Report on natural uranium level in Bahi district, Tanzania

submitted to

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ACRONYMS and ABBREVIATIONS

CESOPE – Civil Education is the Solution for Poverty and Environmental Management

WHO – World Health Organization

EPA – Environmental Protection Agency

CSQS - Canadian Soil Quality Standard

IC – Ion Chromatography

DOC - Dissolved organic carbon

TIC - Total inorganic carbon

ICP-MS - Inductively coupled plasma mass spectrometry

ppm – parts per million

ppb – parts per billion

keV – kilo electronvolt

MeV – mega electronvolt

nSv/h – nano Sievert per hour

mSv/h – milli Sievert per hour

Mlb – Million pounds

IAEA - International Atomic Energy Agency

SRTM – Shuttle Radar Topography Mission

INTRODUCTION

The study was initiated by Civil Education is the Solution to Poverty and Environmental Management Organization (CESOPE) and technically supported by Freiberg Academy of Mining in Germany and University of Dodoma in Tanzania. It is based on field data collected by direct measurement of uranium level by gamma-ray spectrometer and analysis of surface soil and groundwater samples from the villages around Bahi Swamp. The field work was conducted during September-October 2012 and accompanied by A. Mwakipesile (Environmental Scientist, University of Dodoma), Fadhili C. Bwagalilo (Researcher at St. John's University) and K. Kashimbi (Water Specialist, University of Dodoma).

The purpose of this study is to provide information about the current level of natural uranium in the study area. It presents the results of groundwater and soil analysis as well as terrestrial gamma-ray survey data from Nagulu, Chali, Bahi, Ilindi, Makanda and Mkakatika at the same time serving as a baseline study conducted prior to major mining activities which are expected to commence in Bahi region in very near future.

Bahi Lake and the surrounding wetland have significant role in the livelihood within the region since they enable different sources of subsistence to the people of nearby villages in contrast to the extremely dry lands in neighboring areas (Majule and Mwalyosi, 2003).

The main concern is the possibility of soil and/or water contamination within Bahi drainage system where the surficial uranium occurrences are common. Contamination of soil, surface water or ground water might pose health issues, especially, in villages surrounding the swamp where people occupy themselves mainly by crop production, livestock farming and fishing. Moreover, untreated ground water is the only source for consumption.

The area of study is shown on the map (Fig. 2) with the indication of villages where the level of natural uranium was evaluated. We restricted our study to Bahi district and unfortunately, could not acquire any data from the villages belonging to Manyoni district due to permitting issues. This factor should be considered while evaluating the completeness and the scope of the performed work.

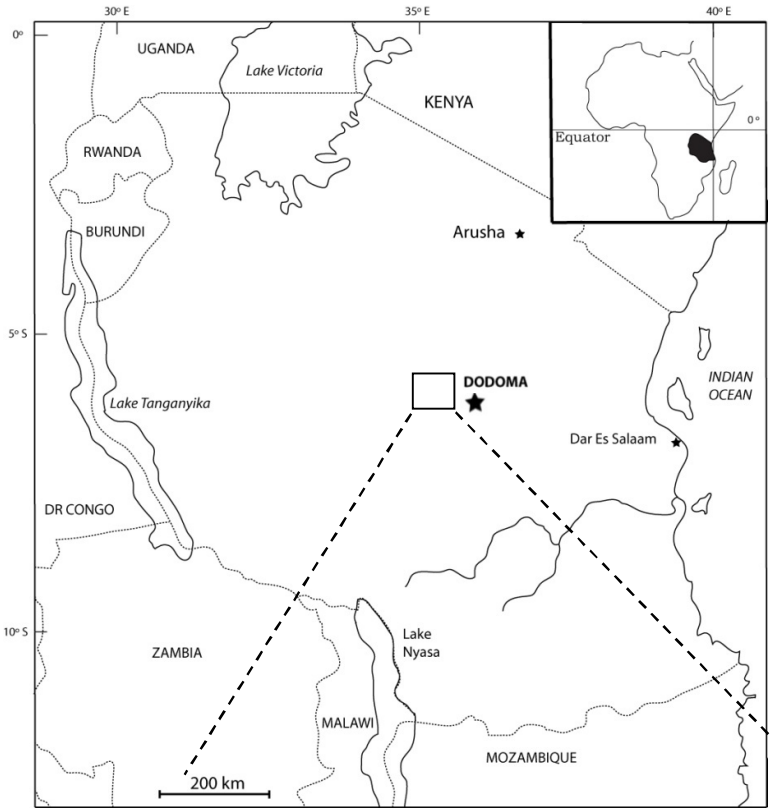

Fig. 1 Regional map showing the study area

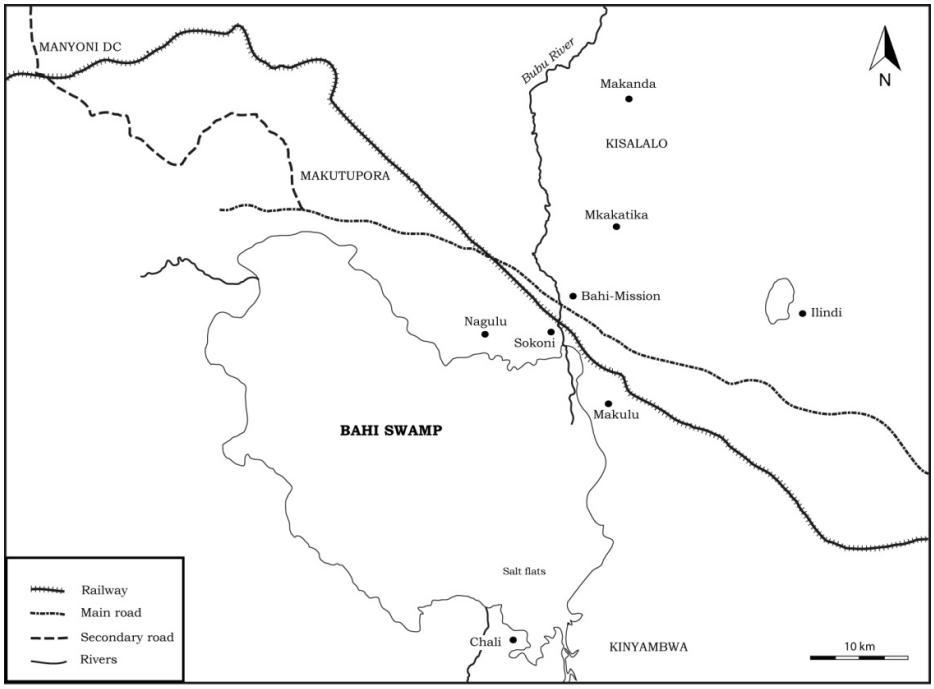

Fig. 2 Villages where the level of natural uranium was evaluated

GEOLOGICAL SETTING

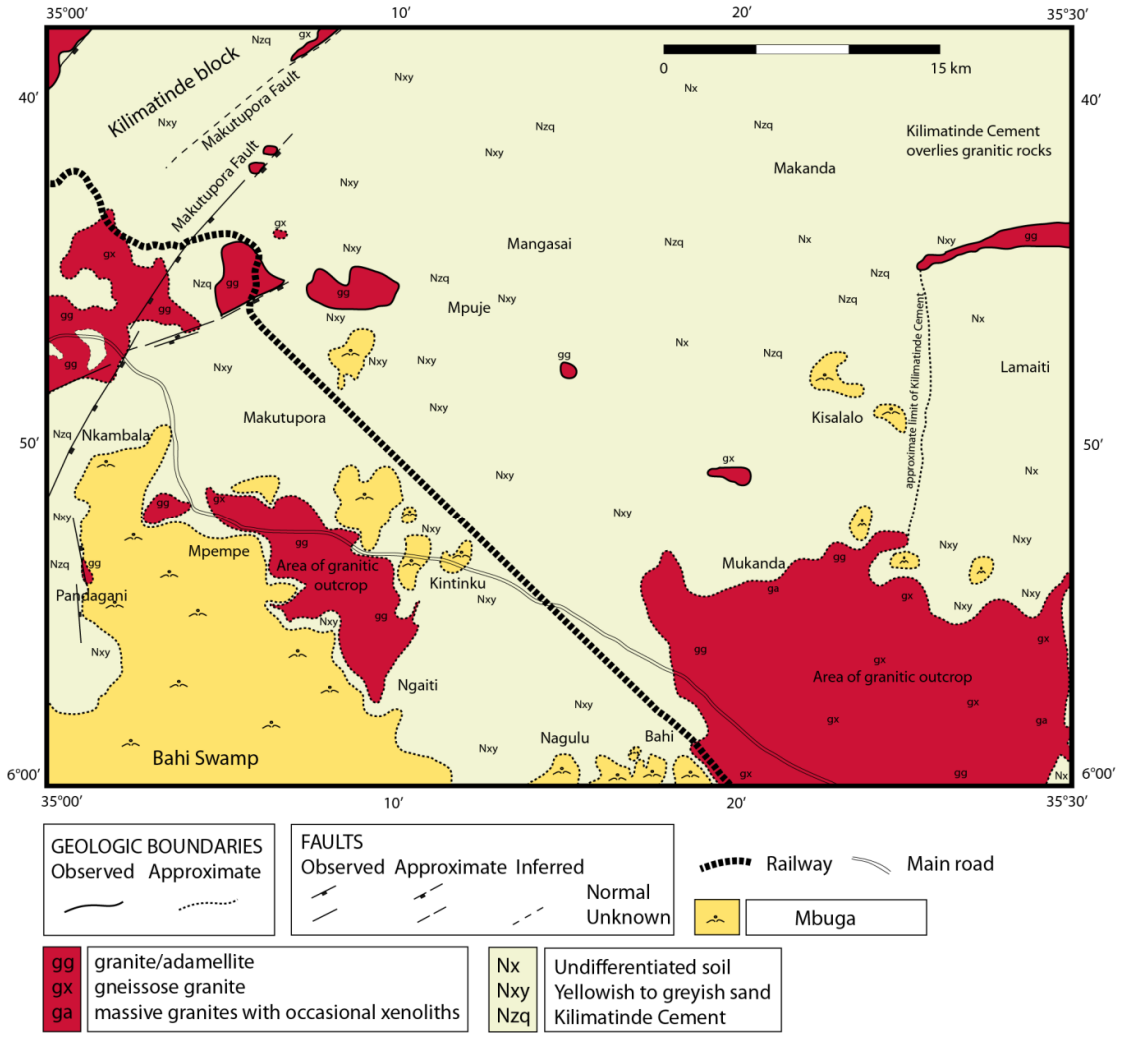

Fig. 3 Geologic map of the area including Makanda, Mkakatika, Nagulu and Bahi (redrawn after Mineral Resources Division Dodoma, 1967)

Late Archean rocks of Tanzanian Shield, mainly comprising biotite granites together with gneisses, migmatites, quartzites and amphibolites underlie the study area (Gabert et al., 1974). Besides quaternary deposits, Kilimatinde cement overlying granitic rocks and mbuga formations, one can notice scattered exposures of the basement rocks of volcanic origin on the geologic map (Fig. 3). Parts of these granites as well as their weathered products seem to be the major source rocks of uranium in the region. Weakly mineralized shear zones in granitic rocks, quartz veins containing significant concentrations (60-390 ppm) of U_3O_8 are also present in certain places (Bianconi and Borshoff, 1984).

In response to active faulting associated with the East African Rift System during Miocene-Pliocene, interior sedimentary basins were formed in the area and later infilled by valley-fill and lacustrine sediments (Pickering, 1958).

Dissection of the area and tilted blocks occurred during Pliocene-Pleistocene due to extreme rift faulting, which in turn disturbed and significantly changed the paleodrainage system. Some parts were uplifted and actively eroded, whereas down-faulting of a specific area and later coverage by younger sediments formed the Bahi Swamp (Bianconi and Borshoff, 1984).

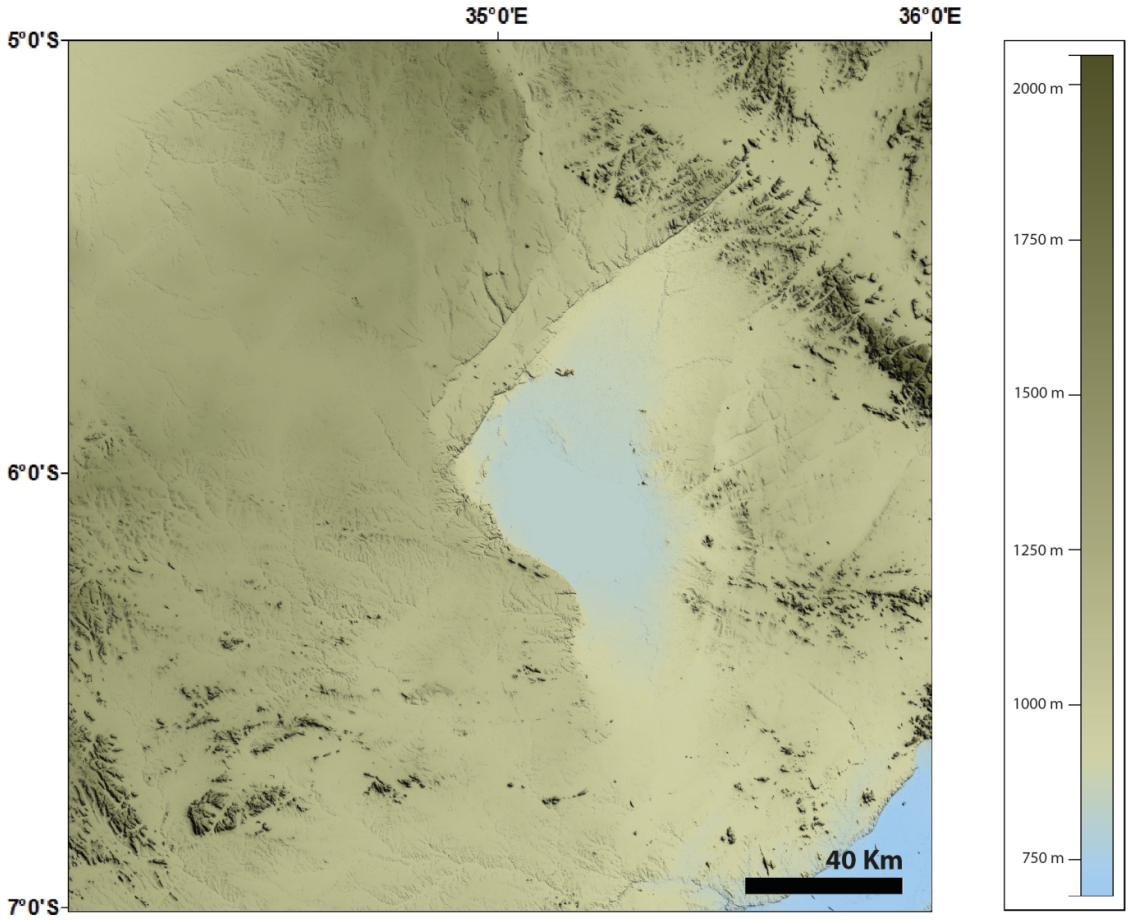

Fig. 4 Map based on SRTM data shows the Bahi topographic depression

BAHI LAKE

Bahi Lake is a large playa lake fed by an extensive closed internal drainage system. It typically exists after the high rate of precipitation in the region; 90% of lower than average annual precipitation falls from December to March and the area is almost dry throughout the rest of the year. High rates of evapo-transpiration take place during the period from May to October (UNDP/UNFAO, 1983). Location of the swamp is roughly 55 km to the north-east of Dodoma (Fig. 1), the radius of the waterbody can reach ~30 km in rainy seasons.

URANIUM MINERALIZATION

Lower Proterozoic mobile belts surrounding Archean shield and a long sedimentary history involving internal and intramontane basins seem to have created conditions suitable for the significant uranium mineralization in this part of Tanzania (Bianconi, 1987).

Uranium leached from weathered Archean granites within the Bahi catchment area has been transported in solution and chemically trapped within the paleodrainage system and eventually deposited in the playa lake sediments.

Most of the uranium anomalies within or near to Bahi interior drainage system are hosted in mineralized sediments found in so-called 'mbuga' depositional environments – Late Tertiary to Quaternary internal basins infilled with fluviatile and lacustrine clastic sediments. These 'mbugas' seem to have depths of 90 m in Makutapora and at least 102 m in Bahi Swamp (Bell et al.1981, Fawley, 1956).

Uranium minerals determined so far in this type of deposits contain carnotite and metatyuyamunite disseminated in calcretes within mbuga clays found close to the surface (Bianconi, 1987).

Another type of the surficial uranium occurrence is spotty uranium mineralization observed in highly-silicified sheet calcretes above weathered granite. This type of secondary mineralization in the form of spotty discontinuous uranium minerals was not considered as economic deposits in the past due to the low-grade of the ore; nevertheless, they appear on regional airborne radiometric anomalies map for its near-surface occurrence (Bianconi and Borschoff, 1984).

Radiometric anomalies and occurrence of surficial uranium deposits in Bahi interior drainage system were recognized already in late 1970s when Tanzania was systematically explored at a country scale by airborne geophysical surveys including gamma spectrometry and magnetometry (Batterham et al., 1983)

Drillhole data from central part of the Swamp obtained during salt exploration program in 1953 had also suggested accumulation of uranium in the Bahi catchment area showing 0.15 meters @ 2400 ppm U_3O_8.

Increasing exploration campaigns around Bahi Swamp at present time and the results of their follow-up ground investigations by international uranium mining companies such as Mantra Resources and Uranex additionally prove the presence of economically viable uranium deposits close to Bahi, Kisalalo and Ilindi. To give some figures, according to the report published in 2011 on the company website, Manyoni Uranium Project by Uranex is estimated to host 29 Mlb U_3O_8 at 100 ppm cutoff, whereas, analysis of grab and trench samples taken at Kisalalo anomalies within the scope of Bahi North Project by Mantra Resources yielded mineralization in the range of 130 ppm to 470 ppm U_3O_8.

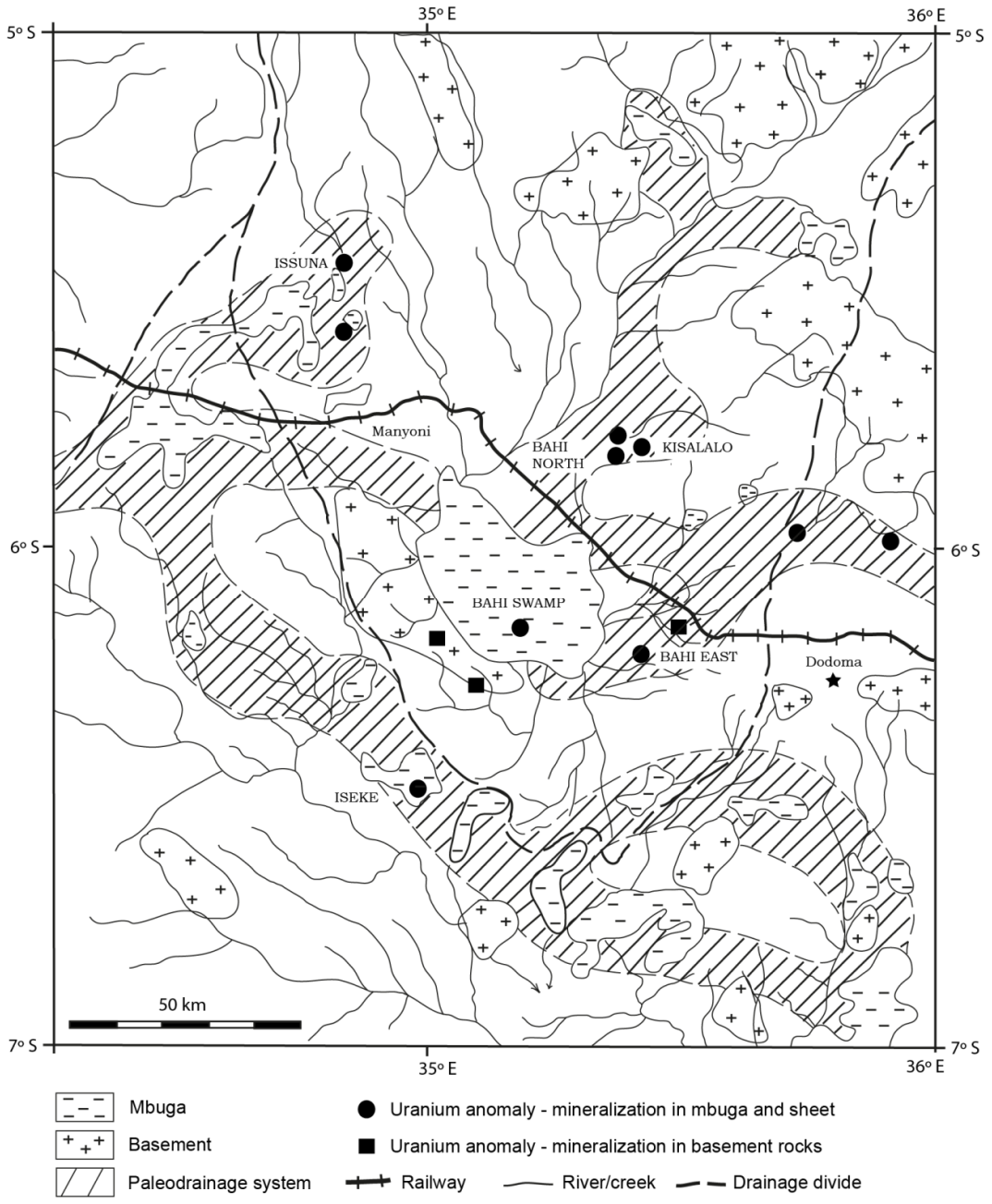

Fig. 4 Occurrences of surficial uranium around Bahi Swamp (redrawn after Bianconi and Borschoff, 1984)

METHODOLOGY

SAMPLING

Water sampling

Due to the dry season in the region, collecting surface water samples, unfortunately, was not possible; the Bahi lake as well as Bubu river was completely dry. Therefore, only groundwater samples were collected from water-supply wells in each village or populated

area. Majority of them, practically, are open, relatively shallow wells (< 6-8 m) made by local people as a water source for people and domestic animals (Fig. 7, 8). Closed, cased deep wells with an installed pump are present only in few locations such as Ilindi, Bahi-Mission and Bahi-Sokoni (Fig. 5-6). While taking samples from this type of closed deep wells, the stagnant water in the well was first removed by proper purging**.**

Parameters such as temperature, pH, oxidation-reduction potential, percentage of dissolved oxygen and electric conductivity were measured directly at the well-site using WTW Multi 3430 and WinLab portable multiparameter analyzers.

4 samples with volumes in the range of 30-50 ml were collected in bottles at each sampling point for different test types, namely, to determine:

- trace elements
- dissolved organic carbon (DOC)
- major ions
- total inorganic carbon (TIC)

Samples for DOC analysis were only filtered while the samples for trace element analysis were both filtered and acidified with nitric acid (40%) until the pH value of the sample is <2.0 to preserve trace elements and reduce microbial activities as well as precipitation. Samples for the analysis of major ions were filtered only after being delivered to the Water Analysis Laboratory at Freiberg Academy of Mining.

Fig. 5 Water-supply well in Ilindi

Fig. 6 Drinking water source in Bahi-Sokoni

Fig. 7 Hand-dug open well in Bahi-Makulu

Fig. 8 Water pumped out of open well for livestock

Soil sampling

4-5 surface soil samples of 50 grams each were taken from each of the above-listed areas, randomly from different parts of the village or farming area. We paid attention not to take samples at points too close to a road, tree or some other obstructions. 0.5 m × 0.5 m marked area was first cleared of debris after which the surface soil was taken from the upper 0-5 cm layer from different parts of the marked area. Obtained soil sample was mixed and representative sample out of the mixture was put into plastic bags (Fig. 9). Total of 28 samples were collected from the study area and the position of each sampling point was determined with an average accuracy of approximately ± 3-4 m with the help of Garmin GPS12 handheld device.

Fig. 9 Soil sampling

ANALYSIS

The entire analytical work was performed at laboratory facilities of Freiberg Academy of Mining with great technical support from the experienced lab staff.

Analysis of water samples

Content of trace elements in the ground water samples were analyzed by inductively coupled plasma mass spectrometry (ICP-MS). The method was applied in X Series 2 ICP mass

spectrometer of Thermo Scientific (Fig. 10) where Ge, Rh and Re were used as internal standards. Samples were diluted where necessary depending on the values of electrical conductivity for an individual sample.

Concentrations of major ions in the water samples were determined with the help of Ion Chromatography (IC) using 881 Compact IC Pro and 672 Extension Module of Metrohm.

Total inorganic carbon (TIC) and dissolved organic carbon (DOC) analysis were performed using Elementar LiquiTOC equipment.

Fig. 10 Water analysis

Acid extraction of soil samples and ICP-MS analysis

Most of the soil samples we collected were extremely dry due to climatic conditions in the region, therefore, only few samples were dried in a drying oven before being ground. In order to achieve the required fineness, we ground them in Fritsch ball mill using ceramic balls of different sizes for better grinding and homogenization of the material (Fig. 11).

Trace elements were extracted out of the soil samples by adding strong acid and further heating the mixture:

10 ml of distilled water was added to 2 g of soil sample, 40 ml of nitric acid (60 %) was input afterwards with the aim of dissolving all the trace elements.

Fig. 11 Acid extraction of soil samples

The mixture was heated at a temperature between 70-80°C on a hot plate for 3 hours while being stirred at the same time. Solution obtained this way (Fig. 11) was diluted and analyzed

by computer-controlled X Series 2 ICP mass spectrometer of Thermo Scientific. Ge, Rh and Re were used as internal standards.

TERRESTRIAL GAMMA-RAY SPECTROMETRY

Terrestrial radiation results in response to radionuclides present in the rocks; the major sources of the radiation are potassium, uranium, and thorium and their decay products. Radon isotopes, radioactive gases in ^{235}U, ^{238}U and ^{232}Th decay series are the sources of aerial radioactivity (Culbert et al., 1981).

Low-energy gamma-ray spectrometry originally designed and developed for uranium exploration can also be used to evaluate the concentration of radioactive elements in the soil. The principal idea is the use of low-energy gamma emissions < 400 keV from U and Th decay series which enables the direct measurement of the mentioned elements (Jegannathan et al., 2005).

Instrumentation

EG & G BERTHOLD LB 123 UMo, portable gamma-ray spectrometer:

LB 123 UMo is a radiation protection instrumentation that consists of a battery-driven data logger unit and various contamination detectors. For our purpose, we used LB1236 proportional counter probe for gamma-ray detection. The calibration constants are stored in the instrument memory; automatic calibration eased our task during field work.

Fig. 12 EG & G BERTHOLD LB 123 UMo

The designed energy range for the probe is 30keV-2MeV while the dose rate that can be detected is between 50nSv/h and 10 mSv/h.

Data acquisition

Guidelines for radioelement mapping using gamma ray spectrometry data by International Atomic Energy Agency (IAEA) from July 2003 was followed during data acquisition.

Field measurements were carried out in static mode; the radioactivity was measured at discrete points for 5 minutes. Dose rate at each point was measured with the help of LB 123 UMo and LB 1236 probe technical details of which were given above. The registered value for each point is the average of measurements obtained within 300 seconds.

30-40 point data were collected in a regular pattern for several villages (Ilindi, Makanda, Nagulu, Chali) depending on the size of the latter. The areas covered by the villages are relatively large with a radius of at least 4-6 km due to the scattered distribution of the huts and cropped acres; therefore, we tried to obtain at least one value for each 300 m × 300 m

area. In some cases, geometry of the data acquisition pattern slightly changed due to the presence of physical obstacles such as barns, graveyards, etc. as well as acceptable inaccuracies in positioning.

With the aim of minimizing the influence of local change of relief and variation in radioelement distribution, geometry of the source-detector remained the same for all measurements; detector was held at a constant height of 1 m above the ground surface. For the given geometry, the area of influence should have a radius up to 5-10 meters and the soil thickness evaluated is in the range of 30-50 cm (Kogan et al., IAEA 1989).

Moisture content in soil might become a considerable source of error in terrestrial gamma ray surveying; 5-10 % increase in soil moisture may already cause unacceptable deviations in the instrument accuracy (Charbonneau & Darnley, 1970). For this reason, all the measurements were done above dry surface soil. Position of each measured value was determined within accuracy level of ± 3-4 m by a handheld GPS device and registered.

RESULTS

Results of ground water analysis

General layout of the water sampling points is shown in Fig. 12; red points show the places where elevated levels of uranium in water composition were determined. Short descriptions of the sampling points, concentrations of trace elements as well as the values of other measured parameters are summarized in the table below (Table 1).

Fig. 12 Groundwater sampling points. Red spots demonstrate the elevated U level. See Table 1 for the values

The image above demonstrates the entire area of the ephemeral lake; however, Sulunga Lake was almost completely dry during sample collection period. For instance, sample NA3 with elevated ^{238}U content (37.9 ppb) is not a surface water sample, instead comes from the man-made pit with a depth of ~ 7-8 m.

Although the technical report is dedicated to the evaluation of natural uranium level, it is important to mention that one of the samples from Nagulu indicated slightly high concentration of arsenic (NA3, 16.5 ppb); excess exposure to arsenic can give rise to cancer and skin lesions (WHO, 2008).

While the ground water samples from Chali contain uranium well below the guideline values, elevated concentration of lead (CH1, 30.9 ppb in contrast to 10 ppb guideline value set by WHO) in one of the samples was determined; this might be worth to mention since lead can cause adverse neurological effects (WHO, 2008). It is known that in areas where the water is relatively more acidic, the pipes, plumbing materials or coatings can become a source of elevated lead in water. But this does not seem to be the case since the sample was collected from an open-well.

Table 1 Results of ground water analysis

Sample name	MA1	CH1	CH2	MK1	IL1	IL2
General						
Location	Makanda	Chali	Chali	Mkakatika	Ilindi	Ilindi
Type of well	open, shallow well	open, shallow well	deep, closed well with installed pump	open, shallow well	deep, closed well with installed pump	open, shallow well
Approximate well depth (m)	2	4	55	3	100	1
Parameters measured on-site						
EC (µS/cm)	369	301	748	308	2980	1015
pH	6.92	7.10	7.15	6.38	7.30	7.18
T (°C)	30.7	30.3	26.5	29.9	29.1	29
DO (mg/L)	1.45	4.03	4.50	5.20	8.38	>15
Redox (mV)	1100	35	67	105.8	74.5	50.5
Trace elements in ppb						
238 Uranium	0.85	1.10	2.98	0.65	**250.80**	4.42
Arsenic	1.36	0.82	0.46	0.78	0.32	0.60
Barium	248.30	112.60	187.70	27.99	238.50	125.70
Beryllium	0.02	0.04	0.02	0.21	< 0.02	0.05
Bismuth	0.00	0.01	0.00	0.00	0.00	0.00
Cadmium	0.02	0.02	0.01	0.02	0.03	0.01
Chromium	0.23	1.48	0.07	0.61	0.13	0.45
Copper	3.09	4.61	1.88	2.32	6.86	2.52

Lead	0.96	**30.91**	7.85	0.87	0.34	0.73
Silver	0.12	1.05	0.02	0.08	0.13	0.38
Thallium	0.04	0.02	0.01	0.02	0.01	0.05
Thorium	0.04	0.14	0.02	0.44	0.01	0.32
Zinc	97.37	125.70	1520.00	414.70	71.06	33.49
Dissolved organic carbon (mg C/L)	4.66	2.08	1.27	2.12	4.33	11.57
Total inorganic carbon (mg C/L)	34.73	36.31	72.31	13.20	160.50	40.50
Cations (concentration in mg/L)						
Li^+	<LOD	<LOD	0.01	<LOD	0.09	<LOD
Na^+	32.82	53.71	96.71	60.48	554.07	171.46
K^+	7.71	1.03	4.10	1.02	5.92	13.46
Ca^{2+}	26.80	13.01	52.39	0.91	73.07	19.33
Mg^{2+}	6.63	2.90	12.74	0.49	34.75	10.77
NH_4^+	<LOD	0.03	0.01	0.01	0.05	0.62
Anions (concentration in mg/L)						
F^-	0.72	0.46	0.79	0.76	2.16	0.79
Cl^-	22.01	7.59	40.88	42.65	476.25	154.72
Br^-	0.15	0.08	0.21	0.17	1.17	0.58
NO_3^-	4.21	4.63	<LOD	39.35	57.13	67.61
PO_4^{3-}	<LOD	1.86	0.26	0.27	<LOD	0.99
SO_4^{2-}	16.15	6.16	33.51	9.22	106.61	51.35

Table 1 Results of ground water analysis (continued)

Sample name	NA1	NA2	NA3	BAM	SOK	MKL
General						
Location	Nagulo	Nagulo	Nagulo	Mission	Sokoni	Makulu
Type of well	open, shallow well	open, shallow well	open, shallow well	deep, closed well with installed pump	open, shallow well	open, shallow well
Approximate well depth (m)	3	5	5	70	6	6
Parameters measured on-site						
EC (µS/cm)	375	96.1	10660	2380	1381	2390
pH	7.43	6.45	7.34	7.24	7.19	7.24
T (°C)	28.6	29.2	27.7	31	26.1	24.7
DO (mg/L)	8.70	4.25	2.80	5.05	3.15	2.41
Redox (mV)	120	123	97	46.3	400	70.8
Trace elements in ppb						
238 Uranium	2.05	1.22	**37.88**	**249.10**	20.95	19.65

Arsenic	0.91	0.37	**16.46**	0.11	1.41	0.75
Barium	59.15	41.97	169.70	211.20	296.60	334.30
Beryllium	0.01	0.10	< 0.05	0.03	< 0.01	< 0.01
Bismuth	0.00	0.00	0.02	0.01	0.00	0.00
Cadmium	0.01	0.01	0.02	0.04	0.01	0.02
Chromium	0.19	1.63	0.19	0.12	0.07	0.08
Copper	4.37	14.17	1.99	2.30	0.94	1.94
Lead	11.62	4.72	0.96	7.51	1.31	1.21
Silver	0.17	0.12	0.87	0.59	0.07	0.17
Thallium	0.01	0.03	0.02	0.01	0.01	0.03
Thorium	0.04	0.19	0.04	0.09	0.02	0.02
Zinc	81.14	35.01	18.37	96.41	75.75	58.18
Dissolved organic carbon (mg C/L)	4.50	1.37	5.10	1.67	3.62	7.49
Total inorganic carbon (mg C/L)	28.90	10.44	399.39	106.62	129.53	85.10
Cations (concentration in mg/L)						
Li^+	<LOD	<LOD	0.24	0.10	<LOD	0.03
Na^+	52.02	18.28	2134.67	440.97	201.06	335.47
K^+	11.56	3.42	19.90	5.37	4.60	3.79
Ca^{2+}	15.54	2.14	69.54	61.73	78.52	107.03
Mg^{2+}	5.73	1.05	102.95	19.15	10.57	37.27
NH_4^+	<LOD	<LOD	<LOD	<LOD	0.01	0.02
Anions (concentration in mg/L)						
F^-	0.44	0.17	1.31	1.58	1.31	0.78
Cl^-	34.15	9.88	2269.76	417.58	87.37	480.40
Br^-	0.24	0.06	11.92	1.54	0.49	1.59
NO_3^-	3.25	6.21	<LOD	42.89	0.67	14.69
PO_4^{3-}	0.21	0.08	12.67	<LOD	0.65	1.27
SO_4^{2-}	24.11	5.45	800.16	127.03	58.57	103.34

Uranium may cause a serious concern about health when it is present in excess amount. According to the standards set by World Health Organization for drinking water quality, the provisional guideline value for uranium is 15 ppb based on its chemical toxicity for the kidney and other negative effects; nephritis seems to be the major chemically induced disease caused by uranium in human body. However, WHO suggests that uranium concentration values up to 30 ppb may be still protective when considering possible kidney diseases.

Considering now the above-mentioned guideline values, obtained results show that in some villages, the quality of the groundwater utilized for drinking and other purposes might be critical also in terms of uranium content:

As listed in Table 1, groundwater samples both from Bahi-Mission (BAM) and Ilindi (IL2) seem to contain around 250 ppb Uranium which definitely exceeds the guideline value of 20 ppb set for drinking water by Environmental Protection Agency (EPA) or 15 ppb suggested by World Health Organization (WHO).

Worldwide, general occurrence of uranium in drinking water is less than 1 ppb (while not considering specific supplies with extreme values) whereas, almost half of the samples collected within Bahi district is either very close to or exceeds the guideline value of 15 ppb set by WHO. Normally, intake of uranium by drinking water is very low, but in circumstances like in the case of Ilindi and Bahi where the concentration of uranium in drinking water is high, the majority of uranium intake by local population might be through drinking water (WHO, 2008).

Results of chemical analysis of soil samples

Locations of the surface soil sampling points are illustrated in Fig. 13:

28 soil samples collected from different villages were thoroughly analyzed for its uranium content and the concentrations of heavy metals. Apparently, surface soil in Ilindi contains relatively high concentration of Uranium where the maximum value reaches 33.3 mg/kg. It is higher than the guideline value of 23 mg/kg set by Canadian Soil Quality Standard (CSQS) for residential and agricultural purpose. However, the samples from the rest of the villages demonstrate modest concentrations of Uranium ranging from 0.16 mg/kg up to 3.17 mg/kg.

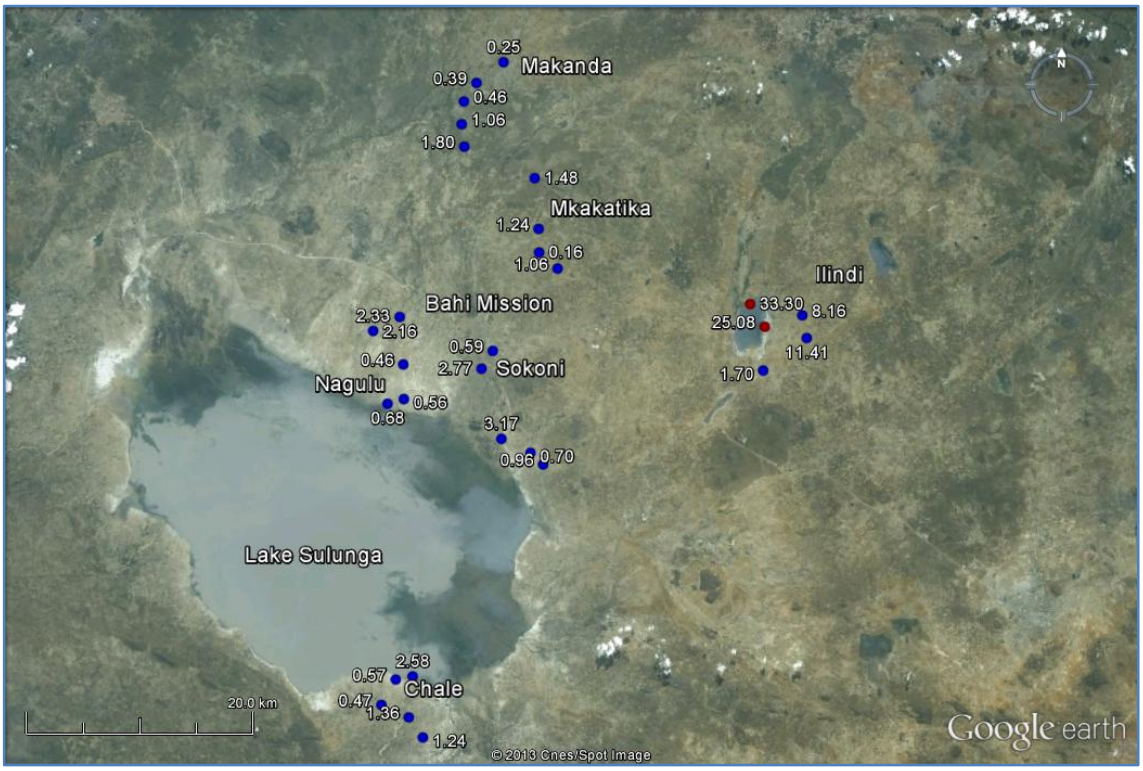

Fig. 13 Soil sampling points and corresponding concentration values of U (mg/kg of soil). Red spots show the uranium content in soil higher than the CSQS guideline value of 23mg/kg

Table 2 Results of chemical analysis for soil samples

micrograms per gram of soil

	U	As	Ba	Be	Bi	Cd	Cr	Cu	Pb	Ag	Tl	Th	Zn
Makulu (n = 3)													
Mean	1.61	0.99	158.28	0.56	0.03	0.03	8.63	7.93	8.11	0.04	0.11	11.61	8.57
Maximum	3.17	2.14	226.55	1.20	0.06	0.03	19.66	18.02	14.73	0.09	0.23	25.83	15.14
Nagulu (n = 5)													
Mean	1.24	0.67	95.18	0.41	0.02	0.01	5.70	5.73	5.75	0.03	0.12	7.48	6.99
Maximum	2.33	0.98	155.50	0.61	0.03	0.03	8.74	7.60	8.29	0.05	0.19	11.37	8.82
Chali (n = 5)													
Mean	1.25	1.02	150.75	0.64	0.06	0.03	13.35	8.48	9.20	0.05	0.21	10.26	16.29
Maximum	2.58	1.79	273.75	1.21	0.13	0.06	26.20	16.62	17.04	0.08	0.41	18.85	32.30
Ilindi (n = 5)													
Mean	15.93	2.37	177.35	0.73	0.04	0.04	14.10	6.56	9.75	0.05	0.14	10.33	11.66
Maximum	33.30	5.27	232.30	1.08	0.07	0.06	22.13	9.57	12.77	0.07	0.23	15.05	16.34
Mkakatika (n = 4)													
Mean	0.98	0.50	37.29	0.24	0.01	0.01	5.08	4.81	4.93	0.02	0.07	3.97	2.90
Maximum	1.48	0.75	79.58	0.39	0.02	0.02	14.14	12.78	7.16	0.04	0.12	7.02	3.91
Makanda (n = 5)													
Mean	0.79	0.44	33.54	0.22	0.01	0.01	3.04	1.64	3.47	0.05	0.06	8.71	2.09
Maximum	1.80	0.72	67.45	0.52	0.02	0.01	5.22	2.54	6.53	0.10	0.13	18.48	4.12
Sokoni (n = 2)													
Mean	1.68	1.13	128.36	0.62	0.03	0.02	18.54	9.27	7.92	0.04	0.31	12.39	17.26
Maximum	2.77	1.94	211.70	1.18	0.07	0.04	36.13	17.47	13.89	0.08	0.60	22.83	32.75

Results of gamma-ray spectrometry

Results of gamma-ray spectrometry for Ilindi, Makanda and Nagulu villages are presented below (Fig. 14-17), positions of the surveyed area are shown on general layout and the exact coordinates are given on the uranium distribution maps. Inverse distance square method was used for interpolation between discrete point values. But one has to keep in mind that number of point data is far from sufficient for given areas. Therefore, visualized data serve just as a rough guide to see the contrasts in surface radioactivity level.

25 point data from Makanda correspond to values between 0.11-0.54 µSv/hr (Fig. 15). 35 point data acquired in Nagulu village are demonstrated in Fig. 16; no significant anomalies were determined.

38 point measurements were done in Ilindi; readings of the equipment were in the range of 0.12-0.35 µSv/hr; few values exceeded 0.30 µSv/hr (Fig. 17).

Resulting values of gamma-ray spectrometry for 21 points in Chali were in the range of 0.11µSv/hr and 0.20µSv/hr without observable anomalies, therefore, was not visualized in the current report.

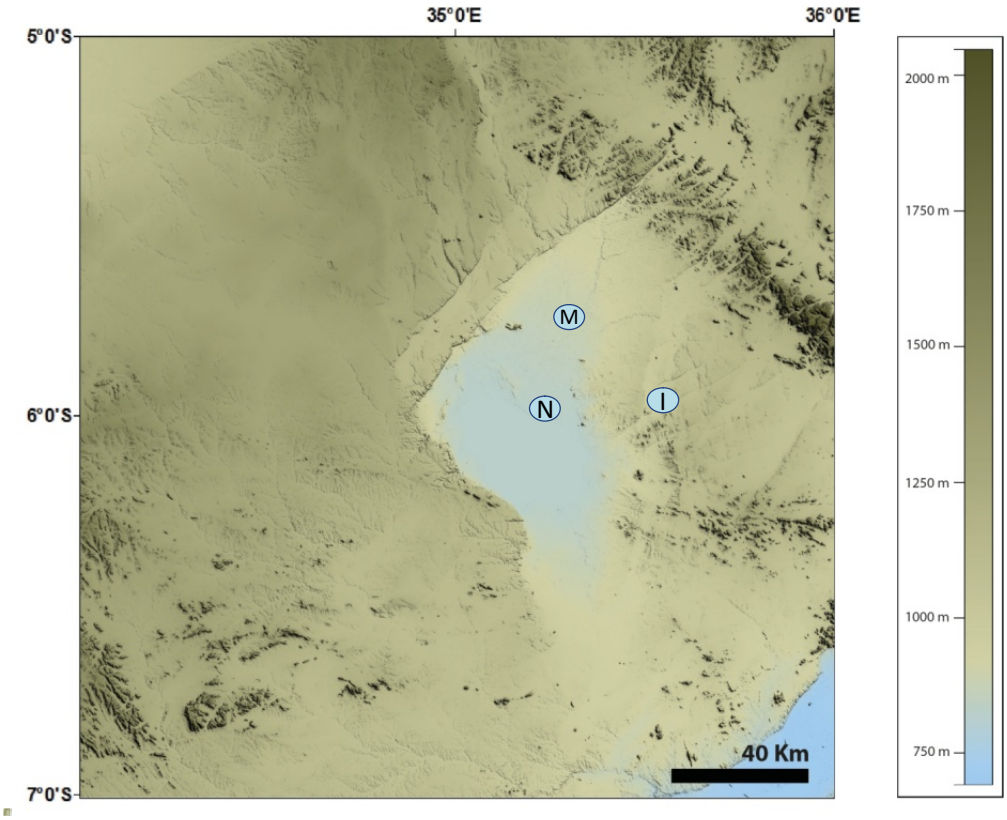

Fig. 14 Gamma-ray spectrometry locations: Makanda (M), Nagulu (N) and Ilindi (I)

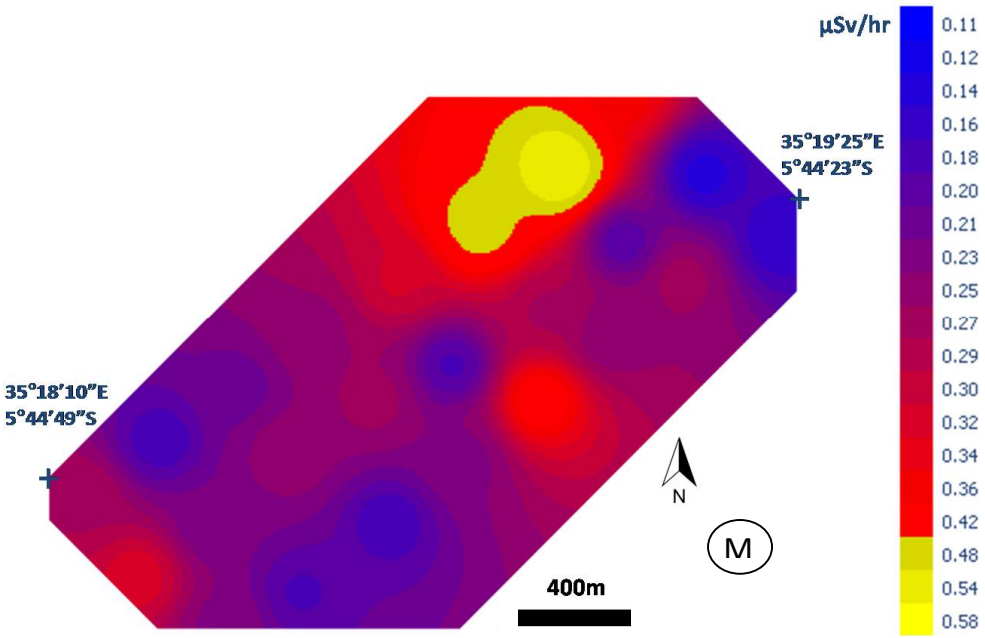

Fig. 15 Results of ground gamma-ray survey in Makanda, direct surface measurements

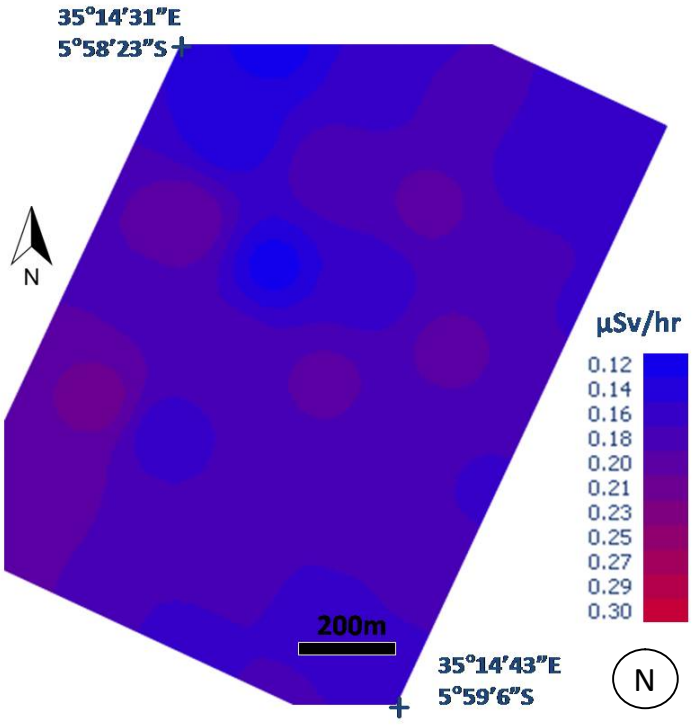

Fig. 16 Results of ground gamma-ray survey in Nagulu, direct surface measurements

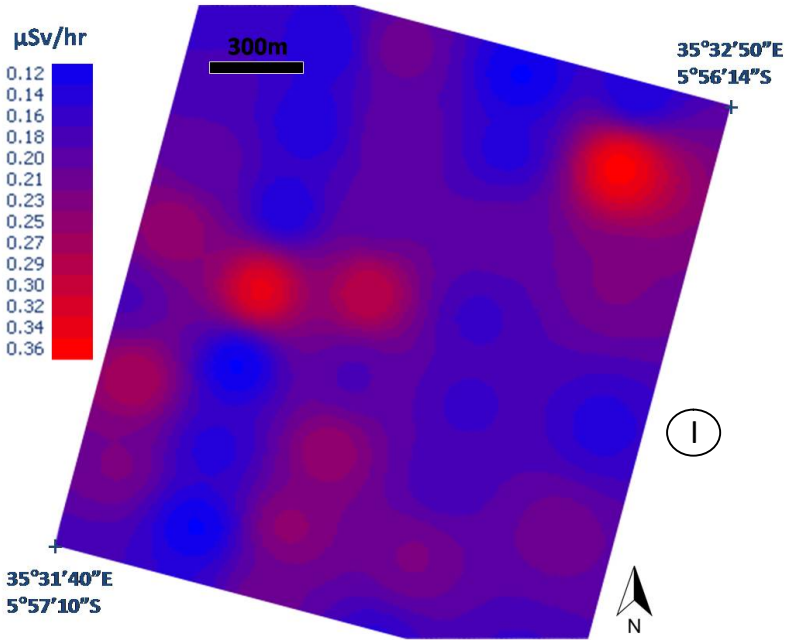

Fig. 17 Results of ground gamma-ray survey in Ilindi, direct surface measurements

CONCLUSION

The presented results of ground water analysis show that the quality of drinking water in villages such as Bahi-Mission, Ilindi and Nagulu do not meet the minimum requirements in terms of chemical composition; high content of uranium, arsenic and lead might pose serious health issues for local people who use these untreated water supplies on a regular basis. It is known that scarcity of water resource is a major problem in the region; nevertheless, consumption of highly contaminated ground water should be avoided and application of alternative solutions as far as possible is recommended.

While surface soil samples mostly do not demonstrate extreme values of uranium concentration, they still do not give robust idea about the overall distribution of uranium on the surface of such a big study area. Moreover, the results are limited to the maximum depth of 5 cm due to time and technical constraints. Therefore, additional analysis of soil quality and analyzing plants and crops cultivated in these areas might be useful.

Ground gamma-ray spectrometry results in Makanda and Ilindi show higher than normal levels of gamma-ray emission at the ground surface whereas in Nagulu and Chali relatively lower values were determined. Having access to the results of airborne radiometric mapping mostly done by mining and exploration companies in this region would also be helpful to evaluate the surface radioactivity level.

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APPENDICES

Fig 14. Water supply source in Bahi-Mission

Fig 15. Picture from Nagulu

Fig 16. Secondary water source in Ilindi

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