Geochemistry of Fumarole Discharges and Borehole Waters of Korosi-Chepchuk Geothermal Prospect, Kenya

Leakey Ochieng, Jeremiah Kipng'ok, Isaac Kanda, George Igunza, and Charles Wanjie

Geothermal Development Company (GDC), Nakuru, Kenya
lochieng@gdc.co.ke • jkipngok@gdc.co.ke • ikanda@gdc.co.ke
gigunza@gdc.co.ke • cwanjie@gdc.co.ke

Keywords

Fumaroles, boreholes, geothermal, geothermometers, meteoric, isotope

ABSTRACT

Korosi-Chepchuk geothermal prospect is situated immediately to the north of Lake Baringo and south of Paka in the Kenyan Rift. This paper aims at discussing chemical characteristics of the borehole waters, and uses the fumarole gas discharge in the determination of subsurface temperatures and establish the source of water feeding the hydrothermal system using stable isotopes. Korosi volcanic complex and Chepchuk ridges have an active and exploitable geothermal resource with estimated reservoir temperatures in excess of 240°C as deduced from gas geothermometers. Korosi Chepchuk fumaroles show a trend where d^2H and $d^{18}O$ are considerably depleted. The source of the fumarole discharge is the local meteoric waters. Two boreholes; Nyaunyau and Loruk have the highest measured temperatures and plot differently from the others, implying they could be representing waters with geothermal input unlike the others. From Na-K-Mg ternary diagram it is observed that none of the borehole waters have attained equilibrium with aquifer rocks and therefore are not suitable for use to estimate reservoir temperature, except the Loruk and Nyaunyau borehole waters that are close to partial equilibrium and could be suitable for solute geothermometry.

1.0 Introduction

Korosi is a quaternary volcanic complex neighbouring Chepchuk ridges to the north – east and both lie immediately to the north of Lake Baringo and south of Paka Volcano (figure 1). The geothermal surface manifestations are in the form of fumaroles, hot and thermally altered grounds, steaming grounds and relatively high temperature water boreholes (above ambient). The fumaroles in the prospect are located around Korosi and Chepchuk volcanic centres most of which discharge at low pressure especially those found within Korosi area. Temperatures of up to 95.4ºC were measured for the Chepchuk fumaroles while temperatures of up to 96°C were recorded for the Korosi fumaroles. The data used in this report were those collected for the Geothermal Development Company in a geochemical survey conducted in 2010 to prioritize the potential of geothermal systems in the Kenya rift. The survey involved fumarole and the borehole water sampling and analyses. The data are used to evaluate the geothermal energy potential of the area through interpretations of the chemical characteristics of the fluids, determination of subsurface temperatures using gas

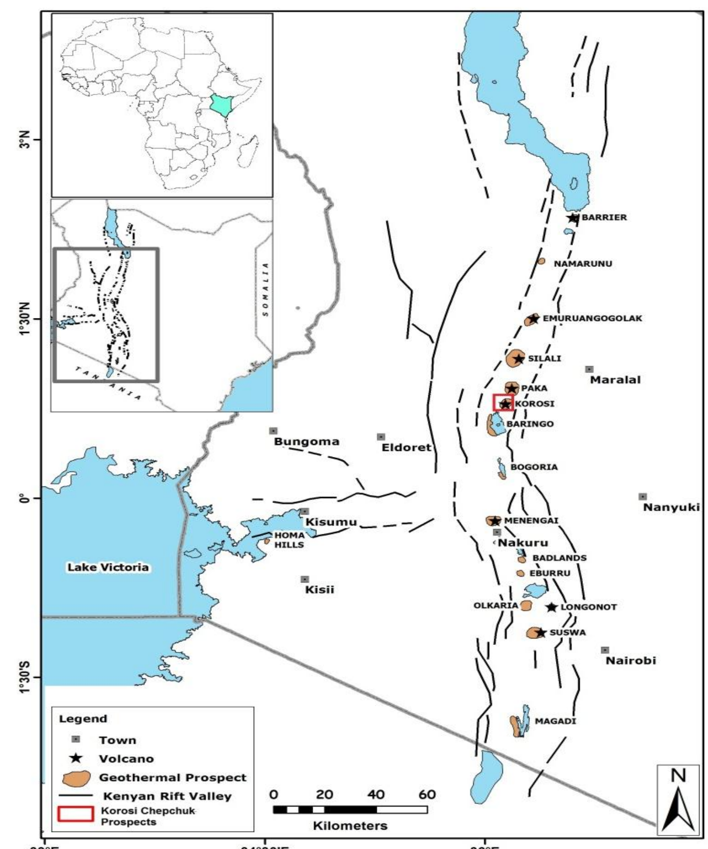

Figure 1. Location of Korosi-Chepchuk in the Kenyan Rift.

geothermometry and use the stable isotope data to establish the source of water the hydrothermal system.

1.1 Geothermal Activity in Korosi – Chepchuk Prospect

Geothermal surface manifestations occur in the form of hot grounds, steaming grounds and fumaroles. Hydrothermal alterations are associated with active manifestations and also with extinct thermal areas at ambient temperatures. The main areas active fumarolic activity and with the highest recorded temperature of 96°C are on the north and north-west flanks of Korosi and seem to be constrained on the western side of Nakaporon fault according to Ofwona. C et al (2006). Another isolated fumarolic area with a relatively high temperature occurs to the south-west. Surface activity within all these areas is located upon faults or in close proximity to them (Figure 2). At Chepchuk, activity occurs on the northern part where it is located upon a number of N-S trending fault-bounded ridges parallel to the main Nagoreti fault (Figure 2). Dunkley et al. (1993) found that the principal areas of activity are located where the main N-trending faults are intersected by E-trending minor faults. Anomalous ground temperatures in excess of 70°C also occur in a wider area within the prospect area, indicating that this area may be associated with a larger thermal anomaly than is evident from surface manifestations.

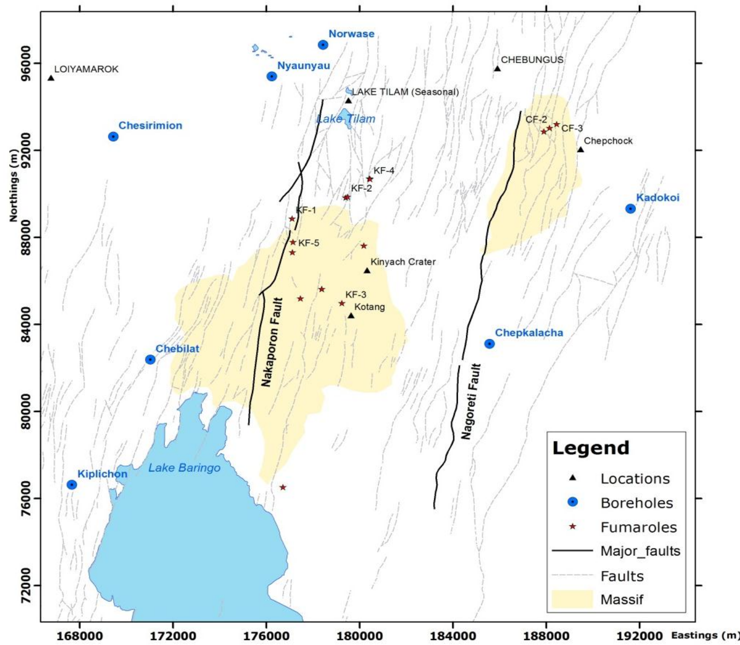

Figure 3. Location map of Korosi-Chepchuk boreholes and fumarole.

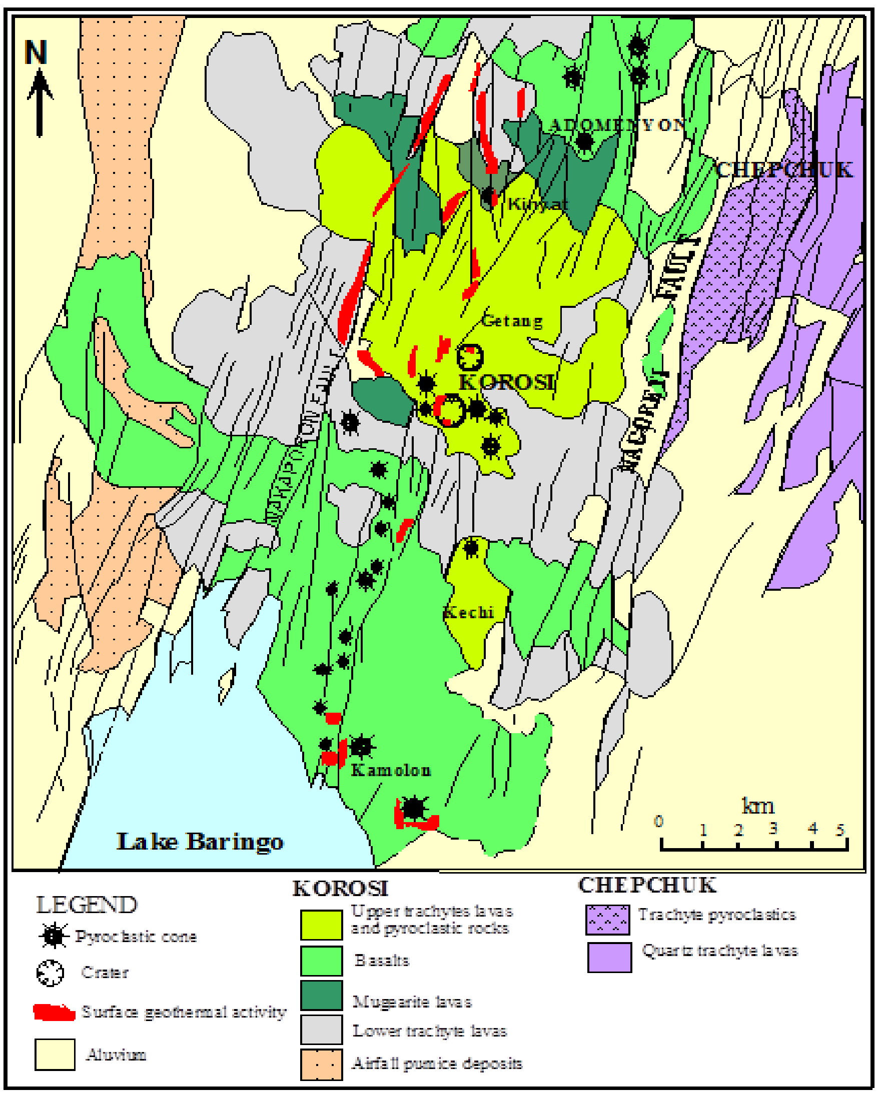

Figure 2. Geological map of Korosi-Chepchuk prospect showing geothermal manifestations.

2.0 Geological Setting

The Kenya Rift System, which forms an integral part of the East African Rift System, hosts several geothermal prospects. Korosi-Chepchuk geothermal prospect is one of the Quaternary Volcanoes located in this system. It is a trachyte-basalt volcanic complex (Figure 2), occupying an area of approximately 260 km^2 and rising about 450-500 m above the sea level, with a maximum height of 1446 masl. Korosi is a multi-vent complex composed predominantly of trachyte lavas which have build up a low volcanic shield, upon which lesser amounts of basalt, mugearite and pyroclasts deposits have been erupted. Chepchuk is a complex whose western part is intensively fractured by N-trending faults and consists predominantly of pyroclastic deposits which interbedded trachyte and benmoreite lavas. The eastern part is composed of strongly faulted, easterly dipping trachyte lavas.

3.0 Data Collection

A total of seven fumarole discharge points in the Korosi-Chepchuk prospect were sampled as shown in Figure 3 and analyzed for H_2, H_2S, CO_2, CH_4, N_2 and CO_2, the results are presented in Table 1. The borehole water samples were analyzed for the major elements which include Na, K, Mg, Cl, SO_4 and HCO_3, the results are presented in Table 2. The Cl-SO_4-HCO_3 and Na-K-Mg ternary plots were used to classify the borehole waters and to determine their suitability for geothermometry use as outlined by Giggenbach (1988). KF and CF denote fumaroles located within Korosi and Chepchuk areas respectively as used in the Figure 3.

4.0. Results

4.1 Korosi-Chepchuk Fumarole Gas Compositions

Table 1. Korosi-Chepchuk fumarole gas compositions.

Fumarole	Temp. (°C)	Concentrations in mmol/kg					
		CO_2	H_2S	H_2	N_2	O_2	CH_4
KF-1	96	1514	0.03	0	3849	1036	0
KF-2	74.9	14241	0.63	0	10392	2797	0
KF-3	94.5	3063	0.08	0	34084	9147	406
KF-4	90.6	15093	0.63	0	1929	519	0
CF-1	93.9	3206	0.12	0	4013	1069	0
CF-2	94.7	3822	0.15	0	2065	535	15
CF-3	95.4	1239	0.01	0.03	5	0	23

4.2 Korosi-Chepchuk Borehole Water Chemistry

Water from boreholes located within the prospect area was sampled and analyzed to determine the extent (if any) of geothermal input in the waters. The chemical composition of the water is presented in Table 2. The temperature of the water discharged by the boreholes sampled varied between 33°C measured at Chebilat borehole situated at the south–western edge of Korosi, to 60°C measured at Norwase borehole located at the northern edge of Korosi (Table 2). Most of the hottest boreholes are located to the northern part of Korosi while the cooler ones are located towards the southern part except for the one at Loruk which measured 53°C. Most of them show relatively high dissolved silica in excess of 170ppm, high TDS (more than 2000 ppm) and high Cl^- levels which would indicate relatively high source temperatures. Similarly, all of these boreholes exhibiting elevated silica, total solids and Cl content are again located to the northern part of Korosi. This implies that the hottest part of Korosi is at the north and the field cools southwards where the boreholes are characterized by relatively low silica and Cl^- contents. This observation is supported by the concentration of magnesium (Mg^{+2}) in the borehole waters, which decreases with increasing source temperatures.

Table 2. Chemical composition of boreholes water.

Site Name	Temp (°C)	pH	Cond	Water Samples (ppm)											
				TDS	CO_2	H_2S	SO_4	Cl	F	SiO_2	B	Na	K	Ca	Mg
Chebilat	33	7.8	1139	568	578	0.34	7.5	76	24	50	0.5	174	31	75.5	13
Loruk	53	8	-	-	253	0.17	126	359	21	64	1	266	10	0	1.2
Kiplichon	-	8.2	1118	561	189	2.65	105	64	3.7	173	1.3	69	4.7	0.27	1
Chepilat	33.5	8.6	659	331	222	0.19	26	40	4.2	56	0.5	129	14	2.51	2.4
Norwase	60	9.2	2883	1442	539	0.17	104	103	24	286	0.16	260	19	22	13.1
Nyaunyau	48	9	5492	2790	429	0.17	173	471	78	210	0.2	588	44	9.63	5.1
Kadokoi	34.8	7.9	826	415	382	0.07	27.9	76	1.8	65	0.68	108	10	45	6
Chepkalacha	35.1	6.6	1629	848	151	3.92	0.03	83	19	25	0.83	318	9.4	39	14
Chesirimion	33	8.1	620	310	694	0.07	5.6	30	2.5	49	1.04	126	7.4	28	10

5.0 Discussion and Interpretation

5.1 Fumarole Gas Chemistry Results

From the results of the gas compositions, the dominant gas is carbon dioxide and a notable presence of Nitrogen and Oxygen. It is noted that fumaroles with high atmospheric gases are weak and are therefore prone to atmospheric contamination. Fumarole CF-3 has a strong discharge and does not show any atmospheric contamination and is the only one with measurable hydrogen. Hydrogen sulphide levels are low and this is attributed to dispersion and oxidation on its ascent to the surface. Methane gas is a good indicator of active geothermal system but is vulnerable to other sources like biogenic activities.

5.1.1 Gas Geothermometers

Geothermometers enable the temperature of the reservoir to be estimated. Reservoir temperature was estimated using chemical geothermometer functions developed by Arnorsson and Gunnlaugsson (1985) and Giggenbach (1991).The calculated subsurface temperatures are presented in Table 3. CO_2 temperatures record the highest readings. This indicates a possibility of some magmatic CO_2 input rather than equilibrium controlled CO_2; giving temperature estimates of between 335°C and 371°C which appear to be relatively higher compared to other gas functions.

Table 3. Korosi-Chepchuk Gas geothermometers TCO_2, TH_2S and TH_2 are based on Arnorsson and Gunnlaugsson (1985); TCH_4/CO_2 based on Giggenbach (1991)

Fumarole	TCO_2	TH_2S	TH_2	TCH_4/CO_2
KF-1	341	181	-	-
KF-2	-	238	-	-
KF-3	364	198	-	213
KF-4	-	238	-	-
CF-1	364	205	-	-
CF-2	371	210	-	305
CF-3	335	-	246	260

The geothermometry temperatures calculated using the H_2S gas function indicate relatively lower source temperatures in the range of 181°C to 238°C for the prospect. These may have been affected by possible oxidation of H_2S during its ascent to the surface. The H_2 gas being the most reactive and least soluble in water is a good indicator of higher subsurface temperatures and the 246°C could be the true reservoir temperature. High H_2 concentrations in the discharged steam would therefore indicate proximity to a high temperature resource. The absence of atmospheric contamination in this fumarole implies closeness to the up flow zone as compared to the others. This implies that CF-3 is located close to a hot geothermal source. In the absence of H_2 and H_2S, methane (CH_4) is considered to be the best indicator of reservoir characteristics assuming no biogenic source of the gas. Only one fumarole in Korosi and two in Chepchuk had detectable CH_4 levels. CH_4/CO_2 geothermometer looks reasonable as their values lies between those of CO_2 and H_2S temperatures.

5.1.2 Stable Isotope Chemistry of Korosi-Chepchuk Fumarole Condensate

Hydrogen and oxygen stable isotope values calculated by Sturchio N et al. (1993) and Dunkley et al. (1993) for lakes Baringo and Turkana and the Korosi-Chepchuk fumarole condensate are presented in Figure 4. The isotopic composition of the rift margin groundwater in this area has d²H and d¹⁸O of around -16‰ and -3‰ as from Table 4. Korosi Chepchuk waters show a trend where d²H and d¹⁸O are considerably depleted. Gianni et al. (2005) the $\delta^{18}O$ of geothermal waters is often higher (less negative) than those of local meteoric waters. The Korosi-Chepchuk fumaroles are depleted with heavy isotopes and originate from the rift margin groundwater They plot along the Kenya Rift Meteoric Water Line but below the Rift margin ground water implying that the Korosi-Chepchuk fumaroles have suffered evaporation.

Table 4. d²H against $\delta^{18}O$ for Korosi-Chepchuk fumaroles (Dunkley et al. 1993)

	δ^2H	$\delta^{18}O$
Korosi	-53	-9.6
Korosi	-50	-9
Korosi	-51	-8.6
Korosi	-33	-6.5
Chepchuk	-38	-7.1
Chepchuk	-48	-8.8
Chepchuk	-55	-9.5
L.Baringo	47	8.8
L. Turkana	38	6.2
Rift Margin Ground Water	-16	-3

5.2 Classification of Korosi-Chepchuk Borehole Waters

5.2.1 Cl-SO₄-HCO₃ and Na-K-Mg Ternary Diagrams

The Cl-SO_4-HCO_3 diagram (Figure 5) is used to classify geothermal fluids on the basis of the major anion concentrations (Cl, SO_4 and HCO_3) (Giggenbach, 1988). Most of the borehole waters from this area are characterized by high Bicarbonate species and tend to form a mixture of Cl and HCO_3 rich waters. The two boreholes; Nyaunyau and Loruk have the highest measured temperatures plot differently from the others, implying two different sets of water and could therefore be representing waters with geothermal input unlike the others. Bicarbonate waters mainly form as a result of either mixing of high Cl waters with near surface groundwater or due to condensation of CO_2 in near surface waters.

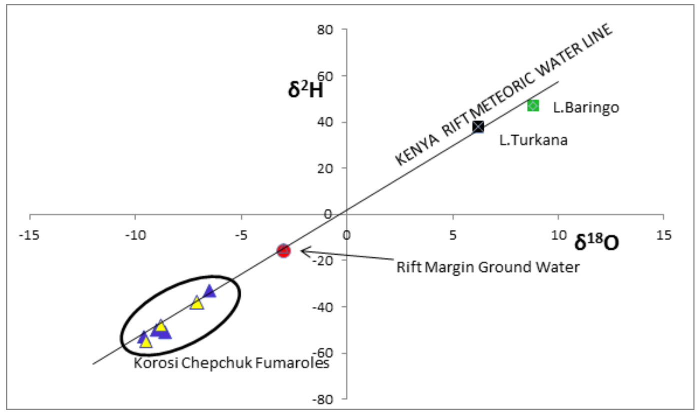

Figure 4. Plot of d²H against $\delta^{18}O$ for Korosi-Chepchuk fumaroles and lake waters. (Modified from Dunkley et al. (1993) *Blue triangles are Korosi fumaroles and Yellow triangles are Chepchuk fumaroles

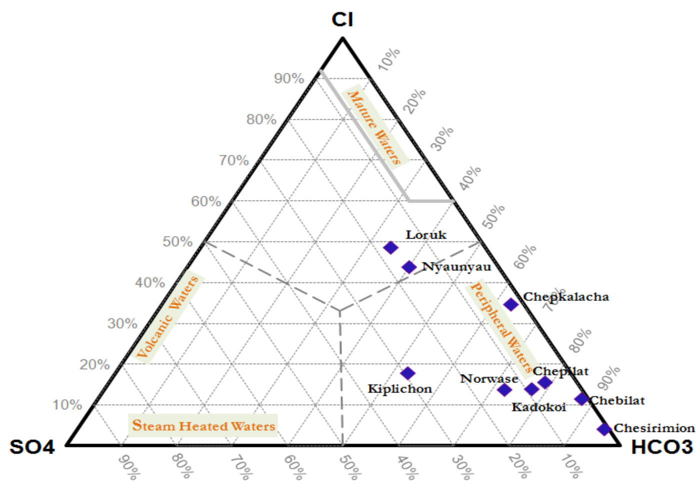

Figure 5. Cl-SO₄-HCO₃ ternary diagram for Korosi-Chepchuk boreholes.

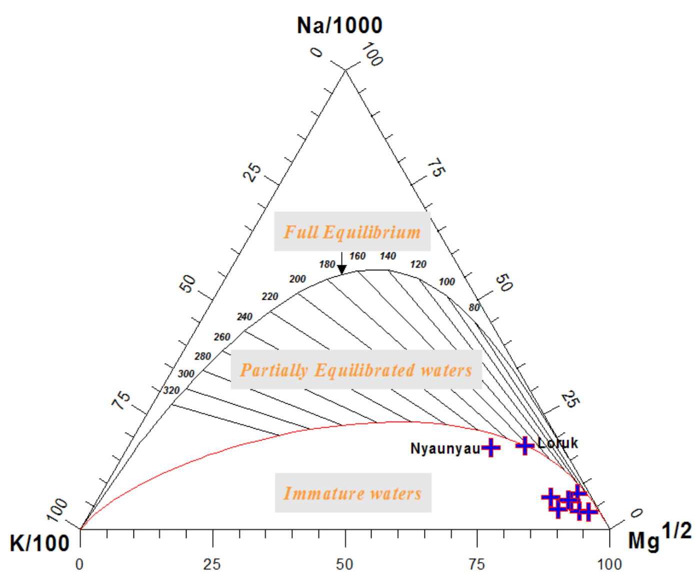

Figure 6. Na-K-Mg ternary diagram for Korosi-Chepchuk boreholes.

From Na-K-Mg ternary diagram (Figure 6) it is observed that none of the borehole waters have attained equilibrium with aquifer rocks and therefore are not suitable for use to estimate reservoir temperature, with the exception of the Loruk and Nyaunyau borehole waters that are close to partial equilibrium and could be suitable for solute geothermometry. Na/K equilibrium temperatures are about 123°C and 180°C for Loruk and Nyaunyau boreholes respectively according to Arnórsson et al (1983) functions.

6.0 Conclusion

Korosi Chepchuk has an exploitable geothermal resource with estimated temperatures in excess of 240°C as deduced from the gas geothermometer. However solute geothermometers calculated from Borehole waters give lower temperatures possibly due to high contamination with condensates. Chepchuk fumarole CF3 is closer to the up flow zone as inferred from the concentration of hydrogen .Further detailed work in needed involving other geoscientific disciplines to identify sites for exploration drilling. The Korosi-Chepchuk fumaroles are depleted with heavy isotopes and originate from the rift margin ground water. They plot along the Kenya Rift Meteoric Water Line but below the Rift margin ground water implying that the waters suffered evaporation and water-rock interaction. The two boreholes; Nyaunyau and Loruk have the highest measured temperatures plot differently from the others, implying two different sets of water and could therefore be representing waters with geothermal input unlike the others.

7.0 Acknowledgement

I would wish to express my gratitude to those of whom their contribution made this paper a success. First and foremost special thanks go to Dr.Silas Simiyu, Managing Director and CEO, Geothermal Development Company, for his support that facilitated the acquisition of the data used in this paper during the surface exploration. I am particularly indebted to the Manager, Geothermal Resource Assessment for his guidance and advice. I am grateful to my co-authors, Charles Wanjie, Isaac Kanda, Jeremiah Kipngok and George Igunza for their invaluable information and contribution that made this paper complete.

8.0 References

Arnórsson S., A. Stefánsson, I. Gunnarsson H. Kaasalainen, and E. Gunnlaugsson, 2010. “The geochemistry and sequestration of H2S into the geothermal system at Hellisheidi, Iceland.” Institute of Earth Sciences, University of Iceland, Sturlugata 7, 101 Reykjavík, Iceland.

Arnorsson S., and E. Gunnlaugsson, 1985. “New gas geothermometers for geothermal exploration–calibration and application.” Geochim. Cosmochim. Acta, 47, 567 – 577pp.

Arnórsson. S., E. Gunnlaugsson, H. Svavarsson 1983. “The chemistry of geothermal waters in Iceland III, Chemical geothermometry in geothermal investigations.” Geochim. Cosmochim. Acta, 47, 567-577 pp.

Dunkley, P.N., M. Smith, D.J. Allen, and W.G. Darling, 1993. “The geothermal activity and geology of the northern sector of the Kenya Rift Valley.” British Geological Survey Research Report, SC/93/1.

Gianni, C., B. Tiziano, M. Mario, H. Christian, C.M. Lameli, and B. Maurizio, 2005. “New chemical and original isotopic data on waters from El Tatio geothermal field, northern Chile.” Geochemical Journal, Vol. 39, pp. 547 to 571.

Giggenbach W.F., 1980. “Geothermal gas equilibria.” Geochim. Cosmochim. Acta, 44, 2021-2032 pp.

Giggenbach. W., 1988. “Geothermal solute equilibria, derivation of Na-K-Mg-Ca geoindicators.” Geochim. Cosmochim. Acta 52 : 2749-2765.

Giggenbach, W., 1991. “Chemical techniques in geothermal exploration.” D’Amore, F. (ed). “Application of geochemistry in geothermal reservoir development.” UNITAR: 253–273.

Ofwona, C., J.M. Wambugu, P. Omenda, N. Mariita, G. Mwawongo, B. Kubo, 2006. “Surface Geothermal Exploration of Korosi and Chepchuk Prospects.” Ofwona, C. (Editor). KenGen Internal report, unpublished, 45-62.

Sturchio, N., P.N. Dunkley, and. M. Smith, 1993. “Climate driven variations in geothermal activity in the northern Kenya rift valley.” Nature, Vol. 362, 233-234.