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Soil Gas Survey of Kibiro, Buranga and Panyamur Geothermal Field

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ABSTRACT

Soil-gas and flux surveys were carried out in Kibiro, Buranga and Panyimur geothermal prospects to zone out permeable diffuse degassing structures that may have geothermal significance. The studies focused on the measurement of Carbon dioxide, Methane, ^{222}Rn and Soil temperature. CO_2 and CH_4 were measured by gas flux meter equipped with LICOR LI-820, while ^{222}Rn was measured with Durridge RAD7 radon meter. The data sets were subjected to graphical statistical analysis using a cumulative probability plot to evaluate potential sources of the measured gases.

The probability plots divided Buranga data into different populations with a ^{222}Rn- population of 65.5 to 725cpm and CO_2 flux population of 3354 to 6786gm-2d^{-1} possibly representing a geothermal related source. Highest ^{222}Rn concentrations were measured around Nyansimbe and Mumbuga and low values around Kagoro hot springs while high values of CO_2 were recorded around Nyansimbe. ^{222}Rn distribution map shows a NE-SW linear structures that represents fault identified from previous structural geology mapping. The CO_2 does not show a linear pattern like ^{222}Rn possibly due to CO_2 dissolving in water to form carbonated waters. The low values of ^{222}Rn counts and low CO_2 flux around Kagoro need further investigated in relation to geology and geophysics for possibility of mapping the cap rock. Despite the differences between CO_2 flux and the radon maps in Kibiro geothermal field, high ^{222}Rn activity values occur together with or close to high CO2 flux values. This suggests that most high ^{222}Rn activities are controlled by a gas flux from below, that moves the gases towards the surface. The distribution of the gases shows low CO2 flux and low 222Rn activity, in the central part of the surveyed area suggesting an effective cap rock corresponding to the Kibiro fan delta. In Panyimur geothermal field the values of Radon-222 and CO2 flux are generally low. Rn-222/CO2 and Rn-222 distribution maps show high ^{222}Rn- and ^{222}Rn/CO2 ratio in the middle of the surveyed area depicting a permeable zone in the south of Okumu and Avuka hot springs. The maps show a zone of low ^{222}Rn counts and low CO2 flux measurements around Amoropi that represents a less permeable zone that could coincide with the position of the cap rock.

1. Introduction

Soil gas survey is used to infer the nature of the subsurface based on the fact that active geothermal systems produce gases that migrate through over lying cover by diffusion or transported by raising fluids or migration along fractures and faults. The gases with high mobility are used to identify regions of high permeability, active faults/fractures. It also helps identify concealed geothermal resource in areas without or with limited manifestations or tectonic structures or in areas of thick clay cover where plastic behavior can mask identification of faults by field mapping or geophysical methods (Voltarttonini et al., 2010).

The first soil gases survey was carried out in Uganda in November 2015 in Kibiro geothermal field that was rolled to Buranga and Panyamur. The parameters measured include CO^2 flux, ^{222}Rn, and CH4 and soil temperature. Carbon dioxide and methane were measured by LICOR (LI820) flux meter while ^{222}Rn was measured by Duribridge Radon meter.

2. Literature Review

A number of soil survey studies have been carried out on Carbondioxide soil diffusion or degassing from volcanic or geothermal areas (e.g. Chiodini et al., 1998, Fridman., 1990; Fridriksson et al., 2006; Voltattorni et al., 2010,) and most of them show that gas is not released uniformly from the whole volcanic area, but rather from relatively restricted regions. Such areas have been called diffuse degassing structures by Chiodini et al., 2005). Anomalous concentrations of radon in volcanic regions occur when there is a rapid movement of hydrothermal fluids, transporting the gas adjectively or convectively. Radon's overall abundances require it to be carried by other gases (e.g., CO_2), whose advective flux is controlled by pressure gradients (Baubron et al., 2002; Giammanco et al., 2007). The radon concentration (radon counts) can be affected by a number of factors which include permeability, distance travelled between source and detection point, mineralogy of reservoir rocks. The short half-life of radon and its physical characteristics can limit its mobility .This means that it has to travel long distance in a short time to be detected at the surface. Hence the high concentrations of ^{222}Rn like Carbondioxide must travel through high permeable zone to be detected at the surface.

3.0. **Methodology**

Carbon dioxide flux measurement was done using a portable LICOR (LI820) CO2 flux meter. It has an accumulation chamber of 20 cm in diameter which was pressed into the undisturbed soil to determine methane and CO_2 flux that diffuses out of soil. A seal was made between soil and the collar by covering the circumference of the collar with soil to stop any air contamination or leakage.

^{222}Rn and ^{220}Rn were measured at the same survey point with Durridge RAD7 radon meter. It measured concentrations of both ^{222}Rn (radon) and ^{220}Rn (thoron) in gas phase, by exclusively collecting radon and then counting the alphas emitted by the decay of their respective daughter nuclides 218Po (t1/2 = 3.04 min) and 216Po (t1/2 = 0.145 sec).

The soil gas sample containing radon was pumped from the steel probe into the decay chamber of the radon meter consisting of a cylindrical copper can, whose walls are coated with zinc sulphide where the radon decays into other radio-nuclides by emitting alpha particles. The alpha emissions are detected by a photomultiplier tube attached to the detector and a rate meter displays the signals. Three background counts were recorded at two-minute intervals prior to introduction of the sample into the radon meter. After introduction of the sample, three readings were taken at two-minute intervals to give the total radon counts. Radon (^{222}Rn) and

thoron (^{220}Rn) values were measured every 5 minutes (third cycle reliable for the final reading of the two components).

4.0. Soil gas survey in Kibiro geothermal field.

The data was collected by the staff of Directorate of geological survey and mines together with a Gorge Igunza consultant from GDC, Kenya and interpreted by Luigi Marini (Alexander et al., 2016). The CO2 flux from soil was collected from ninety stations (92) in November 2015 and sixteen stations (16) in February-March 2016 while ^{222}Rn activity in soil gases was measured in 91 stations in November 2015 and 25 stations in February-March 2016.

4.1. Carbondioxide flux from soil in Kibiro prospect

The statistical analysis of 2016 soil gas survey data shows that the data was affected by rain and was not considered for further interpretation. It was the November 2015 data that was considered for further processing. The CO_2 fluxes from soil measured in November 2015 range from 1169 to 3.5 g m-2 d-1.

The CO_2 flux data was processed further after eliminating one low-value outlier, the cumulative distribution was partitioned into five log-normally distributed five populations(A, B, C, D, and E) whose main statistical parameters are as follows (SEM is the Standard Error of the Mean)(Table 1).

Table 1: *Summary of CO_2 soil flux measurements of Kibiro Prospect.*

Population	N	%	Mean	Median	Std. Dev.	SEM	Range
			g m^{-2} d^{-}	g m^{-2} d^{-}	g m^{-2} d^{-1}	g m^{-2} d^{-}	g m^{-2} d^{-1}
A	4	4.3	696	579	465	233	1169-266
B	6	6.5	201	200	20.1	8.21	164-266
C	21	22.8	119	117	18.1	3.95	84.9-164
D	53	57.6	58.0	55.6	17.3	2.37	26.3-84.9
E	8	8.7	18.8	18.3	4.68	1.65	11.3-26.3

Populations A and B are characterized by relatively high values of the CO_2 flux from soil which may be sustained by CO_2 either from the hot waters or coming from deep environments along faults and fractures. Populations D and E probably represent the local background, related to biogenic CO_2 produced in soils by decay of organic matter and root respiration. Population C has intermediate characteristics

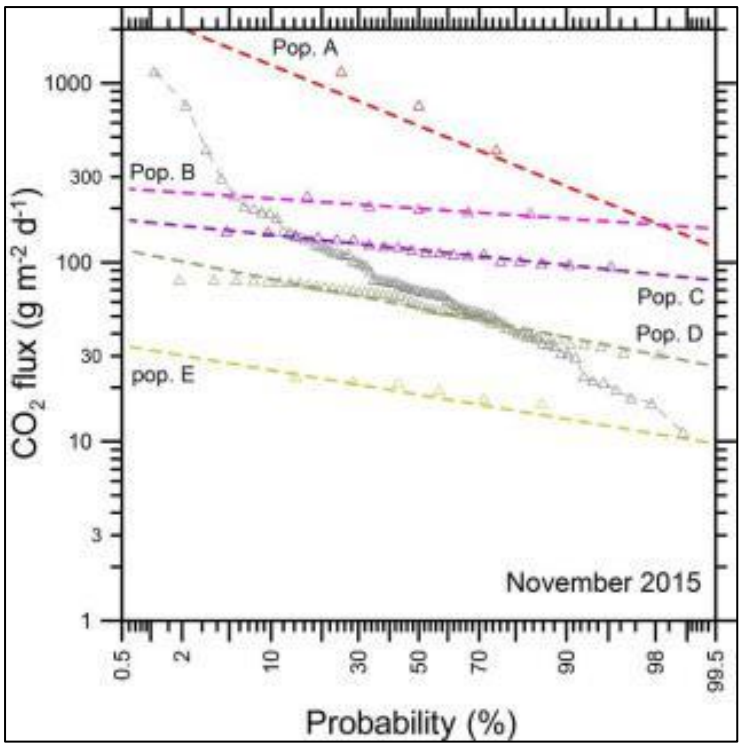


Figure 1: *Log-probability plot of the CO2 flux from soil*

In Figure 1,the gray triangles refers to the cumulative distribution, whereas the red, purple, violet, khaki and banana yellow triangles identify the five component populations these are separated adopting the partitioning procedure of Sinclair (1974, 1976). Computed individual populations are represented by dashed lines of the same colors.

The contour map was prepared adopting the inverse distance-squared relationship as interpolation technique since it was not possible to obtain an effective semivariogram(Figure.2). Both the post and contour maps show the absence of high CO_2 flux values in the central part of the surveyed area, close to Kibiro, apart from a single station situated close to the Mukabiga hot spring where the highest value of 1169 g m-2 d-1. They also show the presence of clusters of high CO_2 flux values, with ENE-WSW orientation, both to the ENE and the WSW of the central area.

This geographical distribution of CO_2 flux values suggests that an effective cap rock may be present in the central part of the surveyed area, roughly corresponding to the Kibiro fan delta. This seal, which prevents the escape of CO_2-bearing gases towards the surface, is apparently absent only close to the Mukabiga hot spring, where the maximum CO_2 flux value was measured, although this hot spring releases a CH_4-rich gas mixture with a CO_2 concentration of ~5 % by volume only.

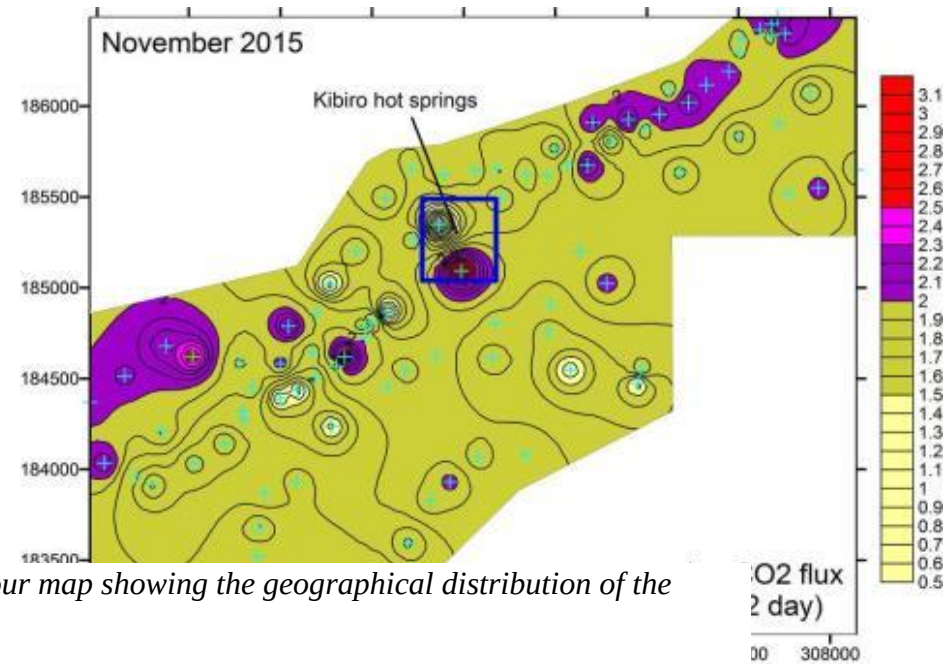


Figure 2: *Contour map showing the geographical distribution of the populations*

4.2. *Activity of 222Rn in soil gases in Kibiro Prospect*

The ^{222}Rn activity in soil gases in November 2015 were collected in 91 stations. The 222Rn activity measured in November 2015 varies from 399 to 0.54 counts per minute (cpm). The log-probability plot of the ^{222}Rn activity partitioned the data into five log-normally distributed populations A, B, C, D, and E (Figure.3) with the following statistics (Table 2)

Table 2; Summary of ^{222}Rn soil flux measurements of Kibiro Prospect.

Populatio	N	%	Mean	Median	std. Dev.	SEM	Range
			cpm	Cpm	Cpm	cpm	Cpm
A	3	3.3	256	221	150	86.7	121-399
B	5	5.5	95.2	94.7	9.05	4.05	72-121
C	12	13.2	52.4	52.2	4.99	1.44	43-72
D	46	50.5	24.0	22.8	8.07	1.19	12-43
E	25	27.5	6.40	4.15	7.52	1.50	0.54-12

The geographical distribution of the five component populations of the 222Rn activity in soil gases is shown by the contour map (Figure.4). The contour map was prepared using the inverse distance-squared relationship as interpolation technique since it was not possible to obtain an effective semivariogram. The two maps shows absence of high ^{222}Rn activity in soil gases in the central part of the surveyed area, close to Kibiro, apart from a couple of stations positioned close to the Kibiro hot springs. They also show presence of clusters of high ^{222}Rn activities, including the highest values belonging to population A both to the ENE and the WSW of the central area.

In contrast to the CO_2 flux maps, there is no or limited clustering of high ^{222}Rn activity values and have no spatial orientation. However, inspite of these differences between the CO_2 flux maps and the radon maps, most high ^{222}Rn activity values occur together with or close to high CO_2 flux values. This suggests that most high ^{222}Rn activities are controlled by a gas flux from below, that moves radon towards the surface. If this is true, then the geographical distribution of ^{222}Rn activity is consistent with the presence, in the central part of the surveyed area, roughly corresponding to the Kibiro fan delta, of an impervious cap rock which precludes the leakage of deep gases. This seal is apparently absent only close to the Kibiro hot springs.

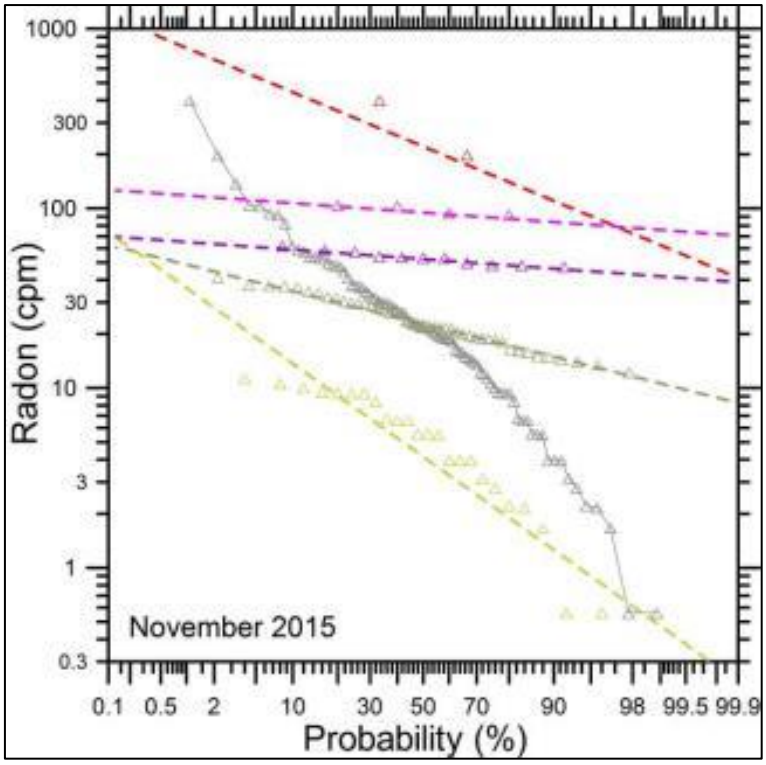


Figure 3: Log-probability plot of ^{222}Rn activity in soil gases.

In Figure 3 the gray triangles refers to the cumulative distribution, whereas the red, purple, violet, khaki and banana yellow triangles identify the five component populations separated adopting the partitioning procedure of Sinclair (1974, 1976). Computed individual populations are represented by dashed lines of the same colors

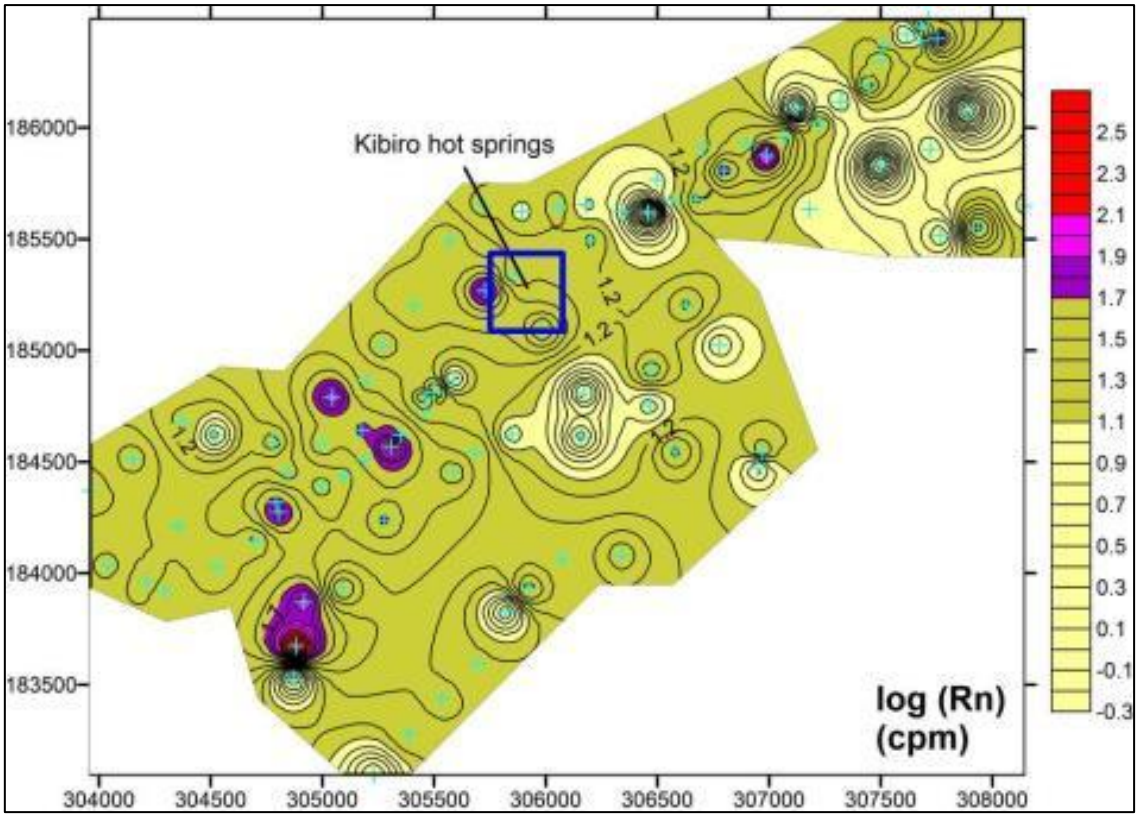


Figure 4: Contour map showing the geographical distribution of the five component populations of the ^{222}Rn activity in soil gases

4.3. ***Soil Temperature***

The soil temperature was measured at depth of ~70 cm in 39 stations during the February-March 2016 survey and varied from 25 to 70°C.

The probability plot of the soil temperature partitioned into three normally distributed individual populations called A, B, and C(Figure 5) with the following statistical parameters in the following table below:

Table 3: *Summary of Temperature soil flux measurements of Kibiro Prospect.*

Population	N	%	Mean	Median	Std. Dev.	SEM	Range
			°C	°C	°C	°C	°C
A	5	12.8	62.7	62.7	5.26	2.35	55-70
B	10	25.6	47.1	47.1	2.58	0.82	42-55
C	24	61.5	35.2	35.2	4.18	0.85	25-42

Population C represents the background; that is of soils unaffected by geothermal activity. The population A is represents geothermal activity, either upflow of hot deep fluids or conductive heat transfer. Population B has intermediate characteristics

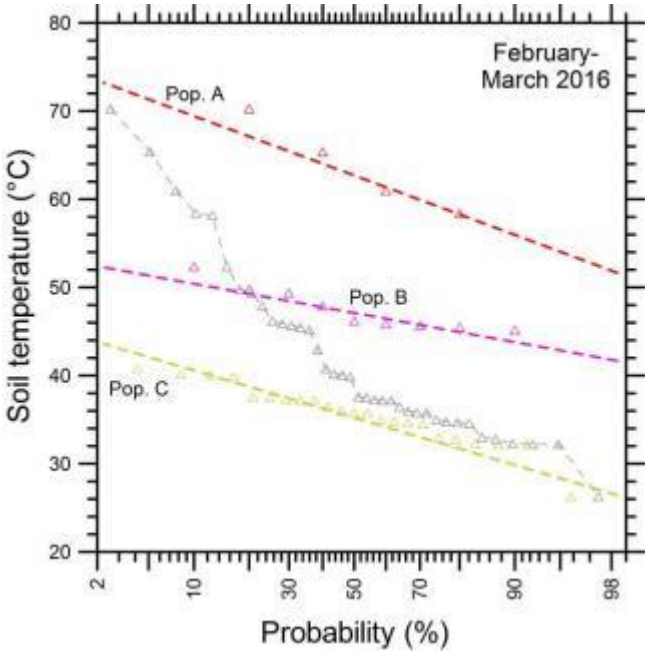


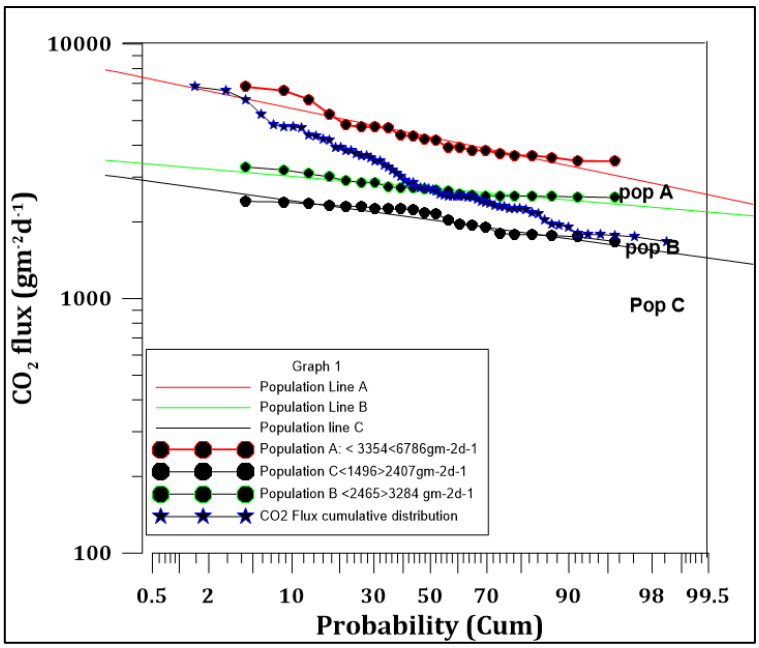
Figure 3: Probability plot of the soil temperature measured at ~70 cm depth during the February-March 2016 survey carried out in the Kibiro prospect. The gray triangles refers to the cumulative distribution, whereas the red, purple, and banana yellow triangles identify the three component populations separated adopting the partitioning procedure of Sinclair (1974, 1976). Computed individual populations are represented by dashed lines of the same colors.

5.0 **Soil gas survey in Buranga Geothermal Field.**

In January 2018 DGSM staff carried out soil gas survey from seventy three (73) stations at a depth of about 30cm

5.1. Carbondioxide flux from soil Buranga

The log probability plots divided the data into three populations consisting of twenty three (23) each. Population A is probably the background population B biogenic and C of 3354 to 6786gm-2d-1 possibly geothermal related (Figure.6). The highest CO_2 flux concentrations were measured around Nyansimbe(Figure 7)



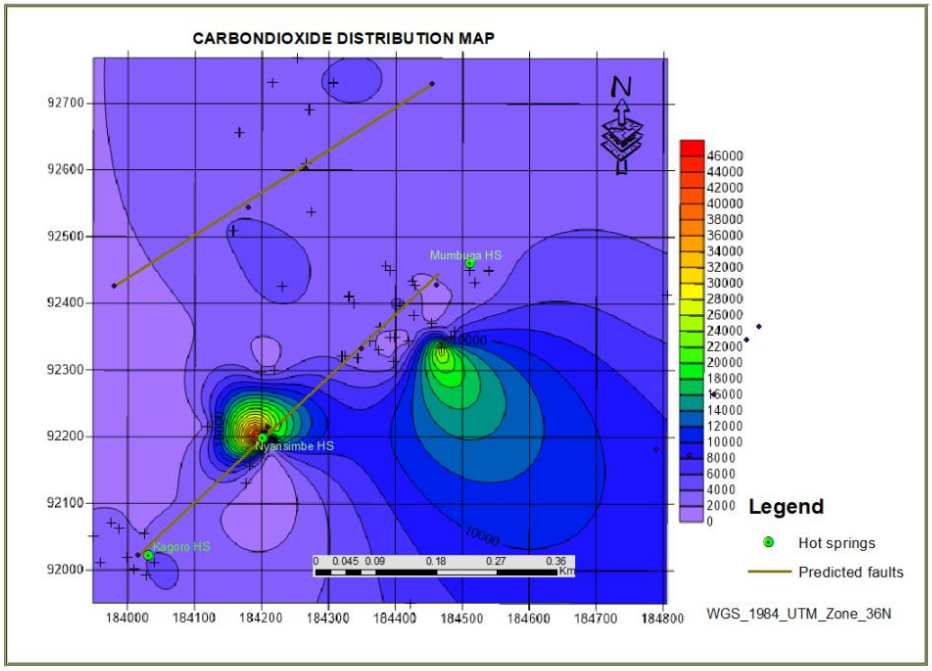


Figure 5: *Carbondioxide distribution map*

5.2. ^{222}Rn Activity in soil gases in Buranga Geothermal Prospect

The log probability plot of ^{222}Rn data divided the data into three populations consisting of twenty three (23) each (Figure. 8A). Population A is probably the background or biogenic, population B biogenic and C of 65.5 to 725cpm is possibly geothermal related. The highest ^{222}Rn concentrations were measured around Nyansimbe and Mumbuga(Figure. 8B) and the anomalies show NE-SW linear orientation representing earlier predicted fault. The break in anomaly between Nyansime and Mumbuga was due lack sampling points because the area is boggy and covered by geothermal grass.

The ^{222}Rn and $^{222}Rn/CO_2$ distribution maps have similar pattern with high concertation around Mumbuga and Nyansimbe and low values around Kagoro hot springs.

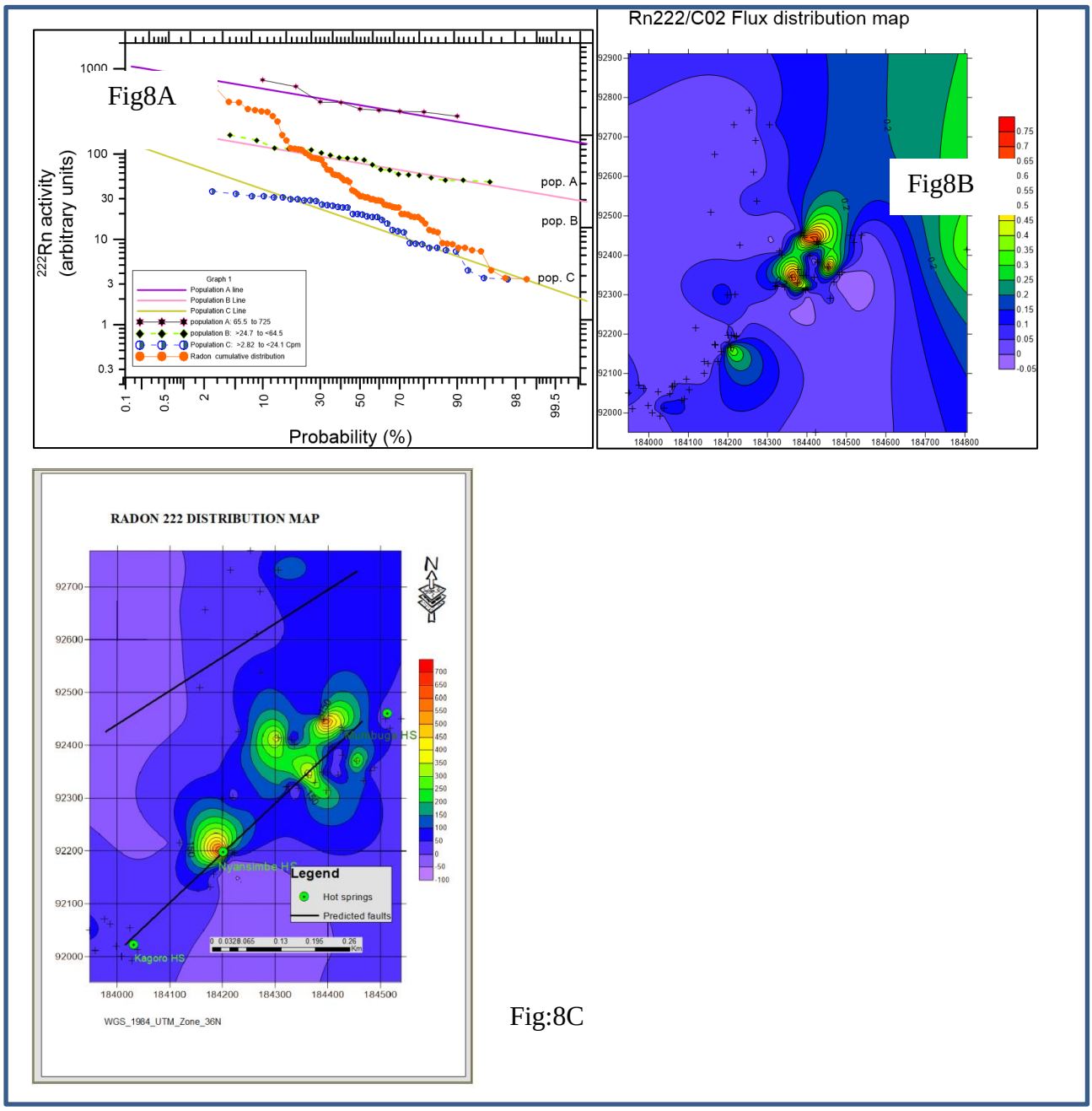


Figure 6A Log probability distribution map of ^{222}Rn, Fig 11B ^{222}Rn distribution map, Fig 8C $^{222}Rn/CO_2$ distribution map.

6.0. Soil gas survey in Panyamur geothermal Field.

The soil gas survey was done in fifty seven (57) survey points over the area selected by considering previous geophysics and structures interpretation. The points were planned along profiles in NE-SW direction perpendicular to the fault system at spacing of about 300m. The survey was done in sediments with a few control points in the basement. It was carried out in a dry season though there was interruption by the rain towards the end of the field work.

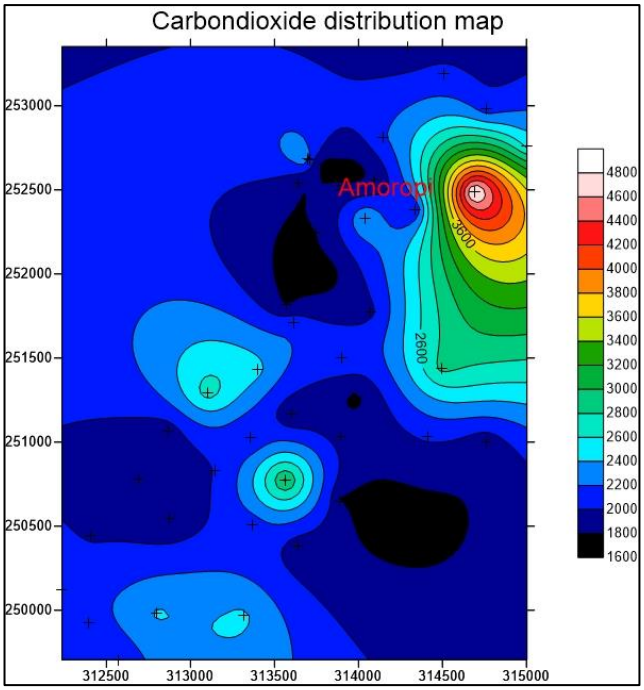


Figure 7 *Carbondioxide flux data distribution*

6.1.Carbondioxide CO_2 flux in soil gases.

The Carbondioxide flux measured in panyamur range from 1725.3 to 53531.8, with an average of 3762.4g/m2/day. The carbondioxide distribution map shows the highest carbondioxide flux was measured in the north east of the surveyed area while the lowest flux values were measured around Amoropi hot springs (Figure.9).

6.2. 222Radon and 222Radon/CO2 ratio

The Rn 222 readings in panyamur had a maximum of 735, minimum of 1.08 with an average 42.3 counts, The ^{222}Rn distributtion map shows high Radon vlues around avuka and Okum and very low values around Amoropi hot springs.Radon and Carbondioxide from other sources other than geothermal or magma was eliminated by using a ratio of ^{222}Rn/CO_2. The ^{222}Rn /CO_2 pattern is similar to that of ^{222}Rn. The low ^{222}Rn counts and low CO_2 flux measurements around Amoropi probably represents a less permeable layer that could probably be a cap rock.

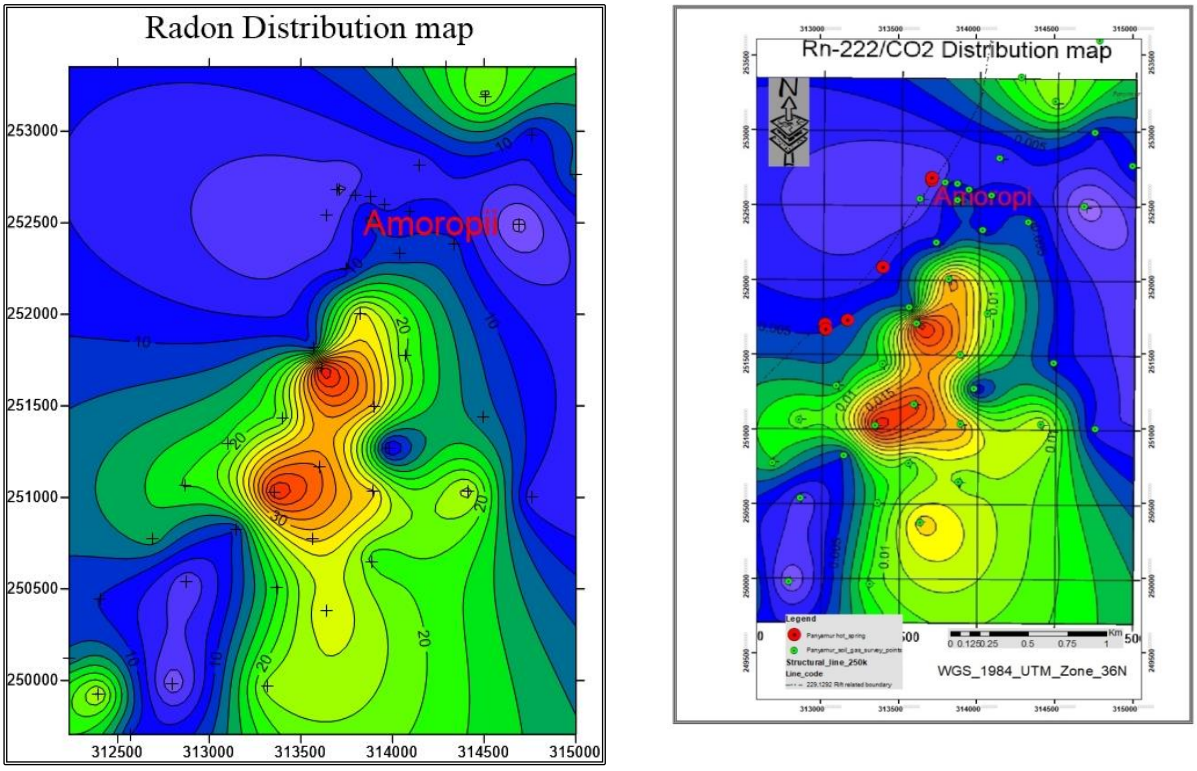


Figure 8 showing ^{222}Rn and $^{222}Rn/CO2$ distribution map

4.0. CONCULUSION AND RECCOMENDATIIONS.

The CO_2 flux maps, ^{222}Rn activity identified permeable zones in Kibiro, Buranga and Panyamur geothermal fields. The survey shows the central part of the surveyed area having an impervious layer roughly corresponding to the Kibiro fan delta. In Buranga ^{222}Rn and $^{222}Rn/CO_2$ shows high values around Mumbuga and Nyansimbe and low values around Kagoro hot springs. A follow-up survey will be conducted in Buranga around Kagoro to find out if it could be an impervious layer causing low values of measured CO_2 flux and 222Rn. In Panyamur the data shows a zone of low Rn-222 counts and low CO2 flux measurements around Amoropi. This probably represents a less permeable zone that could also be probably a cap rock.

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