Surface and groundwater hydrochemistry in the mid-Gregory Rift, Kenya: first impressions and potential implications for geothermal systems

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Abstract. The University of Glasgow has a long tradition of scientific endeavour in the Gregory Rift Valley. This paper details some of the history and inspiration behind current hydrological efforts and details results from a 2016 field excursion to this region. A range of surface and ground waters were sampled and analysed for physical, chemical, and stable isotope composition as scoping investigation into geothermal-related hydrological systems. The results allow us to make some initial observations that will be followed up by additional multi-seasonal data collection. Our initial results show clear chemical and isotopic signals for river, lake, hot spring and Menengai geothermal well waters.

1 The Gregory Rift Valley and the University of Glasgow

The Gregory Rift Valley (GRV) represents the section of the East African Rift System (EARS) that dissects Kenya and Tanzania [1]. This part of the EARS is named after John Walter Gregory, who carried out the first scientific expedition there in 1892-1893 [2], and who would later take up a 25-year tenure as the Chair of Geology at the University of Glasgow (UoG) from 1904 onwards [3]. Gregory is most famous for his recognition and description of a new type of topographic depression, which he recognised as a result of tectonic separation and subsidence, which he called a 'Rift Valley' [4].

In the years since, much work has been carried out to decipher the geological evolution of the EARS, and assess its geothermal power potential. Drilling investigations in the GRV started in 1956, 75 km NW of Nairobi, and by 1981 the Olkaria I power plant was producing 15 MW. Since then over 100 wells have been drilled, the number of power stations has grown to four and capacity has grown to 569 MW [5]. Further exploration and testing is underway to develop multi-MW projects at Eburu, Longonot, Suswa, and Menengai in order to exploit Kenya's estimated reserves of up to 10 GW [6].

The UoG took a greater interest in Kenyan geothermal development in 2012 with the appointment of Prof. Paul Younger to the Rankine Chair of Energy Engineering. Younger was particularly enthusiastic about advancement of hydrogeological cycle knowledge in regions with high geothermal potential but significant hydrological vulnerabilities such as

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the GRV, where structure-magmatism-water connections can have a significant impact on vulnerable populations. In his travels to the GRV and the Main Ethiopian Rift he observed anomalous, non-precipitation-driven lake flooding and related salinization of rivers that provide essential fresh water resources to local populations. He theorised that permeable structural links between deep geothermal waters and fresh surface water bodies could be playing a considerable role. Advised by Younger, a University of Glasgow team set out to investigate the geothermal systems within the GRV from 28 June to 5 July 2016. This paper details the results of this trip and sets a baseline for future hydrological efforts in the region.

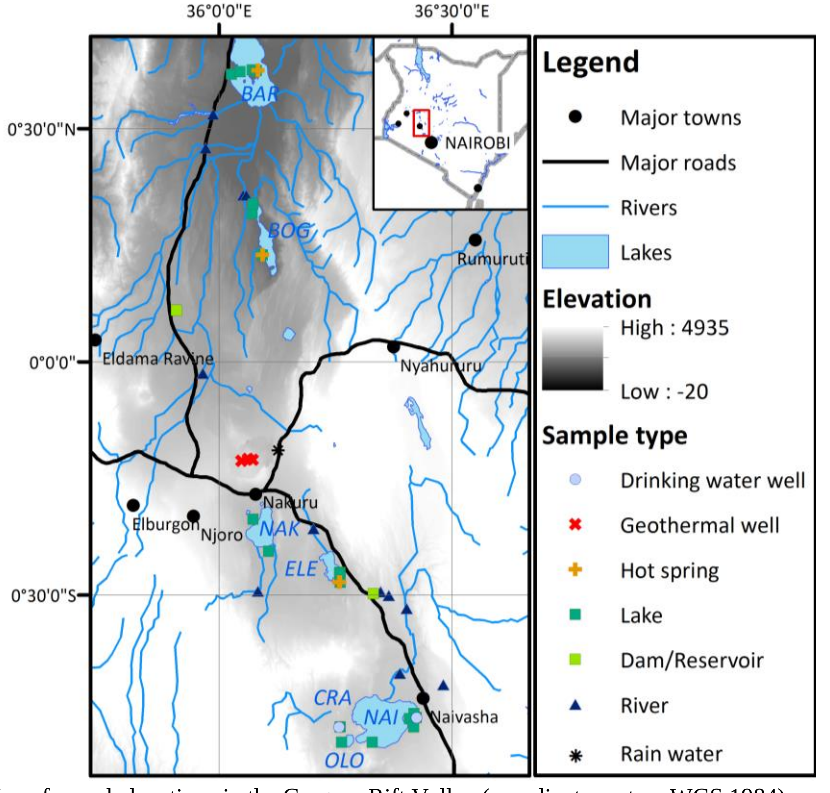

Fig. 1. Mao of sample locations in the Gregory Rift Valley (coordinate system WGS 1984).

2 Methodology and Results

Various surface and ground water samples were collected from across the GRV (Fig. 1). Prior to sampling, field parameters were measured on site. Field, sampling and analytical methodology are available in [7]. In addition, two rain water samples were collected from the field trip accommodation at Maili Saba Camp (5 km NNE of Nakuru; Fig. 1).

Hydrochemical results showed distinct variations between lake, river, hot spring (HS) and Menengai geothermal well (MW) samples (Table 1; Fig. 2). Bogoria (pH ~ 10) and Elementaita (pH ~ 9.7) are soda lakes rich in blue-green algae and have geyser activity. Specific electrical conductivity (SEC) measurements from two Bogoria HSs (~ 6.6 mS/cm) and 16 HS pools on Elementaita (~ 4 mS/cm) – of which three were sampled (K35 to K37) – were considerably lower than lake water values (~ 44.7 and ~ 12.0 mS/cm respectively), so any geothermal impact assessment on these waters is challenging to assess. The high alkalinity of Lake Bogoria consumed all available acid during field titration, so the K18 value was used as a proxy for plotting of subsequent Bogoria samples (Fig. 2).

Table 1. Analytical results for major ions (mg/L) and stable isotopes (‰ VSMOW); 'bd' = below detection, 'nm' = not measured, 'qci' = quality control issue. Sample shorthand as per Figure 2.

Sample	F	Cl	SO_4	HCO_3	CO_3	Na	K	Mg	Ca	$\delta^{18}O$	δ^2H
K1 Molo R	0.5	11.5	5.5	57	0	22.9	10.6	1.9	7.2	-3.2	-14
K2 Kapchelugwan	1.0	1.0	1.0	46	0	7.1	7.3	1.8	6.5	-0.3	3
K3 Pergera R	0.3	5.8	2.3	55	0	13.9	4.6	1.5	7.3	-2.9	-7
K4 Endou R	0.3	4.9	2.1	92	2	20.6	6.3	3.4	15.5	-2.1	-6
K5 L Baringo	2.2	25.5	4.9	199	4	83.5	17.2	5.3	15.2	6.2	34
K6 L Baringo	2.2	25.2	4.9	202	5	82.8	17.4	5.5	15.2	5.9	37
K7 L Baringo	2.3	27.6	5.1	221	3	90.8	18.5	5.9	15.6	5.9	36
K8 Baringo HS1	19.5	257	29.4	1205	25	1082	127.2	4.1	29.7	1.3	6
K9 Baringo HS2	6.2	64.9	5.7	571	55	221	31.8	6.6	38.7	5.2	28
K10 L Baringo	2.2	25.1	4.9	207	6	84.4	18.0	5.6	15.4	5.9	40
K11 Molo R	0.6	8.3	5.4	65	1	21.0	11.7	1.0	5.5	-2.7	-10
K12 Rorwai R	4.0	12.9	15.4	296	0	140	27.0	1.6	9.1	-2.6	-15
K13 Loboi R	3.3	16.8	16.3	193	2	93.4	20.7	1.2	11.7	-1.5	-1
K14 Bogoria HS1	71.5	318	51.4	2566	142	1856	88.6	4.3	30.6	-0.9	-3
K15 Bogoria HS2	72.6	324	49.7	2072	31	1942	233.4	2.1	22.6	-0.7	-2
K16 L Bogoria	2203	3151	81.2	nm	nm	14522	1656	bd	59.0	6.2	39
K17 L Bogoria	2144	3059	78.9	nm	nm	14148	1583	bd	58.5	5.7	37
K18 L Bogoria	2125	3034	77.0	1657	13465	14062	1575	bd	59.5	6.2	38
K19 Malewa R	0.2	3.1	2.5	54	0	8.4	4.2	1.9	7.3	-3.3	-7
K20 L Naivasha	1.0	8.5	1.8	134	0	22.0	15.9	4.6	19.7	3.6	21
K21 L Naivasha	1.1	8.6	1.8	133	2	22.2	15.9	4.6	19.7	3.9	25
K22 L Naivasha	1.0	8.3	1.8	138	1	22.0	15.5	4.7	19.8	3.7	27
K23 Crescent DWW	7.4	126	54.2	1119	2	475	58.9	17.4	73.9	2.8	19
K24 L Naivasha	1.0	8.1	1.7	129	2	23.2	14.9	4.4	18.8	3.2	22
K25 L Nakuru	323	692	63.3	2869	536	2324	249	10.2	16.8	5.7	31
K26 Makalia R	0.8	5.4	4.7	57	0	14.9	8.6	1.3	5.1	-2.7	-4
K27 L Nakuru	345	679	63.3	3211	797	2330	322	bd	12.7	4.6	34
K28 L Naivasha	1.2	9.5	0.5	159	0	25.4	18.7	4.4	22.4	3.6	26
K29 L Oloiden	85.3	85.5	1.3	934	112	628	117	10.1	12.6	qci	qci
K30 Crater DWW	6.1	48.9	84.0	546	5	269	50.1	11.6	34.7	-3.5	-14
K31 Crater L	310.4	218	52.0	2747	635	2005	407	16.0	13.3	9.0	43
K32 Baruku R	0.5	4.9	2.2	96	0	21.9	6.1	2.0	7.6	-3.3	-18
K33 L Elementaita	1242	1857	137	832	1475	3258	437	bd	11.2	7.2	41
K34 L Elementaita	1247	1863	132	1076	1415	3270	450	bd	10.9	7.2	42
K35 Elementaita HS1	500	466	73.0	1052	130	1036	123	4.0	11.7	-1.3	-5
K36 Elementaita HS2	483	436	70.0	1115	141	1043	161	1.5	6.1	-1.4	-4
K37 Elementaita HS3	337	295	57.2	683	60	737	133	1.1	4.7	-1.8	-6
K38 L Elementaita	1297	1948	137	1032	1562	3223	457	bd	11.6	7.4	42
K39 Na Ruwasco	0.2	2.8	17.0	21	0	6.8	3.6	1.9	6.9	-2.7	-5
K40 Murindati R	0.2	3.5	2.2	35	0	9.0	5.0	0.8	3.6	-2.5	-2
K41 Gil Gil stream	1.0	2.9	2.1	101	0	32.1	8.6	1.3	7.0	-3.3	-18
K42 Malewa R	0.4	3.0	2.2	34	0	7.6	4.6	1.2	4.6	-1.6	3
K43 Karati R	5.3	8.9	5.1	85	0	23.0	12.1	1.8	10.2	-1.6	3
MW-03	104	965	383	2352	1735	3910	549	23.9	89.3	-1.1	-7
MW-09	230	670	72.3	2056	261	1923	534	34.8	52.3	5.0	23
MW-17a North	121	510	331	3664	2836	5774	661	45.2	53.7	-1.5	-5
MW-17b South	77.1	425.2	327	4588	1512	4258	755	6.3	32.6	-1.8	-5

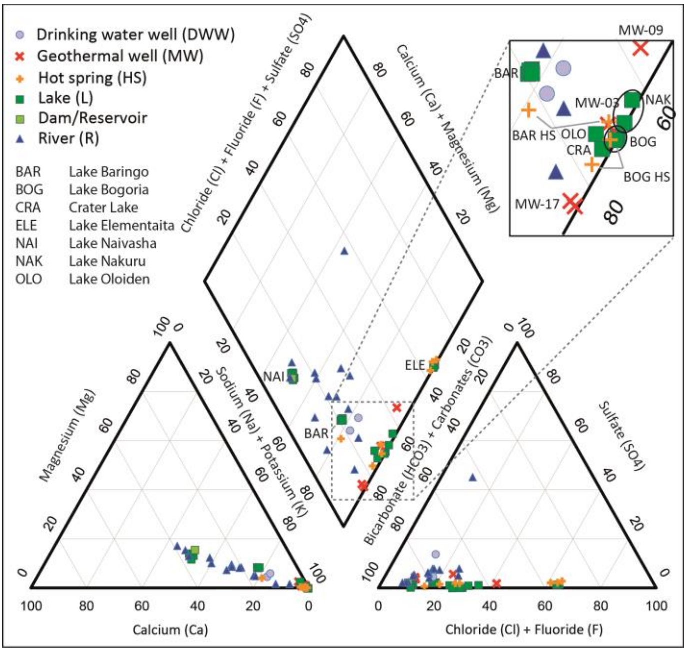

Fig. 2. Piper plot of anion and cation data for waters of the Gregory Rift Valley.

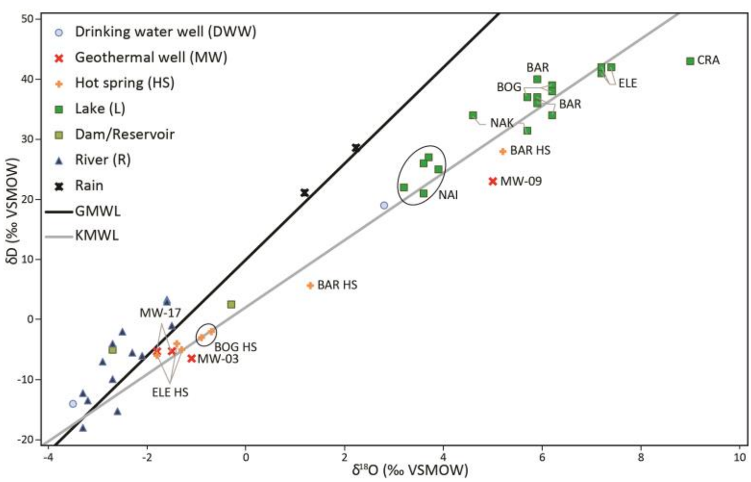

Fig. 3. Plot of δD versus δ^{18}O for waters of the GRV showing the (Global Meteoric Water Line - GMWL [8], Kenyan Meteoric Water Line- KMWL [9]).

Geothermal water temperatures where beyond limit of measuring equipment (> 75°C), measured pH 8.5 to 9.3, and have an enriched Na/Ca ratio in comparison to most surface waters, suggesting ion exchange with Na^+ bearing host rocks. Lakes Nakuru, Bogoria and Elementaita are hypersaline in nature and have equivalent, or greater, ionic values and Na/Ca ratios than geothermal waters due to evaporation driven solute concentration. The H- and O-isotopic data (Table 1; Fig. 3) illustrate that rain and river waters are predominately associated with the GMWL, with rain at isotopically enriched in D and 18O relative to river and geothermal waters, whilst lake and geothermal waters fall along the evaporative trend defined by the Kenya Meteoric Water Line (KMWL) calculated using January/February rainfall [9]. Baringo HS2 (K9) seeps from unconsolidated sediments on the shores of the lake and represents a mixture of geothermal and lake waters.

3 Conclusion

Geothermal waters are of high enough concentration that any significant volumetric discharge to the surface would likely result in noticeable perturbations in fresh water (i.e. Baringo and Naivasha) lake salinity. Lakes Bogoria and Elementaita waters, however, have such high ionic strengths that even substantial ingress of geothermal fluids would be difficult to detect. Lake Nakuru has significant ionic enrichment versus Lakes Baringo and Naivasha; and is similar - in terms of chemical composition - to Menengai waters. Thermal waters and lakes show a clear difference in lighter (thermal) and heavier (lake) isotopic populations, bar one geothermal well and hot spring outlier. The hot spring (BAR HS2) is on the shore of Lake Baringo and has a similar isotopic signature, indicating extensive mixing of thermal and lake waters. The geothermal well sample (MW-09) plots close to isotopic values for Lake Nakuru. When coupled with ionic data, the initial isotopic evidence related to the Menengai Geothermal field and Lake Nakuru looks to be in support of Younger's lake level fluctuation hypothesis and suggests permeable connections between deep thermal and surface waters in this location. Evidence for significant interaction between thermal and lake waters at other sampling locations is inconclusive. A definitive assessment is difficult using this 2016 data set, which represents a single point in time and cannot account for any seasonal variation. However, the data presented here forms a powerful baseline that shows clear distinctions between deep thermal and surface waters that lays the foundations for future investigations. Further work is underway, including inter-seasonal data, to assess potential geothermal fluid flow pathways and the degree of interconnectivity with surface water bodies across the GRV.

Acknowledgements. NMB is funded by a UoG LKAS Research Fellowship; fieldwork and analysis were funded by the Geological Society of London, Glasgow Natural History Society, and EPSRC GCRF ISF (EP/P510968/1). NM is funded by the EPSRC GCRF 'Combi-Gen' project (EP/P028829/1). AJB is funded by ICSF at SUERC (NERC Facility contract F14/G6/11/01). We would like to thank the late Prof. Paul Younger for inspiring the work; Anne McGarity and Alison McDonald for analyses; GDC for access to the Menengai Caldera; and the Kenya 2016 UoG students for sampling assistance (Chris Bonner, Andrew Brown, Ruth Carter, Kevin Casey, Caroline Crawford, Jack Cunningham, Hillary Mulholland, Cadan McLaughlin, Helen Robinson, and Tom Smith).

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