GEOCHEMICAL ASSESSMENT USING RADON AND CARBON DIOXIDE CONCENTRATION LEVELS FROM SOIL GAS SURVEY, CASE STUDY OF MORENDAT EAST GEOTHERMAL PROSPECT, KENYA

Jesca Muga

MINISTRY OF ENERGY AND PETROLEUM
P.O BOX 30582-00100
NAIROBI, KENYA
teshma6@gmail.com

Keywords: Carbon dioxide; geochemical exploration; permeability; radon and soil gas survey.

ABSTRACT

Geochemical assessment was carried out at the Morendat East geothermal prospect by characterizing radon (^{220}Rn) and carbon dioxide (CO_2) concentration levels from soil-gas survey. The primary aim was to locate permeable zones and infer the presence of possible heat source linked to an active geothermal system. The secondary aim was to rank the prospect and facilitate its development by the private sector. This study focused on the distribution of Radon and Carbon dioxide concentration levels in the soil cover within Morendat East area located in Nakuru County. The area was considered as having potential for geothermal resource hence priority was accorded to it in the financial Year 2014/2015 by the ministry of energy and petroleum. The location is characterized by scarcity of surface geothermal manifestations with one warm spring, therefore soil gas survey was considered appropriate for the geochemical study. Random sampling method was used and resulted in the sampling 100 stations in an area of about 90 square kilometers. CO_2 concentration measurements from the soil were done using an Orsat gas sampling apparatus whereas ^{220}Rn gas concentrations were measured using a portable radon detector (emanometer).The CO_2 values ranged from 0-5.4% while the ^{220}Rn ranged from 0- 2834 cpm. Possible faults were inferred north of the prospect area due to the anomalously high levels of CO_2 and ^{220}Rn recorded.

1.0 INTRODUCTION

In order to meet a fast growing demand of electricity in the country, the Ministry of Energy and Petroleum, Kenya has developed strategies for exploration and development of geothermal energy resources in the country, mainly along the East African Rift. Detailed surface geo-scientific investigations comprising of Geology, Geochemistry and Geophysics together with Environmental assessment are carried out using various methods before a field is committed for exploration drilling and finally steam field development. The Ministry of Energy and Petroleum also undertakes its own geothermal resource assessment of prospective areas, besides the ones being assessed by Geothermal Development Company (GDC) and KenGen, for purposes of ranking them. It is in this regard that the Morendat East prospective area was earmarked for initial surface assessment by the Geo-exploration Department of the Ministry during the Financial Year 2014/15.

1.1 Location

The Morendat East prospective area falls within the Suswa-Olkaria-Eburru tectono-volcanic alignments which have already indicated the occurrence of high potential for geothermal resource that already being utilized for power generation (Figure 1.1). It was only logical therefore that the area be evaluated for its potential, bearing in mind the close proximity of the Eburru Geothermal System. The Morendat East prospect area does not have sufficient geochemical surface manifestations (hot springs, steam vents and fumaroles) hence soil gas survey (radon and carbon dioxide) was used to detect possible structures within the area. It was also applied to evaluate possible heat source based on the concept that gases released from active geothermal systems, can freely rise through overlying cover to be detected in the near-surface, (Fridman, 1990).

1.2 OBJECTIVE

The main objective of the soil gas survey was to assess the study area for potential geothermal resource that can be economically exploited for geothermal power generation. The main aim was to locate buried structures, asses the gas concentration levels and establish whether they could be linked to an active heat source below and finally rank the prospect.

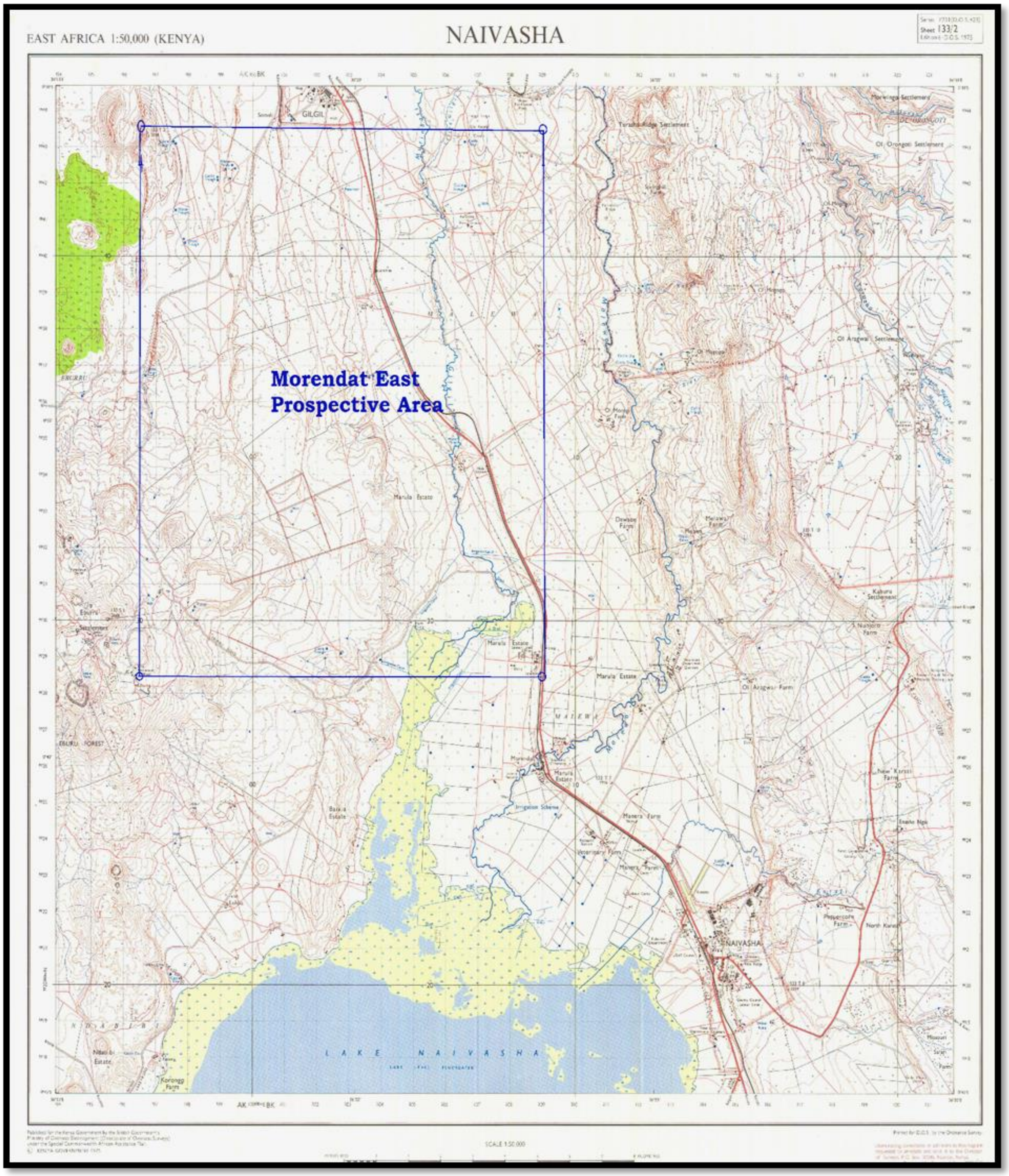

FIGURE 1.1: Location of Morendat East Geothermal Prospective Area within the Eburru prospect FY 2014_15 (delineated).

1.3 GEOLOGY AND STRUCTURES

Considerable geological-geomorphological work has been done in the area, largely in piece meal fashion by individuals, both professionals and amateur, since the later part of the 19th century. The area was however, first systematically mapped in 1955-1956 by (Thompson and Dodson, 1963) in response to interest in the development of geothermal power in the Kenya Rift valley at that time. The rocks of

Morendat East area mainly fall in to two main categories namely; Lacustrine /alluvial deposits, Lavas and pyroclastics. The lavas range from under-saturated basic to acidic rocks, i.e., the Trachytes, and Obsidian respectively found scattered on most parts of the prospect area. The pyroclastics, some consolidated and others incoherent, cover the greater part of the surface and comprise of great thickness as demonstrated in the process of spiking the ground during geochemical data collection. At the floor of the rift and the foot of the domes and cones, thick alluvial sediments (fine volcanic soils) are dominant with very few rock outcrops.

Geological features and structures mapped out in the prospect area include the following; Cones, domes and folds, faults, ridges and flanks and plains. The prospect area lies within the ring structure and this indicates the probability of a very wide spread volcanicity inferring a possible heat source at depth. From previous geological studies, radiocarbon dating of specific layers/ volcanic products attributes this area to be dormant rather than extinct hence emphasize a continued presence of shallow heat sources. Major faults are longitudinal to the Rift System while minor ones trending east – west in this prospect. The structures are of huge implication in the movement and accumulation of both cold and hot water respectively.

Lacustrine sediments and pyroclastics which have been deposited subaqueously in this prospect, consist of thermally insulating thick blankets of sediments covering basement rock and having relatively low-normal heat flow hence sealing geothermal system as a cap rock. The Mau Escarpment, which stands at a high altitude of 2000-3000m above sea level, could be the recharge zone for this area. The pyroclastics some consolidated and others incoherent cover the greater part of the surface area and comprise great thickness in the flanks. The few geothermal manifestations in this prospect are associated with volcanic structures and altered rock types encountered during geological field mapping. The Figure 1.2 below shows the geology and structural pattern of the project area.

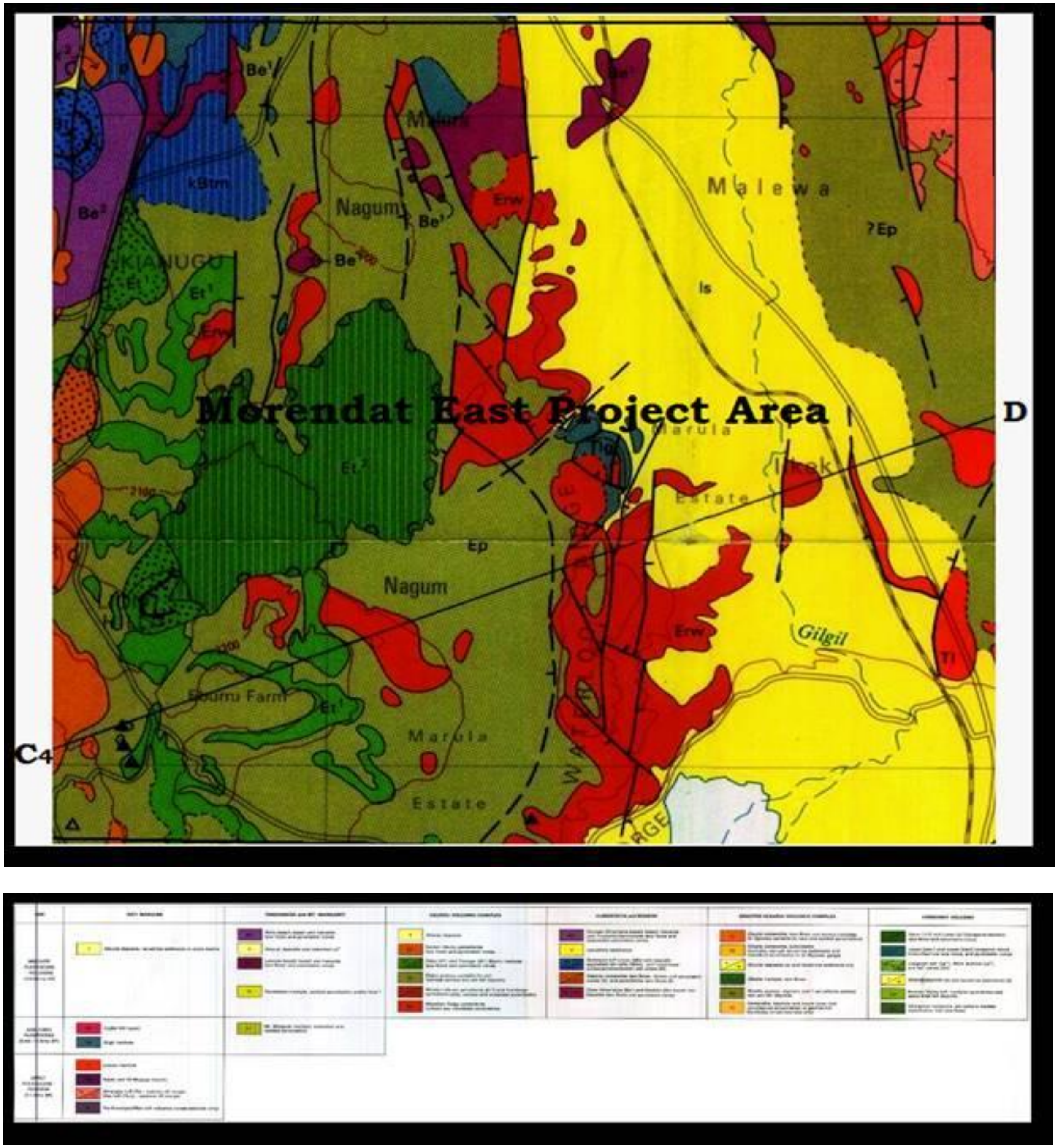

FIGURE 1.2: A Geological Map of Morendat East Area (with scale and legend).

2.0 LITERATURE REVIEW

2.1 CARBON DIOXIDE

Carbondioxide occurs in both magmatic and hydrothermal gases and is the most abundant gas after water vapor. The deep-seated faults in the crust tap magmatic CO_2, which is transmitted to the surface where it is naturally lost through the soil. Carbon dioxide of magmatic origin is normally channeled through deep-seated tectonic structures close to the surface of the earth and then seeps out of the ground through the soil. However, dealing with CO_2 anomalies especially in the Rift Valley ought to be treated with caution owing to the availability of localized sources of this gas as suggested by (Darling et al. 1995) i.e. CO_2 can originate from other sources like organic matter, which are likely to give false impressions of a geothermal source. Due to its magmatic origin, CO_2 has been found to be the most common gas in geothermal fluids. Concentration levels of CO_2 in soils has been used as tool in geothermal exploration in various geothermal prospects in the recent years, (Chiodini et al., 1998); (Fridriksson et al., 2006); (Magaña et al., 2004); (Opondo, 2010) and (Voltattorni et al., 2010).

2.2 RADON 222/220 RADIOACTIVITY IN SOIL GAS

Radon (^{222}Rn) has a half-life of 3.84 days while thoron (^{220}Rn) has a half-life of 55 sec. These two are noble gas isotopes belonging to the ^{238}U and ^{232}Th decay series, (Lopez et al. 2004). They are produced continuously as a result of α–decay of ^{226}Ra and ^{224}Ra in rocks and minerals respectively. Due to thoron's short half-life, its transportation is limited to a few centimeters either by diffusive or convective flows, as compared to radon, (Hutter, 1993). Some of the thoron escape from the rocks and minerals to the surrounding fluid phase, such as groundwater and air, therefore it is difficult to measure its exact quantitative concentration. If we measure the disintegration of thoron, it shows a decrease during the first three minutes after collection of the sample, as opposed to the radon that presents a half-life of almost 4 days, (Magana et al. 2002). Few investigations have been carried out relating to the mechanisms of which radon leak from minerals and rocks and the factors affecting the process, (Gilletti and Kulp, 1995); (Andrews and Wood, 1972); (Rama and Moore, 1984).

Measurement of radon concentration and distribution in the soil-gas has been suggested as a tool for many geochemical investigations. These include; exploration for uranium, earthquake prediction, groundwater flow and assessment of geothermal resources. Soil-gas flux studies have been successfully applied in a number of fields for hydrocarbon, uranium exploration, geothermal exploration, volcanic and seismic forecasting. (Stix and Gaonac'h, 2000). However, it is important to take into consideration other mechanisms which may influence the gas distributions, like climatic effects (rain, humidity, and barometric pressure) that can significantly influence the amount of diffuse degassing, before interpreting spatial or temporal trends of diffuse gases.

3.0 MATERIALS AND METHODS

Soil gas survey was undertaken in order to determine the concentrations and distributions of carbon dioxide and radon gas. This exploration procedure has been applied in geothermal areas during the surface geochemical studies. CO_2 soil gas investigation procedure is similar to the one used in this study has been conducted in various volcanic areas to examine the mechanism of CO_2 flux, (Farrar et al. 1995); (McGee and Gerlach, 1998); (Gerlach et al.1998). The same procedure has also been applied in the estimation of total volcanic flux from volcanic vents and diffuse flank emissions, (Allard et al. 1991); (Chiodini et al. 1996), and to classify tectonic structures related to volcanic degassing (Giammanco et al. 1997); (Bergfeld, 1998).

The CO_2 gas was measured as % of the total gas using the Orsat gas sampling apparatus. Soil gas samples were obtained using a spike, equipped with a steel outer jacket to penetrate the ground to a depth of 0.7-1.0 m. The Orsat gas apparatus consist of absorption vessels and the burrete, which measure about 100 mls and contain a 40% potassium hydroxide (KOH) solution for absorbing the acidic CO_2. The corresponding volume change in the absorption burrete represents the corresponding amounts of the CO_2 gases in volumes given as percentage of the total gas.

For the Radon sampling, the sample was collected from the same hole as of the $CO_{2,}$ using the portable RAD 7 equipment (emanometer) consisting of a cylindrical copper can, whose walls are coated with zinc sulphide where the radon decays into other radio-nuclides by emitting alpha particles. Three background counts per minute (cpm) of Radon were recorded at Five-minute intervals prior to introduction of the sample into the emanometer so as to measure the amount of Radon in the atmosphere presenting the background measurement. The soil gas sample containing radon was pumped into the decay chamber of RAD7 after which three more readings were taken at five-minute intervals to give the total radon counts from the soil.

An infra-red thermometer was used to take the soil temperature by directly pointing it into the hole made by the spike and the resultant temperature recorded. Soil gas sampling points ranged from 500m to 1km depending on accessibility, proximity to manifestations and time. Areas covered by younger lava flow were almost impossible to sample hence few samples represent such areas, a total of 100 points were sampled.

4.0 RESULTS

From the sampling survey, a total of 100 points were sampled, for the construction of the contour maps indicating the distribution and concentration of radon, CO_2 and temperature. Factorial Kriging Analysis (F.K.A) method since the data was concentrated around a certain specific region due to inaccessibility. This method was also going to put into consideration the spatial features in the area by overlaying the contour maps. The mapping of temperature variations at or below the earth’s surface is an essential geothermal exploration instrument. The radon, Carbon dioxide and temperature concentrations obtained from the survey were corrected and used to construct distribution contour maps as indicated by Figures 4.1, 4.2 and 4.3 respectively.

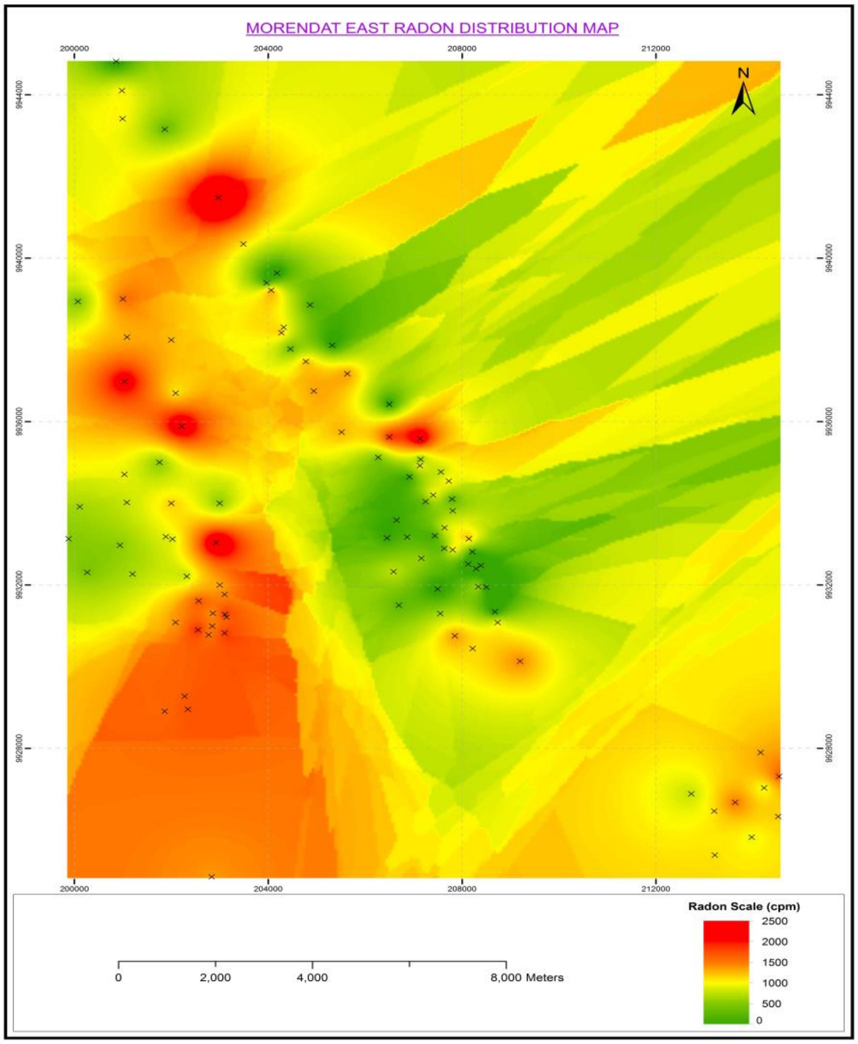

FIGURE 4.1: Radon distribution in the Morendat East geothermal prospect.

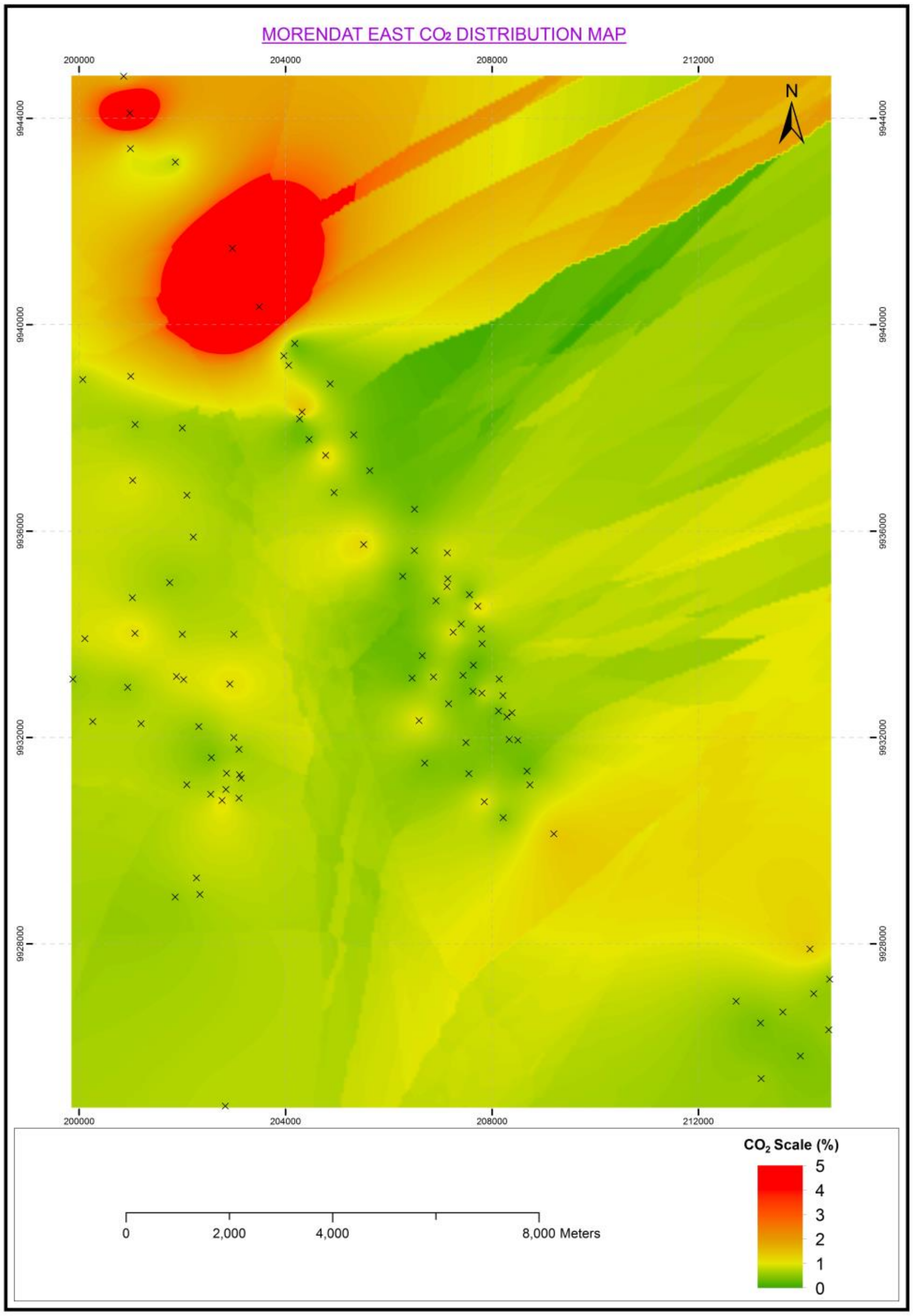

FIGURE 4.2: CO_2 distribution in the Morendat East geothermal prospect.

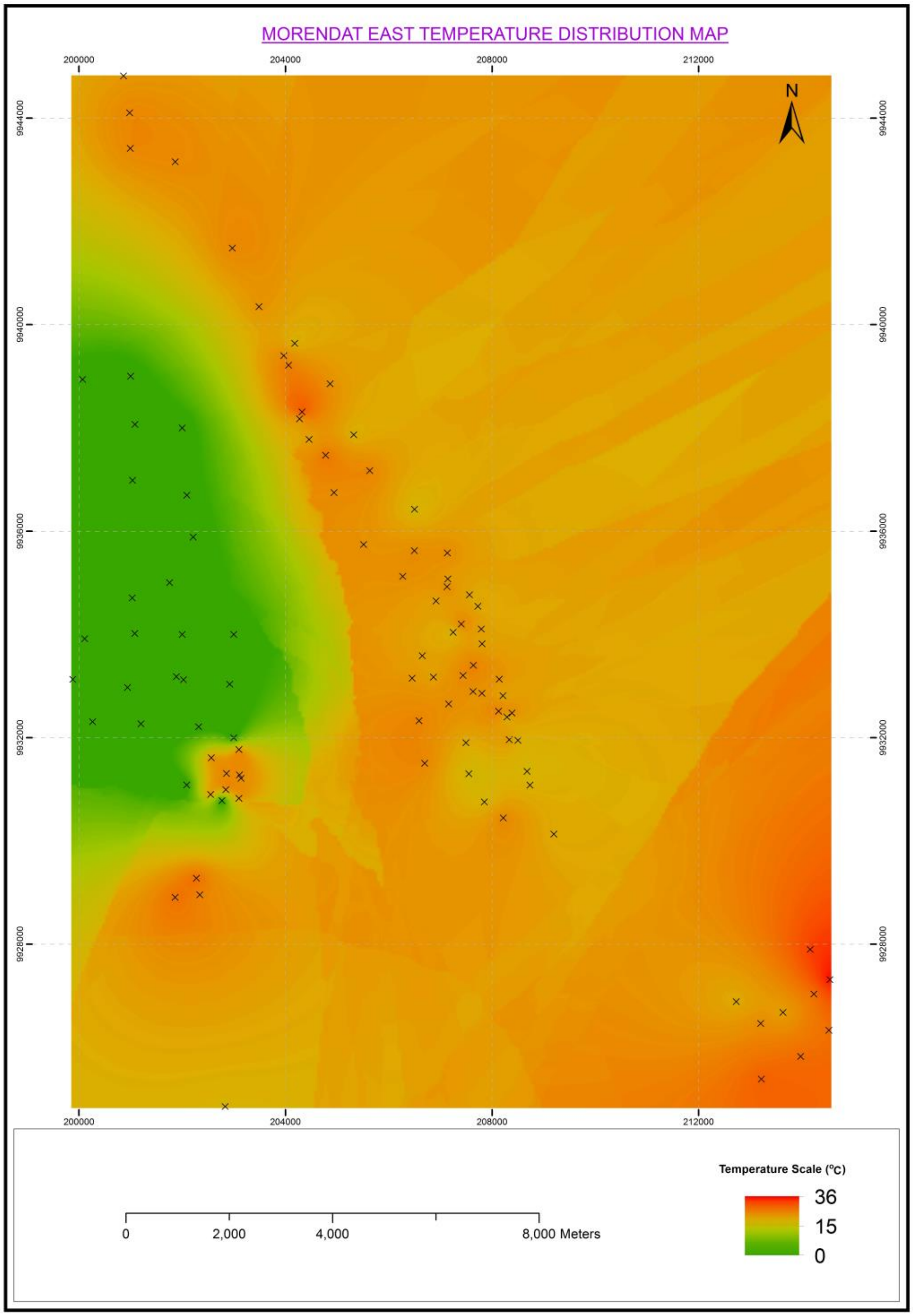

FIGURE 4.3: Temperature distribution in the Morendat East geothermal prospect.

5.0 DISCUSSION AND CONCLUSION

5.1 DISCUSSION

From the results, several indicators of geothermal resource assessment were identified. Temperature results show an anomaly to the southeast though not very clear. The radon counts range between a low of 0 cpm and a high of 2834 cpm indicating the lava covered areas and the prospective permeable areas respectively. The %CO_2 distribution in the area ranges between 0-5.4 percent, this is a probable primary way to locate permeable zones and infer the presence of possible heat source linked to an active geothermal system. The CO_2 variance is attributed to diffuse degassing structures and also the biogenic contribution. Possible faults were inferred north of the prospect area due to the anomalously high levels of CO_2 and ^{220}Rn recorded .The Radon, Carbondioxide and Temperature distribution and structural pattern in the Morendat East geothermal prospect was linked to an active geothermal resource.

5.2 CONCLUSION

The high radon counts could be closely associated with the highly fractured area and a high heat flux. The spatial pattern of the CO_2 flux anomalies as well as Rn soil-gas distribution suggests a structural control on diffuse degassing; in particular, along and near the fault floors.

The Morendat East geothermal prospect indicated satisfactory permeability which was linked to a possible active heat source hence should be ranked for further exploration using other geochemical methods by probably reducing the sample collection interval from 1km to 300m apart coupled with geology and geophysics.

ACKNOWLEDGEMENT

I wish to thank the Ministry of Energy and Petroleum (Kenya) for the opportunity given to the geochemistry section in the Geo-exploration Directorate to carry out the geochemical assessment of the Morendat East geothermal prospect, to the KenGen staff for assistance in data interpretation and to all who contributed to the writing of this paper.

REFERENCES

Allard, P., Carbonnelle, J., Dajlevic D., le Bronec, J., Morel, P., Robe, M.C., Maurenas, J.M., FaivrePierret, R., Martin, D., Sabroux, J.C., and Zettwoog, P.: Eruptive and diffuse emissions of CO2 from Mount Etna. Nature, 351, 387–391 (1991).

Andrews J.N and Wood D.F.: Mechanism of radon release in rock matrices and entry into groundwaters *Tran. Inst. Min. Metall.***B81**, 198-209 (1972).

Bergfeld, D., Goff, F., Janik, C.K., and Johnson, S.D.: CO_2 Flux Measurements across Portions of the Dixie Valley Geothermal System, Nevada. Geothermal Resources Council Transactions, 22, 20-23 (1998).

Chiodini G., Frondini F. & Raco, B.: Diffuse emission of CO_2 from the Fossa crater, Vulcano Island _Italy. Bull. Volcanol., 58, 41–50 (1996).

Chiodini, G., Cioni, R., Guidi, M., Raco, B., and Marini, L.: Soil CO_2 flux measurements in volcanic and geothermal areas. Applied. Geochemistry. 13, 543- 552 (1998).

Darling, W.G., Griesshaber, E., Andrews, J.N., Armannsson, H., and O'Nions, R.K.: The origin of hydrothermal and other gases in the Kenyan Rift Valley. Geochim. Cosmochim. Acta, 59, 2501- 2512 (1995).

Farrar, C.D., Sorey, M.L., Evans, W.C., Howle, J.F., Ken B.D., Kennedy, B.M., King, C.Y., and Southon, J.R.: Forest-killing diffuse C02 emission at Mammoth Mountain as a sign of magmatic unrest. Nature, 376, 675-678 (1995).

Fridman, A. I.: Application of naturally occurring gases as geochemical pathfinders in prospecting for endogenetic deposits, Geochem. Explor, 38, 1–119 (1990).

Fridriksson, T., Kristjánsson, B.R., Ármannsson, H., Margrétardóttir, E., Ólafsdóttir, S., and Chiodini, G.: CO_2 emissions and heat flow through soil, fumaroles, and steam heated mud pools at the Reykjanes geothermal area, SW Iceland. Applied Geochemistry, 21, 1551–1569 (2006).

Gerlach, T.M., Doukas, M.P., McGee, K.A., and Kessler, R.: Three-year decline of magmatic CO2 emissions from soils of a Mammoth Mountain tree kill: Horseshoe Lake, CA, (1995-1997). Geophy. Res. Lett., 25, (1947-1950), (1998).

Giammanco, S., Gurrieri, S., and Valenza, M..: Soil CO_2 degassing along tectonic structures of Mount Etna (Sicily): the Pernicana fault. Appl. Geochem., 12, 429–436 (1997).

Giletti B.J. and Kulp J.L.: Radon leakage from radioactive minerals .*Amer. Mineral*. **40**, 481-496 (1995).

Hutter, A. R.: Thoron/radon (^{220}Rn/^{222}Rn) ratios as indicators of soil gas transport: Geological Society of America Abstracts with Programs, A 195 (1993).

Lopez, D.L., Ransom, L., Perez, N., Hernandez, P., and Monterrosa, J.: Dynamics of diffuse degassing at Ilopango Caldera, El Salvador. In: Rose, W.I., Bommer, J.J., López, D.L., Carr, M.J., and Major, J.J. (eds): Natural Hazards in El Salvador. Geological Society of America Special Paper, 375, 191-202 (2004).

Magaña, M. I., López, D., Barrios, L.A., Perez, N. M., Padrón, E. and Henriquez, E.: Diffuse and convective degassing of soil gases and heat at the TR- 6-Zapotillo hydrothermal discharge zone, Berlin Geothermal Field, El Salvador. Geothermal Resources Council, Transaction 28, 485-488 (2004).

Magaña, M., Lopez, D., Tenorio, J. & Matus, A.: Radon and Carbon Dioxide Soil Degassing at Ahuachapan Geothermal Field, El Salvador. Geothermal Resources Council Transactions, 26, 341- 344 (2002).

McGee, K.A., and Gerlach, T.M..: Annual cycle of magmatic CO_2 at Mammoth Mountain, California: Implications for soil acidification. Geology, 26, 463-466 (1998).

Opondo, K.M.: Radon and Soil Gas Surveys in Paka Geothermal Prospect, Kenya. Proceedings World Geothermal Congress (2010) Bali, Indonesia.

Rama and Moore W. S.: Mechanism of transport of U-Th series radioisotopes from solids into ground water. *Geochim.Cosmochim.Acta* **48**,395-399 (1984).

Stix, J. and Gaonac'h, H.: Gas, Plume, and Thermal Monitoring. Encyclopedia of Volcanoes. Academic Press. pp 1141 – 1153 (2000).

Thompson, A.O and Dodson,R.G.: Geology of the Naivasha area. Report Geological Survey of Kenya. No. 55, (1963).

Voltattorni, N., Sciarra, A., and Quattrocchi, F.: The Application of Soil-Gas Technique to Geothermal Exploration: Study of Hidden Potential Geothermal Systems. Proceedings World Geothermal Congress (2010). Bali, Indonesia.