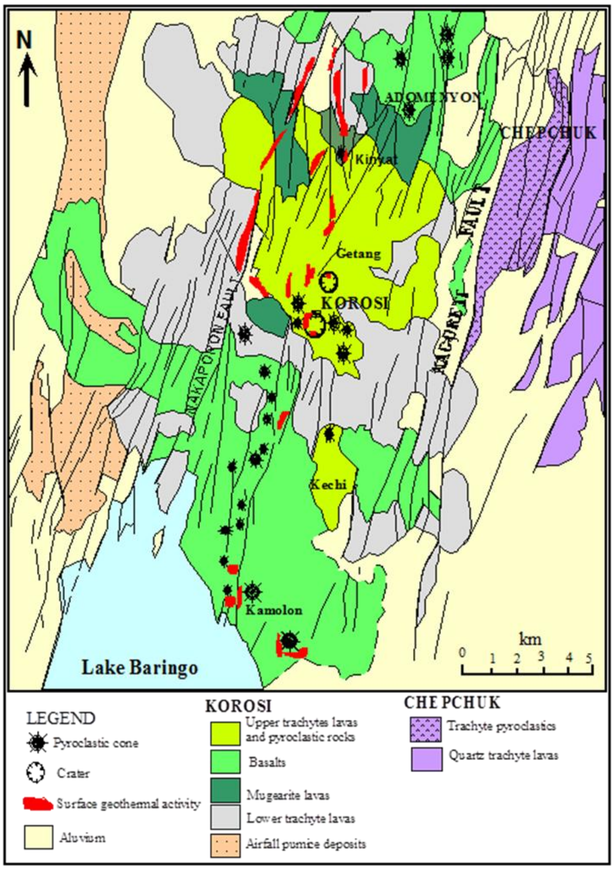

Figure 2: Surface geology map of Korosi and Chepchuk.

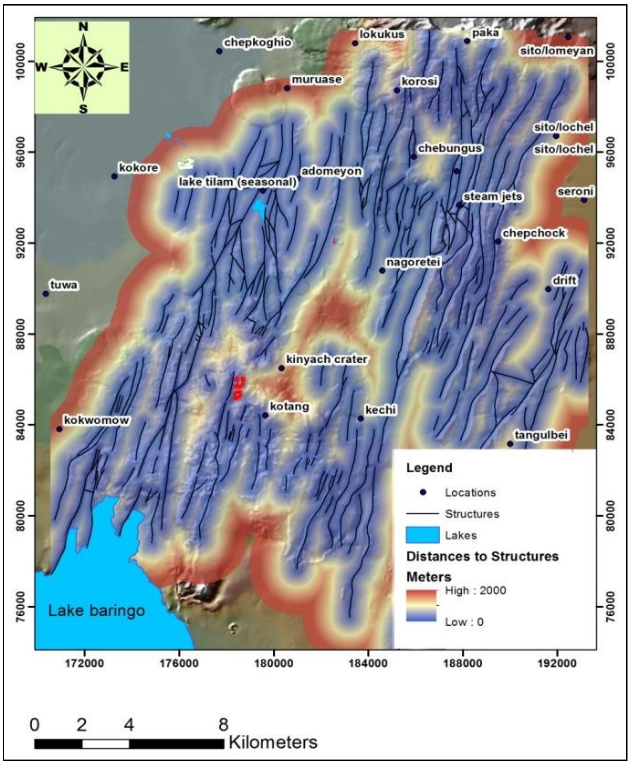

Figure 3: Distances to geological structures.

4.1.2 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 (Figure 4) 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 is probably due to high temperature alterations minerals such as chlorites and epidotes (Lagat et al. 2011. Areas with a resistivity between 10Ωm and 50 Ωm were selected as potential sites with geothermal resource. The trend surface plots and maps for subsurface resistivity were initially done using WinGLink, and Surfer which were then exported into a GIS for further geoprocessing using spatial analysis tools.

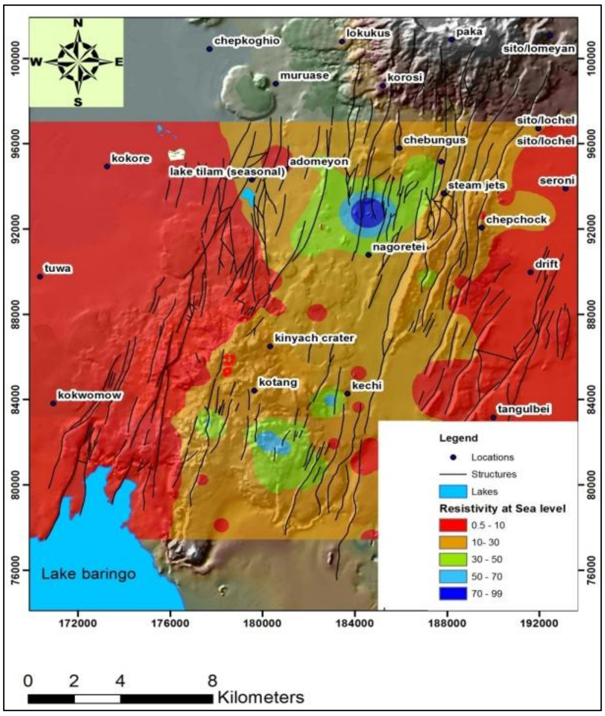

Figure 4: MT anomaly at sea level.

4.1.3 Geochemistry Dataset

The main objectives of geochemical prospecting were 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 was 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 (Figure 5) are related to moving hydrothermal fluids that could also have the capability of altering the rocks (Kanda et al, 2011).

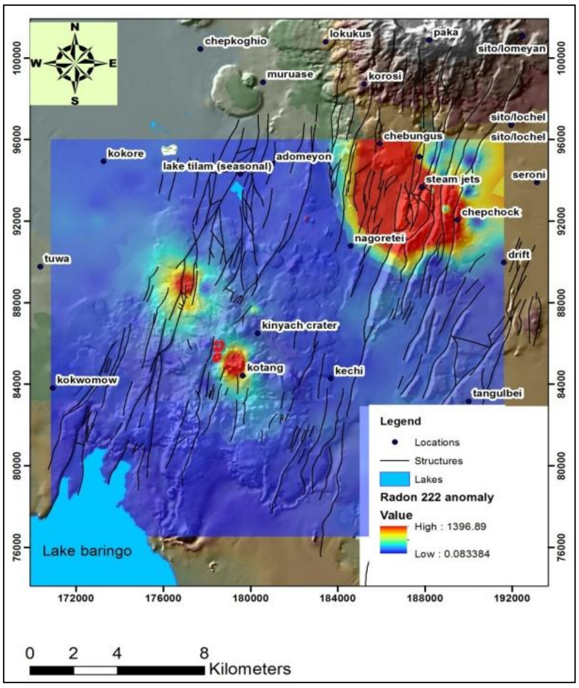

Figure 5: Radon 222 Anomaly Distribution.

4.1.4 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 (Figure 6) while at Chepchuk the trend is not well defined (Mwawongo, 2005).

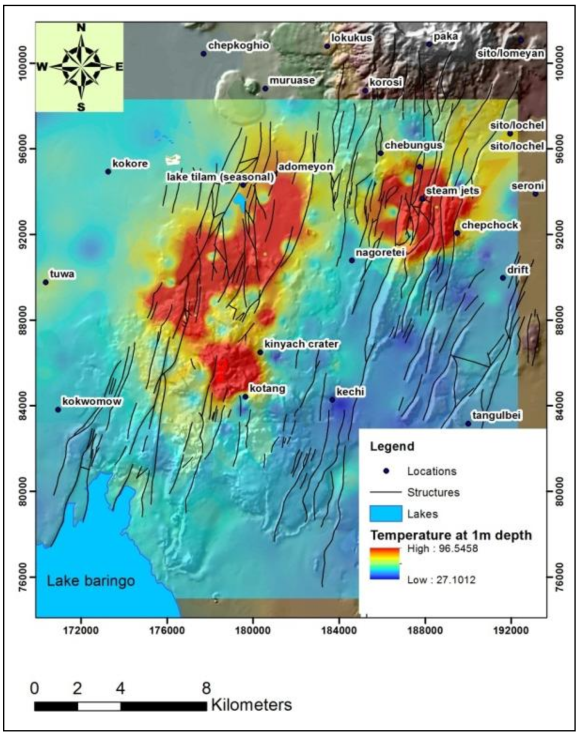

Figure 6: Heat Loss Anomaly Distribution.

5.0 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 disciplines depicting different cadres of geothermal indicators. The use 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 - CO_2 and Radon222 distribution in soil gas, and the ratio of Radon222 to CO_2;
iii. Geophysical data - resistivity plots at different levels of MT soundings and gravity measurements; and
iv. Surface Heat Loss Measurements.

The weighting scheme with regard to geothermal suitability was guided by the following area:

a) Near (less than 500m) from volcanic domes or 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 ratio 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 MT apparent electrical resistivity is between 10Ωm and 50Ωm at target depth (in this case, sea level);
h) Areas with Bouguer gravity anomaly of between -1400 to -1700g.u; and
i) In areas where the soil temperature at 1m depth is above 50^0c.

Weights are important in any suitability modeling and spatial autocorrelations. In weighting the different geothermal indicators from different disciplines, the weights shown in Table 1 were applied. The Index Overlay model uses relevant thematic maps and multiplies them by weight factors with different scores that are assigned to each evidence map according to its relevance for determining the presence of the geothermal reservoir (Table 1)

Table 1: Weighted overlays for evidence layers in suitability model priority map for exploration drilling

Geological Evidence Layer		Geochemical Evidence Layer		Geophysical Evidence Layer		HeatLoss Evidence Layer	
Factor class (Distance in m)	*Weight*	*Factor class (Rn/CO_2)*	*Weight*	*Factor class (Resistivity Ωm)*	*Weight*		*Weight*
0 - 200	9	> 50	9	>10<30	9	> 50	9
200 - 500	8	40 - 50	8	30- 50	8	40 - 50	8
500 - 800	5	30 - 40	6	50 - 70	5	30 - 40	6
800 - 1100	3	20 - 30	5	70 - 90	2	20 - 30	3
>1100	1	0 - 20	1	1 - 10	3	0 - 20	1

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. Figure 7 shows geothermal drilling priority areas using the scheme described above.

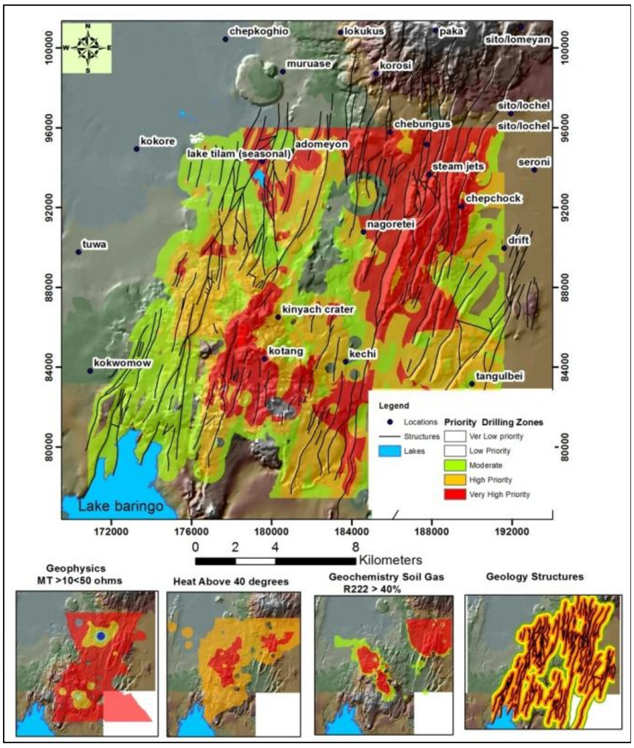

Figure 7: Priority map for exploration drilling.

6.0 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 from the reservoir to the vicinity of the well. Well targeting requires the results of the geological, geochemical and geophysical survey which are combined and analyzed by GIS integration model for exploration data. The final suitability modeling can be advanced by adopting the results of exploration (Figure7). Commonly, production wells are located within the low resistivity anomalies, at the intersection of main faults and at a short distance from the surface manifestations. However, the result from the GIS model shows that more areas may be suitable for geothermal exploitation. The integration of all the available data in a GIS provides an important tool for the evaluation of geothermal prospects in exploration and development stages.

The following Table 2 estimates the areas of the different ranges of suitability of the Korosi and Chepchuk prospects for geothermal exploration drilling purposes.

Table 2: Quantified Priority Areas for Exploration Drilling

Suitability	**Area (sq. Km)**
Very High/High priority	86
Moderate priority	81
Low/Very Low priority	156

7.0 CONCLUSION

Preliminary siting of exploration wells can be achieved via a GIS based on surface geology, soil gas sampling, heat loss and resistivity surveys. This system can also be used to identify areas suited for more detailed exploration before drilling an expensive exploration well. Also, costly detailed geothermal gradient measurements could be performed only in the areas where the Index Overlay model has assigned favorability values higher than 60%, (Prol-Ledesma, 1998). GIS provides a quick and integrated presentation of the various scientific data sets and is a tool for determining viability of geothermal resource as applied in these two prospects.

To contribute and assist in decision making and siting of exploration wells, a suitability model using GIS was developed by weighting different geoscientific data collected from Korosi and Cheopchuk 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.

ACKNOWLEDGEMENT

Our sincere gratitude goes to Geothermal Development Company for approving the publication of this paper. Also to GIS staff, geologists, geochemists and geophysics team for a great job in spatial data collection.

REFERENCES

Bonham-Carter, G.F.: Geographic information systems for geoscientists: Modelling with GIS: Pergamon, Oxford, *(*1994),*398 p.*

Bonham-Carter, G.F.: Integration of geoscientic data using GIS. In: Maguire, D.J., Goodchild, (1991.

Bonham-Carter, G.F., Agterberg, F.P., and Wright, D.F.: Integration of geological data sets for gold exploration in Nova Scotia. Photogrammetric Engineering and Remote Sensing 54, (1988).

Lagat J., Lucy N., Kanda I., Shako L., Mutua J. and Muturia C.: Korosi and Chepchuk Prospect: Investigation for its geothermal potential, GDC internal report, (2011).

Mwawongo G.M: Heat loss assessment of Korosi and Chepchuk geothermal prospects, KenGen internal report, (2006), pp 19.

Ofwona C., Omenda P., Mariita N.,Wambugu J.,Mwawongo G., and Kubo B.: Surface geothermal exploration of Korosi and Chepchuk prospects. KenGen internal report, (2006).

Prol-Ledesma R.M.: Evaluation of the reconnaissance results in geothermal exploration using GIS, (1998).

Omenda P., Opondo, K.: Ranking of Geothermal prospects in the Kenyan Rift, (2000), pp33-40.

Yousef. H, Ehara. S, and Noorollahi. Y.: Geothermal Potential Site Selection using GIS in Iran, *32nd workshop on Geothermal reservoir engineering*, January 22 - 24, 2007, Stanford, CA, USA, (2007).