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Limitations in Applying Silica Thermometry for Geothermal Prospects Evaluation in Rwanda

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ABSTRACT

This report presents the results of hierarchical cluster analysis derived from hydrochemical data of springs and surface waters collected in Kivu Rift System and Virunga Volcanic Range area in Rwanda. The cluster analysis technique enabled me to obtain information about similarities or differences between sampling sites. It separated out three types of waters based on chemical composition. This technique also indicated possible mixing or dilution for the majority of hot and tepid springs that may affect the applicability of silica geothermometry in the studied area.

1. INTRODUCTION

The existing geothermometric data for the geothermal prospects, located in the Virunga Volcanic Range and the Kivu Rift System of Rwanda exhibited a wide range of estimated temperatures. The cation geothermometry estimated underground temperature between 150°C and 210°C whereas the silica geothermometers provided a temperature of 110°C to 141°C. And the hydrocarbon estimated temperature was found to range between 209°C and 349°C [1].

Various authors concluded that cation geothermometry is inappropriate for thermal waters of Rwanda. All the water samples belong to the field termed "immature waters" which have either not reached equilibrium with secondary minerals at reservoir conditions or been significantly mixed with surface waters. Such waters are generally not considered suitable for cation geothermometry [2]. Moreover no conclusion was drawn from hydrocarbon geothermometry. This is probably due to the limited number of data. Only four locations were considered by BGR survey in 2008 [1].

Therefore, the geothermal capacity assessment, in Rwanda, is based on silica geothermometry alone. This may seriously affect the accuracy of results and the level of confidence for taking decisions associated with geothermal energy development.

From 1956 when White and co-workers noticed for the first time that the silica concentration in hot springs was very close to the experimental solubility of amorphous silica, enormous development has been achieved on the silica solubility geothermometry. This development was mainly based on collecting field data and creating empirical temperature dependence silica solubility models. The silica content of water from a well or a hot spring can be correlated with the last temperature of equilibration [3]. Currently, silica solubility geothermometers are extensively used to estimate deep reservoir temperature during exploration and utilization of geothermal systems [4].

However, the predicted temperature generally shows a wide dispersion even when applying a single silica thermometer to all the samples in a geothermal field. Many reasons have been suggested to justify the discrepancies including mixing of different types of fluids, gain or loss of steam phase in the reservoir, re- equilibration during ascension to superficies, precipitation and dissolution. In case of natural manifestations there are still more complications in determining the dilution component, re-equilibration, steam loss or gain etc [5].

Additionally, whether or not equilibrium is established after mixing, the temperature of hot waters cannot be established from a solubility relationship unless mixing is taken into account. In mixed waters, silica estimated temperatures are generally decreased when compared to estimated temperatures from cation geothermometry [6]. Trends of such mixing processes are well illustrated by Hierarchical Cluster Analysis (HCA) [7].

Cluster analysis is a pattern recognition technique whose basic objective is to discover samples groupings called clusters or hierarchies. Hierarchical cluster analysis HCA has proven successful for identifying relationships between water samples by dividing water samples into water groups with similar characteristics. Subsequently, the water groups are correlated with location in order to provide insight into the physical and chemical processes controlling hydrologic systems, as samples with similar characteristics often have similar hydrologic histories, similar recharge areas, infiltration pathways, and flow paths [8].

In the present study, HCA is used to examine water mixing trends and shed further light on the suitability of applying silica geothermometry for accurately assessing the temperature and the potential of the geothermal reservoirs in the studied area.

2. MATERIALS AND METHODS

Water samples considered in the present report were collected in the Virunga Volcanic Range and the Kivu Rift System area in Rwanda (Fig .1.) by Chevron in 2006 [10] and BGR in 2009 [1].The water parameters from chemical analyses are summarized in Table 1.

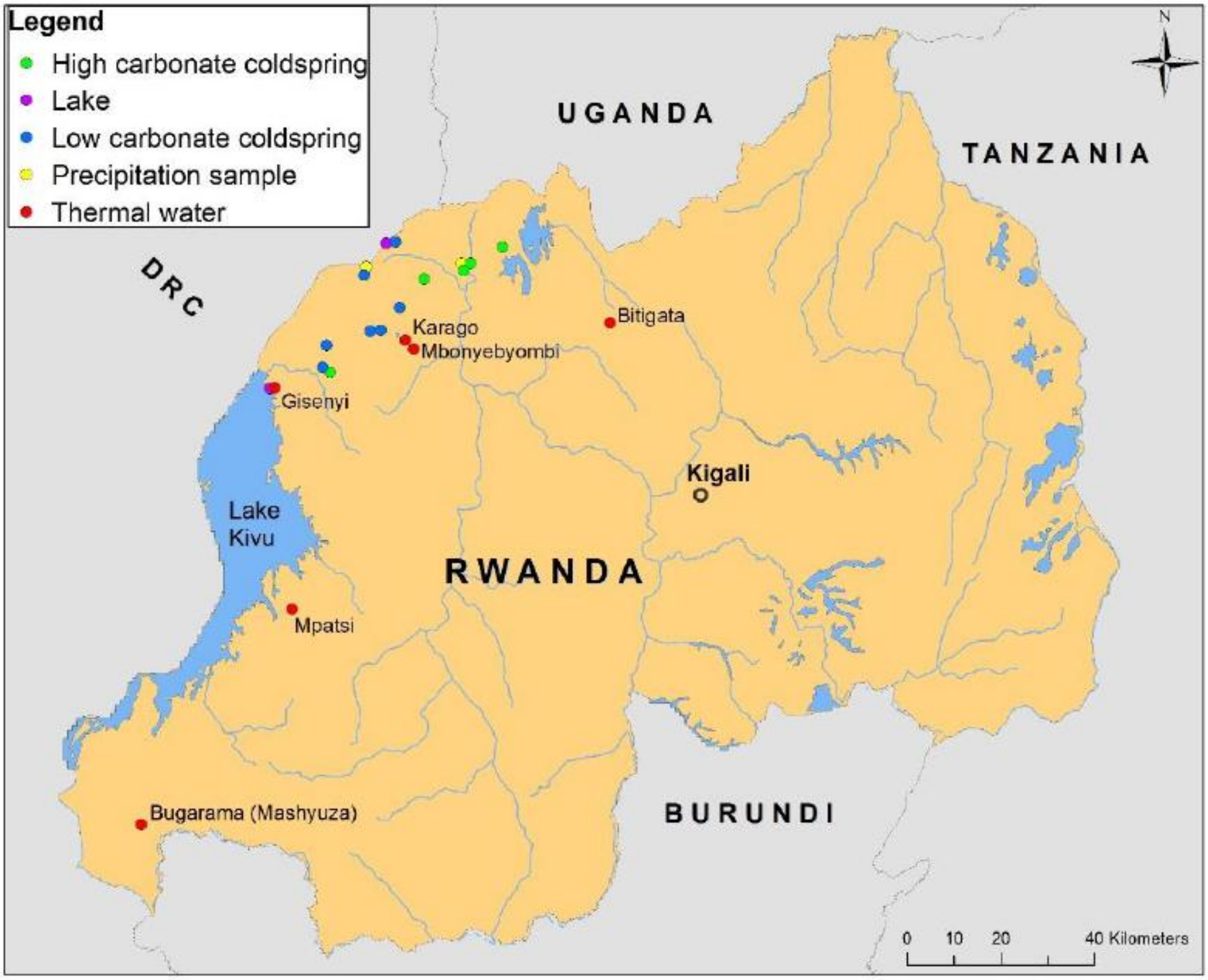

Figure1: Locations of sampling sites for springs and surface waters [2]

Table1: Selected physical and chemical parameters used for cluster analysis of springs and surface waters [1; 10]

Sample name	m asl	T ^{o}C	EC µS/cm	pH	Na mg/L	K mg/L	Ca mg/L	Mg mg/L	Cl mg/L	SO_4 mg/L	HCO_3 mg/L	B mg/L	SiO_2 mg/L	δD $^{0}/_{00}$	$\delta^{18}O$ $^{0}/_{00}$	^{3}H TU	$^{87}Sr/^{86}Sr$
Gisenyi	1451	68	2450	7.4	495	38.2	35.3	11.2	195	55.8	1140	2.14	56.2	-9.7	-3.7	0.03	0.7671
Karago	2288	64.1	1250	7.2	253	14.7	21.2	2.4	76.6	77.9	5378	0.34	84	-12.4	-3.72	0.07	0.7844
Mashyuza	1300	53.7	2280	6.4	307.8	48	76	55	128	46	1061.7	4.5	75.1	-11.9	-3.75	0.05	0.7853
Bitagata	1859	36.6	458	7.1	5.9	9	38.3	31	5	7.68	289	0.07	23.2	-16.6	-4.17	0.36	0.7853
Mbonyebyombi	2220	34.5	921	7	187	11.5	20.2	2.4	51.8	44.2	414	0.22	60.3	-12.8	-3.86	0.3	0.7893
Mpatsi	1698	31.2	1670	7	208	23.1	144	16.8	40.8	31.2	1050	1.28	86.3	-11.2	-3.61	0.36	0.7853
Iriba	2016	22.3	2290	7	394	17.2	76.6	23.2	287	67	846	0.42	58.3	-8.8	-3.44	0.42	0.8004
Nyakageni	1878	20.5	1617	7.3	229	43.1	71.3	23.2	72.6	31.5	854	0.5	62.7	-11.9	-3.75	0.36	0.7853
Buseruka	1823	17.4	4080	6.5	239	226	149	356	12.9	69.4	3200	0.43	99.8	-11.8	-4.32	0.05	0.7065
Mubona	1803	19.5	3050	6.7	160	180	112	225	22.3	41.4	2200	0.28	72.1	-10.5	-3.77	0.3	0.7069
Cyabararika	1816	18.5	2880	6.4	157	159	121	204	7.6	44.6	2100	0.25	69.2	-9.5	-3.77	0.3	0.7071
Rubindi	2104	18	1960	7.1	105	114	32.9	145	14.7	12.2	1320	0.17	94.3	-10	-3.63	0.05	0.7086
Mutera	2383	17.4	215	7.4	4.5	5.1	21.6	9.9	2.6	6.51	91.2	0.02	55.7	-9.6	-3.02	1.92	0.7086
Bukeri	2388	19.1	247	7.5	9.9	9.3	21.3	9.4	5.6	16.1	98.3	0.02	57.4	-5	-2.72	1.89	0.7115
Cyamabuye	2361	16	442	7	13.9	21.3	34.9	17.4	12.5	24.6	158	0.04	47.7	-7.1	-2.77	1.81	0.7108
Kagohe	2374	15	456	7	19.2	6.2	46.6	15.3	11.7	34	166	0.03	41.3	-9.3	-3.36	1.63	0.7264
Bisoke c. lake	3586	10.2	28	4.5	0.5	1.3	0.6	0.3	1.5	1.47	3.5	0.01	2.1	-3.9	-2.29	3	0.7085
Mpenge River	1824	15.5	757	7	37.7	52	28.3	44.8	4.4	7.15	478	0.04	52.6	-8.8	-3.52	3	0.7085
Mutura fall	2245	16.1	190	6.9	7.1	7.9	15.9	7.7	3.4	15.8	78.3	0.01	35.6	-5.9	-2.97	3	0.7085
Bushokoro	2678	11.4	94	6.7	4.2	4.8	8	3.4	1	2.68	51.9	0.02	36.8	-10.6	-3.77	3	0.7085
Ntango c. lake	3574	10.9	37	7.3	1.2	2	2	0.9	2	6.5	6	0.02	13	-5.8	-2.98	3	0.7085
Lake Kivu	1450	20	1189	9	102	83.9	9.3	78.1	25	16 .6	780	0.15	7.3	-7	-3.47	3	0.7085

Hierarchical agglomerative clustering is the most common approach that provides intuitive similarity relationships between any sample and the entire data set typically illustrated by a dendrogram. The dendrogram provides a visual summary of the clustering processes, presenting a picture of the groups and their proximity with a distinct reduction in dimensionality of the original data. The resulting clusters of samples should exhibit high internal homogeneity and high external heterogeneity [11]. Additionally, the results of HCA can be used as extreme cases. An extreme case is defined throughout this approach to be representative of source area. This is based on the uniqueness of that water chemistry. The approach assumes that chemical similarity of samples from different locations is associated with water mixing and/or dilution.

3. RESULTS AND DISCUSSIONS

Physical and chemical parameters (such as temperature and elevation) that are not directly associated with the composition of waters were not considered in the present analysis. SPSS computer program was used for cluster analysis of springs and surface waters and the results are displayed in the dendrogram of Figure 2. Since every sample possesses several variables and each variable has different unit dimensions, standardization was done before cluster analysis in order to set definite measure for each variable.

Cluster 3 composed of Karago hot spring alone constitutes an extreme case. We may conclude that it originates from unmixed thermal groundwater. Cluster 2 encompasses two sub-groups. One is composed of Mubona, Cyabararika and Buseruka cold springs. The second sub-group is composed of Rubindi cold spring and Nyakageni, Mpatsi, Iriba, Mashyuza and Gisenyi hot springs. This cluster represents a mixing trend of waters from different sources. There is similarity in composition but difference in temperature. Cluster 1 is mainly composed of surface water samples. It is also subdivided into two sub-groups. Lake Kivu, Mpenge River and Mbonyebyombi hot spring constitute the first sub-group whereas Bitagata, Kagohe, Cyamabuye, Mutura, Bukeri, Mutera, Bushokoro, Ntango and Bisoke constitute the second sub-group which includes cold springs and surface waters. The mixing component may represent a good explanation for the existence of this similarity in chemical composition. Samples with similar characteristics often have similar hydrologic histories, similar recharge areas, infiltration pathways, and flow paths [8]. Cluster 2 and Cluster1 contains, each, water samples with different temperatures and different locations. However the water chemistry is similar for the respective sub-groups of each cluster. .

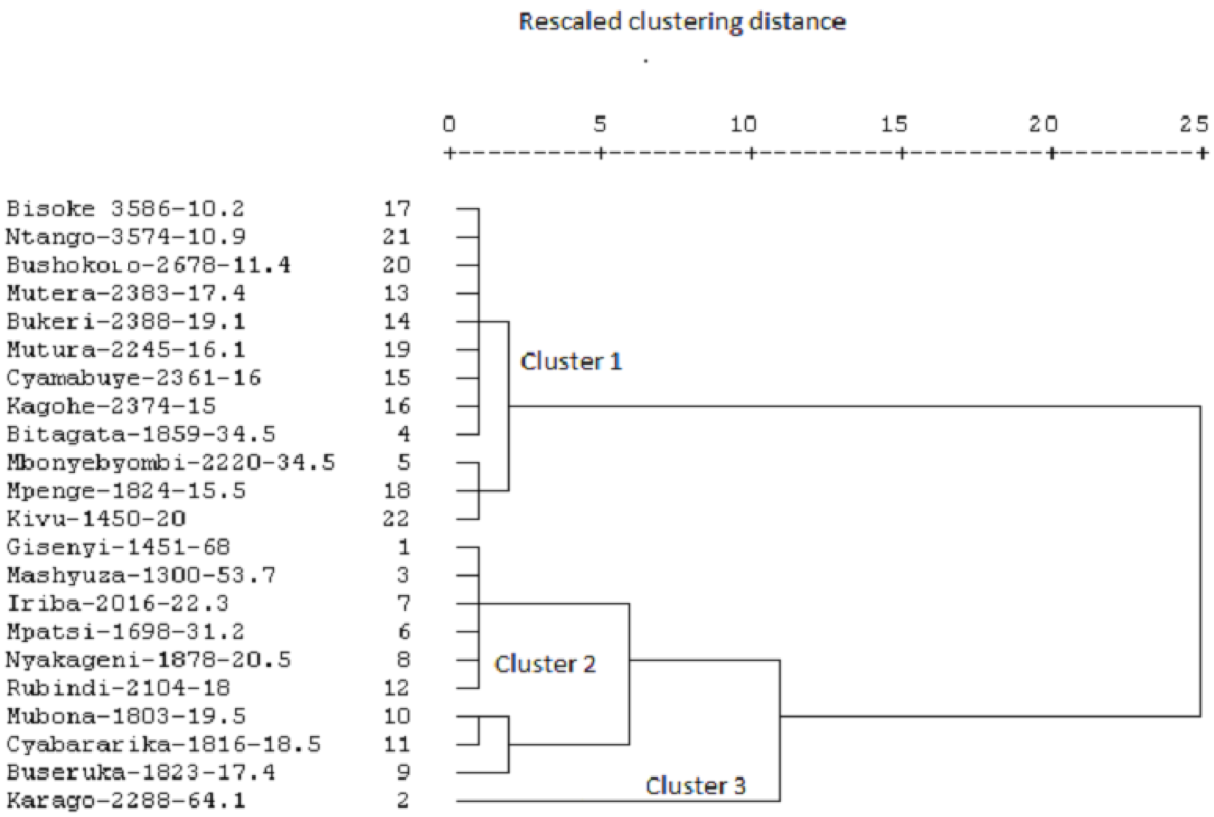

Figure 2: Dendrogram showing clustering of springs and surface waters based on selected physical and chemical parameters

(The name of each sample is accompanied with elevation and temperature)

4. CONCLUSIONS

Dilution and possible mixing of hot water with cold water should not be ignored and caution is required in applying silica geothermometry for temperature and geothermal potential assessment in the studied area. To be confident in any interpretation of mixing, groups of spring should be examined rather than the geochemistry of isolated discharges. The exploration of more suitable geothermometers is recommended. It is also important to identify the groundwater flow patterns and trends in the Kivu Rift System and the Virunga Volcanic Range area for a better understanding and sustainable development of the geothermal resource of Rwanda.

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