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Assessment of Physicochemical and Microbiological Parameters of Drinking Water Samples from a South African Coal Mining Area

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ABSTRACT Globally, water pollution is a critical problem which is inflicting serious damage on human health and the natural environment. In South Africa, many cases of water pollution have been reported. This paper assesed the physical, chemical and microbial properties of water from three locations in a coal mining region of South Africa. A mixed-methods approach involving quantitative analysis of water and qualitative (interviews of participants) was empoyed. Samples were taken from two secondary schools taps and a river. A total number of eleven parameters were assessed and analysed using different analytical methods. The values of each of analyzed parameters were later compared with the South African National Standard (SANS) for drinking water quality. The findings reveal that majority of the parameters conformed to the recommended guidelines while others were either at the threshold limit or present in greater concentrations. It is to be noted that long-term exposure of any of these in water can result in a number of harmful effects as discussed in the paper.

INTRODUCTION

The 21st century has witnessed tremendous industrial development accompanied by mass movement of people from the rural areas to urban centres. This growing influx of people in the urban centres, as it is the case in many parts of the world, has subjected the urban infrastructure and other resources to untold pressure. Incidentally, the population dynamics and its associated anthropogenic activities have direct consequences on the integrity of the natural environment. It is clear that several human activities could be responsible for many environmental problems, including the wasteful depletion of natural resources as well as the destruction of the natural habitats, thus contributing to the loss of biodiversity (Ali et al. 2017; Cloete et al. 2017; Sánchez-Bayo et al. 2016). In South Africa, similar environmental problems emanating from human activities are also encountered. Water pollution and scarcity, for instance, remains an important challenge, especially to the rural dwellers (Edokpayi et al. 2018; Elumalai et al. 2017). In many instances, communities in the vicinity of mining sites, especially coal mines suffer the most because of exposure to the negative effects of these mining activities (Dontala et al. 2015; Mhlongo and Amponsah-Dacosta 2016; Schneider 2015). For example, contaminated water from coal mines and other mining activities generally referred to as acid mine drainage may contain high levels of heavy metals thereby posing a great danger to the general ecosystem (Bwapwa et al. 2017). Besides the increasingly high incidences of atmospheric pollution in these areas, the pollution of water sources via discharges from these mining sites is significant (Butler 2017; Elumalai et al. 2017; Cloete et al. 2017). In fact, it was previously reported that population growth and rapid urbanisation contributed to the water pollution problems and thus had continued be a great challenge to the South African water resources (Mabhaudhi et al. 2016).

Water is of basic importance to human physiology because man's continual existence depends on its availability. Therefore, access to good quality drinking water is essential for everyone (Edokpayi et al. 2018). Countless numbers of people die yearly as a result of drinking contaminated water (World Health Organisation 2017). Specifically, another report of the World Health Organisation reveals that "……over 2.6 billion people lack access to clean water, which

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is responsible for about 2.2 million deaths annually, of which 1.4 million are children….." (Pandey et al. 2014: 2). This scenario is often related to water pollution mainly caused by discharges of industrial effluents and human wastes into water bodies (Elumalai et al. 2017).

To substantiate the above claims, the United Nations Environment Programme (UNEP) states that "…there is a global deterioration of water quality as a result of heavy metals concentration which has direct impact on human health and environment….." (Ali et al. 2017: 2). Concerns about the health and aesthetic effects of water pollution are enormous. These may include the alteration of the physical appearance of the water, prevalence of pathogenic micro-organisms and increasing levels of harmful chemicals that can elicit serious health conditions in humans (Haseena et al. 2017; Rossouw and Görgens 2016).

The presence of certain microorganisms such as total coliform and *E.coli* in water samples serves as a good indicator of faecal pollution. Many of the South African water resources are reported to have been contaminated by faecal matter and many cases of diseases due to exposure to this contaminated water have been documented (Rossouw and Görgens 2016; Osuolale and Okoh 2017). In fact according to the Department of Water and Sanitation, "….An estimated R3.5 billion is spent in South Africa every year as a direct result of diarrhoea….." (Rossouw and Görgens 2016: 26). These microorganisms have been widely explored for this purpose and their presence needs to be strictly monitored to prevent further water-related disease outbreak (Saxena et al. 2015; Osuolale and Okoh 2017).

Similarly, many harmful inorganic chemicals such as lead, arsenic, chromium, mercury, nickel as well as organic chemicals (Polychlorinated Biphenyls – PCBs and Polybrominated Diphenyl ethers – PBDEs) amongst others could be present in natural water, which could result in serious health effects in humans (Alinejad et al. 2016; Bamuwamye et al. 2017; Daso et al. 2013; Olutona et al. 2017; Morakinyo et al. 2017).

Most of the health effects associated with exposure to these chemicals via the consumption of contaminated water have been well documented where children are particularly considered to be the most vulnerable (Bamuwamye et al. 2017; Perera 2017; Vaishaly et al. 2015). In South Africa, for instance, it has been reported that children are more susceptible to the negative effects of pollution that often occur in their homes and schools (Albers et al. 2015; Nkosi et al. 2017). Moreover, the South African Human Rights Commission (2001: 323) reported that "……….a growing number of diseases in children are linked to unsafe environments in which they live, play, learn and grow…"

The study site is one of the most industrialised cities in South Africa due to coal mining activities and other industrial processes that take place in these areas. Similarly, many famous and important South African rivers are found in the vicinity of these areas and these rivers serve as important sources for drinking, agriculture and a host of other domestic purposes. However, for years now, the quality of these rivers has drastically deteriorated due to the presence of high levels of heavy metals from coal mining activities along their catchments (De Villiers and Mkwelo 2009; Griffin et al. 2014; McCarthy et al. 2013). People who depend on water from these highly polluted rivers are threatened with chronic diseases and a large number of aquatic ecosystems such as plants, fishes and crocodiles have been endangered and killed (Dabrowski and de Klerk 2013; Kings 2017). For example, it was reported in a study conducted in one of these rivers that the fishes were contaminated by heavy metals such as lead and cadmium and as a result several of them died (Cloete et al. 2017). Exposure to these metals either from water or food may inflict chronic diseases such as kidney, brain and lung damage, liver cirrhosis, sterility, respiratory problems, anaemia, cardiovascular diseases and cancer of various types (Ayangbenro and Babalola 2017; Hamilton et al. 2017; Hou et al. 2017). There have been warnings from a number of reports that if these problems persist, water from these rivers might be unfit for users in the future and this can also lead to the collapse of the catchment (Davies 2014; Kings 2017). Many farmers have complained about the growing damaging effects of the mining activities on their lands and crop yields and have stressed that these may also result in a serious national food crisis if care is not taken (Bureau for Food and Agricultural Policy 2012; Mkentane 2016; Parliamentary Monitoring Group 2016).

Based on all these facts and claims, the researchers of this study deemed it fit to conduct a comprehensive physical, chemical and microbiological assessment of drinking water so as to ascertain its portability in accordance with the recommended guidelines established by the South African National Standard (SANS) and World Health Organisation (WHO) for drinking water quality.

Research Objectives

The objectives of this study were to:

- Assess the physical, chemical and microbial properties in drinking tap water;
- Assess the physical, chemical and microbial properties in a river;
- Compare the concentration levels of these parameters with the recommended guidelines established by the South African National Standard (SANS) for drinking water quality; and,
- Assess the views of people from the community about water pollution.

RESEARCH METHODOLOGY

Study Area

This study was conducted in a town called Emalaheni in South Africa (Olufemi 2012) Emalahleni formerly known as Witbank means 'a place of coal' (Mpumalanga Happenings 2018). It is a city situated on the Highveld of Mpumalanga Province with about 45 collieries and 12 coal fired plants (Yende 2016). Emalahleni in the last few years has doubled its population due to development in terms of industrialisation and increased job opportunities (Emalahleni Municipality 2016). On a yearly basis, around 220 million tons of coal are mined in this area (Baillie 2015). In addition to this, Emalahleni supplies coal to the various power stations for electricity generation and also smelting companies. Due to coal mining, electricity generation and other industrial activities in Emalahleni, there is a continuous release of effluents and chemicals into water sources and air respectively (McDaid 2014). In fact with regards to air pollution, Emalahleni is regarded as one of the most polluted areas in the world (McDaid 2014). As a result of this, the Department of Environmental Affairs declared this area a Highveld priority area in terms of the National Environmental Management: Air Quality Act 39 of 2004 (Department of Environmental Affairs 2011; Munnik et al. 2010).

Quantitative Sample Collection and Analysis

Water samples were collected from three locations in the study area. Firstly, from the taps of two secondary schools and secondly, from a river (dam). These schools were selected on purpose, because they were in the vicinities of coal mines and combustion industries. The two schools were named A and B in order for them to remain anonymous. The river was also chosen, because it runs right next to a coal-fired electricity generating power station. Water from this dam is used by households in the study area for consumption and other domestic purposes. To collect water samples from both the schools and river, sterile bottles that ranged from 250 ml to 1 litre in volume were used. The parameters were analysed using established analytical methods (Table 1) in order to determine their concentration levels in the sampled water.

Table 1: Parameters and analytical methods

	Physical and chemical parameters	*Analytical methods*
1	Colour	pt-co method comparison
2	Conductivity	Conductimetric
3	Turbidity	Nephelometric
4	Total dissolved solids [TDS]	Gravimetric
5	pH	Electrometric
6	Lead	ICP
7	Nickel	ICP
8	Arsenic	ICP
9	Mercury	Solid vapour generation
	Microbiological Parameters	
10	Total coliform	Membrane filtration
11	*Escherichia coli*	Membrane filtration

Note: CMP = Chemistry method; MMP = Microbiology method; TDS = Total dissolved solids;
ICP = inductively coupled plasma atomic emission spectrometry
Source: Olufemi 2012

RESULTS

For physical and chemical properties, the values for conductivity were 58 mS/m (School A), 62.2 mS/m (School B), and 66.6 mS/m (River water). These values were lower levels compared to <170 mS/m recommended by the SANS. Similarly, for pH, the values were 7.6 (School A), 7.8 (School B), and 8.2 (River), which were within the recommended >5 to <9.7 SANS. The values of turbidity were 0.5 NTU (School A), 0.4 NTU (School B) and 4 NTU (River). In addition, the values for total dissolved solids were 434 mg/l (School A), 411 mg/l (School B) and 471 mg/l (River). With regards to colour, the values were 5 mg/L Pt-Co (School A), 9 mg/L Pt-Co (School B) and 55 mg/L Pt-Co (River). The above findings suggest that the values complied with the recommended standards with the exception of turbidity (4 NTU) and colour (55 mg/L Pt-Co) which were high in the river sample compared to <1 NTU and <15 mg/L Pt-Co of the SANS respectively. The values for nickel in all three locations was <0.02 mg/l. The values for arsenic were 0.00111 mg/l (School A), 0.0015 mg/l (School B) and 0. 001989 mg/l (River). With regards to mercury, the values were <0.001 mg/l (School A), 0.001 mg/l (School B) and 0.002 mg/l (River).

It is to be noted that the compounds nickel, arsenic, and mercury all conform to the SANS recommended guidelines except for lead (<0.01 mg/L) which falls at the threshold of the recommended guidelines (<0.01 mg/L) in all the three locations. Regarding the microbiological water quality parameters, total coliform and *E. coli* were found to be at 0 level in both schools A and B which were found to be at acceptable levels when compared to the SANS guidelines. However, for a water sample from the river, the concentrations were 20 count/100 ml for total coliform against <10 count/100 ml, SANS and 4 count/100 ml for *E. coli* against 0 count/100 ml, SANS.

Thy Department of Water Affairs and Forestry recommended the acceptable levels of parameters that could be in drinking water, which was originally derived from the WHO Guidelines for drinking-water quality (WHO 2011). These parameters are listed in the South African National Standard (SANS 241-2011, Edition 1) (Department of Water Affairs and Forestry 2011) and the updated version SANS 241- 2015, Edition 2 (Vinlab 2015) for drinking water quality. This is on the same table with the results of the analysis for comparison. In the standards, it is anticipated that drinking water is to comply with the values for the physical, chemical, and microbiological parameters. In fact, the Department of Water and Sanitation (2017) declared that all drinking water should comply with the South African National Standards for portable drinking water. The values of the different analysed parameters are presented in Table 2.

Qualitative Data

Apart from the researchers' intentions to conduct a scientific study, the problem investigated in this study was also inspired by conversations held with quite a number of members of Emalahleni community. A total number of twenty people participated in these conversations. However, conversations with only seven participants were reported. These included three school principals, two university lecturers, one school learner and a community member.

The following responses echo the concern about the cleanliness of the water. Respondents expressed their views on the detrimental effects of the coal mines close to the chosen schools. They mentioned the fact that bottled water was a luxury reserved for a privileged few and that the inhabitants' health was at risk, since many

Table 2: Results of water analysis and South African National Standard for drinking water quality

Sample ID	*Units*	*Tap water*		*River water*	*SANS[a]*
		School A	*School B*	*Power station*	
Conductivity (CMP 14)	mS/m [25°C]	58	62.2	66.6	< 170
pH (CMP 11)	pH units [25°C]	7.6	7.8	8.2	>5 to <9.7
Turbidity(CMP 13)	NTU	0.5	0.4	4	< 1
TDS (CMP 15)	mg/l [180°C]	434	411	471	< 1 200
Colour (CMP 12)	mg/l [Pt-Co]	5	9	55	< 15
Lead (CMP 1)	mg/l Pb	< 0.01	< 0.01	< 0.01	< 0.01
Nickel (CMP 1)	mg/l Ni	< 0.02	< 0.02	< 0.02	< 0.07
Arsenic	mg/l As	0.00111	0.0015	0.00198	< 0.01
Mercury(tot) (CMP 3)	mg/l Hg	< 0.001	0.001	0.002	< 0.006
Total coliform (MMP 2)	count/100ml	0	0	20	< 10
E. coli (MMP 8)	count/100ml	0	0	4	Not detected or 0

Recommended Guidelines Source: Vinlab 2015; Department of Water Affairs and Forestry 2011
Note: [a] = South African National Standard for drinking water quality

were hospitalised due to the consumption of dirty drinking water. Their observations that the water was polluted correspond with the quantitative findings shared above. They made their own observations and said the following:

Principal 1: "*There were approximately 15 mines in the general vicinity of my school*" (Refilwe).

Principal 2: *"Children and everybody bath and drink water that is contaminated … many as a result of constant health problems are being hospitalised from time to time apparently without realising that their health issues may be linked to the pollution in this area"* (Thapelo).

Principal 3: *"Pollution from the mines, foundries and the power generating plants were affecting the schools in so many ways"* (Theophilus).

Lecturer 1: *"Sometimes when you decide to leave a cup of water on the table for few hours or overnight, by the time you come back you see some black particles (coal dust) already settled at the bottom of the cup. We do not even have a choice; we still drink it because we were all born here and this is the water we have been drinking since we were born. So don't tell me about any health effects"* (Jacob).

Lecturer 2: *"One of my students was diagnosed of kidney problem recently and died. He was born and grew up in this community and he happened to come from a poor family. We all suspected this problem might be as a result of drinking coal polluted water from his childhood"* (Victoria).

A Secondary School Teacher: *"Some of our learners sometimes fall sick and are absent from school but we are not sure of the cause"* (Beatrice).

A Secondary School Learner: *"This is the water we have been drinking all our lives. We all drink this every time we are thirsty, because we do not have another alternative except for learners whose parents are rich and are able to afford bottled water. We are not even sure if it has any health effects on us or not"* (Amanda).

A Community Member: *"Many people especially illiterates and poor people have to be forced to drink this contaminated water because they cannot afford bottled or still water"* (Peter).

DISCUSSION

This study assessed the physical, chemical and microbial properties in drinking water in the vicinity of the coal mines. The results reveal that all the analysed parameters in the two schools' drinking water were at aceptable limits except for lead which was at the threshold of the recommended guidelines. This suggests that this particular compound is present in the water even though not at a high concentration when compared to other studies. For example, a study conducted in British Colombia on lead exposure reported that lead levels in drinking water of school children in a particular community exceeded the Canadian drinking water guidelines (Wachtel et al. 2017).

Similarly, in Michigan, a study conducted on lead revealed that the drinking water consumed by children was highly contaminated with lead which exposed them to both short term and long term health hazards (Laidlaw et al. 2016). Moreover, the analysis of the water samples taken from the river reveals that all the physical and chemical parameters were within acceptable levels except for colour, turbidity, and lead. Colour and turbidity were found to be at concentration levels more than the required standards for river water quality. It is to be noted that when turbidity is present at a high level or concentration in water, it affects the colour of the water (Kitchener et al. 2017). The result of this study is in support of a study conducted in Malaysia where concentrations of turbidity in the rivers sampled were very high (Ling et al. 2017). This was reported to be as a result of industrial and domestic waste water being continuously discharged into rivers (Ling et al. 2017). The lead content in the river was also at the threshold of the recommended guidelines. This result of Lead is in contrast with a study conducted in China where the concentration of lead in the two river water sampled were generally high (Yao et al. 2016).

Similarly, microbiological (total coliform and *E.coli*) levels in the studied river were at a higher concentration compared to the required standards. This is in support of studies conducted in Iran (Khoramnejadian and Fatemi 2016) and South Africa (Mulamattathil et al. 2015) where it was reported that microbial organisms such as coliforms and *E.coli* were present in the sampled river at levels higher than the required standards.

Even though most of the parameters were at acceptable limits, it should be cautioned that the above-mentioned elements were however present. For example, arsenic and mercury were detected in the water though at low concentrations. The fact remains that exposure to these heavy metals on a daily basis can be dangerous because it is reported that long-term exposure to these pollutants in drinking water can result in chronic health problems (Amadi et al. 2017; Ayangbenro and Babalola 2017). For example, studies have reported that the prolonged consumption of arsenic polluted water, may result in cancer of various types and respiratory infections (Mandal 2017). This issue is more critical for children as several studies have been reported about prolonged exposure to arsenic in drinking water affecting the academic performance of school children (Tsuji et al. 2015).

Lead is rated among the top priority metals which is known to be dangerous to human health (Su et al. 2017). In fact, in the United States, high concentrations of lead in the blood were associated with increased mortality from cardiac diseases (Lanphear et al. 2018). It is reported in the case of children that lead exposure can affect the nervous system (Landrigan 2018; Olufemi et al. 2018; Wani et al. 2015; United States Environmental Protection Agency 2018; Kalia et al. 2017). Though it may look in this study that lead levels in the water was at the threshold limit of the recommended standard, the fact remains that it could result in major health problems in children. To substantiate these claims, quite a number of studies have reported that no safe blood-lead level for children has been identified and even small exposures can result in reduced Intelligent Quotient (IQ), inability to pay attention, poor academic performance and other health problems children suffer from (Centers for Disease Control and Prevention 2017; Carrel et al. 2018; Gao et al. 2017). The most critical thing about lead exposure is that once a person is exposed, the effects cannot be corrected, so it is better not to be exposed at all (Quince 2018).

This study also reported that the concentration levels of microbiological parameters (total Coliform and *E.coli*) were far higher than recommended standards. It is to be realised that these bacteria are not to be detected in any water system at any level. A problem with their presence in water is that they may result in gastrointestinal illnesses such as diarrhoea (Daud et al. 2017; Ekopai et al. 2017; Kulinkina et al. 2016). To support this argument, SANS 241: 2011 declares that microbiological determinants in water should comply with the standard numerical limits. In a situation where a microbiological value exceeds this limit then an unacceptable risk to human health is implied. As the microbiological value increases, an increasing risk to health is implied (Department of Water Affairs and Forestry (RSA) 2011).

The fact that the lives of many people in South Africa are being endangered due to exposure to contaminated water on a daily basis is a cause of great concern. However, Section 24 of the Constitution of the Republic of South Africa Act 108 0f 1996 clearly states that "…everyone has a right to:

(1) an environment that is not harmful to their health and well-being; and
(2) have the environment protected for the benefit of the present and future generations, through reasonable legislative and other measures that:
a) prevent pollution and ecological degradation;
b) promote conservation; and
c) secure ecologically sustainable development, and the use of natural resources while promoting justifiable economic and social development" (Goolam 2000: 124).

CONCLUSION

This study assessed the physical, chemical and microbial properties in drinking water from a coal mining region which was conducted in Emalahleni, Mpumalanga, South Africa. A total number of eleven parameters were investigated. The results indicate that all the parameters tested for in the two schools' drinking water were present at acceptable limits with the exception of lead which was at the threshold value of the recommended guidelines. For river, the findings reveal that all the parameters were within acceptable levels except for lead which was at the threshold value. Colour and turbidity were present at higher concentration. Total coliform and *E.coli* were found to be at concentration levels greater than the required standards. This suggests that the river water had unacceptably high values taking into consideration these parameters.

Even though some of the parameters investigated in this study were within acceptable limits, a source of concern here is the fact that long-term exposure to them can result in a number of harmful effects as earlier discussed. It has also been highlighted in the study that the negative impact of coal mining activities in Mpumalanga region for several years now has resulted in severe pollution of water systems and depletion of aquatic bodies. It is the responsibility of South African government as stated in the constitution to safeguard the natural resources and the health of the citizens by ensuring that everyone has access to a continual supply of clean, safe drinking water. This is most critical for the young ones as they are the most vulnerable.

RECOMMENDATIONS

In this study, physical, chemical and microbial properties of drinking water from a coal mining region were assessed. Based on the findings of this study, a number of recommendations are advanced. The results of the analysed parameters revealed that they were found in water at different concentrations below within and above the recommended guidelines. Though it may appear from the results that most of the tested parameters were within acceptable limits, the fact remains that a number of the community members depend on this water for drinking and other domestic purposes as reported in the qualitative aspect of this study. Moreover, some of the school children who have to drink the water on a daily basis may be vulnerable to the long-term exposure of those compounds. For example, it was reported that lead was at the threshold of the recommended guidelines.

Report from some of the residents of this community revealed that they are not sure if the water affects their health or not. Sometimes one may not see the effects on these compounds until after a long period of time. It is therefore advisable that both children and adults are medically checked from time to time. For example, children's blood and urine could be tested from time to time to measure the level of lead. This will enable doctors, school management, government and even parents to take preventive measures. What makes the situation critical is the fact that most of the school children were born and still growing up in this pollution as stated in the qualitative section. If they are to drink this polluted water until adulthood, then their health is at great risk.

It was also revealed from the converstions that a number of these community members are poor and illiterate; they are unaware of the risk which they are daily exposed to. Hence, there should be health programmes organised in these communities from time to time to raise their awareness. Through such interventions, these people could be educated about how drinking contaminated water can affect their health. Furthermore, they could be educated on how they can purify their water in local and simple ways before drinking. Otherwise, the government if possible could make an arrangement through which all those who are not able to afford bottled water could be supplied freely from time to time.

It is also very important that a monitoring equipment is made available to manage the water quality within this community from time to time in order to ensure that drinking water is always in compliance with the recommended standards. Most importantly, the government should adopt a better policy that will make the mining industries treat their wastewater before discharging into waterways, to prevent the problems of water pollution and even contamination of aquatic organisms. Finally, it is very crucial to urgently address the issue of water pollution in this community and in South Africa in general. Failure to address this issue now may result in a future laden with more problems.

LIMITATIONS OF THE STUDY

With regards to the sampling of water especially from the river, the practical situation is such that one can only measure at a point in time. That is, for all intent and purpose one cannot be sampling forever. For example, one could collect a sample in one minute and the power stations may release its effluent in the river system a minute later. This will mean that whatever is contained in the effluent will be missed. In addition, an assessment of the health status of children and other community members should have been carried out in order to check for the levels of these compounds in their bodies but this was not possible due to time and financial constraints.

SUGGESTIONS FOR FURTHER RESEARCH

This study was conducted Emalahleni in Mpumalanga province South Africa where coal is mined. This country is rich in several mineral resources. It is suggested that this kind of study could also be conducted in other mining hotspots within the nation where other mineral resources such as gold and platinum are mined. Such studies will also add to the body of knowledge already generated here. It could be that such studies will validate what was reported here or may report different findings. Future studies may also try to consider other areas that do not have pollution potential.

Since this study found that the parameters were present at various concentrations, it is suggested that the cumulative effect of these in the blood of both the school children and other community members should be evaluated.

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