ASSESSMENT OF HEAVY METAL CONCENTRATION IN WATER AROUND THE PROPOSED MKUJU RIVER URANIUM PROJECT IN TANZANIA

Firmi P. Banzi[1], Peter K. Msaki[1], Najat K. Mohammed[1]

[1]Department of Physics,
University of Dar es Salaam,
P.O. Box 35063, Dar es Salaam, Tanzania.
Email: fpbanzi@yahoo.com

ABSTRACT

Effective verification for compliance *with water quality standards in uranium mining in Tanzania requires data sensitive to monitor heavy metal concentration in water around the Mkuju River Uranium Project before mining commences. The area susceptible for pollution by the project was estimated using AERMOD dispersion model and found to cover about 1300* km^2*. Thirty one surface and groundwater samples were collected and analysed for heavy metals and physicochemical properties using ICP-MS and standards techniques, respectively. The physicochemical properties for water samples analysed ranges from 5.7 to 7.8 for pH, 2.8 to 80.2 mg/L for TDS and 15 to 534.5 mS/cm for EC. These values show that the water in the vicinity of the Mkuju River Uranium Project is normal. The ranges of concentration of heavy metals (*μgL^{-1}*) determined in water ranges were: Al(2 to 9049), Cr(0.2 to 19.96), Mn (0.1 to 1452),Fe(2 to 53890),Co(0.02 to 27.63), Ni(0.2 to 9.7), Cu(2 to 17), Zn(2 to 62.94), As(0.4 to 19.17), Cd(0.02 to 0.14), Pb (0.02 to 78.68), Th (0.002 to 1.73),U(0.002 to 29.76). These values are below the tolerance levels of concentrations set by different International organisations. Therefore heavy metal toxicity in the study area is marginal. The parameters that could serve as baseline data because of their enhanced sensitivity to pollution were (i) concentration of chromium, cobalt, nickel, copper, zinc, arsenic, cadmium and lead in water (ii) pH, TDS and EC for water, (iii) TDS ratio for surface to ground water values and (iv) correlation coefficients between the heavy metals. However, since TDS values are season dependent, this indicator can serve as baseline data when measured during the dry season as was the case in the study.*

Keywords: Baseline, Heavy Metal Pollution, Mkuju River Project, Uranium Mining, Water Pollution

1. INTRODUCTION

Both natural processes and anthropogenic activities are the main sources of surface and groundwater contaminations by heavy metals (Nriagu and Pacyna 1988, Nriagu 1989, Peplow 1999, Ato et al. 2010, Naveedullah et al. 2014). Regardless of origin, increase of heavy metal concentration in water is becoming a serious threat to human health and aquatic ecosystems (Humood 2013, Naveedullah et al. 2014).The common heavy metals of health concern to human include arsenic, cadmium, chromium, lead, nickel and zinc (EU 1998, TBS 2005, WHO 2008).When heavy metal concentrations in water exceed environmental tolerance limits, use of such water in agricultural (irrigation and aquaculture) activities could be harmful to the aquatic ecosystem and human via the food chain (Wright and Welbourn 2002).

Implicit in the increased mining activities in developing nations is that water contamination by heavy metal is likely to increase rapidly beyond these tolerance limits if best practices in mineral extraction and processing are not in place (IAEA 2010). In efforts to implement best practices in mineral exploitation, some nations in Africa including Tanzania, have formulated mining regulations that limit soil and water resources pollution by heavy metals (SA 1996, Akabzaa 2004, MEM 2010, TAEC 2011, Kenya 2014). For these regulations to be effective there must be a mechanism for verification of compliance with soil and water quality standards in the regulations. Such method requires establishment of heavy metal concentration in soil and water prior to the commencement of a mineral exploitation practices (IAEA 1998, IAEA 2005, IAEA 2009, Banzi et al. 2015). The data established for water in the area which would be affected by the mining activities is called baseline data. Lack of this information, for example, in areas surrounding the Geita gold mine and North Mara gold mine in Tanzania, have created unresolvable controversies on the observed increase of detrimental health effects known to be associated with heavy metal pollution in water as a result of mining activities (Bitala et al. 2009, LHRC 2011). This is expected because it is rather difficult to establish for certain the incremental heavy metal concentrations in water when the mining activity is in progress.

For heavy metal concentration to serve as baseline data, it must therefore be established prior to the commencement of planned mining activity in a region (LTC 2003, IAEA 2009, Banzi et al. 2015). For the data to serve this purpose, it must be recognised that in practice, heavy metal concentration in water can also be influenced by natural processes such as weather parameters (e.g. erosion, atmospheric deposition, volcanic activity) and forest fires (Nriagu 1989, Nagajyoti et al. 2010). The amounts of heavy metal that dissolve in water or deposited onto sediments depend on pH, Total Dissolved Solids (TDS) and seasonal temperature and rainfall variation in a region (Bartram and Balance 1996). It has to be noted that the dependency of heavy metal concentration on rainfall variations can be complex (Meybeck et al. 1996). Therefore, effective verification for compliance to best practice in mining based on incremental heavy metal concentration and tolerance limits for heavy metal intake requires that these factors are taken into consideration during the establishment of baseline data to be used as reference. The work therefore aims to establish concentration of heavy metals and the associated physicochemical parameters in surface and groundwater that will serve as baseline data needed for best practice in proposed Mkuju river uranium mining project.

2. MATERIALS AND METHODS

2.1 Study Area

Mkuju River Project (MRP) as shown in Figure 1A, is located in Ruvuma region between latitudes 9° 59′ 50″ to 10° 07′ 15″ S and longitudes 36° 30′ 00″ to 36°37′55″E. The study area excludes the uranium deposits consists of the surrounding area likely to be affected by the project. The surrounding area estimated by AERMOD dispersion model as described in a previous work is about 1300 km^2 (Banzi et al. 2015). The MRP is characterized by rain season which commences in January and ends on April with an average annual rainfall of 70 mm with temperatures ranging from 11 to 29ºC and dry season which commence on May and ends in December with temperature ranging from 14 to 37ºC. The average wind is 6 ms^{-1} with maximum (NE and N) and minimum (SW and S) wind speeds used to demarcate the study area were about 13 ms^{-1} and 2 ms^{-1}, respectively. Since the MRP is being located in the Selous which is a world heritage, the heavy metal concentrations would have little influence from anthropogenic activities and therefore could be used as reference data.

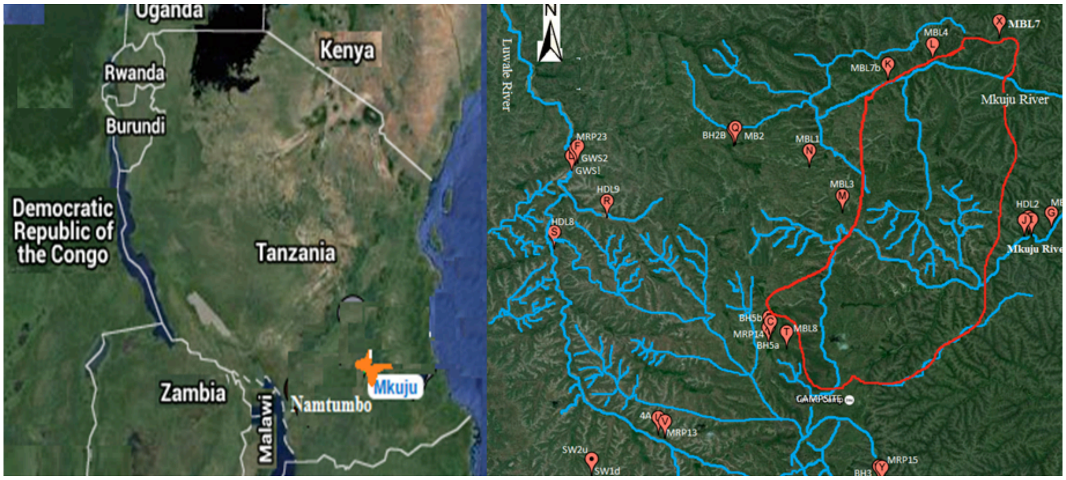

Figure 1: A map of Tanzania showing the location of Mkuju (Left) and sampling blocks indicated by red flags outside the Mkuju concession area enclosed by solid red line (Right).

2.2 Water Sample Collection and Pre-treatment.

To avoid the influence of rain on heavy metal concentration, thirty one (31) surface and groundwater samples were collected between May and September, 2014. The water samples were collected randomly from up and downstream of Mkuju and Luwale river's tributaries and monitoring boreholes plausible to be polluted by the proposed mining activities shown in Figure 1 (right) and referenced using a Global Positioning System (GPS) receiver, Garmin, 75 according to standards sampling procedures described elsewhere (Goddard 2002, MW 2012). To avoid contamination, 1 litre transparent polyethylene bottles were pre-cleaned with distilled water. At each location, prior to water sampling, the sample bottles and bailer were thoroughly rinsed with the water to be collected. The process of drawing water sample by bailer several times before taking a sample made it possible to obtain water samples with representative heavy metal concentration of the sampling point. Finally one litre of water sample was drawn and filled in the transparent polyethylene bottle and stored in a cooler at 4°C. Each sample was then divided into two portions. The first portion was used for pH, Electrical Conductivity (EC) and TDS measurements according to standard procedure described elsewhere (APHA 1992). The second portion of each sample was passed through a 0.45 µm pore size filter to remove extraneous materials (Yeskis and Zavala 2002) and initial portion of the filtrate was used to rinse the 100 ml conical flasks used to collect the sample filtrate. The sample filtrate was then stabilized (acidified) with 2 mL nitric acid to prevent bacterial activities and adsorption of heavy metals on the container wall. Each pretreated sample was then kept into a 50 mL polypropylene centrifugal tube, packed and stored in a fridge at 4°C ready for transport to the analytical laboratory at the TU Freiberg in Germany.

2.3 Measurements of Physicochemical Properties of Water

Since concentration of heavy metals in water depends on pH and TDS, determination of these quantities in the first portion of the samples was made in-situ using a multi parameter instrument WTW pH330i (Wissenschaftlich–Technische Germany). The pH probe was calibrated using buffer solutions with 7.00. The mean values for pH, TDS and EC obtained for water samples collected from different locations are presented in Table 1.

2.4 Determination of Heavy Metal Concentrations

Determination of heavy metal concentration was done with Inductively Coupled Plasma-Mass Spectrometer (ICP-MS Thermo Scientific x Series 2) based on ionization of analytes in a sample, separation and detection the ions for determination of metal concentration (ICP-MS 1987). The technique involved two steps. In the first, the spectrometer was calibrated by introducing in the inductively coupled plasma and the mass analyser a multi-element standard solution to obtain a spectrum used for generating a calibration curve. In the second, water sample stored in centrifuge vial was diluted by adding 5 mL of deionized water to 5 mL of sample and the solution acidified with 1% w/v nitric acid to bring more concentrated analytes into the specified range. For the sake of improving the accuracy and sensitivity of the ICP-MS data, Rh, Re and Ge as internal standards were added to the sample solution before it was introduced in the ICP-MS and the nature and concentrations of elements were then determined according to standard procedures described elsewhere (Skoog et al. 2007). According to this procedure, the spectrum generated and displayed on a Multi-Channel Analyser (MCA) is compared to the calibration curve to identify the elements and determine their concentrations after using the internal standards for quality control. The concentrations values for the quantified elements in water taken from the study area were expressed in micrograms of metal per litre of water (μgL^{-1}) and the minimal detection limits of device for each element are presented in Table 2. In cognisance of heavy metals as carcinogen to human and ecosystem, agencies and countries in the world have come up with threshold limits beyond which mitigation measures are recommended. Thus for the sake of comparison, the Maximum Permissible Concentrations (MPC) of these elements in drinking water and aquatic ecosystem together with limits of detection are recorded in Table 2.

3. RESULTS AND DISCUSSION

The data of measured physicochemical Properties and heavy metal concentrations in water are presented in Tables 1 and 2, respectively

3.1 Physicochemical Properties of Water

From Table 1 it is clear that about 65% of the water samples (SW6D, SW5D, SW7U, SW7D, SW5U, BH4A, MRP14, MB2, SW3D, MRP16, MB1, BH5A, BH5B, SW2U, SW2U, BH2B, MBL7, MBL1, MBL4, MBL2 and HDL15) were acidic:$5.7 \leq pH \leq 6.8$ and about 35% of samples (BH30, HDL3, SW4D, SW4U, MBL8, MRP15, BH13, MRP13, SW2D, HDL9 and GWS1) were alkaline: $7.1 \leq pH \leq 7.8$. The pH range of values from 6.0 to 8.5 for pristine surface and groundwater is an indication that

Table 1: Data of mean pH, EC (mSm^{-1}) and TDS (mgL^{-1}) in the dry season (May to September) for the surface (SW, MRP) and ground (BH, MB, HDL BH GWS) water samples obtained at locations indicated by GPS coordinates (X, Y) (number =31).

Sampling Locations	**Easting** (X)	**Northing** (Y)	pH	**EC** $mScm^{-1}$	**TDS** mgL^{-1}
BH30	37L0239874	8887885	7.1	77.4	445.6
SW6D	37L0209213	8860986	6.5	2.8	18.6
SW5D	37L0209618	8861304	6.4	3.8	25.7
SW7U	37L0207694	8860501	6.6	3.5	25.4
SW7D	37l0207700	8860559	6.7	4.2	30.3
SW5U	37L0209629	8861303	6.4	3.9	23.9
BH4A	37L0230319	8882798	6.7	3.2	15.0
MRP14	37L0233182	8885255	6.4	7.3	44.6
HDL3	37L0239796	8887938	7.1	42.3	282.5
MB2	37L0234000	8801002	6.1	7.3	144.2
SW3D	37L0227913	8875007	6.8	7.8	52.7
MRP16	37L0232250	8890145	6.3	6.3	40.0
MB1	37L0234153	8889570	5.7	9.7	64.0
BH5A	37L0233126	8885087	5.7	8.2	49.0
BH5B	37L0233140	8885367	5.8	8.7	53.2
SW4D	37L0213216	8867527	7.3	8.4	51.5
SW4U	37L0223240	8867535	7.3	8.9	55.0
MRP15	37L0236080	8881586	7.0	9.0	57.8
MBL8	37L0233602	8884984	7.6	17.3	107.6
BH13	37L0235989	8881609	7.1	57.0	370.0
MRP13	37L0230489	8882699	7.2	9.7	58.3
SW2D	37L0229512	8877624	7.1	10.7	65.4
SW2U	37L0229538	8877601	6.4	24.9	166.4
BH2B	37L0232200	8890109	6.4	19.7	117.4
MBL7	37L0236143	8891776	6.1	20.0	139.5
HDL9	37L0228956	8888266	7.8	36.6	250.5
MBL4	37L0237288	8892284	6.2	39.0	260.5
GWS1	37L0228061	8889395	7.7	43.4	291.0
MBL1	37L0234153	8889570	6.8	51.1	340.0
MBL2	37L0240380	8888047	6.2	63.6	428.5
HDL15	37L0239012	8892875	5.8	80.2	534.5

the water in the study is normal. Since the MRP is located in a national part free of industrial air pollutants, it is clear that rainfall with normal pH about 5.6 will have negligible effect on the range of the physicochemical parameters recorded in Table 1. Similarly, since pH depends on free hydrogen ions concentration in water, draught will have no effect on the ranges presented in Table 1. Since the introduction of heavy metal in water forms hydroxide ions which increase pH or forms acidic water especially with sulphide minerals such as pyrite, the pH values presented in Table 1 could be used as baseline for assessment of heavy metal pollution in the study area.

As seen in Table 1, higher values of the TDS were recorded in groundwater samples (BH30, HDL3, MB2,MBL8, BH13, BH2B, MBL7, HDL9, MBL4, GWS1, MBL1, MBL2 and HDL15) than the surface water (SW6D, SW5D, SW7U, SW7D, SW5U, MRP14, SW3D, MRP16, SW4D, SW4U ,SW4U, MRP15, MRP13,SW2D and SW2U). This difference is attributed to the fact that ground water has longer residence time in rocks and therefore has sufficient time for heavy metals to dissolve than surface water. In absence of soil erosion in the vicinity of sampling points, this information could be used as baseline data for open pit uranium mining which is proposed for MRP because atmospheric deposition of heavy metals which is dominant in this type of mining would result in higher concentration of heavy metals in surface water. In the case of underground mining, groundwater pollution is expected to be dominant therefore the ratio of TDS for ground and surface water could be used as baseline data. The ratio of TDS for ground and surface water for corresponding sampling points would increase in the presence of heavy metal pollution. For the TDS values presented in Table 2 to serve as baseline data, verification of pollution due to uranium mining using this information requires measurements to be made during the dry season (May to December) when the influence of rain on TDS is marginal.

A plot of EC against TDS in Figure 2 shows a strong linear fit of the data with an R^2 of 0.9798, denoting that 98 % of the variance in

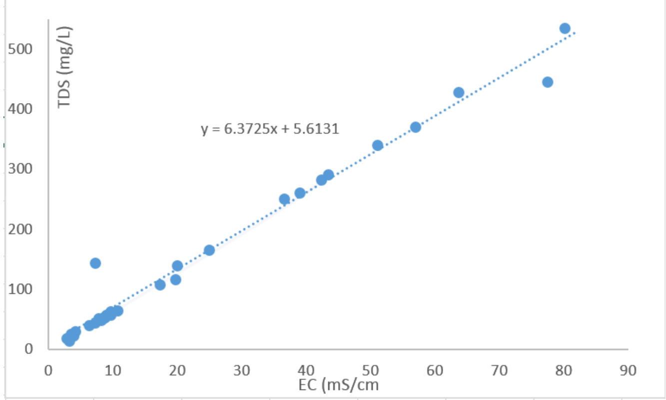

Figure 2: A plot of EC and TDS values for water samples obtained in different location in MRP.

the data set accounted for by the linear fit represented by equation 1:

$$[TDS]=6.3725 \times EC+5.6131 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where [TDS] is the predicted concentration based on the EC expressed in mS/cm. The strong correlation established for EC and TDS in Figure 1 is an indication that knowledge of one could be used to predict the other which also removes the need to measure them simultaneously.

3.2 Heavy Metal Concentrations

From Table 2, with the exception of aluminium, iron, manganese and lead with concentrations above permissible limits at some sampling points, concentrations of other metals in all sampling points are below the Maximum Permissible Concentration (MPC) set by different International organisations (EU 1998, TBS 2005, USEPA 2008, Australia 2011). This information indicates that the concentration values of heavy metals (at Mkuju area) dissolved in water do not exceed the MPC provided for by the drinking water standards, showing that the quality of water in the samples analyzed is good. These values could also be used as baseline data since measurements of concentrations of these metals in specified sampling points above MPC would constitute heavy metal pollution.

The concentrations of copper and cadmium were found below the Limits of Detection (LOD) for the instrument used in all sampling points. The concentration of chromium, nickel and arsenic were found below the LOD in some sampling points (SW6D, SW5U, MRP14, MRP16, SW4D, SW4U, HDL9, GWS1, MBL1 and MBL2), (BH30, SW6D, SW7U, SW7D, HDL9, GWS1, MBL1 and MBL2) and (BH30, SW6D, SW5D, SW7U, SW7D, SW5U, HDL9, MBL4, GWS1 and MBL2), respectively. The LOD (μgL^{-1}) for chromium, nickel and arsenic were 0.2, 0.2, and 0.4, respectively.

Table 2: Sampling Locations for Surface water (SW, MRP) and Groundwater (BH, MB, HDL BH GWS) from different locations, Limit of Detection (LOD), International (EU, WHO, USEPA, Australia) and national (TBS) Limits in drinking water and ecosystem*, and concentrations of 13 metals (µgL^{-1}) (number of samples=31).

Locations	**Al**	**Cr**	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Cd**	**Pb**	**Th**	**U**
OD	2	0.2	0.1	2	0.02	0.2	2	2	0.4	0.02	0.02	0.002	0.002
BH30	65	0.26	395	212	0.1	< 0.2	< 2	17.9	< 0,4	< 0,02	23.06	0.004	0.161
SW6D	71	< 0,2	8	321	0.15	< 0.2	< 2	8.98	< 0,4	< 0,02	0.106	0.01	0.017
SW5D	63	0.23	86	1048	0.57	0.41	< 2	14.42	< 0,4	< 0,02	0.127	0.035	0.023
SW7U	53	0.22	10	180	0.09	< 0.2	< 2	9.33	< 0,4	< 0,02	0.033	0.006	0.011
SW7D	80	0.35	15	283	0.16	< 0.2	< 2	10.02	< 0,4	< 0,02	0.159	0.011	0.024
SW5U	38	< 0,2	72	919	0.44	0.23	< 2	3.4	< 0,4	< 0,02	0.064	0.03	0.019
BH4A	110	0.24	382	7369	0.58	0.66	< 2	16.68	0.577	< 0,02	23.74	0.051	0.361
MRP14	134	< 0,2	127	2714	0.63	0.36	< 2	9.71	0.833	< 0,02	0.257	0.057	0.326
HDL3	121	0.69	65	387	0.47	0.34	< 2	29.02	0.793	< 0,02	1.139	0.017	0.554
MB2	445	1.43	37	773	0.51	0.74	< 2	24.24	0.434	< 0,02	52.1	0.023	9.431
SW3D	235	0.33	975	2272	1.99	1.29	< 2	20.75	0.455	< 0,02	0.282	0.061	0.039
MRP16	86	< 0,2	109	3197	0.53	0.21	< 2	7	0.406	< 0,02	0.081	0.049	0.124
MB1	2317	2.12	95	2820	1.55	1.89	< 2	13.24	1.34	0.022	11.7	0.179	29.76
BH5A	240	2.1	26	335	0.31	0.38	< 2	14.31	0.843	< 0,02	9.521	0.021	5.58
BH5B	176	0.36	36	843	0.9	1.14	< 2	34.96	0.473	< 0,02	12.77	0.013	1.067
SW4D	94	< 0,2	136	3009	0.51	0.44	< 2	16.12	0.5	< 0,02	0.144	0.058	0.088
SW4U	77	< 0,2	108	2737	0.37	0.37	< 2	5.45	0.46	< 0,02	0.083	0.054	0.08
MRP15	178	0.4	677	8649	3.02	1.11	< 2	< 2	2.537	< 0,02	0.459	0.205	0.827
MBL8	41	0.23	13	116	0.09	0.42	< 2	19.34	0.576	< 0,02	15.93	0.01	0.443
BH13	9049	19.96	1452	53890	27.63	8.7	14	33.41	19.17	0.095	78.68	1.725	22.27
MRP13	100	0.23	186	1378	0.87	0.43	< 2	8.79	0.79	< 0,02	0.143	0.051	0.399
SW2D	144	0.24	132	1900	0.45	0.79	< 2	10.07	0.651	< 0,02	0.139	0.059	0.049
SW2U	112	0.24	117	1656	0.41	0.8	< 2	14.39	0.552	< 0,02	0.126	0.048	0.051
BH2B	223	1.52	8	190	0.15	1.03	< 2	15.02	0.833	0.136	18.47	0.006	16.17
MBL7	79	0.22	995	1329	1.19	0.58	< 2	10.94	0.53	< 0,02	0.664	0.023	0.179
HDL9	57	< 0,2	34	467	0.15	< 0.2	< 2	9.46	< 0,4	< 0,02	3.27	0.003	0.258
MBL4	91	0.25	110	1242	0.35	0.2	< 2	8.07	< 0,4	< 0,02	0.722	0.02	0.254
GWS1	29	< 0,2	15	189	0.07	< 0.2	< 2	11.61	< 0,4	< 0,02	0.231	0.002	0.388
MBL1	25	< 0,2	1123	30520	0.27	< 0.2	< 2	8.52	1.092	< 0,02	0.334	0.019	0.053
MBL2	32	< 0,2	268	2732	0.15	< 0.2	< 2	12.79	< 0,4	< 0,02	1.392	0.017	0.301
HDL15	184	0.35	920	4992	1.4	5.17	17	62.94	3.918	0.092	1.143	0.014	1.357
USEPA 2008	N	100	50	300	100	100	1300	5000	10	5	15	N	N
EU1998	200	50	50	200	N	20	2000	N	10	5	10	N	N
WHO2008	200	50	500	300	N	20	2000	3000	10	3	10	N	1400
TBS2005	N	50	500	300	N	20	2000	5000	7	2	10	N	N
Australia	N	N	500	N	N	20	2000	N	10	2	10	N	N
2011	55*	1*	1900*	N*	N*	11*	1.4*	8*	13*	370*	3.4*	N*	N*

This study suggests also the use of elements with concentrations below LOD as sensitive indicator for pollution in the specified sampling points. Since the LOD values for these elements were very low, introduction of a similar heavy metal can cause noticeable change in the concentrations above the LOD. Thus LOD values could also serve as baseline data for verification of compliance. As seen in Table 2, the concentration of heavy metals in groundwater was higher than surface water. Since this trend was also evident in TDS values, hence, this heavy metal concentration trend can be used in a similar manner as TDS, to serve as baseline data.

3.3 Statistical Analysis

The Analysis of Variance (ANOVA) of heavy metal concentrations were carried out using a professional statistical packages, SPSS version 16 to get the mean and standard error of the mean which was then subjected to statistical tests of significance. The mean of heavy metal concentrations were fitted to normal and lognormal distributions. The p-values for both distributions are less than 0.05, indicating a null hypothesis that elements in water occurs by chance is rejected at a 95% confidence level. The mean concentration values obtained in Table 2 were used to establish correlation coefficients presented in Table 3. In order to accommodate the measured concentrations, the LOD values for copper, cadmium, nickel and arsenic were replaced by a mean value equal to one half of their LOD to avoid missing the data points (Ndengerio-Ndossi and Cram 2005, Mohammed 2008).

Table 3: Correlation coefficient of heavy metal concentrations in water samples from Mkuju River Basin.

	Al	**Cr**	**Mn**	**Fe**	**Co**	**Ni**	**Zn**	**As**	**Pb**	**Th**	**U**
Al	1.00										
Cr	0.98	1.00									
Mn	0.52	0.57	1.00								
Fe	0.83	0.96	0.74	1.00							
Co	0.97	0.98	0.60	0.86	1.00						
Ni	0.86	0.84	0.74	0.87	0.87	1.00					
Zn	0.28	0.25	0.40	0.22	0.32	0.65	1.00				
As	0.96	0.97	0.61	0.86	0.98	0.92	0.38	1.00			
Pb	0.77	0.80	0.33	0.61	0.74	0.66	0.36	0.74	1.00		
Th	0.98	0.98	0.56	0.86	1.00	0.85	0.26	0.98	0.74	1.00	
U	0.68	0.60	0.15	0.40	0.52	0.52	0.18	0.50	0.61	0.55	1.00

Since high correlation coefficient between the heavy metal concentrations means the elements have common origin (Yuanan et al. 2013, Juan et al. 2015), it is plausible to use correlation values as baseline data. Thorium, zinc, lead, copper and arsenic are commonly associated with uranium deposits (USGS and USBM 1984) therefore their correlation coefficients would be sensitive indicators that can serve as baseline data to assess movement of these metals from the uranium deposits to the study area. Such movement would significantly lower the respective values of correlation coefficients for these metals.

4 CONCLUSION

Baseline data for physicochemical parameters (pH, TDS, EC) and heavy metal concentration in water in the vicinity of the Mkuju River Uranium Project were established for verification of compliance with the acceptable water quality standards before the proposed project commences. Four indicators were identified as baseline quantities sensitive to change the water quality due to pollution related to the proposed uranium mining. Increase of heavy metal in water forms hydroxide ions therefore pH values at convenient sampling points could be used as baseline for assessment of heavy metal pollution related to uranium mining in any season. Since the proposed uranium mining project will be open pit, increase of TDS ratio for surface water to ground water values would be sufficiently sensitive indicator to determine pollution of water due to uranium mining. Since TDS values is influence by rain, the ratio should be determined during the dry season which is between May and December for the study area. The heavy metal concentration below detection limits is an additional index that could be used as baseline data. In this case, increase of concentrations of copper and cadmium would be indicators of pollution for all sampling points while concentrations of chromium, nickel and arsenic would be indicators of pollution in some sampling points. Concentrations levels of all elements analysed except aluminium, iron, manganese and lead could serve as indicator for pollution. The values of correlation coefficients of heavy metals established in this study can serve as an indicator of water pollution by heavy metal associated with uranium mining.

5 ACKNOWLEDGEMENT

The authors gratefully acknowledge the property owners of MRP, the Uranium One, for the permission to take samples in the area and the logistical support from Mr Beria, site Manager and John Ntukula Environmental Manager for supplying valuable background information and transport to sampling points. The authors would also like to thank Prof Dr Broder Merkel and Mandy Hoyer of the TU Freiberg Germany for coordinating sample analysis in ICP-MS Laboratory and technical advice. Thanks also go to COSTECH for financial support and the TAEC for granting a study leave.

6 CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest

7 AUTHOR'S CONTRIBUTIONS

All authors read and approved the final manuscript

8 REFERENCES

Akabzaa T 2004 Mining legislation and net returns from mining in Ghana in Campbell (ed) Regulating mining in Africa: For whose benefit? (Nordiska Afrikainstitutet, Discussion Paper 26, Uppsala) 25-29.

APHA (American Public Health Association) 1992 Standard methods for the examination of waste and wastewater, 18th Edition. Washington DC 72-265.

Ato AF, Oscar YD, Akoto B, Samuel O, Moi PAN 2010 Mining and heavy metal pollution: assessment of aquatic environments in Tarkwa (Ghana) using multivariate statistical analysis J. *Environ. Statistics* **1** (4):1-13 http://www.jenstat.org

Australia 2011 Australian drinking water guidelines version 3.1. https://www.nhmrc.gov.au/_files_nhmrc /publications/attachments/eh52_australian _drinking_water_guidelines_150527.pdf

Ayotte JD Gronberg, JM and Apodaca LE 2011.Trace Elements and radon in groundwater across the United States: [US geological survey scientific investigations report 2011-5059] 115

Banzi FP, Msaki PK and Mohammad NK 2015 Distribution of heavy metals in soils in the vicinity of the proposed Mkuju uranium mine in Tanzania. *J. Environ. and Poll.* **4**(3) 42-50.

Bartram and Balance 1996 Water quality monitoring a practical guide to the design and implementation of freshwater quality studies and monitoring programmes (eds) Jamie Bartram and Richard Balance Published on behalf of United Nations Environment Programme and the World Health Organization © 1996 UNEP/WHO

Bitala MF, Kweyunga and CM, Mkabwa LK 2009 Levels of heavy metals and cyanide in soil, sediment and water from the vicinity of North Mara gold mine in Tarime district, Tanzania. A report presented to CCT http://www.pambazuka.net /images/articles/ 450/ERROR% 20FREE% 20NORTH%20MARA%20REPORT%20-%20FINAL.pdf

EU (European Union) 1998 Drinking water standards. Council Directive 98/83/EC on the quality of water intended for human consumption. Adopted by the Council, on 3 November http: //w ww.lenntech.com/applications/drinking/standards/eu-s-drinking-water-standards. Htm # ix zz3ckvlxdFA

Goddard CC 2002 Measurement of outdoor terrestrial gamma radiation in the sultanate of Oman. *HPS*. 82: 869–74

Humood AN 2013 Assessment and management of heavy metal pollution in the marine environment of the Arabian Gulf: A review *Marine Poll. Bull.* **72**(1) 6-13.

IAEA (International Atomic Energy Agency) 1998 Guidebook on good practice in the management of uranium mining and mill operations and the preparation for their closure IAEA-TECDOC-1059, VIENNA.

IAEA 2005 Guidebook on environmental impact assessment for in-situ leach mining projects IAEA-TECDOC-1428

IAEA 2009 Nuclear energy series establishment of uranium mining and processing operations in the context of sustainable development technical reports No. NF-T-1.1

IAEA 2010 Best practice in environmental management of uranium mining IAEA Nuclear Energy Series No. NF-T-1.2.

ICP-MS 1987 Inductively coupled mass spectrometry for analysis of metals on membrane filters *Am Indust Hygiene Assoc J.* **48**: 977-979.

Juan R, Zhen S, Ling T, Xia W 2015 Mulivariance analysis and heavy metals pollution elevation in Yellow river surface sediments. *Pol. J. Environ Stu.* **24**(3):1041-1048

Kenya 2014 The mining bill of Kenya 2014

LHRC (Legal and Human Rights Centre) 2011 Fact finding mission report May, 2011. Killings around North Mara gold mine: the human cost of gold in Tanzania. The shootings of the five. http://www.olengurumwamanofthepeople.com/wp-content/uploads/2012/07/killings-around-north-mara-mine-final.pdf

LTC (Legal and Technical Commission) 2013 International Seabed Authority ISBA/19/LTC/8 Nineteenth session Kingston, Jamaica 15-26 July (2013) https://www.isa.org.jm /sites/ default/ files/ files/documents/isba-19ltc-8_0.pdf

MEM (Ministry of Energy and Minerals (MEM) 2010 Tanzania, mining (Radioactive Minerals) Regulations of 2010

Meybeck M, Friedrich G Thomas R and Chapman D 1996 Water Quality assessments - a guide to use of biota, sediments and water in environmental monitoring - Second Edition Ed. Deborah Chapman © 1992, UNESCO/WHO/UNEP ISBN 0 419 21590 5 (HB) 0 419 21600 6 (PB) Chapter 6* - Rivers. http://www.who.int/water_sanitation_health/resourcesquality/wqachapter6.pdf

Mohammed NK. and Mazunga MS. 2013 Natural Radioactivity in Soil and Water from Likuyu Village in the Neighborhood of Mkuju Uranium Deposit International Journal of Analytical Chemistry Volume 2013, Article ID 501856, 4 pages http://dx.doi.org/10.1155/2013/501856

Mohammed NK 2008 *Nuclear techniques applied to biological samples from Tanzania to monitor the nutritional status of children*. PhD Thesis, Faculty of Engineering and Physical Sciences University of Surrey UK

MW (Ministry of Water) 2012 Tanzania guidelines for water resources monitoring and pollution control. Ministry of water the United Republic of Tanzania.

Nagajyoti PC. Lee KD. Sreekanth TV 2010 Heavy metals, occurrence and toxicity for plants: a review *Environ Chem Lett 8:199*–216. http://link.springer.com/article/10.1007%2Fs10311-010-0297-8#page-1

Naveedullah, Muhammad Z, Hashmi, Chunna Yu, Hui S, Dechao D, Chaofeng S, Liping L, Yingxu C 2014 Concentrations and human health risk assessment of selected heavy metals in surface water of the siling reservoir watershed in Zhejiang province, China. *Pol. J. Environ, Stud*. **23 (**3): 801-811

Ndengerio-Ndossi J and Cram G 2005 Pesticide residues in tableready foods in Tanzania. *Intern J. of Environ Health Res,* **15:** 143–149

Nriagu JO and Pacyna JM 1988 Quantitative assessment of worldwide contamination of air, water and soil by trace metals. *Nature* **333:**134- 139.

Nriagu JO 1989 A global assessment of natural sources of atmospheric trace metals. *Nature*. **338:**47–49.

Peplow D 1999 Environmental impacts of mining in eastern Washington. Centre for water and watershed studies fact sheet, University of Washington. Seattle.

SA (South Africa) 1996 Mine health and safety Act 29 of 1996 - Regulations and Notices - Government Notice R 992 (1996).

Skoog DA, Holler FJ and Crouch SR 2007 Principles of instrumental analysis 6th Edition Thomson higher education

TAEC (The Atomic Emery Commission) 2011 The Atomic Energy (Radiation Safety in the Mining and Processing of Radioactive Ores) Regulations of 2011.

TBS (Tanzania Bureau of Standards) 2005 Drinking (potable) water: specification (TZS 789:2005). National environmental standards compendium, Tanzania Bureau of Standards. 26-27.

USGS and USBM (US. Geological Survey and US. Bureau of Mine).Wilderness Mineral Potential Assessment of Mineral Resource Potential in US. 1984 forest service lands studied 1964-84. Geological professional paper 1300 (eds) Marsh SP. Kropschot & SJ Dickinson RG Library of Congress Catalog Number 83-600569 US. Government Printing Office, Washington.

WHO (World Health Organization) 2008 Guidelines for drinking water quality 3rd Ed. Incorporating the first and second agenda volume recommendations. WHO, Geneva,

Wright DA and Pamela W 2002 Environmental toxicology. Cambridge University Press, Cambridge, U.K.

Yeskis D and Zavala B 2002 Ground-water sampling guidelines for superfund and RCRA Project Managers http://www.epa.gov/tio/tsp/downloads/gw_sampling_guide.pdf

Yuanan H, Xueping L, Jinmei B, Kaimin S, Eddy Y, Zeng and Hefa C 2013 Assessing heavy metal pollution in the surface soils of a region that had undergone three decades of intense industrialization and urbanization *Environ Sci Pollut Res* **20**:6150–6159.