GEOCHEMICAL CONTRAST OF THERMAL WATERS OF RUNGWE VOLCANIC PROVINCE IN SW TANZANIA AND GREGORY RIFT IN NE TANZANIA AND THEIR POTENTIAL ECONOMIC IMPORTANCE

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ABSTRACT

Rungwe Volcanic Province (RVP) situated south of Mbeya town in SW Tanzania sits on the triple junction of the East African Rift System. The magma chamber of Ngozi volcano is acting as heat source for a high-temperature geothermal system with reservoir temperatures of more than 200°C in >2000m depth. Similarly, the Lake Natron-Oldoinyo Lengai area of Gregory Rift in north-eastern Tanzania has active volcano, which the temperatures at similar depths are expected to be higher. Both the two provinces are potentially sources of geothermal energy along East African Rift System. Geochemical studies indicate that the natural waters in the Gregory Rift are characterized low Arsenic but exceptionally high fluoride contents in cold springs (3-15 mg/l) and (15–70 mg/l), which discharges into Lake Natron at different spring discharge rates, ranging from 30 to over 400 l/s; these F-values exceed the WHO recommended values of 4mg/l. Thermal waters of Rungwe Volcanic Province on the other hand have high concentration of Arsenic, ranging from 48 to 640 ppb, but very low F values. On average thermal springs have up to 17 times WHO recommended As-values in drinking water. The thermal discharge at Songwe Valley ranges from 300l/s with surface temperatures above 70C, which is an indication of subsurface thermal activity. Using remote sensing it is evident that underground water in RVP percolates through the tectonically active fault network, gets heated and discharges these thermal fluids, which can be utilized for energy.

1 INTRODUCTION

Using technology available today, the East African Rift System geothermal potential is estimated to be 9,000 MW of power generation capacity from hot water and steam based geothermal resources (BCSE, 2003). The up-front costs of locating and drilling to geothermal power reservoirs are however major barriers to the development of this form of renewable energy (Kinabo, 2006). Whereas partial risk guarantees against drilling nonproductive wells have been a common feature in exploration of geothermal reservoirs, detailed technical and scientific work can reduce the risk (REA, 2009). For instance, the application of gravity, seismic, and magnetic alone are not enough for locating deep structures of geothermal reservoir; they have to be augmented with modern electrical methods including Transient electromagnetic (TEM) and Magneto Telluric (MT), which characterize vertical and lateral extension of geothermal source at deeper depths, reaching 1000m (Chiragwile, 2010). The resulting higher resolution geophysical models and more accurate assessments will increase the probability of finding productive steam reservoirs in highly permeable formations. Hence a well detailed geology, fluid movements and geomorphology is a pre-requisite to locate an economical geothermal reservoir. In addition, several key benefits of geothermal energy over other energy systems have been discussed (Stefansson, 1999; Kinabo 2009).

2. PREVIOUS WORK

The geology of Tanzania is well documented; in summary it comprises of Archean rocks forming Craton in Central and Northern Tanzania, overlain by Paleoproterozoic Ubendian and Usagaran Belts in SW and SE respectively (Delvaux et. al., 1998; Bahat, 1979; Delvaux, et. al., 2010; Scarab Report, 2010). Later, different rifting episodes took place resulting into Permian (Karroo) to Quaternary sediments (Nilsen et. al., 2001; Wopfner et. al., 1991). The Quarternary processes included volcanic eruptions related to East African Rift System (Ebinger et. al., 1998; Delvaux, 1993; WoldeGabriel, 2000). The Rift has two arms namely western and eastern branch, Figure 1, which they meet and form a triple junction at Rungwe Volcanic Province (RVP) in Mbeya Region (Chorowicz, 2005; Delvaux et. al., 1998). The Province is characterized by the potential volcanic heat sources and fluid pathways along fractures of the Rift System (Delvaux et. al., 1993; Ebinger et. al., 1989; Delvaux et. al., 1998; Kebede, 1991). In elevated areas of the Rift, where there is sufficient surface and groundwater, percolates along fractured zones resulting cold and hot springs (URT, 2006). Consequently, the majority of the thermal springs are aligned along the major structural trends of the Rift hosting the Rukwa and Nyasa basins (Delvaux and Hanon, 1993; Delvaux et .al., 1998). Similarly, most of these thermal springs which are potentially a source of geothermal energy, have been described by various researchers (Walker, 1959; Harkin, 1960; James, 1967; SWECO, 1978; Makundi and Kifua, 1985) and related temperature ranges exceeding 40°C (Hochstein, 2000; Mnzava et. al., 2004; DECON et. al., 2005).

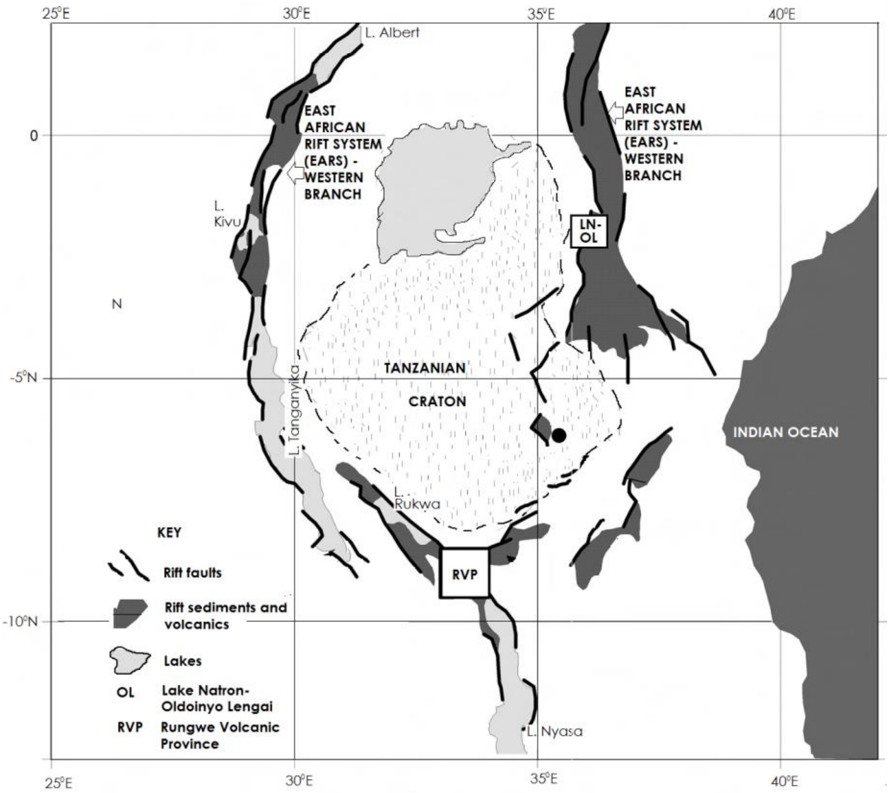

Figure 1: The East African Rift System and the location of study areas – Oldoinyo Lengai (OL) and Rungwe Volcanic Province (RVP).

Using Na/K geothermometer it was predicted that Songwe springs have sub-surface max. reservoir temp of 220°C at Songwe fracture springs and a geothermal reservoir with temperature of 211°C at Makwehe, Rungwe and Songwe (Mnzava et. al., 2004). Geotherm (2006) calculated reservoir temperatures of RVP and concluded the existence of two energy systems; high energy enthalpy > 200°C in North-Western and South systems medium energy enthalpy, significantly < 200°C. Research findings of 2000 to 2006 concluded that fluids and related thermal energy of 10 MW are lost from Songwe Valley hot springs, nonetheless the source remained unknown (Hochstein, 2000; PITRO Report, 2008; GEOTHERM, 2006). Consequently the Region attracted further scientific work including using new geophysical, geochemical field approach (Chiragwire, 2010). The combined

interpretation of multidisciplinary data from geological, geophysical (Remote Sensing, Transient electromagnetic (TEM) and Magneto Telluric (MT)), geochemical (chemical and isotopic) analyzes show that the geothermal resource in RVP has temperature ranges of 150 – 240 ˚C, which is above the verge value for geothermal power generation (PITRO, 2010; Charagwire, 2010; Torssander, 2007). The work conducted by GEOTHEM (2006 - 2009) concluded that there is a sufficient recharge in the high elevated areas for filling up the naturally lost fluids, located at the Northern Ngozi-Songwe system (GEOTHERM 2008). Using geological and seismotectonic evidence, it was found that the geothermal system is associated with the Ngozi volcanic activity; and the geological structural set up forms hot fractures and heat meteoric waters which circulate down-gravity through the active fault network to Songwe Valley (Delvaux, 2010; Kraml 2010).
This study summarizes part of the results of the 2008-2010 PITRO Project on "Geohazards Assessment and Monitoring of Volcanic Eruptions and Earthquakes in Gregory Rift of East African Rift Systems, North-Eastern Tanzania" of the Department of Geology, University of Dar es Salaam. It augments the earlier and on-going work done by other researchers on possibility of exploiting geothermal energy in Rungwe Volcanic Province.

3. METHODOLOGY AND PROCEDURES

Surface geology maps were obtained from the Tanzania Geological Survey. The maps show the major geologic formations in the study area at a scale of 1:250,000. The surface geology quadrangles were merged using GIS. A composite Shuttle Radar Topography Mission (SRTM) 90-m resolution DEM of RVP was downloaded from the U.S. Geological Survey National Elevation Data set (NED). The DEM for this study has a consistent datum, elevation unit, and projection. A DEM is a two-dimensional raster representation of topography that consists of uniformly spaced points (resolution in meters) for which the x, y (geographic coordinates), and z (elevation) values are known and referenced to a datum. U.S. Geological Survey DEMs are used in research and represent one of the best digital topographic products available.

During sampling of thermal springs, water samples for chemical analysis were collected in a set of a pair in a polyethylene bottles, as follows (i) 100 ml water sample for pH, conductivity, alkalinity and anions measurements; (ii) a 50 ml water sample, filtered through a 45µm filter, acidified with 1 ml concentrated HNO_3 (14M for the analysis of cations. The sample analyses were done in Sweden as follows: major and trace elements were analysed with ICP-OES (cat-ions; Varian Vista Ax Pro) and IC (Anions; Dionex) technique. Alkalinity was measured with standard titration methods. Both temperature, pH and conductivity were measured in the field using Hanna Instruments. The detection limit during the analysis of major elements were 0.46ppm for Ca, 0.92 ppm for K, 0.07 ppm for Mg, 0.00 ppm for Na, 35.75 ppm for S and 5.12 for Si.

4. RESULTS

Physicochemical thermal and cold springs parameters in Rungwe Volcanic Province

Among 72 spring water analyzed in RVP, Table 1, the temperature average lies between 35.2°C to 44.4°C, with minimum temperatures of 13.3°C at Ngozi South in Shiwaga (UTM coordinates 554913 and 8999504; 1696 m); and maximum of 82.4°C at Lupa Fault, Ibayi Springs (UTM coordinates 522279 and 9043381; 879 m).

In-situ field pH measurement results showed that is a no significant pH difference between the geothermal-heated and cold water springs; the averaged values for the RVP range from 6.4 to 7.2, with minimum pH value of 4.5 at Kandete, Kabila Springs (UTM coordinates 585605 and 8991160; 1621 m) and a maximum of maximum of 8.2 at Mbeya – Nsongwi, Hombo Springs (UTM coordinates 558729 and 9010370; 1950 m). pH values for the Kiejo CO_2 cold springs (17.6°C) range from 5.4 to 6.7 with an average value of 6.2, while high temperature springs of Songwe Valley (53.2°C) have for instance pH value varying from 6.7 to 8.1, with an average level of 7.7. The Kyela Kilambo-Kasumulo medium-hot springs (49°C), at Malawi-Tanzania border had pH-values ranging from 6.9 to 8.18 with an average of 7.4. Both thermal and cold springs showed CO_2 bubbles, which is the source of weak acid. In general, all the water samples are generally of Na-HCO_3^- type, which is also substantiated by thick travertine deposits in the study area.

Conversely, the field measurement results showed a significant electrical conductivity dependence on temperature and pH vales of the geothermal-heated and cold water springs for the Province. Table 1 presents average physical spring water parameters. The average values for the Province range from 2.1 to 2.46; lowest electrical conductance values of .078 mS/cm were recorded at Kiejo CO_2 cold springs (UTM coordinates 584890 and 8976124; 1508m) and maximum of 7.4 were recorded at Kyela, Kilambo Springs (UTM coordinates of 587566 and 8943975; 518 m) at Kasumulo at Tanzania-Malawi border in Kyela.

Table 1: Physical water parameters of Rungwe Volcanic Province.

Spring location	**N**	**Temp, °C**		**Cond. mS/cm**		**pH**		**AVERAGE**		
		min	**max**	**min**	**max**	**min**	**max**	**Temp**	**Cond**	**pH**
Ngozi-S	4	13.30	16.90	0.12	0.23	6.70	8.20	15.18	0.17	7.15
Kiejo C O_2 Springs	3	16.30	20.00	0.08	0.11	5.40	6.70	17.60	0.10	6.23
Rungwe-S	3	15.70	19.60	0.24	0.24	6.50	8.00	17.60	0.24	7.40
Kandete	3	17.90	18.60	0.15	0.27	4.50	5.50	18.23	0.21	4.97
Kibira village	1	19.00	19.00	0.58	0.58	7.01	7.01	19.00	0.58	7.01
Mbaka/Rungwe	3	21.80	23.70	0.61	0.97	5.70	7.41	22.50	0.74	6.34
Livingstone fault	2	26.40	26.50	0.32	0.43	6.40	6.40	26.45	0.38	6.40
Rungwe-West	3	28.70	53.00	3.01	3.01	5.90	7.20	38.37	3.01	6.63
Ifisi river	5	36.90	44.10	0.67	0.73	6.75	6.97	40.70	0.68	6.83
Ngozi-Mbeya	3	40.60	44.10	0.38	0.65	6.74	6.85	42.37	0.56	6.80
Kyela Kilambo Kasumulo	9	40.00	55.50	5.40	7.40	6.90	8.18	49.30	6.46	7.43
Mgubwisi River	4	43.70	54.00	5.30	5.80	6.60	6.70	49.57	5.57	6.63
Mbaka river	10	38.30	61.20	5.10	5.80	6.60	7.70	50.22	5.47	7.03
Mbaka fault	4	46.80	59.60	3.70	4.90	7.80	7.90	52.58	4.55	7.84
Songwe Valley	5	43.00	74.00	3.37	4.30	6.70	8.10	53.20	3.91	7.71
Mbeya Range	5	55.10	59.70	2.71	2.82	6.10	6.60	57.70	2.78	6.60
Usangu	4	47.00	68.00	3.40	3.45	6.90	7.20	61.48	3.43	7.03
Lupa fault	1	82.40	82.40	2.64	2.64	6.80	6.80	82.50	2.64	6.80
Calculated average values	72	35.16	44.44	2.10	2.46	6.44	7.19	39.70	2.30	6.82

In particular, cold springs with average temperature of less than 20°C have very low electrical conductance, < 0.2 mS/cm; while hot springs with average temperature exceeding average temperature of 45°C have average conductance exceeding 2.6 mS/cm, as illustrated in Figure 1 .
Figure 2 shows that the RVP is characterized by two conductance regions, demarcated by temperature of 45°C. Springs with temperatures > 45°C have an average conductivity which ranges from 2.7 mS/cm (Mbeya Range) to a maximum of 6.0 mS/cm at Kilambo Kasumulo area in Kyela, while springs with temperatures < 45°C have average electrical conductance of < 0.7 mS/cm.

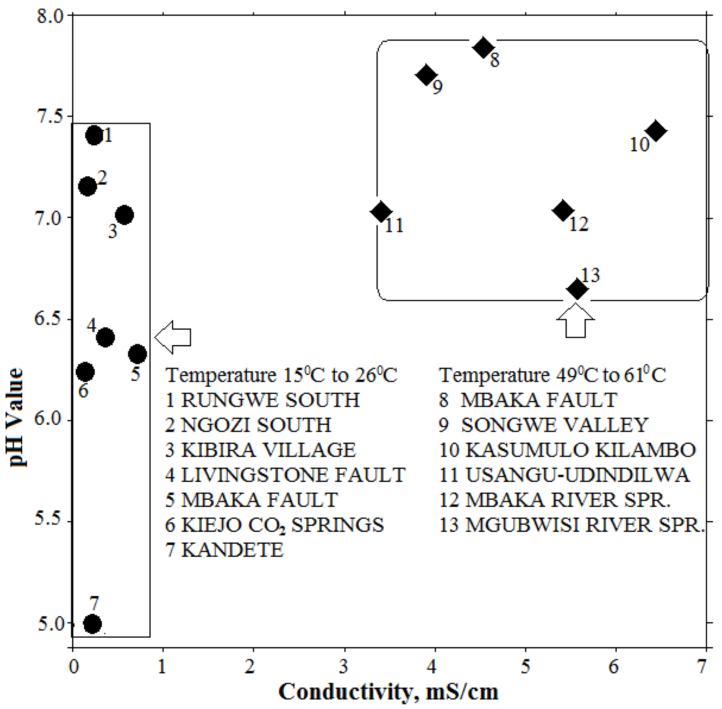

Figure 2: The influence of pH and electrical conductance on the spring waters

Similarly, high temperature (>45°C) springs have higher average thermal conductivities as compared to low temperature springs (<25°C), at similar pH range values of 6.5 to 7.3. For example, the average conductivity varies for the hot spring waters (>45°C) between 3.4 mS/cm at Usangu Udindilwa to 7 mS/cm at Kasumulo-Kilambo; cold water springs v(<25°C) vary from 0.1 mS/cm at Kiejo CO_2 springs to 0.74 mS/cm at Mbaka Fault Rungwe.

High temperature values thus reflect the thermal activity associated with the EARS, while the high conductance is due leaching and dissolution of ions by the meteoric water percolating in fractures of the rocks.

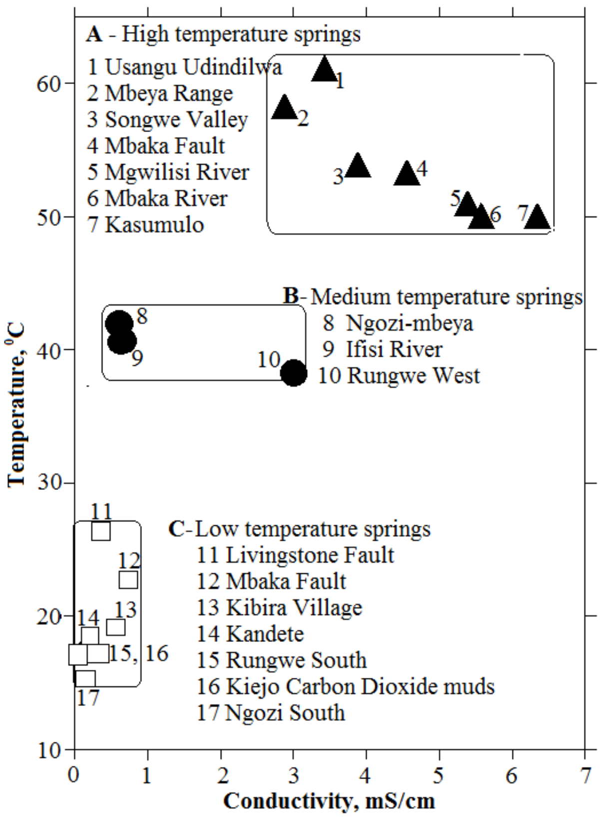

Figure 3: The influence of temperature and electrical conductance on the spring waters

Figure 3 shows three temperature arrays A to C of the springs in RVP. The first array (C) comprises of the low temperature springs which cover Ngozi South springs (15.2°C); Kiejo CO_2 springs (17.6°C); Rungwe South springs (17.9°C); Kandete springs (18.2°C); Kibira Village springs (19°C) Mbaka Fault springs (22.5°C) and Livingstone Fault springs (26.4°C).

The second array (B) is the medium temperature springs which cover Rungwe West springs (38.4°C); Ifisi River springs (40.7°C) and Ngozi Mbeya springs (42.4°C). The third array (A) consists of Kasumulo springs (49.3°C); Mgubwisi River springs (49.6°C); Mbaka Fault springs (52.5°C); Songwe Valley springs (52.6°C); Mbeya range springs (57.7°C) and Usangu Idindilwa springs (61.5°C).

Chemical analysis of major elements

The physical water parameters showed same trend as explained above. Low temperature spring waters (<20°C) from Shiwaga, CO_2 plant Kiwera River, Bwibuka River, Isebe primary school and Mlagala River have low electrical conductivities which is less than 1 mS/cm. Conversely, higher temperature springs (>40°C) have higher electrical conductivities which exceeds 3.5 mS/cm, as reflected in Table 1.

All the major elements analyzed in both cold and hot water spring samples showed lower concentration in the surface waters as compared to thermal springs (Table 2). Elements which are strongly influenced by the temperature include calcium, potassium, sodium, sulphur, floride, chloride and sulphate ions. The rest, magnesium, silicon and nitrate ions are significantly not influenced by the temperature changes.

Table 2: Concentration of major elements in spring water samples, in ppm

Sample no	Ca	K	Mg	Na	S	Si	F	Cl	NO_3	SO_4
1	6.13	8.29	3.074	18.88	0.59	25.30	0.27	3.90	0.00	2.52
2	4.54	4.60	1.957	12.17	0.23	20.44	0.15	1.46	0.90	0.58
3	19.37	4.43	8.649	10.98	0.26	16.05	0.12	1.14	0.14	0.56
4	24.81	23.68	16.977	76.92	0.82	47.99	0.42	4.91	0.22	2.59
5	36.26	34.68	13.118	169.87	1.71	43.34	0.26	11.60	0.00	5.42
6	36.85	119.58	8.142	907.99	53.79	26.18	8.09	207.10	0.00	162.87
7	64.35	99.53	37.760	1145.39	72.98	45.24	1.85	405.87	0.00	219.47
8	72.39	77.24	27.186	938.95	51.67	38.13	1.61	284.56	0.81	155.43
9	19.14	131.26	10.821	1652.15	148.73	45.34	2.14	353.24	0.00	419.50
10	59.33	100.11	40.617	1178.07	77.59	50.10	1.94	432.56	0.00	232.51
11	55.47	115.19	9.410	839.70	52.05	28.40	7.08	194.90	0.00	153.51
12	70.98	97.83	32.457	1167.89	77.89	48.23	2.56	435.55	0.12	233.43

This is also apparent for the alkalinity; the molar concentration of surface waters ranged between 1 and 10 mM compared to the geothermal waters concentration between 30 and 60 mM. All the sampled springs are CO_2 springs and the surface waters contain a large proportion of gaseous CO_2 which is not measured as alkalinity. All the waters are generally of Na-HCO_3^- type irrespective of concentration although some waters need to be characterized with additional Cl or Ca.

Geomorphologic and structural set up of RVP

On the DEMs the picturesque representation of the morphology of the RVP, the natural water flow direction, drainage and structural features can be easily recognized. The drainage network is concentrated on the central part of while linear features, which are striking NW-SE, are well recognized on the north-western part of the RVP Figure. The major structures present in the area area Mbeya Range, Ifisi and Mbaka Faults. Most of the thermal springs are aligned parallel along these fault systems.

Comparing the high temperature springs in array (A) of Figure 2 above with the structural set up of the tectonic movements of the RVP 90m-DEM (Figure 4), it can be postulated that there is large high altitude groundwater system along the fracture zones of the EARS, which recharges Lake Ngozi. This system discharges its waters in various geothermal paths. From the structural set up, three geothermal models can be deduced: Songwe Valley Spring System, which receives its water from the higher altitude Ngozi reservoir. The waters are heated when they percolate downstream through the active

Mbeya Range and Ifisi Faults; and Mbaka-Mgubwisi Spring System (B), striking NW-SE direction (black and white lines). This geothermal system receives its water again from the same source, which percolates downstream across the Mbaka Fault. the Usangu Udindilwa Spring System (A) which receives its waters from the Ngozi groundwater reservoir and discharges it to the Usangu Basin located on the North-East of RVP. The water is heated as it percolates through the active fracture zones which strike NE-SW, as indicated by black and white lines in the Figure 4.

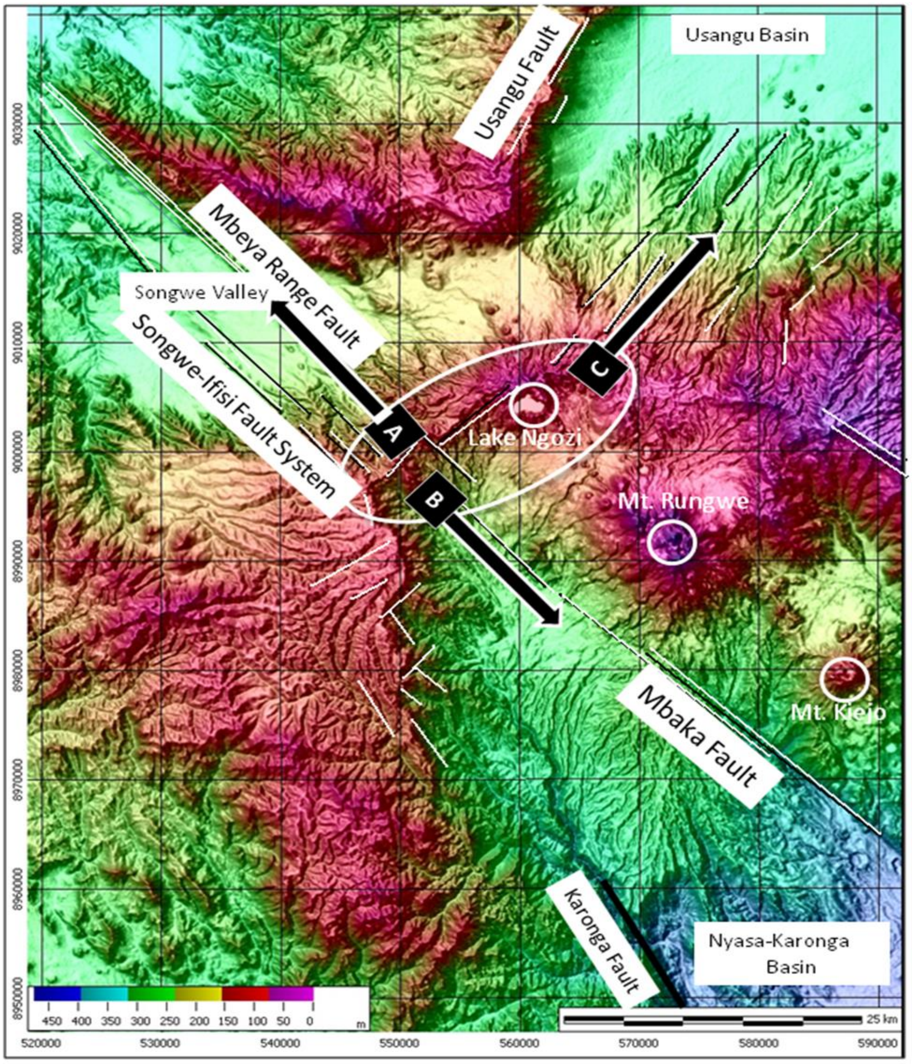

Figure 4: STRM 90-m DEM showing RVP and movement of thermal fluids

5 DISCUSSION

High electrical conductivity values and high concentration of major elements obtained in hot water springs indicate the ability of hot water solutions to leach ions from the rock minerals. Current results revealed relatively high conductivity in the hot springs (5560 µS/cm) and cold spring water samples (108 µS/cm) compared to WHO (1998) acceptable values of (500 µS/cm) for drinking water (PITRO Report, 2010). High pH values observed are reflection of carbonate minerals, which dissolves to produce alkaline solutions. However, in some river samples collected, the pH of water was quite low (4.68). This can be explained by the CO_2 emanations from underground due to volcanic activity that reacts with fresh river water, small amounts of carbonic acid are formed, which then dissociate into hydrogen ions and bicarbonate ions. This increase in H^+ ions makes the water more acidic and lowers the pH.

The drainage pattern follows the topography of the area; however the observation of DEM there is a clear hydrological divide striking NE-SW surrounding Lake Ngozi. The NW block receives its waters from Poroto Mountains surrounding Lake Ngozi via Songwe valley to Lake Rukwa Basin; the water gets heated as it percolated through gravity to the fracture zones of the NW-SE striking active Songwe, Ifisi and Mbeya Block Faults. The drainage pattern of the SE Block receives its waters from same source and drains to Lake Nyasa / Karonga Basin, through similar NW-SE striking active faults of Mbaka and Karonga. Ebinger et al. 1989 showed the triple junction faulting system covering the two block faults including the NE-SW which follows the Usangu Border Fault. These three fault systems are geologically important because they are medium to high energy enthalpies sources of potential geothermal energy, which are also shown in Figure.

These are North-Western System covering Ngozi Volcano-Songwe hot springs, South-Eastern System or Rungwe-Kiejo System covering hot springs along Mbaka Fault and Kyela area and North-Eastern System which is Usangu-Udindilwa hot springs. They are also aligned along the major NW-SE rift trend that controlled the long term development of the Rukwa and North Malawi (Nyasa) rift basins. Fluid flow is mainly controlled by fracture permeability along these active faults of the rift.

6 CONCLUSION

Geochemical investigation of the thermal waters agrees quite well with the results obtained by the GEOTHERM Project in Tanzania (). The geothermal models augment the geochemical and geophysical model of the GEOTHERM Project and allow site potential geothermal energy model to be Ngozi-Songwe part of the Rungwe Volcanic Province. The Poroto Mountains in Rungwe forms recharge area, which the geothermal reservoir is hosted; hence thermal waters circulate under gravity in hot active fault network towards the discharge areas in the Songwe Valley in northwest; Mbaka Fault in southeast; and Usangu Udindilwa Fault in northest direction following the natural slope gradient. This study also concludes that there are three geothermal systems that are located within the triple junction of the EARS, as indicated by alignment of the thermal springs along the fault zones.

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