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Effects of Menengai Geothermal Power Project on Fluoride Levels in the Drinking Water Sources of Menengai Caldera in Kenya

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Abstract: Surface disturbances that arise from geothermal power exploitationactivities such as pressurized fluidflows, andthe disposal of brine, rock cuttings,etc. can lead to contamination of nearby water sources. Thispaper analysesFluoride (F) concentrations in water sources ofthe Menengai caldera area, the site of the Menengai Geothermal Power Project (MGPP) in Kenya. Groundwater sampleswere taken from sixboreholes within the caldera and tested for F concentration using the Ion Selective Electrode (ISE) analysis. Results showed F concentration ranging from 5.83mg/Lto7.51mg/L whichexceededthe 1.5mg/Llimit recommended by the World Health Organizationfor drinking water. Similar results were observed in a study by Wambu and Muthakia (2011) in the neighboringGilgil-Elementaita area which is 20km South–East of Menengai. The Nakuru Water and Sanitation Services Company (NAWASSCO) obtainwater from groundwatersources.Borehole and pipedwater samples obtained from NAWASSCO water supply system showed average F concentration of 6.05mg/L and 7.05mg/L, respectively. The higher F levels in the pipedwater supply are likely to arise from solubilization in the earthen filtration media, extensive evaporation from the open water treatment tanks, and contamination through leaking pipes. Intake of high F concentrations causes fluorosis of the enamel and skeleton. The Caldera findings suggest that the MGPP activities are unlikely the cause of the high F concentration in the NAWASSCO drinking water supply. The studytherefore recommends an audit of the NAWASSCO water treatment works and distribution network to ascertain the cause of the higher F levels and the possible mitigation strategy.
Keywords: Analysis, water quality,fluoride, Menengai

1. Introduction

The year 2004 marked the onset of geothermal energy exploration activities in Kenya by the Geothermal Development Company (GDC). Menengai area was then largelyan unoccupied expanse [1]. However, population growth in the neighboring Nakuru town, and the livelihood opportunities that come with projects such as the MGPP have led to settlements around the caldera, such asBahati, Banita, Engoshura, Kabatini, Kiamaina, Kiamunyi,Kwa-Gitau, Mashiaro, Olive, Rongai, Solai and Wanyororo.Land use/cover andgeological formations are known to affect groundwaterquality, recharge, storage and availability[2].The local water utility provider NAWASSCOobtains its water mainly from groundwater sources[3].The pipedwater distribution network coverage is inadequate particularly in thenew settlements,even though the average distance to its access in the entire Nakuru County has reduced from 1000m to 500 m[4]. Residents supplement their domestic water needs from natural streams such as the Wanyororo springs (Figure 1). They also harvest rainwater, although local rains are scarce and sporadic [5]. The GDC also provides raw borehole water to locals e.g. at Wanyororo, as part of its Corporate Social Responsibility (CSR) program (Figure 2).

On the rift floor, drainage is mainly from the caldera northwards, while that from the southern edge is southbound into Lake Nakuru [6].Contamination of the caldera water resources is likely to spread both ways. Nakuru area is known to have water quality problems, particularly related to F levels.

Source: **[6]**

Figure1: A resident fetching water for domestic use from the Wanyororo springs.

Source: **[6]**

Figure2:A tank for borehole water at Wanyororoarea.

A 1982 survey [7]showed underground water in the region had maximum F concentrations reaching 50 mg/L.The caldera area has a general north–south trending fault/fracture system that providesunderground channelsresulting to stream water disappearing underground at some places[6].Geothermal power exploitation activities canintensify the F levels when water resources are exposed tothe F richgeothermal fluids, rock cuttings, and soils from the drilling processes and discharging wells.Thus, the purpose of this study was to establish thesuitability of water for drinking from local sources in Menengai Caldera area found in the Rift Valley in Kenya, with their close proximity to the on-going activities of theMGPP.

2. Methodology

2.1 Study Site

The study area was the Menengaicaldera, locatedapproximately 10km north of Nakuru town on the floor of theRift Valley in Kenya (Figure 3).

Source: www.mountain-forecast.com/peaks/Menengai

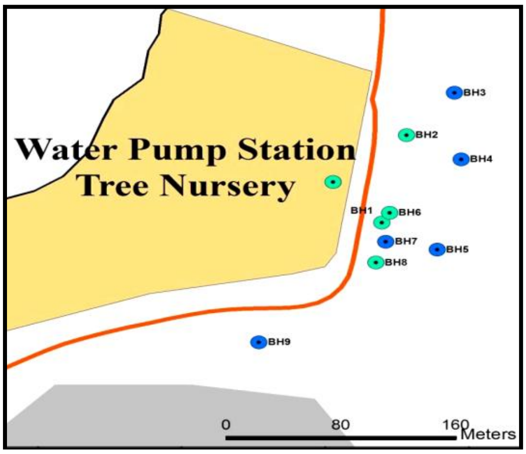
Figure 3: Location of Menengai in Nakuru

Nakuru is approximately 150km north-west ofNairobi(Figure4).

Source:AFP-Getty Images

Figure4: Map of Kenya, showing Nakuru

Menengai is Africa's second largest caldera, covering approximately 90km^2. The groundwater sourcessampled inside the caldera were within a radius of 150m to theMGPPtree nursery (Figure 5).



Source: GIS section, GDC
LEGEND: Caldera edge
Access road

Figure3: The GDC Menengai boreholes

2.2 Sampling Procedures

Water samples were collected over a period of two months of June through July in 2015. These are rainy months and therefore the likelihood of groundwater movement of F from the MGPP re-cycled water and brine around the caldera aquifers is high. The sampling containers used were 100mLbottles made of high-density polyethylene (HDPE). To maintain the collected water sample quality,all sampling bottleswere cleaned in dilute Nitric acid (0.1M HNO_3) then rinsed thoroughly indeionized water and placed in clean plastic bags after drying, until use. Water from the boreholes was let to run for approximately 20minutes before collecting samples to avoid any foreign matter or precipitates carried from the well bore and surface linings. Samples were collected from six boreholes inside the caldera, namelyBH2, BH3, BH4, BH5, BH7 and BH9, and from one NAWASSCO borehole (NBH) at Naka areawithin the Lake Nakuru national park (Figure 6). The NBH borehole was used for reference purposes.

Figure4: NAWASSCO borehole outlet at Naka area, with Lake Nakuru in the background.

Samples from Wanyororo springs and Kanduturastreamwere collected by complete immersion of the sampling bottle while capped, then opening against thedirection of flow with minimal disturbance to the flow matrix. Samples ofNAWASSCO tap water were obtained directly from eight end-of-pipe tap outletson six alternate working days staggered within the two months. Each day's samples were collected between 9am and 11amafter the morning peak water demand hours to minimizealterations in the water properties that could arise from stagnation or very slow flows within the distribution pipenetwork. All the bottles were capped and labeled immediately after sample collection, and placed in a cold box at 4˚c - 5˚c temperature for transportation to the laboratory for analysis.

2.3 Analytical Methods

Fluoride levelsin the water samples were determined by ISEanalysis, using a single junction Silver Chloride (ELIT-001) reference electrode, andan F ion (ELIT-8221) measurement electrode,onan ELIT ion analyzer (electrode-computer interface). The electrodes were pre-conditioned in fresh Sodium Fluoride (NaF) solution of 1000ppm F concentrations, prepared by dissolving 0.223g of 99% pure NaF in 100mL of deionized water.The ion analyzerwas calibrated using sequentially diluted portions of the NaF solution to 0.1ppm, 1.0ppm, 10ppm, 10ppm and 1000ppm F ion concentrations.5mL of each sample was transferred by pipette into a thoroughly rinsed 100mLglass beaker, and mixed with 5mL(1:1 volumetric ratio) of Total Ionic Strength Adjustment Buffer (TISAB)solution.

3. Results and Discussion

Results showed thatKandutura stream waterhad an F concentration of 0.97mg/L, making it safe for drinking as per the World Health Organization (WHO)standards. The recommended limit for drinking water F levels is 1.5mg/L **[8]**. Its source is surface runoff from the adjacent forested escarpments and via ground seepage**[6]**. Being a seasonal source, F levels vary with season because of variation in seasonal flow volumes and catchment characteristics, including anthropogenic F rich substance deposits from the MGPP activities. An earlier report **[6]** had found it to have an unsafe F level for drinking at 1.76mg/L.All other samples analyzedexceeded the WHOlimit, withgroundwater Fvalues ranging between5.83mg/Land7.51mg/L(Table 1).

Table 1: Average F concentrations in ground water

Borehole	Average F (mg/L)
BH2	6.76
BH3	6.90
BH4	7.14
BH5	7.51
BH7	6.18
BH9	5.83
Mean	6.72
NBH	6.05

The meanF value in the calderaborehole sampleswas6.72mg/L.A study conducted by Wambu and Muthakia(2011)in the neighboringregion of Gilgil and Elementaita, 20kmto the South–East of Menengai showed thatthe mean F value in ground water was6.57mg/L**[5]**, while the analysis of this studyon water from a NAWASSCO borehole (NBH)at Naka, 10km south of Menengai showed a mean F value of 6.05mg/L.Compared to the NBH F concentration value, the mean value of the sampled boreholes was higher by 11% (< 1mg/L). The Wanyororo springs watershowedF content of1.99mg/L, which was lower than the 3.17mg/L value obtained by GDC**[6]**. However, since the source of the spring is shallow groundwater which has percolated through the ground along lithological contacts**[6]**, such variationwas assumed normal. Although the average ground water F levels near the MGPP area are slightly higher, thevariationis not significant enough to indicatea possible exacerbation of the water F problem bythe project'sactivities. Pipedwater from NAWASSCO had even higher F levels, with dailyaverage concentrations in tap water ranging between 6.15mg/L and 7.98mg/L for the two months period sampled on three different staggered occasions (Table 2).

Table 2: Average daily F concentrations in tap water

Sample		Average F level (mg/L)
June	Sampling 1	6.42
	Sampling 2	7.10
	Sampling 3	6.15
July	Sampling 1	6.81
	Sampling 2	7.83
	Sampling 3	7.98

The average F concentration in the water supplied from NAWASSCO taps was 7.05mg/L, approximately five times the WHOlimit of 1.5mg/L. The elevated levels were assumed to have resulted fromF solubilization from earthen filtration media and extensive evaporation of water from the open tanks at the water treatment plant. Also,infusion of local F rich soils through leaking pipesdue to cracks and faulty joints in the water distribution pipe network. There is an elevated risk of skeletal effects at F intakes above 6mg/day, and continued consumption of water with F concentrations above 1.5mg/L may cause enamel and skeletal fluorosis **[9]**.With an exception of the Kandutura spring water, all samples had F levels above the 1.5mg/L limit recommended by WHO for drinking water quality standards (Figure7). A comparison of the findings of this study to baseline data andthat from previousreports could however not establish any compelling evidence of exacerbation of the water F problem in Menengai as a result of MGPP activities.

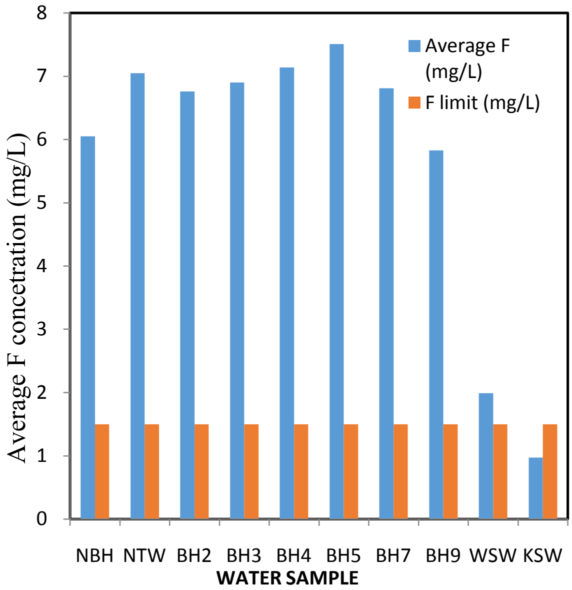


Figure5: Analysis of F ion concentrations in all the water sources sampled

4. Conclusions and Recommendations

Water samples were collected from surface, ground and tap sources and analysed for F concentrations. All except the Kandutura spring waterhad F levels above the 1.5mg/L limit recommended byWHO for drinking water.The safe Kandutura water is however not available to majority of the locals, owingto the long walking distances and rugged terrain encountered before accessing it. The Menengai area groundwater average F concentration is6.72mg/Lwhile that in pipedwater from NAWASSCO is7.05mg/L, representing unsafe drinking water supplied to the community by both GDC and NAWASSCO.

Comparison of the F values obtained from water sources in the study area to those away from theMGPP siteand to baseline data showed no possible exacerbation of the water F problems by the project activities. There is an elevated risk of skeletal effects at fluoride intakes above 6mg/day, and continued consumption of water with F concentrations above 1.5 mg/L may cause enamel and skeletal fluorosis **[9]**. Groundwater naturally has high F levels, notably in the Rift Valley of East Africa **[9]** within which the study area falls. The groundwater F levels which have been known to reach 50 mg/Lin the region **[7]**are a resultof natural rock chemistry and formations of the area. However, the water can be corrected for drinking at household level using simple adsorption filters such as bone char, but their disposal when saturated should be monitored to avoid recontamination of nearby water sources. The elevated F levels in tap waterabove that in thesource water is possibly due to evaporation in open water tanks, and Fsolubilization from earthen filtration media **[5]**.The process at NAWASSCO water treatment plant does not include any defluoridation measures. An audit of theirwater treatment facilitiesand distribution network is therefore recommended, and if possible install F removal mechanisms.F level of 0.7mg/L to 1.2 mg/L in drinking water is beneficial, especially to children when developing permanent teeth**[10]**.

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Acronyms and Abbreviations
BH– Borehole
CSR – Corporate Social Responsibility
F – Fluoride
GDC – Geothermal Development Company (Kenya)
GIS – Geographical Information System
HDPE – High Density Polyethylene
HNO_3 – Nitric Acid
ISE – Ion Selective Electrode (Analysis)
KSW – Kandutura (crater) Stream Water
MGPP – Menengai Geothermal Power Project
mg/L – milligrams per litre
MKU – Mount Kenya University
NaF – Sodium Fluoride
NAWASSCO – Nakuru Water and Sanitation Services Company
NBH –NAWASSCO Borehole water
NTW – NAWASSCO Tap Water
ppm – parts per million
TISAB – Total Ionic Strength Adjustment Buffer
WHO – World Health Organization
WSW – Wanyororo Spring Water

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