PROCEEDINGS, 42nd Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 13-15, 2017
SGP-TR-212

Investigation into the Possibility of Ground Water Contamination and Possible Effects of Olkaria Geothermal Developments to Lake Naivasha

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Keywords: *Ground Water Contamination, Shallow re-injection wells, Lake Naivasha, Olkaria Geothermal Field*

ABSTRACT

Geothermal power generation involves drilling to deeper depths to tap natural steam that is used to generate geothermal power, the steam is accompanied by geothermal effluents which are considered to be a significant aspect and hence can pollute the environment majorly surface and ground water if by any chance they interact.

The methods used in this paper will involve desktop studies that will give an insight of the geological structures of the area under study in addition to secondary data that will obtained from KenGen data base. The data will be analyzed using ternary plots in addition to studying geological structures and the up down flow and up flow of water into the geothermal reservoir.

This paper seeks to investigate the possibility of contamination of ground water by shallow re-injection wells that have been embraced to solve the problem of effluent discharge into the environment and give a detailed study of the connectivity between the Olkaria Geothermal reservoir and Lake Naivasha underground drainage. This being one of the major concerns raised by regulatory bodies, conservation groups, local and international environmental activists

1. INTRODUCTION

The exploration for geothermal energy began in the nineteen fifties when the resource was discovered in Olkaria in the southern part of Lake Naivasha and the resource extends to Eburru that is in the Northern part of Lake Naivasha, the first geothermal well was drilled in 1972 and the construction of the first geothermal power plant was in 1982.

The design of the first geothermal power plant never took to into consideration the disposal of the effluents but rather left the effluent in open conditioning ponds at Olkaria I then drained the effluent into Hells gate gorge where the effluent mixed with the hot springs and for this reason it raised environmental pollution concerns from financiers and environmental conservation groups; this lead to resolution of drilling shallow re-injection wells to mitigate the effect of geothermal effluent pollution.

The resolution was to drill one re-injection well for every six production wells efficient geothermal effluent management, the re-injection wells for the Olkaria I production fields were sunk to a depth of between seven to one thousand eight hundred meters and for Olkaria II and IV the wells are between two thousand meters to three thousand meters. This has put the area south of Lake Naivasha especially Olkaria under scrutiny by both local and international environmental conservation groups and financiers where by most of such groups speculate that utilization of geothermal especially from the Olkaria geothermal complex is interfering with the hydro geological flow regimes in the area that can otherwise affect livelihoods of communities down south of Olkaria geothermal fields and the most out spoken is the periodic fluctuation of water levels in Lake Naivasha.

Embracing the shallow re-injection wells as a way of recharging the Olkaria geothermal reservoir and as a mitigation measure against environmental pollution, shallow re-injection wells are speculated to contaminate ground water in areas around Olkaria and down south of Olkaria geothermal complex and this project seeks to elucidate whether geothermal utilization has any direct connection to lake Naivasha water levels fluctuation and find out any possibility of ground water contamination by shallow geothermal wells re-injections.

2. PROBLEM STATEMENT, LITERATURE REVIEW AND METHODOLOGY

2.1. Problem Statement

Geothermal utilization over the years has been considered to be a renewable and clean source energy and recently but in recent years there has been an outcry and complains locally and internationally that geothermal energy is no longer a clean energy source nor is it sustainable since its effluent or brine has some trace elements and by generating geothermal power from Olkaria geothermal complex has impacted on lake Naivasha.

For compliance since the Olkaria geothermal project is found within a sensitive ecosystem which is Hells gate National park, the effluent could not be left on the surface after use because the M.O.U between KWS and KenGen has a detailed tough regulatory enforcement; KenGen the power generators came up with a mitigation measure of disposing off the effluents through shallow re-injection wells as stated in their Environmental Impact Assessment reports submitted to the National Environmental Management Authority (NEMA) as a way of preventing surface water and surrounding environment from pollution. The shallow re-injections might contaminate ground water if they get to mix with ground water since the effluent constitutes trace elements like Arsenic (As), Cadmium (Cd), Mercury (Hg), Zinc (Zn),Boron(B),Barium (Ba) and Copper (Cu).

With such information in the public domain as it has been picked from the recent Environmental Social Impact Assessment (ESIA) the company risks project rejection from stakeholders like financiers and local communities unless it come out clearly on the issue of effective and sustainable effluent management which is in place but not well communicated and this project seeks to expedite. This is coupled with the recent government and emphasis to spearhead and shift focus to the utilization of geothermal energy somehow gives a negative perception on geothermal utilization locally and internationally if such information is not readily available just like the misleading information.

2.2. Literature Review

The Rift area around the Olkaria geothermal field is bounded by the Mau escarpment in the west rising to an altitude of up to 3000m and the Nyandarua escarpment in the east with an elevation of 3999m.The area is further bounded by a relatively high lying fault, particularly the Kinangop plateau of 2100m elevation in the Eastern rift (Allen D.J, 1989). Lake Naivasha is the only freshwater lake in the Rift Valley, although it has no surface outlet which means it has underground drainage as it was later proofed by (Allen D.J, 1989). It gets its recharge from direct precipitation and the two rivers Gilgil and Malewa.

The lake water, therefore, recharges some of the boreholes around it. Other studies on the gradual falling of the lake water level since 1971 had been done, but not much has been done on the recent mean rise of Lake levels in the rift system, Lake Naivasha included but speculations are, climate change and far effects of tectonic activities but yet to be confirmed.

There are few boreholes south of Longonot but between Longonot and Suswa there are no bore holes and if present they are either dry or produce steam (Allen et al.1989). Therefore, it is difficult to draw piezometric maps and the water table fluctuations and the boreholes available have not been monitored regularly. It is known that the rift groundwater is being recharged from the rift escarpments, where rainfall is substantial. However, the movement of and the chemical processes taking place in the water from the escarpment to the rift floor are complicated by geological structures.

The Olkaria geothermal field lies to the south of the lake and therefore the recharge to this field could possibly be connected to ground water on the Rift floor. (Allen et al.,1989) used stable isotopes to trace Lake Naivasha water. They found out that river waters discharging to the lake have very depleted isotope composition indicative of their origin at higher altitudes, more specifically the Nyandarua ranges. This is facilitated by major Rift faults which act as conduits for lateral flow or barriers which lead to deeper flow paths and by grid faulting which tends to align flow paths within the Rift along its axis. However the lake water is enriched in stable isotope ratios due to evaporation to which it is subjected. They also indicated that lake water appeared to be detected at least 30km to the south of Suswa volcano which is to the south of the Olkaria geothermal field. (Arusei1991) used halide ratios, a Cl/Br ratio diagram, to determine whether Lake Naivasha has an exposed ground water table and also to determine the origin of recharge to wells in the Olkaria geothermal fields. He concluded that there exists a correlation between the escarpment Rift floor and geothermal waters and showed that the Olkaria geothermal reservoir gets recharge water from both the Rift groundwater and the escarpment waters although he was not able to infer to a single recharge from any of this, He was also able to conclude that Lake Naivasha is not an exposed ground water table since the concentrations of many of the constituents increase away from the lake and for this reason he concluded that the flow in the lake is both in the northern and southern directions.

The existence of faults and other structural features like dykes and intrusions is paramount in geothermal utilization because they control the types and nature of the water rock interaction processes as well as the fluid movement within the rock system. It is also necessary to determine the influence of the faults in the existing fault pattern and map the fluid flow through available channels. Fault systems in the Olkaria field include ENE-WSW, NW-SE, N-S, E-W structures and are associated with fluid movement. They are all defined as normal faults through the correlation of lithology and alteration mineralogy zones. These faults include the N-S faults (Ololbutot fault, Olkaria fracture and OlNjorowa Gorge), ENE-WSW (Olkaria fault) NW-SE (Gorge farm fault) and the Ring structure. These faults control fluid movements and also impact on mixing fluid patterns. The reinjection wells in the study are strategically located in roughly along the fault structures with the cold reinjection wells being located in area perceived to be the down flow zones while the hot re-injections are locate in up flow zones.

Subsurface processes change the original isotopic characteristics of geothermal water. The exchange at high temperature due to water-rock interactions leads to an increase in the oxygen-18 content of the water and a subsequent oxygen decrease in the country rock. This phenomenon can be identified on δD- δ^{18}O plots as the $O^{18}$of the water will plot towards less negative values (a positive oxygen shift). A negative oxygen isotope shift may also occur where the CO_2 content of the fluid is relatively high (Truesdell and Hulston, 1980). Generally, little or no corresponding shift is observed in the deuterium value because rocks contain relatively little hydrogen. Thus deuterium isotope ratio has been used as an excellent tracer in hydrological systems. In this report the stable isotopes of deuterium and oxygen 18 are used to roughly assess the flow direction of re-injected effluents or brine in the Olkaria geothermal field and elucidate possible mixing with ground water if any. Clays and argillaceous rocks are generally enriched in fluorine because of micaceous minerals (Day, 1964). Apatite has been reported in dolerite rock in Olkaria geothermal field (Muchemi, 1985). An abundance of fluorite as an alteration mineral has also been reported in the cavities of acid (rhyolite) rocks, in the same field. Fluoride in the rift waters may be associated with rhyolite, doterite and granite rocks. It has been observed that acid fluids in geothermal reservoirs are rare and their occurrences in geothermal systems are associated with recent volcanism (Truesdell, 1991). This probably indicates that the geothermal reservoir fluid was derived from volcanic fluid incompletely neutralized by reactions with feldspars and micas (Truesdell, 1991). The reaction of Nacl solids with rock minerals at high temperatures (> 325°C) is probably the main source of chlorine in dilute geothermal waters in addition to that present in meteoric water.

Chlorine can occur in nature in the following ways:

a) Chloride ions in solution and evaporites
b) Minerals containing chlorine such as chlorapatite {Ca,(PO,HCl} and soda (Na,A1,SiO_4Cl) (Day, 1964).

Apart from evaporation, there is no chemical process that has any appreciable effect on the Concentrations of chloride ions in aqueous solutions. The only compound which chloride ions can form is perchlorate ion ($ClO_{4'}$) in the dissolution of evaporites.

The long term success of any geothermal energy utilization depends on the understanding of groundwater movements and recharge areas. (Mc Cann 1972) carried out a comprehensive hydrogeological study of the Rift Valley catchment and quantified groundwater flows of the Naivasha area. He calculated the total precipitation in the Naivasha catchment area to be 2761 x l cm^3 per year and estimated evaporation from the lake swamps and surrounding catchment to be 2506 x Hr> *m^3per year and* Leaving 254 x cm^3 per year as outflow from the catchment. From the piezometric levels, he was able to suggest that the water from the lake was flowing in both northerly and southerly directions.

Panichi and Tongiorgi (1974) used data on the stable isotopes of oxygen of the influent water and the lake water to model the groundwater outflow from the lake. Allen et al. (1989) reviewed all the work done in the area and improved the model by using more data. They used more stable isotope analysis and calculated the groundwater outflow from the lake, and their results agreed with McCann's estimate. They also had more piezometric levels from the boreholes in the area and suggested that the lake water was out flowing in both northerly and southerly directions and that lake Naivasha is at a higher altitude and simulates a perched water table. They took the mean estimate of subsurface recharge from Lake Naivasha to be 50 x 10<' m^3/yr with an error of ± 40 x 106. Using the mixing series of stable isotopes of oxygen and hydrogen between lake water and groundwater, they were able to infer the composition of groundwater's beneath the thermal centre at Olkaria. They suggested a 30% lake water contribution to Lake Elementeita and showed an influence of the lake in the south to southeast direction into Olkaria geothermal fields, up to 6 km away, and no flow to the west.

2.1.1 Recharge of the rift floor reservoirs

It is known that the rift groundwater is being recharged from the rift escarpments, where rainfall is substantial. However, the movement of and the chemical processes taking place in the water from the escarpment to the rift floor are complicated by geological structures and the existence of sediments from extinct lakes along the rift floor.

The brine/effluent from Olkaria geothermal wells constitutes trace elements like Arsenic (As), Cadmium (Cd), Mercury (Hg), Zinc (Zn), Boron (B), Barium (Ba) and Copper (Cu) as indicate in KenGen's Aspects register and such are significant aspect and the main source is the deep depths of occurrence of the reservoir and high temperatures that increase the solubility of such elements into solution from the igneous rocks environment that forms the reservoir.

2.3 Methodology

2.3.1 Study Area

The Olkaria geothermal field is located within the central segment of the Kenya Rift system and extends from the Oserian farm in southern part of Lake Naivasha to the western part of Mt. Longonot and covers an area of about 89km^2.

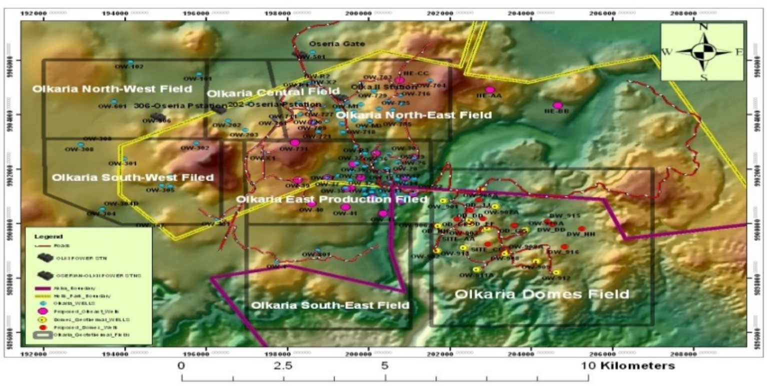

Figure.1: Map of the study area

Data Source

The data used in this research was obtained from Geothermal Development Division's Geochemistry, Environmental compliance, Reservoir and Steam field departments. Secondary information was obtained from desk top studies of previous works in the area and includes geological and structural information and maps.

Methods

The methods employed in the study and interpretation of available data to come up with a conclusive outcome for the project includes:

- Desktop studies from which piezometric maps, and structural information was derived in which the piezometric maps were used to determine the flow direction of the rift escarpment meteoric waters to form ground water and subsequently recharge Lake Naivasha from which it was possible to come up with the north ward and southward movement of Lake Naivasha subsurface waters while the structural maps makes it possible to study the structural controls of ground water flow regimes and be able to come up with the wells to be sampled for this research project.
- Using EXCEL to plot ternary plots makes it possible to classify ground water into mature waters, steam heated waters and; peripheral waters and from such be able to deduce if by any chance bore hole waters could plot in either steam heated or mature waters as an indicator of contamination by geothermal reinjection.
- The down flow and up flow and down flow zones as well as drilled depths of reinjection wells are used to study the inflow zones into the geothermal reservoir and predict the possible source of the waters that recharge the reservoir and location of reinjection wells and deduce whether by any chance they contaminate ground watering such areas.
- Isotope analysis were used to study the relationship between the source of water that recharge the geothermal reservoir and that tat recharges Lake Naivasha water and elucidate the connectivity between Lake Naivasha and the recharging of the greater Olkaria geothermal reservoir.

Absolute concentrations are difficult to determine and therefore isotopes are always given in relative abundance and therefore reported as ratios of proportion of light to heavy species in the sample relative to those in the standard for this case VSMOW (Vienna Standard Mean Ocean Water) (Geyh, 2000).

2.3.2 Results, Interpretation and Discussion

Ground water and re-injected water movement are best studied using the general flow regimes of waters into and along the rift floor, the depths of re-injection wells, structural controls like the fault line, the up flow zones of the greater Olkaria geothermal complex, the isotope composition of surface, ground and geothermal waters and finally the ternary diagram classification of ground and geothermal waters. All this will elucidate the deference or similarity between ground water and geothermal waters and confirm any mixing if present.

Recharge and Flow Regimes of Ground Water

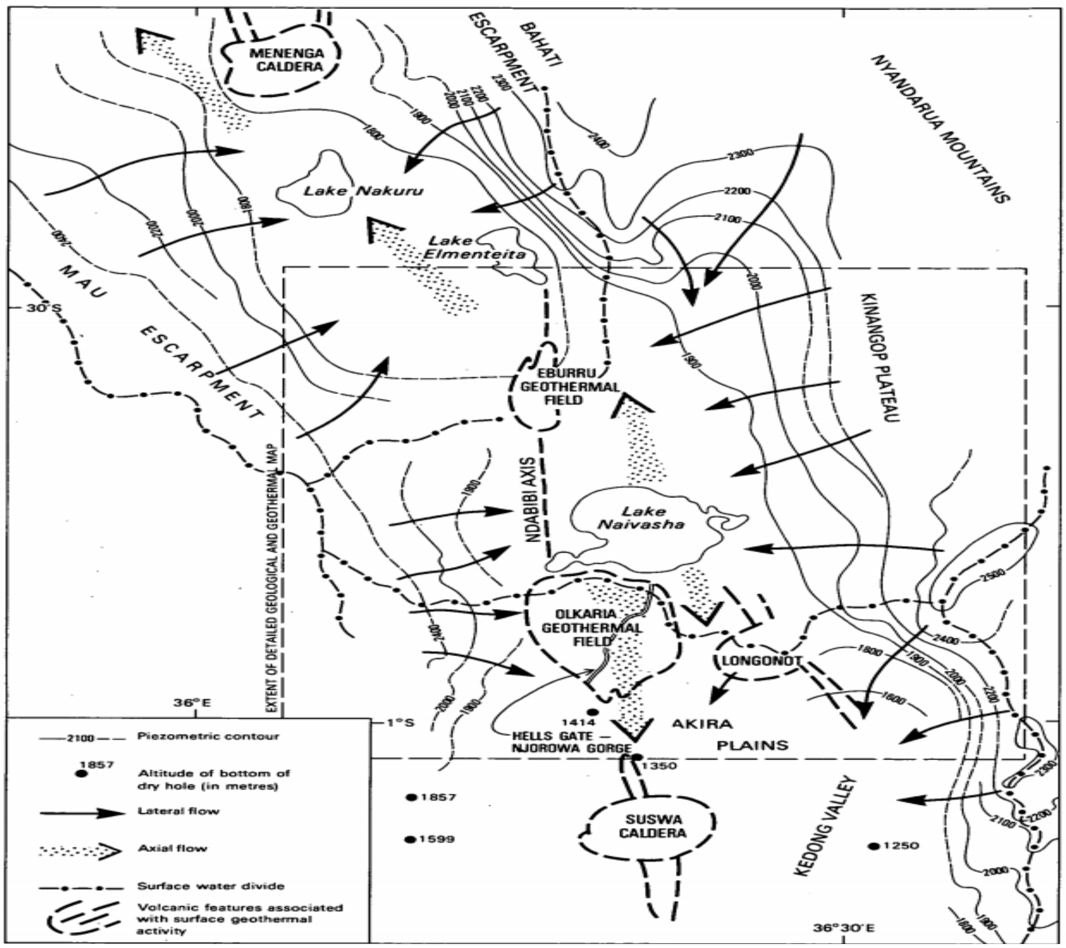

Figure .2: A piezometric map of the Kenya Rift Valley System adapted from Allen et al. (1989)

From the above figure it is clearly evident that the escarpment meteoric waters account for a larger percentage of waters recharging the aquifers of the rift floor and thus recharging both Lake Naivasha and the Olkaria geothermal complex; Olkaria geothermal complex is recharged both from the Western and Eastern margins of the rift. It is also evident that the lake has subsurface discharge of which 70% flow southwards towards Olkaria while 30% flow northwards towards Lake Elementaita (Allen et al., 1989).Therefore any re-injected water will flow into and laterally in the Olkaria complex depending on the point of reinjection whether it is in or along the flanks of the rift and finally get their way into the reservoir, gets heated and flow up at the up flow zones as steam heated waters.

Geothermal Reinjection Wells Design

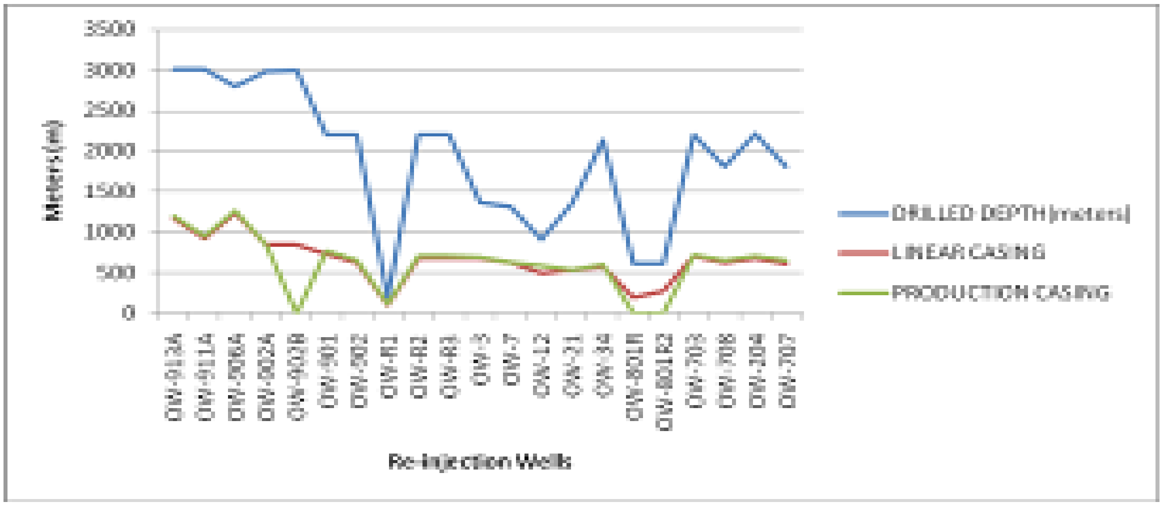

Figure .3: Olkaria geothermal re-injection wells

From the table above its clear that most re-injection wells are drilled to depths below the water table and depths that cannot be economically drilled for ground water and in addition to that the upper parts of the wells are initially drilled and back filled with cement then drilled through the cement and top hole lining of un-slotted casing fixed to mitigate against any peripheral waters flowing directly into the re-injection wells and thus preventing any contamination. The wells 80-R1 and 801-R2 are the most recent cold reinjection wells for Olkaria I unit IV and V drilled to shallow depths to allow reinjection of used geothermal fluids but detailed tracer and isotope studies need to be done on this two wells to study their flow direction and avoid future influx of their re-injected brine to production wells. .

Structural Analysis

The existence of faults and other structural features like dykes and intrusions is paramount in geothermal utilization because they control the types and nature of the water rock interaction processes as well as the fluid movement within the rock system It is also necessary to determine the influence of the faults in the existing fault pattern and map the fluid flow through available channels or conduits.

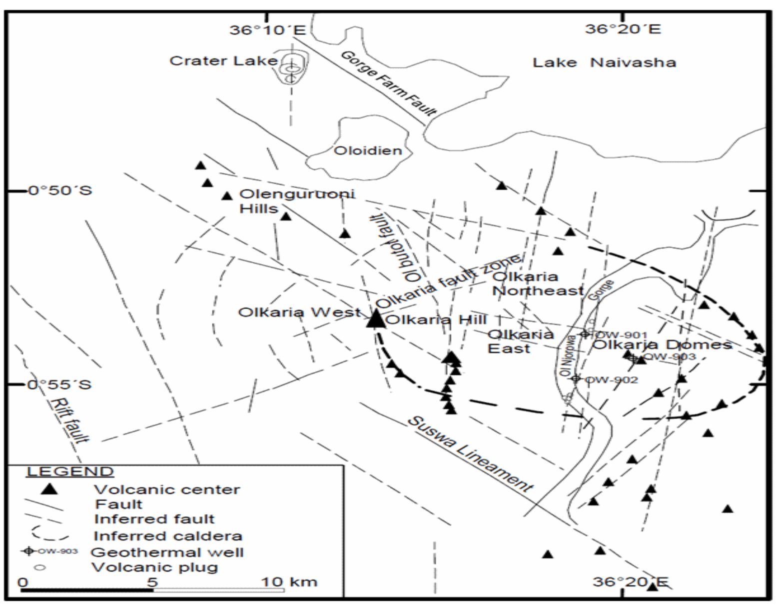

Figure .4: The Olkaria geothermal field fault lines (McCall, 1967)

Reservoir down flow and up flow zones

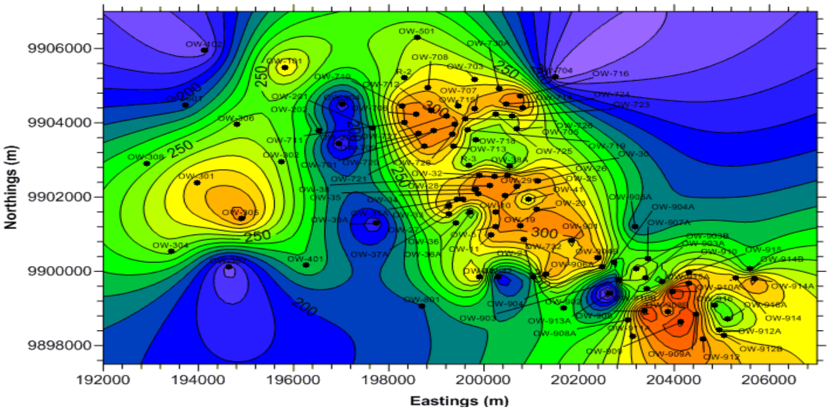

Figure .5: The down flow and up flow zones of Olkaria geothermal field (Mwarania, 2011)

There are four up flow zones within the Olkaria geothermal complex (Mwarania, 2011) and this are surrounded by down flow zones shaded dark blue and this are the regions with most cold reinjection wells location and if such are super imposed on the structural map they align well with the inferred ENE-WSW fault lines while the high production wells are aligned to the inferred N-S fault lines that extend all the from areas near the lake into Olkaria field.

Isotopic composition of wells fluid in the Olkaria geothermal field

Table .1: Isotopic composition of wells fluid in the Olkaria geothermal domes field

Well	Location	Liquid phase	
		Oxygen($\delta^{18}O$‰)	**Hydrogen (δD‰)**
901	Domes	4.97	32.2
902	Domes	3.22	21.8
903	Domes	3.09	21.7

(Sveinbjörnsdóttir, 1988), (Karingithi, 2000)

The isotopes of interest are those of well 901,902 and 903 that are needed for comparison with water quality from the Lake Naivasha and bore holes.

Isotope composition of fumaroles steam, springs and LakeNaivasha

The isotopic composition of the fluids around Lake Naivasha is shown in Table 2 below.

Table .2: Stable isotope composition of precipitation, spring waters, fumaroles steam, borehole fluids and Lake Naivasha water

Sample Identity	Location	Oxygen($\delta^{18}O$‰)	Hydrogen (δD‰)
Spring 1	Hell's gate	3.25	23.4
Spring 2	Hell's gate	2.07	12.5
Spring 3	Hell's gate	3.56	15.7
Spring 4	Hell's gate	2.77	14.9
Spring 5	Hell's gate	4.55	22.9
Spring 6	Hell's gate	4.86	14.9
Spring 7A	Hell's gate	3.69	16.2
Spring 7B	Hell's gate	4.86	15.6
Fume role 1	Hell's gate	-0.5	9.1
X-2 fumerole 1	Olkaria	-2.91	-6.2
Ndabibi borehole	North of L. Naivasha	-2.9	-11.8

Olsuswa borehole	North of L. Naivasha	3.1	20
Mau Escarpment	Mau Escarpment	-0.33	-1.4
28	Eastern Rift wall	-4.8	-28
39	Eastern Rift wall	-4.5	-20
82	Eastern Rift wall	-4.1	-24
93	Eastern Rift wall	-3.5	-17
95	Western Rift wall	-3.5	-16
96	Eastern Rift wall	-4.7	-24
101	Western Rift wall	-5.3	-35
122	Western Rift wall	-4.8	-27
Lake Naivasha		6.6	36

(Sveinbjörnsdóttir, 1988), (Karingithi, 2000)

The deuterium component in lake water and that in the reinjection wells (OW-901, OW-902, and OW-903) is almost equal meaning that the source of water into the reservoir and the lake are the same and therefore Olkaria geothermal field draws its waters from both the lake Naivasha and the rift escarpment.

Ternary Diagram Plots for Ground Water

Ternary diagram plot for Olkaria II reinjection Wells

The ternary diagrams plots for the bore holes and Olkaria wells were plotted and their results are as indicated in the following ternary diagrams.

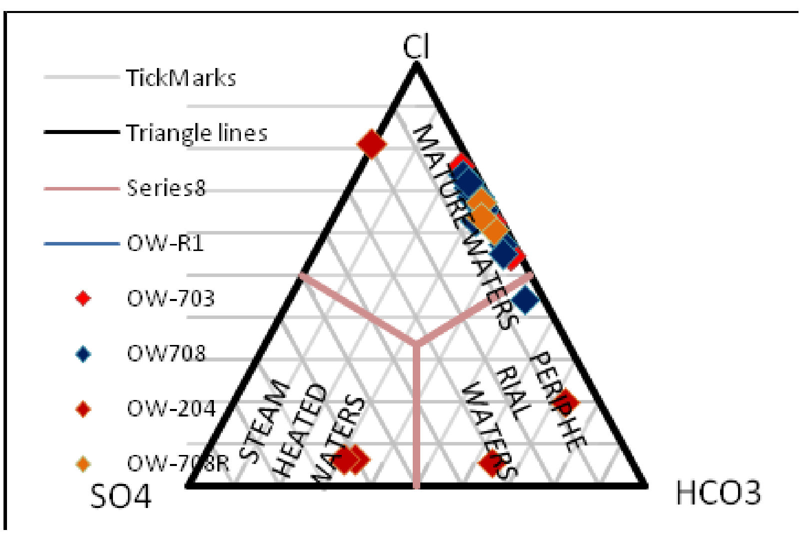

Figure .7: Ternary diagram plot of Olkaria II re-injection wells

From the ternary plot for Olkaria II wells, it's clear that the field fluids is of mature waters that have undergone rock water interactions hence inferring that the field draw its geothermal fluids from reservoirs that have taken a long time to reach their current chemical state and most of the re-injections wells are from a depth of around 2000 meters deep and at this levels it is uneconomical to get ground water and up to this depth no ground water was ever encountered in all the re-injection wells.

Ternary diagram plot for Olkaria IV reinjection wells

The Olkaria domes re-injection wells which host the 280Mw vision 2030 power plant, their brine plotted at the peripheral waters and basically found in the interior of the greater Olkaria geothermal complex but due to their depth of occurrence of roughly between 2000 meters to 3000 meters for most of them it's quite unlikely that this could be ground water that can be tapped viably for domestic use, but rather this region of occurrence of most of this reinjection wells indicates an inflow zone of both meteoric water and the lake Naivasha underground drainage regimes which can be deduced from the parallel fault lines from lake Naivasha into Olkaria geothermal complex in figure .4 that align themselves in the ENE-WSW and this also concurs with Mwarania's up flow and down flow zones of the Olkaria geothermal complex in figure .5. (Mwarania,2011)

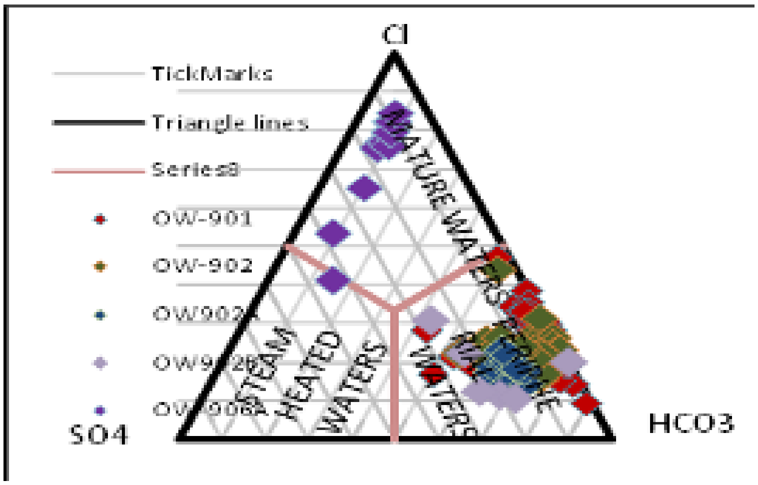

Figure .7: Ternary diagram plot of Olkaria IV re-injection wells

Ternary diagram plot for Bore holes

The bore holes from both the Eastern and western boundaries of the rift system especially areas around Olkaria and Lake Naivasha indicate that their waters are of peripheral in origin and hence meteoric waters that are flowing from both the eastern and western margins of the rift system into the escarpment.

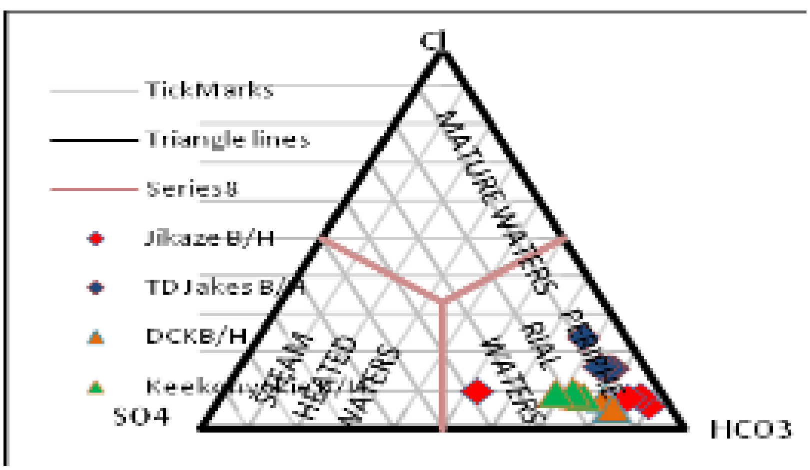

Figure .8: Ternary diagram plot of bore holes

The Eastern part bore holes constituted Jikaze, T.D Jakes both at areas around Maai mahiu while DCK was sampled at areas near Lake Naivasha, the western margins had only Keekonyokei borehole near Narok falling in the area of interest and scarcity of ground resource around the western margin escarpment at areas like Suswa market where boreholes have been tried to a depth of up to 240 meters deep but are either dry or give steam(Allen D.J and Darling 1987).This is an indication that the southern regions of the Olkaria geothermal system does not contain economically viable ground water resource and the only available ones are suitable for geothermal utilization basing on their depth of occurrence at around 300metres deep.

Lake Naivasha water levels

The Lake Naivasha levels have shown an increase in recent years especially in the year 2014 of which some scientists attributed it to increase geothermal energy utilization, but from the studies it's clear that geothermal energy generation involves extraction of the geothermal waters in form of steam to generate electricity. It should be expected that the lake levels were to drop but contrary to this the lake level rose despite the fact that more geothermal wells had been drilled to increase the generation capacity of geothermal energy in the year 2014 but as the figure .9 below indicate the lake levels rose drastically increase in that year. This gives a conclusion that even if Lake Naivasha recharges the Olkaria geothermal system, the periodic lake level fluctuations area not in any way connected to the increase geothermal utilization even though it recharges the Olkaria reservoir.

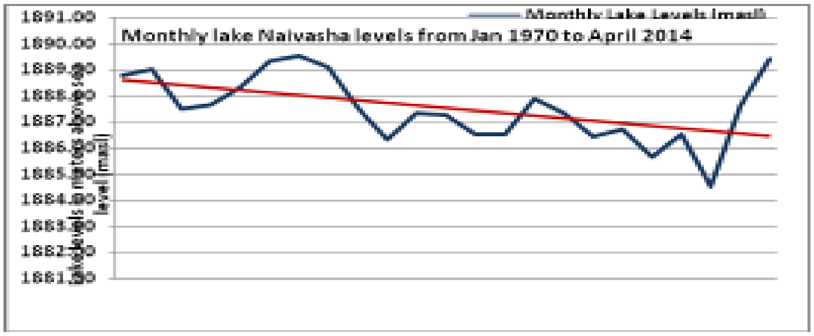

Figure .9: The annual averages of Lake Naivasha levels

DISCUSSION

The various diagrams and data indicate that the lake water and geothermal reservoir waters are recharged from the escarpment and that the water from Lake Naivasha moves laterally both to the North and to the southern part of the lake. The structural alignment and gradient of the lake indicate that even though Lake Naivasha is connected to the Olkaria geothermal complex as a recharge zone, the recharge does not however take place as a direct stream line flow but rather a complex process that is controlled structurally and by the transmissivity of the rock units in the area. that takes a period of up to around two years before the lake water gets into the geothermal reservoir (Allen et al 1978) and for this reason geothermal utilization does not have direct effect on the periodic fluctuation of the lake of which almost 98% goes southwards and 2% flows towards other directions away from the North and this lowers the salinity of lake Naivasha making it a fresh water lake. The isotope data indicated traces of lake water in the southern region of Suswa crater (Allen et al 1978) which is an indication that not all the 98% recharges the Olkaria reservoir.

As the peripheral water penetrates deeper into the ground more(inflow zones) ,CO_2 is substituted with Cl^- which is stable at high temperatures from rock interactions with water reaching an equilibrium at which Cl^- indicate mature waters which undergoes SO_4 ion exchange as a result of geothermal gradient heat change at the up flow zone. The CL-SO_4-HCO_3 plotted values indicate that bore hole and lake waters are of meteoric source from the escarpment and the chemical composition changes as the water moves deeper into the geothermal reservoir due to increased water-rock interaction and the geothermal gradient of temperature that increases in Cl^- and SO_4 ions as HCO_3 ion reduces making the water saline and re-injected waters are always from production wells of which most of them are rich in either Cl^- or SO_4 and this was not found in any of the bores holes of interest sampled down south.

The larger share of recharge into the Olkaria geothermal fields is from the escarpment, the areas around the up flow and down flow zones do not have economically viable ground water and any ground water available has high salinity hence not suitable for human consumption and this is evidenced by the presence of either dry bore holes or bore holes that produce steam at a depth between 200 to 250 meters where economically viable ground waters resource are expected to be found reason being deep seated fault like act as conduits that deliver water into the geothermal reservoir, for this reason the possibility of ground water contamination is not possible. Allen 1978 proofed presence of Lake Naivasha waters down south of Suswa geothermal system but conclusions for this report postulate the possibility of fault lines that evaded interaction with the Suswa fault system into the reservoir.

CONCLUSION

The shallow re-injections do not at all have any possibility of contaminating ground water because of the depth of occurrence of ground water that is on a shallow depth than that of geothermal reinjection wells and the well development mechanisms put in place to avoid any interaction of ground water and geothermal effluents.

The utilization of geothermal does not have any direct or indirect connection to the periodic fluctuation of the lake levels since the flow is based on rocks transmissivity, ground water pressures differential between the Olkria field reservoir and underground drainage water from Lake Naivasha waters.

A detailed bore hole sampling further down south of Suswa geothermal resource area needs to be done to find out the extend of the fault conduits and if they might be having any effects on ground water quality.

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