Assessment of the Influence of Coal Mining on Groundwater Quality: Case of Masisi Village in the Limpopo Province of South Africa

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Abstract

Coal mining in different coalfields in South Africa is known for decades (≈146 years) and its economic importance to the country has recently surpassed commodities such as gold. One of the Coalfield that is well known for coal production in the Limpopo province of South Africa is Pafuri Coalfield where Tshikondeni Colliery operated for 32 years before closure in 2014. In general, coal extraction has several environmental problems which include acid mine drainage that is now a serious problem currently confronting the government of South Africa. This therefore creates a need to proactively prevent or minimize potential groundwater impacts through long term monitoring of water quality meant for both domestic and commercial use. Assessment of borehole water quality at Masisi Village was vital due to its close proximity to Tshikondeni Coal mine.

Groundwater samples were collected from 22 active boreholes at Masisi Village and were analysed for a range of chemical constituents such as electrical conductivity, pH, total dissolved solids, turbidity, PO_4^{2-}, SO_4^{2-}, NO_3^{2-}, Mg, Zn, Cu, Cd, Cl^-, Cr, F^-,Fe, Mn, Ni, Se, Na, Mo, Ca, Pb, Sb, Ba, Al, Co, V, K, Al and As. Anions were analysed using the Ion Chromatography whilst, cations were determined using the Inductive Coupled Plasma Mass Spectroscopy technique. The physico-chemical parameters were compared with the Department of Water Affairs and Forestry (DWAF) and World Health Organization (WHO) standards for drinking water and public health. This was done in order to establish the quality of the groundwater resources in the study area.

Most parameters complied with the DWAF and WHO guideline values for drinking-water. However, TDS, EC, Cl^- , NO_3^{2-}, Mn, As, Cd, Cr, Pb, Mo, K, V, Sb, Ba and Mg exceeded WHO and DWAF permissible concentration with Pollution index >1 in all the boreholes. This gave an indication that groundwater resources at Masisi could be significantly contaminated. According to DWAF (1996) and Peplow and Admunds (2004). Long term exposure to polluted water can cause neurological disorders, cancer, renal damage and respiratory problems resulting in high mobirdity and mortality rates from water borne disease that lead to epidemics.

The study concluded that all boreholes at Masisi were contaminated and hence not suitable for human consumption. The outcome of this study may be used as baseline data for groundwater quality control for both domestic and commercial use by municipal authorities. A study of acid producing potentials of discard dumps at the mine was suggested in order to ascertain the source of the contaminants. Continuous monitoring of ground water quality within 10 km radius of Tshikondeni mine and making primary and secondary treatment mandatory before using it was also advised.

Key words: Coal mining, Groundwater quality, Pollution index, Permissible concentration

1. Introduction

Groundwater is an important commodity as an alternative source of water when surface water dries out. It can be used for various purposes such as agricultural, industrial, and domestic purposes. It is naturally replenished by surface water precipitation, streams and rivers when recharge reaches the water table (Todd, 1980). However, human activities such as mining impact on groundwater in terms of quality degradation and quantity depletion (Kuma, 2001; Dermietze and Christoph, 2001). Groundwater quality is intrinsically linked to the chemical properties of the aquifer's geology through which it flows (Aston, 2000). The oxidation of iron sulphides present within the discard dumps and stockpiles from coal mining may further influence the hydrochemistry, by generating acid mine drainage (MacDonald and Vermeulen, 2014). Acid mine drainage (AMD) and the release of toxic elements and transition metals, are possible due to mining operations (Ashton, *et al*., 2001; Ravengai *et al*., 2004). Acid and alkaline mine drainage alter pH and EC conditions hence the mobility of toxic elements and transition metals in the environment (Meck *et al*, 2006).

In South Africa, most rural communities in areas such Limpopo, Northern Cape and Northwest Provinces are currently experiencing water shortages. Though mining is not a major consumer of water in the Limpopo province, mining operations are widespread in the basin. One such mine is Tshikondeni Coal mine which operated for 32 years prior to its closure in 2014. The mine which was the main source of economic activity in the area prior its closure is located in the vicinity of villages such as Masisi, Tshikuya and Tshamavhudzi. It is also adjacent to the Kruger National Park. The geology of the area is typified by a succession of mudstone, sandstone, siltstone, and shale horizons of the Karoo sediment. The Karoo formations are overlain by a recent calcrete deposit with an interbedded alluvial boulder bed. The coal-bearing succession, consisting of the Madzaringwe and Mikambeni Formations of the Ecca Group, is approximately 250 m thick, with a basal zone, 25 to 34 m thick, consisting of shale and interbedded coal.

Salinisation in the water resources of the Limpopo are also attributed to mining activities (Chenje and Johnson, 1996; Warnick, 2003; Zilberman, 1999). In coal mines the pyrite in the coal is roughly three times as high as in the surrounding rock and this results in the generation of sulphate, heavy metals and acidity, and can have numerous environmental consequences (Usher *et al*, 2003). The assessment of water quality is of high importance because human health requires water that is both safe to drink and palatable (DWAF, 2006). Safe drinking water, as defined by the WHO (2003), is water which does not represent any significant risk to health over a lifetime of consumption. Drinking water must especially be low in metals, fluorides, nitrates and nitrites (WHO, 2004). In order to understand the impact of Coal mining on groundwater resource for communities in the vicinity of the mine, a study was proposed to assess the ground water quality at Masisi village in the vicinity of Tshikondeni Coal mine.

2. Site description, sampling, and methods

Masisi is the most populous village in the Mutale Municipality and is located about 8 km northwest of Tshikondeni mine in Limpopo province (Fig.1). The rapid expansion of this village has exacerbated demand for groundwater resource for domestic and agricultural needs. This water is accessed through numerous boreholes sunk by local authorities. The area has a semi-arid climate with 30-90 mm of precipitation annually between October and April. High precipitation is in February whilst July is the driest Month (S.A weather and climate, 2013). Mopani trees dominate in the area and it is also characterized by spaced thick grass cover such as Afromontane grassland. Its topography forms part of the Soutpansberg Mountain range, with a series of plateaus and low mountain lands.

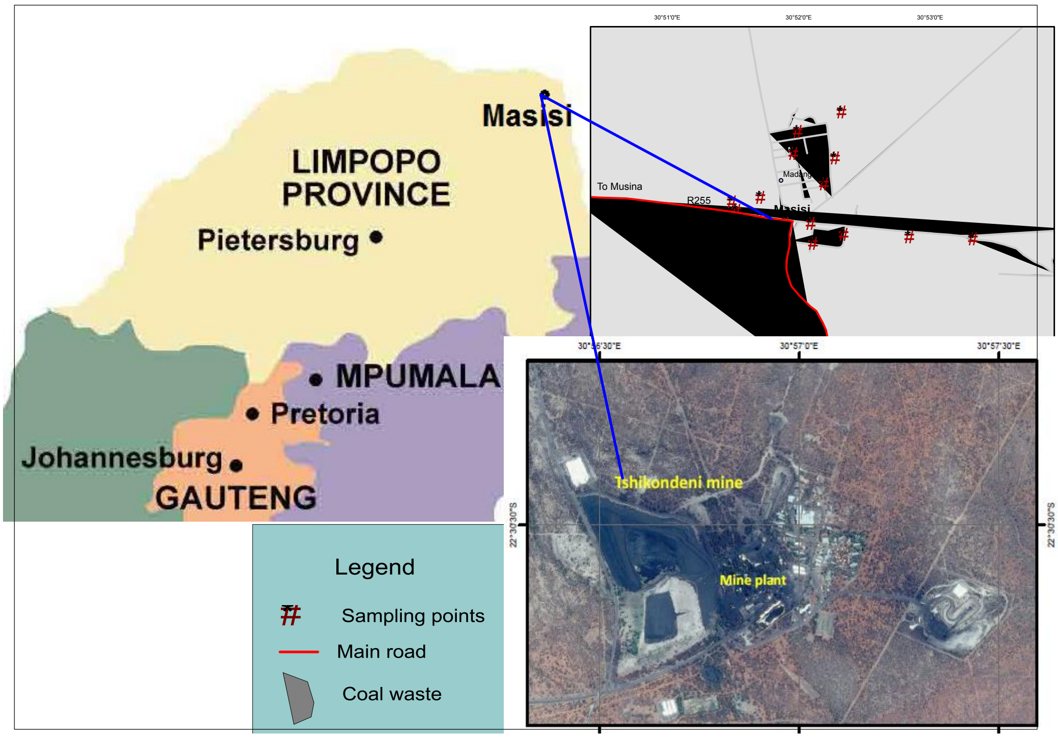

Figure 1 *Location map of the study area.*

Sampling was carried out during summer in 2014 and at least 22 samples were collected from communal boreholes around Masisi village for laboratory analysis. During sample collection, polypropylene bottles which were acid-washed, deionized water-rinsed were used to store the samples. All sample bottles were stored in a refrigerator at the University of Venda in an upright position to prevent water entering into or leaking from the container. Samples were subsequently pre-treated by filtering and preserved by adding 1% HNO_3 (Nitric cid). Consequently, major and minor cations (Mg, Zn, Cu, Cd, Cr, Fe, Mn, Ni, Se, Na, Mo, Ca, Pb, Sb, Ba, Al, Co, V, K, Al and As) were analyzed by Inductively Coupled Plasma-Mass Spectrophotometry (ICP-MS). Anions (NO_3^{2-}, Cl^- and F^-) were determined by Ion Chromatography (IC). Physical parameters such as electrical conductivity (EC), pH, total dissolved solids (TDS) were determined using Thermo Scientific Orion Star A215 pH/ Conductivity Bench top Meter after calibration with standards and buffers.

All the reagents used for analysis were AR grade and de-ionized water used for preparation of solutions. In order to ensure that the analytical results are accurate and precise, quality control measures were incorporated during sample analysis such as blank or spiked samples, and equipment decontamination. There was no detectable major and trace elements in the distilled water which served as the control. After sample analysis, the analytical data was evaluated and compared with the water quality guidelines of World Health Organization (WHO, 2003) as well as Department of Water Affairs and Forestry of South Africa (DWAF, 1996).

3. Results and Discussions

Physical parameters and major and trace elements for the 22 borehole water sample results are presented in Table 1. In general the concentration of cations increased in the orders Na>Mg>Ca>K>Al>As>Cr>Ba>V>Pb>Mn>Cu>Fe>Se>Sb and anions NO_3^{2-}>Cl^->F^-. The pH levels, Turbidity, F^-, Cu, Mn, Ca, Cr, Fe, Na, Zn, K, Mg and Sb were below the WHO (2003) and DWAF (1996) threshold concentration in all the boreholes. However, TDS ranged from 592-1506 ppm and exceeded WHO and DWAF threshold concentrations of 500 and 450 ppm respectively. Even though no direct health effects are known for TDS, certain components of TDS, such as chlorides, sulphates, magnesium, calcium, and carbonates, result in excessive scaling in household appliances and consequently the service life of these appliances (McQuillan and Spenst, 1976). Normally at a high TDS concentration, water becomes saline and water with a TDS above 500 ppm is not recommended for use as drinking water (USEPA, 2005). Since TDS can be regarded as a crude indicator of water quality for many purposes, it is related to the sum of all ionized solutes or total dissolved solid (TDS) content.

The conductivity of the groundwater ranged from 1082 - 2555 µS cm^{-1}. For groundwater, EC values greater than 500 µS cm^{-1} indicate that the water may be polluted, although values as high as 2000 µS cm^{-1} may be acceptable for irrigation water. Concentration of chloride was within WHO and DWAF permissible limit with only 5 boreholes indicating concentration > 250 ppm and these ranged from 267-439 ppm. Nitrate concentration exceeded the permissible limit by two folds with a range of 22-750 ppm.

Table 1 *Summary statistics for borehole geochemical data for Masisi village.*

Parameter	Unit	Max.	Min.	Mean	STD Dev.	Threshold (WHO, 2003)	Threshold (DWAF, 1996)
pH	-	7.99	7.05	7.58	0.26	6.5-8.5	6-9
TDS	ppm	1506	592	707	212.46	500	450
EC	µS/cm	2555	1082	1285	366.26	500-800	700
Turbidity	NTU	0.73	0.00	0.07	0.25	1	1
Cl^-	ppm	439	90	205	83.53	250	200
NO_3^{2-}	ppm	750	22	102	182.74	50	50
F^-	ppm	0.94	0.31	0.4	0.40	1.5	4
Cu	ppm	0.1	0.02	0.07	0.05	1	1
Mn	ppm	0.12	0.09	0.1	0.01	0.04	0.15
Ca	ppm	38.9	0.93	11	6.97	200	80
Cd	ppm	0.06	0.02	0.03	0.01	0.01	0.02
Cr	ppm	0.99	0.04	0.38	0.53	250	5
Fe	ppm	0.1	<0.01	0.09	0.01	0.3	0.3
Pb	ppm	0.15	0.09	0.12	0.02	0.1	0.05
Al	ppm	4.8	0.09	0.71	1.04	0.2	0.5
Na	ppm	160	66	111	28.05	200	200
Zn	ppm	0.17	0.02	0.08	0.05	5	10
K	ppm	5.9	3.5	5.18	0.70	10	50
Mg	ppm	133	74	84.95	12.43	150	400
As	ppb	1553	0.83	76.5	329.84	50	200
Se	ppb	16	1.16	6.55	4.60	10	50
V	ppb	243	18.9	44.6	49.31	200	200
Sb	ppb	0.23	0.02	0.05	0.05	5	-
Ba	ppb	406	7.6	256	129.66	50	-

Parameters that indicated elevated concentration were plotted on a box whisker plot to evaluate the geochemical data for the groundwater samples. Box plots are another convenient way of examining the distribution of a data set and for identifying variations caused by natural and human factors. Box plots of EC, Cl-, NO_3^{2-}, TDS, As, V and Ba content showed a significant difference between the median and maximum values with the median and mean values being near the lower quartile (Fig. 2). This suggested local contamination of the groundwater system with respect to these parameters. The wide range of EC (1082-2555 ppm), NO_3^{2-} (22-750 ppm), TDS (592-1506 ppm) and As (1-1553 ppm) may be a result of the lateral geological variations in the subsurface formation. The increase concentration of these parameters may also be attributed to different mechanisms such as water rock interaction processes.

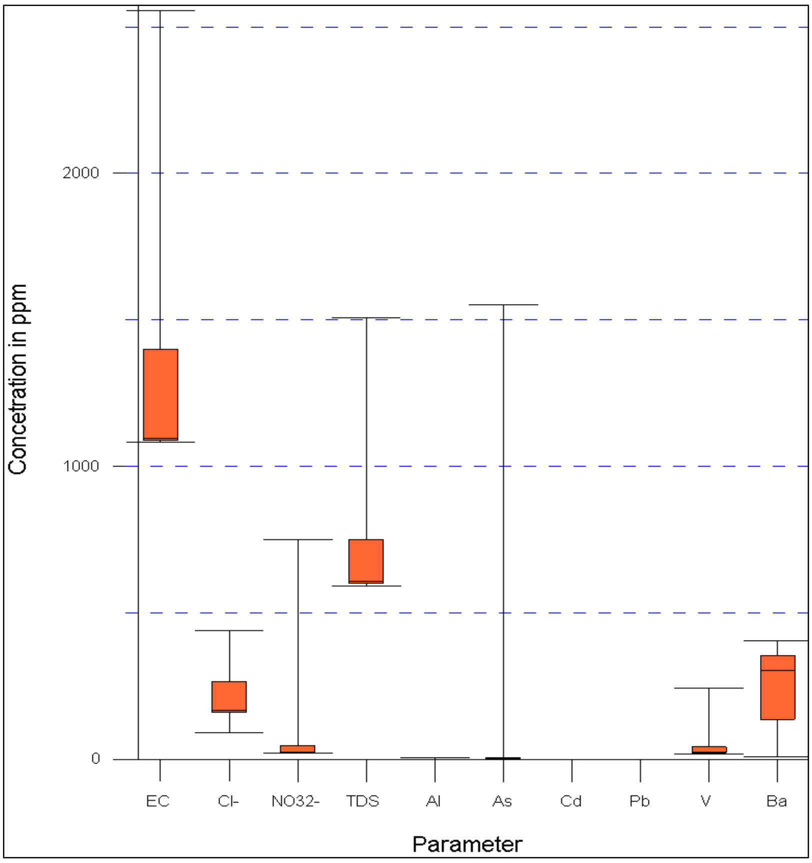

***Figure 1** Box and Whisker plot for parameters of groundwater samples.*

To examine the geochemical parameters, a correlation matrix was generated from the derived groundwater parameters (Table 1). The correlation matrix exhibited strong positive correlation among Ca^{2+}, Mg^{2+}, Cl^-, EC and TDS. A positive correlation observed between TDS and EC implies that conductivity increases as the concentration of all dissolved constituents/ions increases. Likewise, a strong correlation was also observed between Mg^{2+} and Ca^{+2} indicating most of the ions are involved in various physiochemical reactions, such as oxidation-reduction and ion exchange in the groundwater aquifer system (Udayalaxmi *et al*, 2010).

Significant correlation among TDS and V, As, Cd and Al also indicated that these metals were dominant in groundwater of the study area. On the other hand, fluoride was found to be negatively correlating with Ca^{2+} and with weak correlation against Mg^{2+} (correlation coefficient = 0.21 and -0.20 respectively). An inverse relationship among F^- and Na^+ was also observed. This might imply that Ca^{2+}might have been replaced by Na in cation exchange reactions as increasing concentration of sodium leads to increased solubility of fluorite in water (Kundu *et al*, 2001; Apambire *et al*., 1997). The weak correlation between pH, Chloride, Calcium, Sodium and Magnesium, against fluoride may be due to the presence of low level fluoride in the rocks that can dissolve in the ground water. Moreover, the occurrence of low levels of fluoride in groundwater from this area may be due to either to the absence of fluoride bearing magmatic solutions or of fluoride containing minerals in the strata through which groundwater is circulating. It could also be attributed to too rapid fresh water exchange resulting in concentration through evaporation or evapotranspiration being not very effective in raising the fluoride content of the groundwater to high values. Similar phenomenon was observed by studies such as Sreedevi *et al. (*2006), Umar and Alam (2011).

Table 2 *Correlation coefficient between different hydro-geochemical parameters in the study area.*

	pH	EC	Cl-	NO32	F-	TDS	Turb	Al	As	Ca	Cd	Cr	Cu	Fe	Pb	Mn	Se	Na	Zn	K	Co	V	Sb	Ba	Mg
pH	1.00																								
EC	0.16	1.00																							
Cl-	-0.11	0.62	1.00																						
NO32	0.09	0.49	0.51	1.00																					
F-	-0.14	0.27	0.63	0.53	1.00																				
TDS	-0.18	0.48	0.86	0.72	0.84	1.00																			
Turb	-0.12	-0.02	0.43	0.22	0.60	0.62	1.00																		
Al	-0.46	0.04	0.50	0.29	0.69	0.74	0.67	1.00																	
As	-0.42	0.08	0.62	0.35	0.83	0.84	0.78	0.91	1.00																
Ca	0.21	0.56	0.39	0.54	-0.20	0.18	-0.31	-0.28	-0.32	1.00															
Cd	-0.42	0.08	0.63	0.35	0.83	0.84	0.78	0.91	1.00	-0.32	1.00														
Cr	-0.19	-0.13	-0.11	-0.11	-0.16	-0.13	-0.09	0.01	-0.06	-0.01	-0.05	1.00													
Cu	0.20	-0.04	0.08	-0.10	0.02	-0.04	-0.12	-0.09	-0.07	0.01	-0.07	-0.08	1.00												
Fe	0.09	0.33	0.41	0.26	0.23	0.31	0.13	0.02	0.16	0.14	0.17	-0.32	0.24	1.00											
Pb	0.27	0.04	-0.20	0.38	0.34	0.02	-0.08	-0.13	-0.04	-0.15	-0.05	-0.05	-0.07	0.17	1.00										
Mn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00									
Se	0.10	0.43	0.63	-0.18	0.32	0.31	0.09	0.12	0.21	0.01	0.22	-0.14	0.23	0.38	-0.20	0.00	1.00								
Na	0.53	0.47	0.12	0.37	-0.08	0.05	-0.38	-0.26	-0.36	0.50	-0.35	0.04	0.11	0.21	0.31	0.00	0.17	1.00							
Zn	0.37	-0.09	-0.10	0.02	0.10	-0.09	-0.17	-0.16	-0.09	-0.08	-0.10	-0.11	0.17	0.33	0.33	0.00	0.01	0.18	1.00						
K	-0.23	-0.41	-0.15	-0.51	-0.24	-0.19	0.26	0.23	0.15	-0.41	0.16	0.08	-0.01	-0.34	-0.44	0.00	-0.07	-0.45	-0.30	1.00					
Co	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00				
V	-0.18	0.29	0.64	0.64	0.91	0.92	0.68	0.82	0.90	-0.14	0.90	-0.12	-0.08	0.24	0.21	0.00	0.17	-0.03	-0.02	-0.16	0.00	1.00			
Sb	-0.50	-0.25	-0.06	-0.13	-0.01	0.01	0.11	0.37	0.20	-0.15	0.20	0.25	-0.20	-0.40	-0.14	0.00	-0.16	-0.19	-0.28	0.33	0.00	0.02	1.00		
Ba	-0.33	-0.35	-0.33	-0.75	-0.59	-0.59	-0.53	-0.26	-0.37	-0.19	-0.36	0.09	0.18	-0.07	-0.43	0.00	0.13	-0.14	0.07	0.35	0.00	-0.63	0.17	1.00	
Mg	0.18	0.62	0.65	0.76	0.21	0.57	-0.06	0.06	0.07	0.84	0.07	-0.04	0.08	0.30	-0.04	0.00	0.18	0.58	-0.05	-0.52	0.00	0.31	-0.26	-0.37	1.00

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4. Pollution Analysis using Pollution Index (*Pi*)

Pi was used to show the level of pollution of borehole water by each parameter. The critical value being 1.0 and values >1.0 indicating significant degree of pollution while values <1.0 showing no pollution/ danger of pollution (Akpoveta *et al*., 2011). Pollution index (Pi) according to Akpoveta *et al.* (2011) is expressed as a function of the concentration of individual parameter values against the baseline standard (WHO permissible value). It is given as below in equation;

$$\text{Pollution index (Pi)} = \frac{\text{Concentration}}{\text{Standard}} \qquad \text{(i)}$$

For this study, the number of boreholes with Pi>1 were plotted and DWAF threshold concentration were used to derive Pi for the parameters (Fig. 3). The data indicated chemical parameters (Ni, Cu, Co, Al, Ca, Fe, Se, Zn, Na, Turbidity, pH and F^-) with *Pi*<1.0 and therefore implying that all the boreholes were free from contamination by these parameters. Parameters such as TDS, EC, Cl^- , NO_3^{2-}, Mn, As, Cd, Cr, Pb, Mo, K, V, Sb, Ba and Mg had *Pi*>1 in some of the boreholes and consequently indicating significant degree of contamination. Electrical conductivity had *Pi* ranging from 1.6-3 and Total Dissolved Solids Pi ranged from 1.3-3.4 in all the 22 boreholes, whilst Pb, K and Ba had *Pi*>1 in borehole number 21, 15 and 19 respectively.

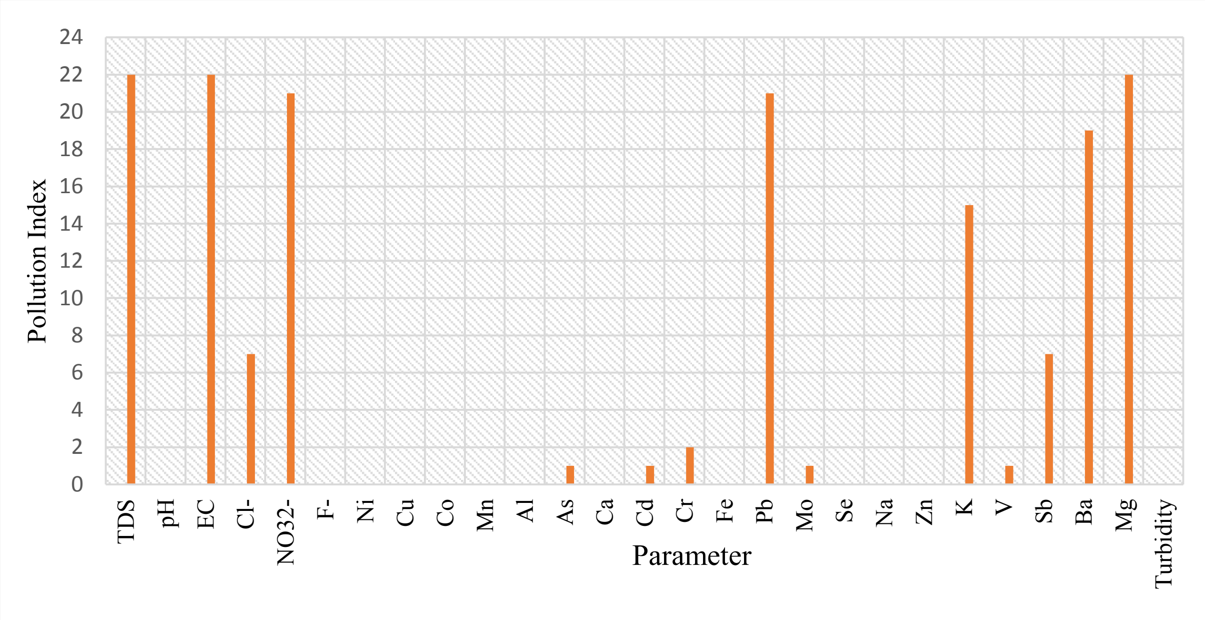

Figure 3 *Pollution Index of Boreholes based on WHO and DWAF threshold concentration.*

5. Conclusion

Overall quality of groundwater in 6 -10 km radius of Tshikondeni mine in the Limpopo Province is not pristine. Therefore, this groundwater should not recommend for its direct use for domestic and agricultural purpose. The water is hard in nature and has high total dissolved solids (TDS) which is not suitable for drinking purpose as described by WHO (2003) and DWAF (1996). Moreover, Pollution index were >1 in all the boreholes sampled which indicated significant pollution to the groundwater resource at Masisi village. Elevated TDS and EC values are indicative of inorganic dissolved solids such as chloride, nitrates and fluorides anions or sodium, calcium, magnesium, iron and aluminum cations derived various physiochemical reactions, such as oxidation-reduction and ion exchange. The increase in concentration of these parameters may also be attributed to different mechanisms such as water rock interaction in the subsurface formation or groundwater migration from point source pollution. Local authorities should look for alternative sources of water supply as these boreholes are polluted and communities are at risk of renal disease (Cd poisoning), blood pressure and kidney problems (Pb poisoning), kidney and liver damage (As poisoning), gastrointestinal disorders (Sb poisoning), cancer and mild neurological effects (V poisoning). Based on the findings of this study, continuous monitoring of ground water quality and water table within 10 km radium of Tshikondeni Coal mine is recommended. Primary and secondary treatment prior to domestic and agricultural use is also recommended.

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References

Apambire. W. B., Boyle D. R. And Michel F. A. (1997). Geochemistry, Genesis, and Health Implications of Fluoriferous Groundwater In The Upper Regions Of Ghana. Environ Geol. 33(1): Pp. 13-24.

Akpoveta, O. V, Osakwe, S. A, Okoh, B. E, Otuya, B. O. (2010). Physicochemical Characteristics and Levels of Some Heavy Metals in Soils around Metal Scrap Dumps in Some Parts of Delta State, Nigeria. J. Appl. Sci. Environ. Manage., Vol. 14(4), pp. 57-60.

Aston, J. J. (2000). Conceptual Overview of the Olifants River Basin's Groundwater, South Africa. An Occasional Paper for the International Water Management Institute (IWMI) in conjunction with the African Water Issues Research Unit (AWIRU).

Ashton, P., Love, D., Mahachi, H. and Dirks, P. (2001). An Overview of the Impact of Mining and Mineral Processing Operations on Water Resources and Water Quality in the Zambezi, Limpopo and Olifants Catchments in Southern Africa. Report to Minerals, Mining and Sustainable Development Project, Southern Africa, 338pp.

Chenje, M. and Johnson, P. (1996). Water in Southern Africa, SADC/IUCN/SARDC, Maseru/Harare, 1996.

Department of Water Affairs and Forestry. (1996). South African Water Quality Guidelines, Vol. 1, Domestic Use, Second Edition.

Department of Water Affairs and Forestry. (2006). Integrated Water Resource Planning Systems Series Sub-series No. WQP1.7.1 Guidelines on Catchment Visioning for the Resource Directed Management of Water Quality. DWAF, Pretoria.

Dermietzel, J. and Christoph, G. (2001). The impact of a lignite seam on contaminated groundwater in the aquifer system of the Bitterfeld region. Water, Air, and Soil Pollution 125, pp. 157–170.

Kuma, J.S. (2001). Hydrogeological studies on the Tarkwa gold mining district, Ghana, Bull. Eng. Geol. Env. 66, pp. 89-99.

Kundu. N, Panigrahi M. K, Tripathy S, Munshi. S, Powell MA and Hart B. R. (2001). Geochemical appraisal of fluoride contamination of groundwater in the Nayagarh District of Orissa, India. Environ Geol. Vol. 41, pp. 451-460.

MacDonald, N and Vermeulen, D. (2014). Spoils Handling from Coal Mines in the Waterberg Coalfield area, Limpopo for the 13th Biennial Groundwater Division Conference and Exhibition: Groundwater: A New Paradigm. Institute for Groundwater studies, University of the Free State, Bloemfontein, South Africa

Meck, M. L., Love, D. and Mapani, B. S. (2006). Zimbabwean Mine Dumps and their Impact on River Water Quality a Reconnaissance Study. Physics and Chemistry of the Earth, Vol. 31, pp. 797-803.

McQuillan, R. G and Spenst, P. G. (1976). The addition of chemicals to apartment water supplies. Journal of the American Water Works Association. Vol 68, pp. 415-419.

Peplow. D and Edmonds. R. (2004). Health risks associated with contamination of groundwater by abandoned mines near Twisp in Okanogan County, Washington, USA. Environ. Geochem Health 26: pp. 69-79.

Ravengai, S., Owen, R. J. S. and Love, D. (2004). Evaluation of seepage and acid generation potential from evaporation ponds, Iron Duke Pyrite Mine, Mazowe Valley, Zimbabwe. Physics and Chemistry of the Earth Vol. 29, pp. 1129-1134.

South African Weather Service. (2013). Climate of the Soutpansberg region. www.southafrica/info/ travel/ advice/ advice/climate.htm.

Sreedevi, P. D, Ahmed S, Made B, Ledoux E and Gandolfi, J. M. (2006). Association of Hydro-Geological Factors In Temporal Variations Of Fluoride Concentration in a Crystalline Aquifer In India. Environmental Geology, Vol. 50(1), pp. 1-11.

Todd, D. K. (1980). Ground-water hydrology (Second Edition): John Wiley and Sons, New York, 535 p.

U.S. Environmental Protection Agency, 2005. Supplemental guidance for assessing cancer susceptibility from early-life exposure to carcinogens. Risk Assessment Forum, Washington, DC.

Umar, R. and Alam, F. (2011). Assessment of Hydro-geochemical Characteristics of Groundwater in parts of Hindon–Yamuna interfluve region, Baghpat District, Western Uttar Pradesh. Environ Monit Assess, DOI 10.

Usher, B. H., Cruywagen, L. M., de Necker, E. and F. D. I. Hodgson, F. D. I. (2003). On-site and Laboratory Investigations of Spoil in Opencast Collieries and the Development of Acid-Base Accounting Procedures, Water Research Commission, WRC Report No. 1055/1/03, Vol.1, pp. 3- 25.

Udayalaxmi G., Himabindu D. and Ramadass G. (2010). Geochemical evaluation of groundwater quality in selected areas of Hyderabad, A.P., India, Indian Journal of Science and Technology, vol. 3(5), pp. 546-55.

Warnick, M. (2003). Impacts and costs of dry land salinity. QNRM03146, The State of Queensland (Department of Natural Resources and Mines) 2003.

World Health Organisation. (1984). Health criteria and other supporting information 101:2.

World Health Organisation. (1996). Framework for safe drinking water. Guidelines for drinking water quality, vol. 2, 2nd edition, Geneva, Switzerland.

World Health Organisation. (2003). Emerging Issues in Water and in Infectious Dieseases. Geneva, World Health Organisation.

World Health Organisation. (2004). Vitamin and mineral requirements in human nutrition, 2nd ed. Report of a Joint FAO/WHO Expert Consultation, Bangkok, Thailand, 21–30 September 1998. Geneva, World Health Organization

Zilberman, D. (1999). Groundwater, Water Logging, Drainage and Water Quality. Department of Agricultural and Resource Economics, University of California at Berkeley, EEP 101 Course Notes, Spring Semester, 1999.