Creation of a Geohazard Monitoring Baseline for the Menengai Geothermal Field

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ABSTRACT

Appraisal drilling for geothermal resources in the Menengai Geothermal Field is on-going with eight geothermal wells already drilled. In the course of drilling, different materials like cement, bentonite, soda ash etc. are used in the drilling process and cementing jobs. This may result in large amounts of pollutants being discharged into shallow and deep acquifers and reservoirs that feed the water boreholes. The quality of water issuing from the boreholes in this surrounding is very important given that they are the main source of water for Nakuru Town. Monitoring of any changes in the chemistry of water and/or gases in boreholes located in the regions surrounding the Menengai Geothermal Field has been put in place. In this monitoring exercise an attempt has been made to assess the possibility of pollution of the ground water during the drilling exercise thus creating a baseline for any future changes that might be encountered. Geochemical sampling for monitoring purposes in this area started in April 2011, just before completion of the first geothermal exploration well. In this paper, the chemical results of the sampled boreholes have been presented and discussed. The results show that over the 8 months of geochemical monitoring, there hasn't been a noticeable change in the physical and chemical parameters of the borehole waters in the area. The results hence form the baseline data for monitoring future changes accompanying the exploitation of the geothermal field.

1. INTRODUCTION

Menengai Geothermal Field in Kenya is currently in its initial stages of development. A total of eight wells have so far been drilled and more are being drilled in an on-going drilling program aimed at producing 1,600 MWe. This geothermal field is located north of Lake Nakuru and south of Lake Bogoria (Figure1). The Menengai Geothermal Field is located within an area characterized by a complex tectonic activity associated with a rift triple junction. This is at the zone where the Nyanza rift joins the main Kenya rift. A large area around the caldera is covered by mainly pyroclastics erupted from centers associated with Menengai volcano. The major structural systems in the area are the Menengai caldera, Molo tecto-volcanic axis (Molo TVA) and the Solai graben.

The Menengai caldera is a shield volcano occupying the floor of the East African Rift with a summit elevation of 2278m (7,474 ft) located at 0°12'0"S and 36°4'0"E. Construction of a 30km^3 shield volcano beginning about 200,000 years ago was followed by the eruption of two voluminous ash-flow tuffs, each preceded by major pumice falls. The first took place about 29,000 years ago and produced a large caldera. The second major eruption, producing about 30km^3 of compositionally zoned per-alkaline trachytic magma took place about 8,000 years ago and is associated with formation of the present-day elliptical 12 x 8 km summit caldera.

More than 70 post-caldera lava flows cover the caldera floor, the youngest of which may be only a few hundred years old. The caldera floor covers an area of about 88km^2, and is partially covered by young rugged lava flows that are post caldera in age (Lagat et al. 2010). No historical eruptions are known from Menengai. Fumarolic activity is restricted to the caldera with a few fumaroles located to the north western part out of the caldera (at Ol' rongai area).

The chronology of syn- and post-caldera events is based on correlation with dated fluctuations in the levels of nearby lakes, suggesting that the two ash-flows may have been erupted at about 29000 and before 12850 years ago. Lake sediments inside the caldera provide evidence for a late intra-caldera lake from about 10300 to 8300 years B.P. (Leat, 1984 and Leat et al., 1984). The ring structure has been disturbed by the Solai graben faults on the NE end and one fracture at the SSW of the caldera wall extending southwards. The Molo TVA / Ol'rongai fracture system intersects the Menengai caldera on the NNW part. Most of the caldera infill lavas are from fissure eruptions that flowed out of the fracture openings.

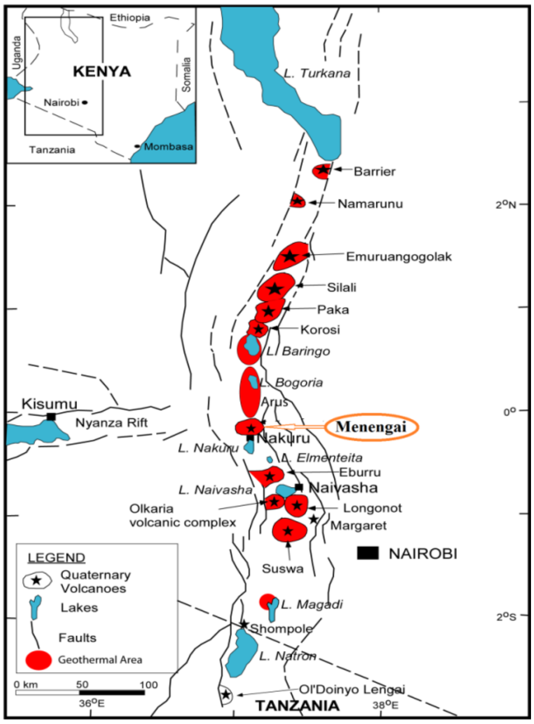


Figure 1: Location of Menengai Geothermal Field and other geothermal areas in Kenya.

Geothermal reservoirs undergo changes during drilling and subsequent fluid discharge. The changes could manifest in the chemistry of geothermal fluids and therefore chemical monitoring is useful in predicting undesirable events associated with volcanoes and geothermal systems like fluxes of gas, fluids and heat. One of the goals of geochemical monitoring is the ability to recognize these processes by monitoring boreholes in the region surrounding the geothermal field. A geohazard monitoring program has been initiated for Menengai and its environs aimed at checking the chemical response of the boreholes to the on-going drilling operations and subsequent discharging of geothermal wells. This study is also considered an important contribution towards minimizing possible risks to the health and safety of flora and fauna.

2. OBJECTIVES

The main objectives for this study were to create a baseline for water and gas chemistry in the regions surrounding the Menengai Geothermal Field in view of the on-going drilling for geothermal steam and future exploitation of the Menengai Geothermal Field, characterize the fluids that are feeding or are peripheral to the geothermal system and monitor any changes that might arise due to exploitation of the geothermal resource in the Menengai field.

3. METHODOLOGY

3.1 Borehole Sampling and Analysis

Borehole sampling in the area surrounding Menengai Geothermal Field has been divided into five regions namely northern, southern, eastern and western with an addition of the GDC water boreholes inside the caldera (Figure 2).

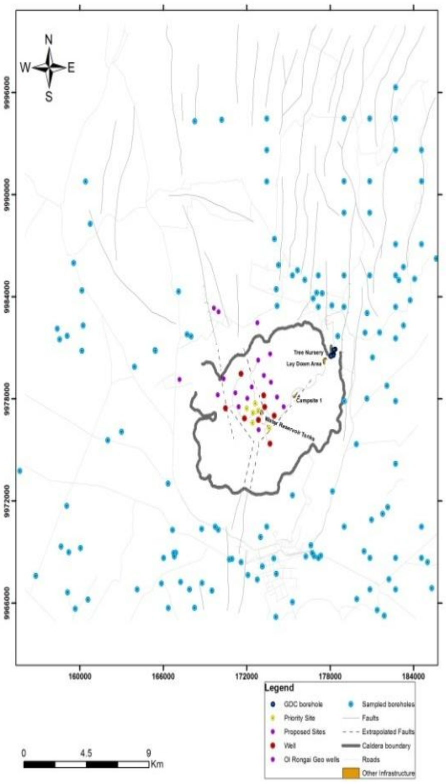


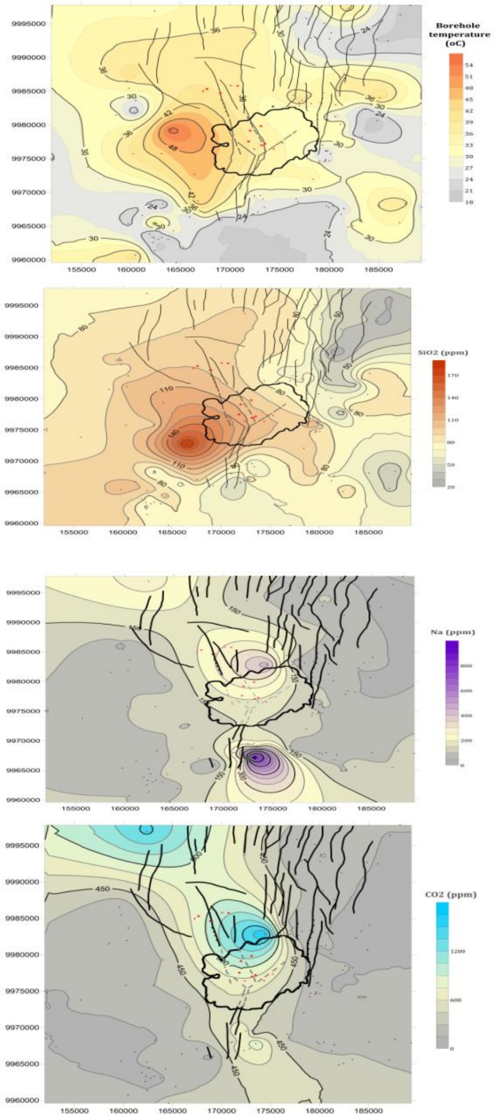
Figure 2: Location of boreholes considered for geohazard monitoring study in the Menengai geothermal field.

Water samples were collected from the boreholes in the aforementioned regions in three major sampling campaigns: March-July 2011, September-November 2011 and February-July 2012. The samples were analyzed for TDS, pH, CO_2, H_2S, SiO_2, Na, K, Ca, Cl, SO_4, F, and NH_3 using different methods suitable for each parameter. Borehole temperatures were also recorded.

3.2 Chemical Characteristics of Borehole Water

3.2.1 Maps Depicting the Distribution of Various Parameters

This sampling program was carried out to monitor the changes that may have occurred in the borehole waters due to the drilling program being undertaken in the Menengai caldera. Figure 3 shows the contour maps depicting the distribution of various major parameters like borehole temperature, SiO_2, Na, CO_2, H_2S, Cl, SO_4, F and Ca) measured from the waters of boreholes in the Menengai region.



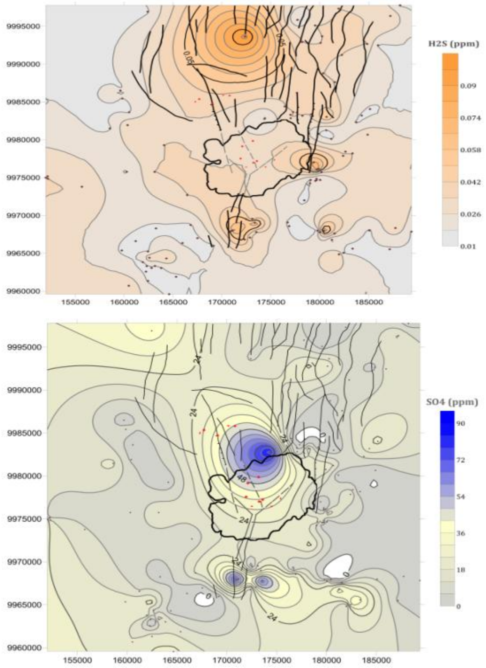


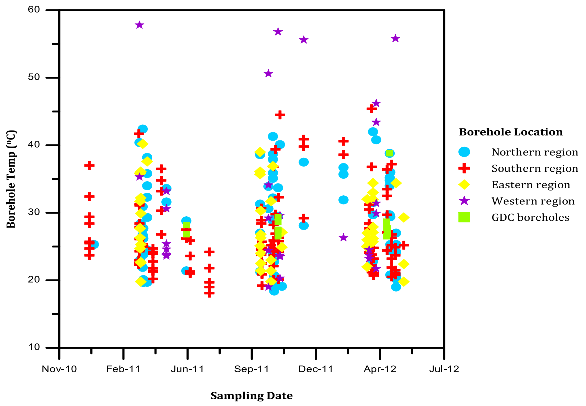
Figure 3: Contour maps depicting distribution of various parameters of borehole waters in the region surrounding the Menengai geothermal field

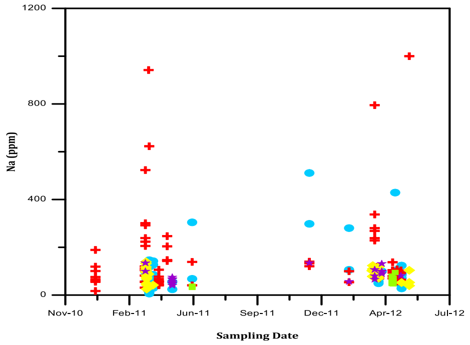
There seems to emerge a clear trend (NW-SE) for most of the parameters and the correlation of the measured temperatures to the silica concentrations suggest elevated temperatures in the region west of the caldera.

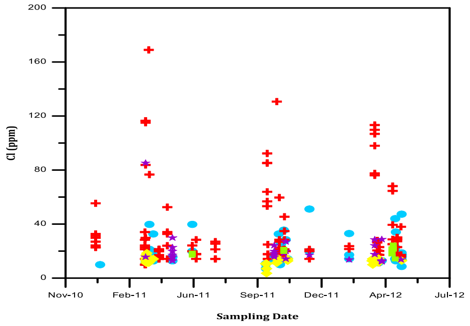
3.2.2 Chemical Trends with Time

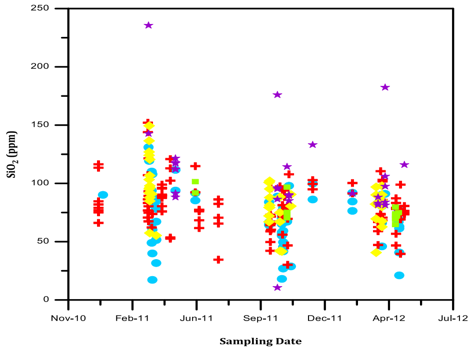
Trends for various elements and parameters have been plotted against time for the sampled boreholes (Figure 4). Grouping these boreholes in regions have aided in distinguishing the various parameters emerging from the various regions e.g. the western region boreholes have the highest recorded water temperature with borehole 10 having a measured temperature of 57.8°C; boreholes 34, 38, 82 and 74 recorded the highest concentrations of cations and anions. The northern region boreholes 74 and 82 have high CO_2 with eastern region boreholes displaying the highest values of H_2S (i.e. boreholes 32 and 39).

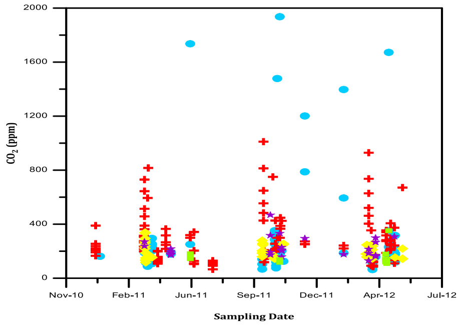
Western region boreholes display the highest SiO_2 content, with borehole 10 giving values of greater than 200 ppm (which tends to concur with the measured borehole temperatures relating SiO_2 concentrations to measured temperature – see silica and temperature contour maps in Figure 3). GDC boreholes have low concentrations of all elements analyzed, with temperatures ranging between 25°C and 40°C.











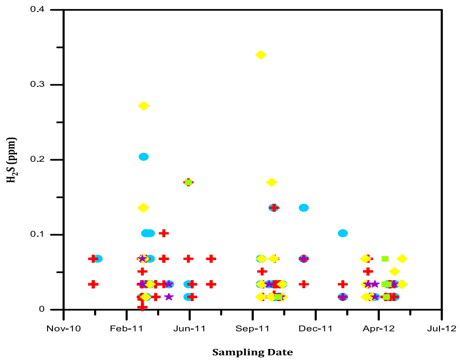


Figure 4: Chemical trends of the waters from boreholes surrounding Menengai Geothermal Field

3.2.3 General Characteristics of Borehole Water

The waters from the boreholes can be classified based on the relative concentrations of the three major anions i.e. Cl, SO_4 and HCO_3 by use of ternary diagrams. Chloride, which is a conservative ion in geothermal fluids, does not take part in reactions with rocks after it has dissolved; it does not precipitate after it has dissolved and its concentration is independent of the mineral equilibria that control the concentrations of rock-forming constituents. Thus, chloride is used as a tracer in geothermal investigations. The Cl-SO_4-HCO_3 ternary diagram is one diagram for classifying natural waters (Giggenbach, 1991). Using it, several types of thermal water can be distinguished: mature waters, peripheral waters, steam-heated waters and volcanic waters. Figure 5 provides an indication of the relative concentrations of the major anions.

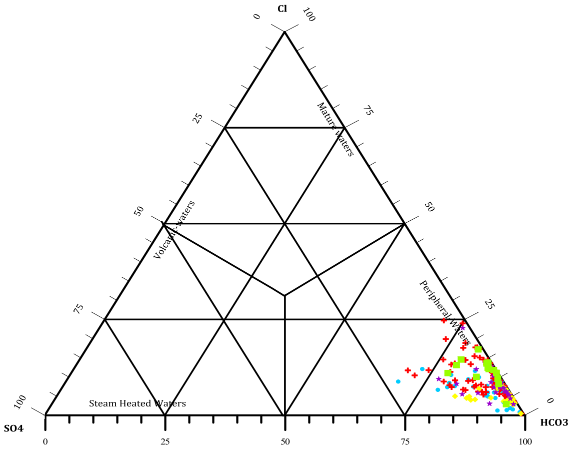


Figure 5: Relative Cl-SO4-HCO3 contents from the boreholes considered for geohazard monitoring surrounding the Menengai Geothermal Project.

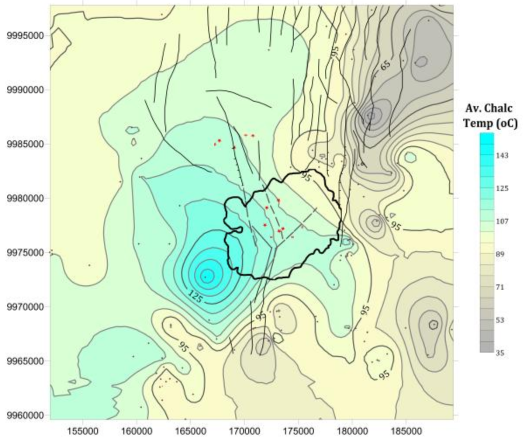
According to Giggenbach (1991), the chloride-rich waters are generally found near the up-flow zones of geothermal systems. High SO_4 steam-heated waters are usually encountered over the more elevated parts of a field. The degree of separation between data points for high chloride and bicarbonate waters may give an idea of the relative degree of interaction of the 'CO_2-charged' fluid at lower temperature, and of the HCO_3 concentrations which increases with time and distance travelled underground.

From the Cl-SO_4-HCO_3 ternary diagram, the borehole waters surrounding the Menengai geothermal field plot in the region of high HCO_3-peripheral waters and low chloride (Figure 5) illustrating that the fluids in these borehole reservoirs are bicarbonate waters and correspond to peripheral waters. It should thus be noted that bicarbonate-rich waters originate through either dissolution of CO_2-bearing gases or condensation of geothermal steam in relatively deep, oxygen-poor ground waters. Because the absence of oxygen prevents oxidation of H_2S, the acidity of these aqueous solutions is due to dissociation of H_2CO_3. Although it is a weak acid, it converts feldspars into clays, generating neutral aqueous solutions. These solutions will typically be rich in sodium and bicarbonate (Harsh and Sukanta, 2007) which is shown by the enriched Na and HCO_3 in the borehole waters.

3.2.4 Geothermal Contours

In order to conclude about the borehole characteristics, various geothermometers have been used to estimate the waters feeding the boreholes. A basic assumption in using geothermometers has been that temperature dependent chemical equilibria prevails in the source aquifer of the waters feeding the boreholes and that chemical reactions are not significantly modifying the composition of the fluid as it ascends from the source aquifer to where the samples were obtained. It has been generally accepted that it's a good choice to assume equilibrium with chalcedony for geothermal systems in volcanic rocks if the chalcedony equilibrium temperature is less than 180°C (Arnórsson et al., 2000).

Averages of the chalcedony (Fournier 1977 and Arnórsson et al., 1983b) and Na/K (Arnórsson et al., 1983b; Giggenbach, 1988and Arnórsson et. al 1998) geothermometers have been evaluated for the boreholes sampled and contoured (Figure 6). The quartz geothermometers coincide with the high measured sample temperatures and form a contour similar to that of the silica concentration contour. The Na/K average contour map gives a little bit higher values for the evaluated geothermometers with the area northwest of the caldera having elevated Na/K temperatures.



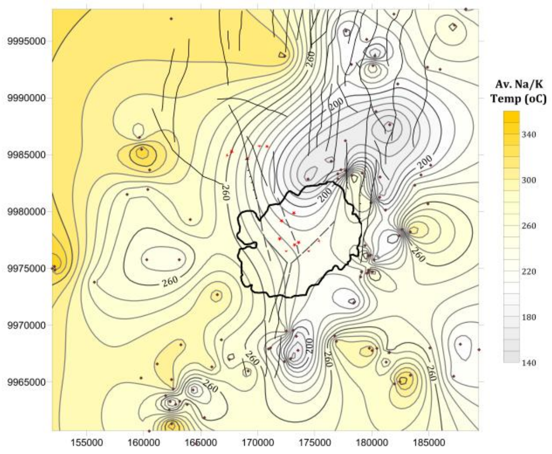


Figure 6: Contour maps depicting quartz and Na/K geothermometers. Symbology as in Figure 3a.

4. CONCLUSIONS

a) No chemical changes have been observed during the monitoring period. This being the baseline creation of the geohazard monitoring program, there is need to establish a continuous sampling campaign in order to monitor any changes in the chemical and physical parameters of the borehole waters.

b) A majority of the boreholes sampled discharge above ambient temperature waters with most having TDS less than 1000 ppm.

c) There seems to emerge a clear trend (NW-SE) for most of the parameters suggesting correlation with the Molo TVA.

d) The correlation between the measured and calculated temperatures and the silica concentrations suggest elevated temperatures in the caldera and the area west of the caldera.

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