Radiological effect of mine dumps on surrounding water resources

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Abstract A study was performed to identify the radionuclides in the tailings from the Princess Mine dump in Roodepoort, South Africa and to determine their corresponding concentrations. Radiation levels were monitored on site using the Electra, Radiagem and Teletector equipment. The samples were collected at different heights above sea level and different positions of the mine dump. The collected soil, leaves and seeds samples were analysed with EDXRF and HPGe detector to identify the trace, toxic, radiotoxic and radionuclides as well as their activity. The presence of the similar radionuclides was detected in water in the area around the mine dump.

Keywords toxic, radionuclide and specific activity

Introduction

South Africa is rich in mineral resources (Wendel 1998). The history of minerals extraction dates back to the discovery of diamonds at Kimberley in 1871 and the discovery of gold-bearing conglomerate on Langlaagte Farm near Johannesburg in 1886 (South Africa – Mining History). In the process of sorting out extracted minerals like Gold, Uranium is recovered as a by-product and also as the main product in Uranium mines. Uranium is naturally occurring element that emits radiation with a half life of 4.5×10^9 years. It undergoes radioactive decay into a long series of 13 different radionuclides before finally reaching a stable state in ^{206}Pb (Canada Nuclear Association). These radionuclides emit alpha or beta radiation and some also emit gamma radiation of widely varying energies. The mineral by-products and unwanted minerals are stored in the tailings storage facilities (TSF) during the period of the operation of the mine until rehabilitation or reclamation of the TSF (Hossner and Hons 1992). Unfortunately the mining industry, in South Africa left behind huge number of unrehabilitated mines and TSF (Audit Report 2009). The TSF are rich in Uranium as a common element in nature and other radioactive elements. Human beings in search of accommodation in the cities have build houses in close proximity to the TSF (Winde 2002; Winde and Walt 2004) and therefore use water from the streams, dams and boreholes dug in close proximity to the mine dumps. This study presents the specific activity levels in and around the mine dumps to the water system.

Materials and Methods

Thirty soil, water, leaves and seeds samples were collected from Princess mine dump, Roodepoort in South Africa shown in Fig. 1. The GPS sample positions are listed in table 1. Six samples were collected from the top 15 cm layer of the tailings (A, C, D, H, K and L1). Six different depth tailings samples were collected and (L1, L2, L3, L4, L5 and L6). Water, seeds and leaves samples were collected (E, F, H).

Soil and leaf samples were placed in the 1 kg plastic bags for the further processing in the laboratory. Water samples were collected in the sealable bottles. During the sample collection process radiation levels were constantly monitored with the Electra, Radiagem, Inspector 2000 and Teletector, and only the background radiation could be detected.

Sample preparations

The collected tailings samples were fine soil

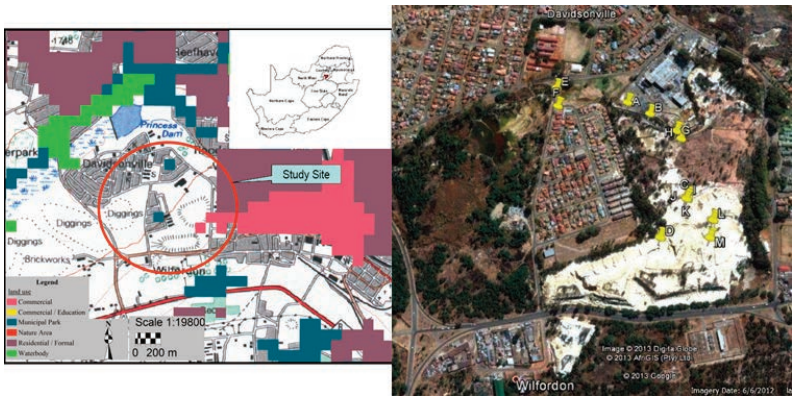

Fig. 1 *Location of the Princess mine dump, in Roodepoort, South Africa. (Ngigi 2009).*

Sample	latitude	longitude	elevation
A	-26.15783	27.853915	1697
B	-26.15814	27.854521	1700
C	-26.16037	27.855434	1710
D	-26.16129	27.854728	1716
E	-26.15738	27.851937	1692
F	-26.15788	27.851987	1692
G	-26.15862	27.855237	1706
H	-26.15883	27.85535	1706
I	-26.16031	27.855468	1711
J	-26.16033	27.855419	1711
K	-26.16037	27.85546	1713
L	-26.1609	27.856088	1724
M	-26.16132	27.855983	1732

Table 1 *GPS sample positions on the Princess mine dump, in Roodepoort South Africa.*

and there was no need for them to be ground. The powdered samples were packed in glass vial and sealing cap, with a diameter and height of 22mm and 50mm, respectively. Each container accommodated the sample with an average mass of 16 g and the samples were given enough time, 24 days, to allow radium daughters to come into circular equilibrium.

The portable gamma spectrometer based on high-purity germanium coaxial detector GCD-35190 Spectrometric device MCA 527 with basic spectroscopy software WinSPEC was used to acquire the data. The detector and sample were placed inside the Lead shield during data acquisition process. The same samples were divided for analaysis with the Energy dispersive XRF.

Results and discussion

Results from the HPGe detector are shown in Table 2 to Table 5. From Table 2, samples L1 of ^{214}Pb, K of ^{232}Th, L1 of ^{214}Bi, C of ^{228}Ac and L1 of ^{226}Ra show the highest concentrations in composite tailings of 767.8±16.0 Bq.kg^{-1}, 13±0.3 Bq.kg^{-1}, 356.1±13.0 Bq.kg^{-1}, 44.6±2.9 Bq.kg^{-1} and 403.9±4.4 Bq.kg^{-1}, respectively. The samples D of ^{214}Pb, D of ^{232}Th, D of ^{214}Bi, D of ^{228}Ac and D of ^{226}Ra show the lowest concentrations in composite tailings of 94.6±25.1 Bq.kg^{-1}, 0.4±0.1 Bq.kg^{-1}, 58.4±17.2 Bq.kg^{-1}, 1.3±0.3 Bq.kg^{-1} and 43.7±5.7 Bq.kg^{-1}, respectively. Sample A shows that ^{223}Ra dissolved in the water from the dump whereas samples L1 to L6 indicate that ^{226}Ra is not detected (ND) as the depth increases. ^{226}Ra shows highest specific activity at

Sample Positions	^{214}Pb (Bq/kg)	^{232}Th (Bq/kg)	^{214}Bi (Bq/kg)	^{228}Ac (Bq/kg)	^{223}Ra (Bq/kg)	^{226}Ra (Bq/kg)
A	ND	ND	ND	ND	78.89±31.19	ND
C	282.3±14.9	ND	347.8±20.8	44.6±2.9	ND	58.0±2.2
D	94.6±25.1	0.4±0.1	58.4±17.2	1.3±0.3	ND	43.7±5.7
H	478.0±4.1	ND	161.6±1.6	ND	ND	ND
K	767.8±16.0	13.1±0.3	300.6±3.3	ND	ND	403.9±4.4
L1	490.9±6.8	ND	356.1±13.0	ND	ND	284.3±1.6

Table 2 *Specific activity of ^{214}Pb, ^{232}Th, ^{214}Bi, ^{228}Ac ^{223}Ra and ^{226}Ra from A, C, D, H, K and L1 of tailings sample from Princess Mine dump.*

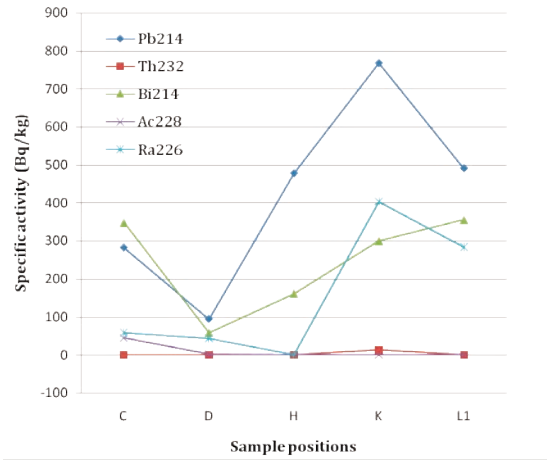

Fig. 2 *Graph of Concentrations of Radionuclides ^{214}Pb, ^{232}Th, ^{214}Bi, ^{228}Ac and ^{226}Ra from the top 15 cm layer at points C, D, H, K and L1 of the Princess Mine dump.*

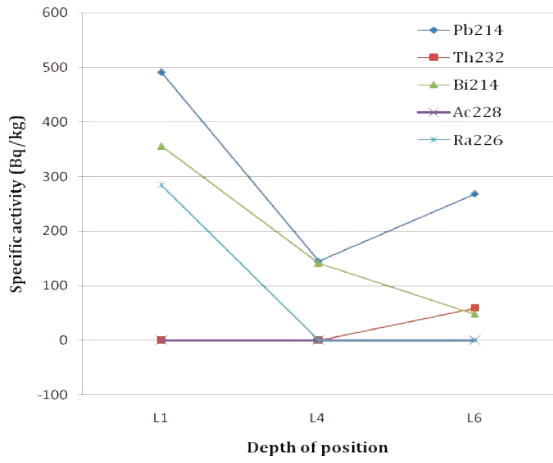

Fig. 3 *Concentrations of Radionuclides ^{214}Pb, ^{232}Th, ^{214}Bi, ^{228}Ac and ^{226}Ra as a function of depth of position L of the Princess Mine dump.*

the depth of L1=15cm. ^{214}Pb and ^{214}Bi are detectable everywhere on the dump except in water (sample A).

From Table 4, Leaves of ^{228}Th, Leaves of ^{7}Be, Blue gum seeds of ^{140}Ba and Blue gum seeds of ^{228}Ac show the concentrations of 143±58 Bq.kg^{-1}, 247±128 Bq.kg^{-1}, 169±77 Bq.kg^{-1} and 105±56 Bq.kg^{-1}, respectively. These results from the leaves on the dump show concentrations of Thorium which indicate that there should be a production of certain amount of ^{220}Rn and ^{222}Rn in the area.

From Table 5, samples K of ^{144}Pr and H of ^{7}Be show the concentrations of 1610±868 Bq.kg^{-1} and 19±5 Bq.kg^{-1}, respectively.

The Table 6 shows the spread of metals at different depth as measured by the Energy dispersive XRF detector. Only a few metals were detected at single level.

From Table 6 the concentrations of toxic elements; Sr, Fe, Si and Cr are relatively constant with depth through the tailing. This might mean that these elements do not leach easily through the sandy mine dump. However Pb concentration increased with depth suggesting relative ease of leaching to the environment due to dissolved nitrates and sul-

Sample depth	^{214}Pb(Bq/kg)	^{232}Th(Bq/kg)	^{214}Bi(Bq/kg)	^{228}Ac(Bq/kg)	^{226}Ra(Bq/kg)
L1	490.9±6.8	ND	356.1±13.0	ND	284.3±1.6
L4	144.5±25.3	ND	141.1±1.5	ND	ND
L6	268.4±4.4	58.9±0.3	47.8±0.4	ND	ND

Table 3 *Specific activity of ^{214}Pb, ^{232}Th, ^{214}Bi, ^{228}Ac and ^{226}Ra from the depth L1, L4 and L6 .*

Sample	^{228}Th(Bq/kg)	^{7}Be(Bq/kg)	^{140}Ba(Bq/kg)	^{228}Ac(Bq/kg)	^{207}Bi(Bq/kg)
G seeds	ND	ND	169±77	105±56	
Leaves	143±58	247±128	ND	ND	
K	ND	ND	ND	ND	
M6	62±27	ND	ND	ND	
W1					39±16

Table 4 *Concentrations of Radionuclides ^{228}Th, ^{7}Be, ^{140}Ba, ^{207}Bi and ^{228}Ac from Princess Mine dump.*

Sample	^{144}Pr(Bq/kg)	^{208}Tl(Bq/kg)	^{7}Be(Bq/kg)	^{228}Ac(Bq/kg)	^{228}Ac(Bq/kg)
Seeds	ND		ND	Double escape	Single escape
H	ND	11±5	19±5	ND	ND
K	1610±868		ND	ND	ND

Table 5 *Concentrations of ^{144}Pr, ^{208}Tl, ^{7}Be and ^{228}Ac from Princess Mine dump.*

	0cm	30cm	60cm	90cm	120cm
Si	87.59	93.59	93.72	94.61	91.21
Fe	8.67	4.68	5.56	4.78	5.49
K	2.63	1.13			2.44
Ti	0.57	0.46	0.41	0.37	0.55
Zr				0.04	
Cr	0.1	0.07	0.07	0.04	0.08
V		0.02			0.02
Sr		0.02	0.02	0.01	0.02
Cu		0.02			
Rb	0.02		0.01		
Pb	0.1		0.06		0.09
As	0.09				
Tm	0.17		0.13	0.12	0.1
V	0.03		0.02	0.02	
Ac				0.02	

Table 6 *The percentage concentration of elements in Sample L at different depth.*

	Leaves	Seeds
Si		
Fe	1.51	2.53
K	24.48	50.71
S	8.84	
Ca	41.77	30.89
Mn	22.64	13.66
Cu		2.19
Ni	0.75	

Table 7 *Concentration of elements in the Leaves and Seeds samples*

phates from mining activities.

The Table 7 and 8 show that some metals were absorbed by the trees and dissolved into the water from the mine dump.

The seeds and leaves contained very small concentrations of the essential elements: Si, Fe, Cu, S, Ca, Mn, Ni and K.

The Table 8 shows that some metals have dissolved into the water from the mine dump. Columns A, E and F show the percentage concentrations of elements in water draining from the mine dump compared to the percentage concentrations of the same elements from the soil sample of the mine dump (columns C and D). In the samples Fe and S dominate in the percentage concentration. These two elements could be a result of mining processing that included use of sulphuric acid and wear and tear of the machinery.

Conclusions

The specific activity concentrations of the radionuclides have to be monitored against the general limits of all nuclides to avoid environmental exposure (Muazu 2004).

The samples L1 of ^{214}Pb, K of ^{232}Th, L1 of ^{214}Bi, C of ^{228}Ac and L1 of ^{226}Ra show the highest concentrations in composite tailings of 767.8±16.0 Bq.kg^{-1}, 13±0.3 Bq.kg^{-1}, 356.1±13.0 Bq.kg^{-1}, 44.6±2.9 Bq.kg^{-1} and 403.9±4.4 Bq.kg^{-1}, respectively. The samples D of ^{214}Pb, D of ^{232}Th, D of ^{214}Bi, D of ^{228}Ac and D of ^{226}Ra show the lowest concentrations in composite tailings of 94.6±25.1 Bq.kg^{-1}, 0.4±0.1 Bq.kg^{-1}, 58.4±17.2 Bq.kg^{-1}, 1.3±0.3 Bq.kg^{-1} and 43.7±5.7 Bq.kg^{-1}, respectively. The ^{228}Th, ^{7}Be, ^{140}Ba and ^{228}Ac show the concentrations of 143±58 Bq.kg^{-1}, 247±128 Bq.kg^{-1}, 169±77 Bq.kg^{-1} and 105±56 Bq.kg^{-1}, respectively.

The concentration of ^{228}Th was detected in leaves and concentration ^{223}Ra was also detected in water from the mine dump. The ^{228}Th and ^{223}Ra as well as the metals in the leaves, seeds and the water presents the possibility of the pathway of the radionuclide and metals to the environment and the water system. Our investigations shows that toxic elements like Sr, Fe, Si and Cr are relatively constant with depth through the tailing but Pb concentration are less at the top surface probably due to ease of leaching from the tailing. The highest concentration of ^{226}Ra, 403.9±4.4 Bq.kg^{-1}, was found

	A water	C	D	E water	F Water
Si		96.3	49.03		
Fe	55.8	1.55	32.99	50.21	69.61
K		0.71	0.92		
S	44.23	0.67	14.26	38.64	
Ti		0.45			
Sm		0.07			
Zr		0.05	0.02		
Ta		0.04			
Cr		0.04			
W		0.02			
Ca		0.02	1.57	11.15	16.34
V		0.02			
Ge		0.02			
Mn		0.01	0.06		
Zn		0.01	0.05		
Sr		0.01	0.02		
Cu		0.01	0.05		14.05
Fr		0.01			
Ni		0.004	0.03		
Th		0.004			
Rb		0.004			
Pb		0.003			
Y		0.003	0.003		
Nb		0.002	0.002		
P			0.44		
As			0.38		
Tm			0.18		
V			0.03		
Se			0.002		

Table 8 *Concentration of elements in the water samples around the mine dump*

in sample K. This value is below the reference level of 800 Bq.kg^{-1} for normal operations of the mine for which regulation is not required (Mobbs 2007).

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