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TECHNICAL ARTICLE

Assessment of the Suitability of Mine Water Treated with Pervious Concrete for Irrigation Use

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Abstract

In water scarce countries, the treatment and re-use of polluted mine water can reduce water shortage problem. In this study, the possible use of pervious concrete to treat Acid Mine Drainage (AMD) for irrigation of agricultural crops, was investigated. Pervious concrete mixtures consisting of 6.7 mm granite aggregate and plain portland cement CEM I 52.5R with or without 30% fly ash were prepared and used to conduct column studies on AMD. The AMD types used in the study were obtained from abandoned coal (TDB) and gold (WZ) mines. Physico-chemical parameters of water including the pH, electrical conductivity (EC), Total Dissolved Solids (TDS), along with element concentrations were analysed. Also the Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP), and Kelly's ratio (KR) of the treated AMD were calculated and compared against the water quality criteria for irrigation use. Results showed that treated TDB water was unsuitable for irrigation use owing to its high TDS, EC, SSP and KP values, even though its metal concentrations were reduced to satisfactory levels. Conversely, treated WZ water gave low SAR, SSP and KP indices, as well as satisfactory metal concentrations, indicating its suitability for use as irrigation water. The study shows that pervious concrete can be effective in treating AMD for irrigation use, but further research is needed to control high alkalinity and salinity levels in the treated water.

Keywords Acid mine drainage · Irrigation · Kelly's ratio · Pervious concrete · Sodium adsorption ratio · Water quality

Introduction

Worldwide there is increasing water demand for domestic, industrial and irrigation uses due to population growth, urbanisation, and growing manufacturing, leading to overexploitation and unsustainable use of available water resources. In addition, several countries are water scarce or stressed such as those nations in the arid or semi-arid climate regions. The sub-Saharan African nations including South Africa, Namibia, Botswana and North African countries, are among the most highly water-stressed nations in the African continent. For example, more than 60% of South Africa's limited natural river networks are currently overly exploited with about only one-third of the country's main rivers being in a fairly good condition. In water stressed countries, one of the options to reduce this stress is water recycling. Unfortunately, there is plenty of wastewater and mine water that is disposed into the environment without being treated for re-use (Donnenfeld et al. 2018; Ochieng et al. 2010). These recyclable water resources include industrial wastewater, grey water and acid mine drainage (AMD).

Acid Mine Drainage and Irrigation Water

Acid mine drainage is of particular interest as it typically comprises large volumes of contaminated water that may decant from various sources including mine dumps, underground mine shafts or surface mines. Worse still, AMD typically flows into existing water courses contaminating these resources and soils, thereby adversely affecting soil fertility and crop production, water supply systems for drinking and

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irrigation, along with various infrastructures. Ultimately, these impacts of AMD endanger the health of humans, animal and aquatic life, causing complications and even deaths (NPEP 2016; Ochieng et al. 2010). Figure 1 shows such a scenario of AMD seepage from an abandoned coal mine in South Africa. It can be seen that the AMD seeps into existing evaporation pond receptors. Often grazing animals drink this polluted water while children naively play and swim in these AMD-filled evaporation ponds. Ultimately, the AMD seepage enters into the river located besides a human settlement destroying aquatic life and contaminating the natural water resource.

It should be appreciated that polluted water sources cannot be directly utilized for beneficial applications owing to the high concentrations of pollutants present. Typically, these contaminant elements include heavy metals, organic and inorganic compounds, biological contaminants such as bacteria and viruses. For irrigation in particular, crop uptake of excessive concentrations of metals and trace elements present in soils or water, adversely affects crop growth and yield. Higher up the food chain, animal and human consumption of the resulting agricultural produce from these crops, would lead to serious health hazards (Libutti et al. 2018; Shakir et al. 2017; Urbano et al. 2017). As such, it is necessary to treat polluted water before it can be used for irrigation and other various practical uses.

Mine water reuse can be a viable source of agricultural water supply that could contribute to the conservation of water resources and to reduction of environmental problems related to effluent discharge into water bodies (Libutti et al. 2018). Van Zyl et al. (2001) reported that mine water which is partially treated for removal of free acidity, metals, magnesium and sulphate to levels less than 2000 mg/l, could be used for irrigation. Annandale et al. (2001) also reported that the use of gypsiferous mine water for irrigation of agricultural crops could alleviate a shortage of irrigation water and address the problem of disposing mine effluent. Their study showed considerable increases in the yield of sugar beans and wheat when irrigated using gypsiferous mine water. However, the cost of treating polluted mine water for irrigation should be affordable. Furthermore, some kinds of treated mine water has the potential to supply (organic) carbon nutrients (NPK) and (inorganic) micro-nutrients to support crop/plant growth (Singh et al. 2012; Vergine et al. 2017), thereby minimizing the use of chemical fertilizer inputs and the related transfer of nutrient concentrations to natural water bodies.

Water Treatment using Pervious Concrete

As discussed, finding alternative water sources through cost-effective treatment of polluted mine water, is essential towards alleviating water stress on natural resources, i.e. by meeting the growing demand for irrigation water etc. while contributing to overall economic development. It is emphasized that the method of water treatment should be sufficiently cost effective to allow the treatment of large volumes of polluted water that can be used for agricultural purposes. The potential use of pervious concrete to treat AMD is one of the recent interesting developments in water treatment research. It has been shown that pervious concrete can be used as a reactive material in a permeable reactive barrier system of AMD passive treatment. In recent studies (Shabalala et al. 2017; Ekolu et al. 2014, 2016; Nnadi et al. 2015; Shabalala 2013; Solpuker et al. 2014; Ekolu and Katadi 2018), the removal of metals from acidic AMD using pervious concrete, has been fully demonstrated.

Study Objectives

Irrigation water quality is generally evaluated using physicochemical parameters, Sodium Absorption Ratio (SAR), Soluble Sodium Percentage (SSP) and Kelly's ratio (KR) (Shah and Mistry 2013). In this research, acidic mine water from

Fig. 1 Seepage of acid mine drainage from an abandoned coal mine besides a river and a human settlement

two sources, one obtained from a coal mine (TDB) and the other from a gold mine (WZ), were treated using pervious concrete. The treated water quality was then evaluated for suitability towards irrigation use. Water quality parameters including pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), metals, SAR, KR, and SSP indices, were determined and compared against standard water quality requirements for irrigation. The present study is part of an ongoing research on the potential use of pervious concrete for effective treatment of contaminated water, to a level of suitability for various uses. The study also provides the scientific basis for innovative use of pervious concrete technology, towards reducing water stress and supporting irrigated agriculture.

Materials and Methods

Acid Mine Drainage Samples

Acid mine drainage samples comprising WZ and TDB, were collected from the field sites for use in the laboratory experiments. Both the WZ and TDB samples were highly contaminated acidic mine water with pH levels of 4.14 and 5.79, respectively. The WZ and TDB water had elevated TDS amounts of 3847 and 12,833 mg/L, and high salinity levels of 4430 and 15,800 µS/cm, respectively. Chemical analyses of WZ showed high metal concentrations of Ca (582 mg/L), Mg (170 mg/L), Na (139 mg/L), Mn (131 mg/L), Fe (12 mg/L), Al (3 mg/L), Ni (1.3 mg/L), Zn (1.4 mg/L) and Pb (< 0.03 mg/L). The TDB water samples also had high contents of Ca (470 mg/L), Mg (214 mg/L), Na (3061 mg/L), Fe (9 mg/L), Al (6 mg/L), Ni (0.6 mg/L), Zn (2.8 mg/L) and Pb (< 0.03 mg/L). Water analysis showed high SO_4 concentrations of 1123 and 2870 mg/L in the WZ and TDB mine water samples, respectively. Additional chemical parameters of the AMD sources are also given later in Table 1, which compares the concentrations of dissolved elements against the standard quality requirements for irrigation water.

Column Experiments using Pervious Concrete

The investigation comprised column tests conducted on AMD using the pervious concrete reactive media. Pervious concrete is typically made of portland cement and a single-size aggregate, typically between 6.7 and 13.2 mm size. Mixtures are proportioned so as to form an interconnected gross pore network with porosity values of 20–30%. As such, pervious concrete has high hydraulic conductivity, basically allowing water to flow through its pore network quite freely. Figure 2a shows water flowing through a 200 mm thick slab of pervious concrete.

Columns made of perspex plastic, each of 650 mm height and 100 mm square internal diameter, were set up. Four concrete cubes of 100 mm size were placed in each column. Pervious concrete was made using 6.7 mm granite aggregate and portland cement consisting of CEM I 52.5R (CEM I) alone or CEM I with 30% fly ash (30%FA). A mixture of 0.27 water/cementitious ratio was used. For each column, an AMD sample was pumped at a flow rate of 0.35 mL/min, from a reservoir to the bottom of columns by using a peristaltic fish pond pump. During the first 3 months, sample collection was done once a day. Afterwards, sampling frequency was decreased to once every third day and, subsequently, to once a week as temporal changes in metal concentrations became less significant. Water samples drawn from the columns on day 1, 28, 60, 90, 133 and 177 of the experiment, were selected and analysed. The methodology used in the present study is already described in Shabalala et al. (2017) and only summarised here for convenience. Figure 2b shows the layout of the column set-up containing pervious concrete cubes. The pH of water was measured using MP-103 microprocessor-based pH/mV/Temp tester, while Na^+, Ca^{2+}, Mg^{2+} and K^+ levels and the heavy metal concentrations were determined using PerkinElmer SCIEX (Concord, Ontario, Canada) ELAN® 6000 Inductively Coupled Plasma–Mass Spectrometer (ICP–MS) system (PerkinElmer 2003). The $SO_4{}^{2-}$, Cl^- and $NO_3{}^-$ were analysed using ion chromatography, Dionex QIC-IC.

Pervious Concrete Characteristics

The effectiveness of pervious concrete as an AMD treatment system, hinges on two most essential characteristics namely its: (1) prolific hydraulic conductivity owing to its open gross pore network and, (2) highly alkaline reactive components. As already mentioned, the pervious concrete's 20–30% porosity forms an interconnected pore network that is responsible for its efficient hydraulic conductivity. This property is typically evaluated by measuring the falling head permeability property, using apparatus such as described in Das (1998). Studies (Zhong et al. 2018; Ekolu et al. 2016) show that pervious concrete typically gives water permeability values of 2–20 mm/s depending on the mixture designs. However, the rate of water passage or flow through the pervious concrete pore network must be controlled so as to allow adequate time for chemical interactions to occur between the polluted water and the concrete's reactive components.

Concrete's key reactive component in this regard is calcium hydroxide (CH). Calcium hydroxide is a by-product of cement hydration with water. Mass quantities of this product are formed during hydration. CH is responsible for the high alkalinity of concrete giving a pH of 12.6–13.0. This product is typically intermixed within the cementitious paste matrix, which forms a lining along pore walls. The paste

Table 1 Chemical analyses of acid mine drainage samples before and after treatment with pervious concrete

Parameter	Standard requirements		AMD before treatment		AMD after treatment with CEM I		AMD after treatment with 30% FA		Treated WZ/TDB vs criteria
	DWA (1996)	Ayers and Westcot (1989)	WZ	TDB	WZ	TDB	WZ	TDB	
pH	6.5–8.4	6.5–8.0	4.15	5.79	10.79	11.04	8.96	9.95	Excessive
EC (µS/cm)	400	700	4430	15,800	3130	13,060	4010	13,570	Excessive
TDS (mg/L)		< 450	3847	12,833	2470	10,787	3593	10,973	Excessive
Na (mg/L)	70	< 69	139.31	3060.97	175.11	3261.09	299.7	3117.6	Excessive
Cl (mg/L)	100	< 142	23.4	133.5	19.7	101	17.5	103.1	Satisfactory
B (mg/L)	0.5	< 0.7	< 0.2	1.04	< 0.2	0.58	< 0.2	0.89	Satisfactory
Al (mg/L)	5	5	3.35	6.15	1.5	0.37	0.4	0.57	Satisfactory
Cd (mg/L)	0.01	0.01	0.004	0.003	< 0.001	0.001	< 0.001	0.0023	Satisfactory
Co (mg/L)	0.05	0.05	0.3	0.4	0.0075	0.0050	0.0266	0.0114	Satisfactory
Cu (mg/L)	0.20	0.20	0.12	0.14	0.074	0.13	0.0628	0.1733	Satisfactory
Cr (mg/L)	0.10	0.10	0.009	0.013	0.021	0.108	0.026	0.104	Satisfactory
Cr^{6+} (mg/L)			0.0474	0.0590	0.999	0.2087	0.0353	0.0666	Satisfactory
Fe (mg/L)	5.0	5.0	11.57	9.17	0.15	0.43	0.10	0.48	Satisfactory
Mn (mg/L)	0.02	0.2	131.05	19.72	0.015	0.024	2.27	0.03	Satisfactory
Ni (mg/L)	0.20	0.20	1.2971	0.6198	0.052	0.00	0.0723	0.0685	Satisfactory
Pb (mg/L)	0.20	5.0	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	0.03	Satisfactory
Zn (mg/L)	1.00	2.00	1.35	2.76	0.477	0.714	3.738	0.7740	Satisfactory

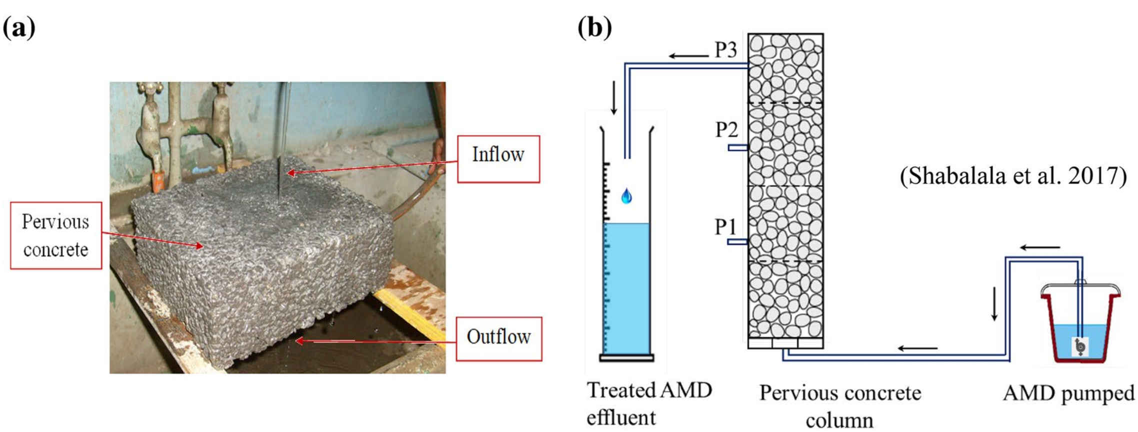

Fig. 2 Experimental set-up showing **a** free flow of water through pervious concrete, **b** column layout taken from Shabalala et al. (2017)

also contains calcium silicate hydrate (CSH) which binds the aggregates. Figure 3 shows microstructural features of CEM I pervious concrete, examined using the scanning electron microscope (SEM) TESCAN VEGA3SEM equipped with AZtec energy dispersive spectroscopy (EDS).

Figure 3a shows the binding of aggregate particles by the cementitious paste matrix. The greyish layered product within the paste appears to contain CH as depicted by the EDS given in Fig. 3b. Also, the multiple whitish specks dotted throughout the paste matrix in Fig. 3a is typically CH. Figure 3c shows a lining of the cementitious paste matrix along a pore wall. As AMD passes through such pores, it encounters the highly alkaline paste which contains CH. The CH in turn disassociates in the presence of water according to Eq. (1), releasing OH^- ions, thereby increasing the pH of the water and causing precipitation of metals out of solution (Aube 2004; Seneviratne 2007).

$$Ca(OH)_2 \rightarrow Ca^{2+} + 2OH^-. \quad (1)$$

Indicators of Water Quality for Irrigation

Irrigation water quality indicators are used to determine if a water resource has the required quality for application in agriculture. Important irrigation water quality parameters include a number of specific water properties that are relevant to the yield and quality of crops, maintenance of soil productivity and protection of the environment (Alobaidy et al. 2010). Several variables are typically considered in evaluating the quality of water and its suitability for irrigation purpose. The most widely established water quality classification for agriculture is the Food and Agriculture Organization of the United Nations (FAO) classification (FAO 1992). In the present study, the parameters comprising EC, pH, TDS, SAR, KR, and SSP, were used to assess the suitability of pervious concrete-treated mine water for irrigation purposes. Equations (2)–(4) give the formulae for calculation of the SAR, KR, and SSP indicators. Also, the concentrations of sulphates, nitrates, and heavy metals, were evaluated against the specified standard limits for irrigation water.

SAR is calculated from the concentrations of Na^+, Mg^{2+} and Ca^{2+} (meq/L):

$$\mathrm{SAR} = \mathrm{Na}^+/\left[\left(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}\right)/2\right]1/2. \quad (2)$$

where Na^+, Ca^{2+}, and Mg^{2+} are the concentrations expressed in milli-equivalents per litre (meq/L) (Suarez et al. 2006).

KR is calculated employing Eq. (3) as follows (Kelly 1963)

$$\mathrm{KR} = \mathrm{Na}^+/(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}), \quad (3)$$

SSP is calculated using the formula given in Eq. (4) (Alobaidy et al. 2010)

$$\mathrm{SSP} = \mathrm{Na}^+ \times 100/\left(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+} + \mathrm{Na}^+ + \mathrm{K}^+\right). \quad (4)$$

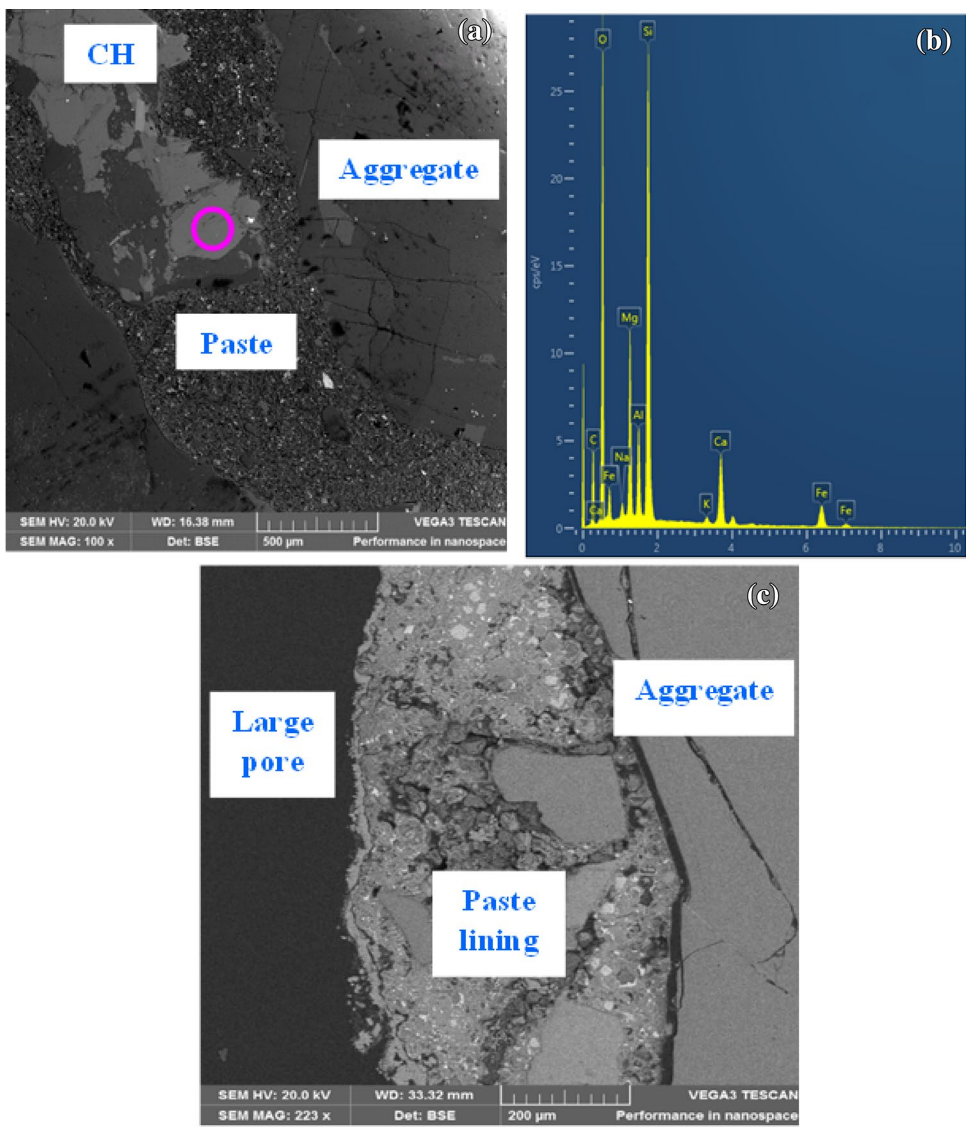

Fig. 3 SEM micrographs of CEM I pervious concrete, **a** Calcium hydroxide (CH) product; binding of aggregates by the paste matrix, **b** EDS spectrum taken at a point marked with a circle in **a**, **c** a paste lining along pore walls

Results and Discussion

Table 1 gives the physico-chemical properties of the raw AMD and the treated AMD water. The water parameters were compared to the water quality criteria for irrigation use, as specified by FAO (Ayers and Westcot 1989; FAO 1992) and the National Department of Water Affairs (DWA 1998).

pH

The pH values of non-treated WZ and TDB mine water were 4.15 and 5.79, respectively. The results obtained after AMD treatment with pervious concrete, gave pH values of 9.0–10.8 for WZ and 10.0–11.0 for TDB water. These pH levels exceed the maximum permissible range of 6.5–8.4 for irrigation water (FAO 1992; DWA 1996). High pH values tend to adversely influence the availability of nutrients thereby affecting crop growth and production.

Electrical Conductivity

The suitability of irrigation water with respect to salinity, is assessed on the basis of EC or specific conductance of a water sample. Irrigating with highly saline water adds salt concentrations to soils, which can be harmful to crops. Saline conditions restrict or inhibit the ability of plants to take up water and nutrients. This leads to stunted plant growth and yield reduction. Saline water may also contain elevated concentrations of some elements which can be toxic to plants. Such elements include boron, sodium, and chloride. However, saline water irrigation can be employed for plants such as wheat, maize and oleic sunflower that are moderately tolerant of salinity (Feng et al. 2017). Conductivity in water is affected by ions that carry a negative charge (i.e. chloride, nitrate, sulphate, and phosphate) and by ions that carry a positive charge (i.e. sodium, magnesium, calcium, iron, and aluminium). In the present study, the EC of treated mine water varied from 3100 to 13,600 µS/cm whereas the maximum permissible limit of EC for irrigation water is 700 µS/cm (FAO 1992; DWA 1998). There were no significant changes on the EC values following treatment of TDB or WZ using CEM I and 30% FA, throughout the duration of experiment, as shown in Fig. 4a.

Total Dissolved Salts

The acceptable TDS concentrations for irrigation water is limited to 450 mg/L (Table 1). Figure 4b gives the changes in TDS of the treated AMD over the duration of the experiment. Again the use of CEM I or 30% FA treatments did not change the TDS levels of the treated WZ or TDB water, as similarly observed for EC. The TDS values of both types of mine water varied from 2470 to 10,973 mg/L, which are well above the permissible limit. Just like EC, high TDS is an indication of high salinity of water, which can reduce crop production and water infiltration into soils, as already discussed above.

Metals

Elevated levels of metals in irrigation water leads to contaminated agricultural soils and subsequent uptake of these metals by the crops grown on these soils. In turn, this leads to an increase of metal concentrations in the animal and human diet, causing various health complications. Following the treatment of AMD using pervious concrete, the concentrations of all the metals tested including Al, Co, Cu, Cd, Cr, Fe, Mn, Ni, Pb, and Zn in both the treated WZ and TDB, met the standard permissible limits for irrigation water, as seen in Table 1 (FAO 1992; DWA 1998). Of concern, is the concentration of hexavalent chromium (Cr^{6+}) ion which was determined to be 0.999 mg/L and 0.209 mg/L for the treated WZ and TDB samples, respectively. These values exceed the maximum limit recommended by the World Health Organisation for Cr^{6+}, which is 0.05 mg/l (WHO 2003). Cr^{6+} is considered to be a severe health hazard to human and animal life, whether exposure to it occurs by skin contact, inhaling, or ingestion. Exposure to Cr^{6+} can cause nausea, gastrointestinal distress, stomach ulcers, skin ulcers, allergic reactions, kidney and liver damage, reproductive problems, lung and nasal cancer (WQA 2003; Tseng et al. 2018). Chromium has several oxidation states but it exists in the environment in its natural form as trivalent chromium (Cr^{3+}). Hexavalent chromium (Cr^{6+}) forms through the oxidation of Cr^{3+} during various industrial processes; it is often discarded to the environment along with industrial wastes (Pradhan et al. 2017). Raptis et al. (2018) reported that organic matter such as leonardite can be applied to chromium contaminated soils to accelerate the reduction of Cr^{6+} to the less hazardous form Cr^{3+}, thereby minimizing the associated health risks to human and animal life.

The concentrations of metals given in Table 1 for the treated mine water were analysed at 26 weeks of running the pervious concrete column. Evidently, the metals present in the contaminated water were effectively removed following the WZ or TDB treatment using CEM I or 30% FA pervious concrete. As mentioned earlier, the heavy metal concentrations in the treated WZ and TDB fell within the required limits for irrigation water, which underscores the potential of a pervious concrete reactive barrier as an effective water treatment technology.

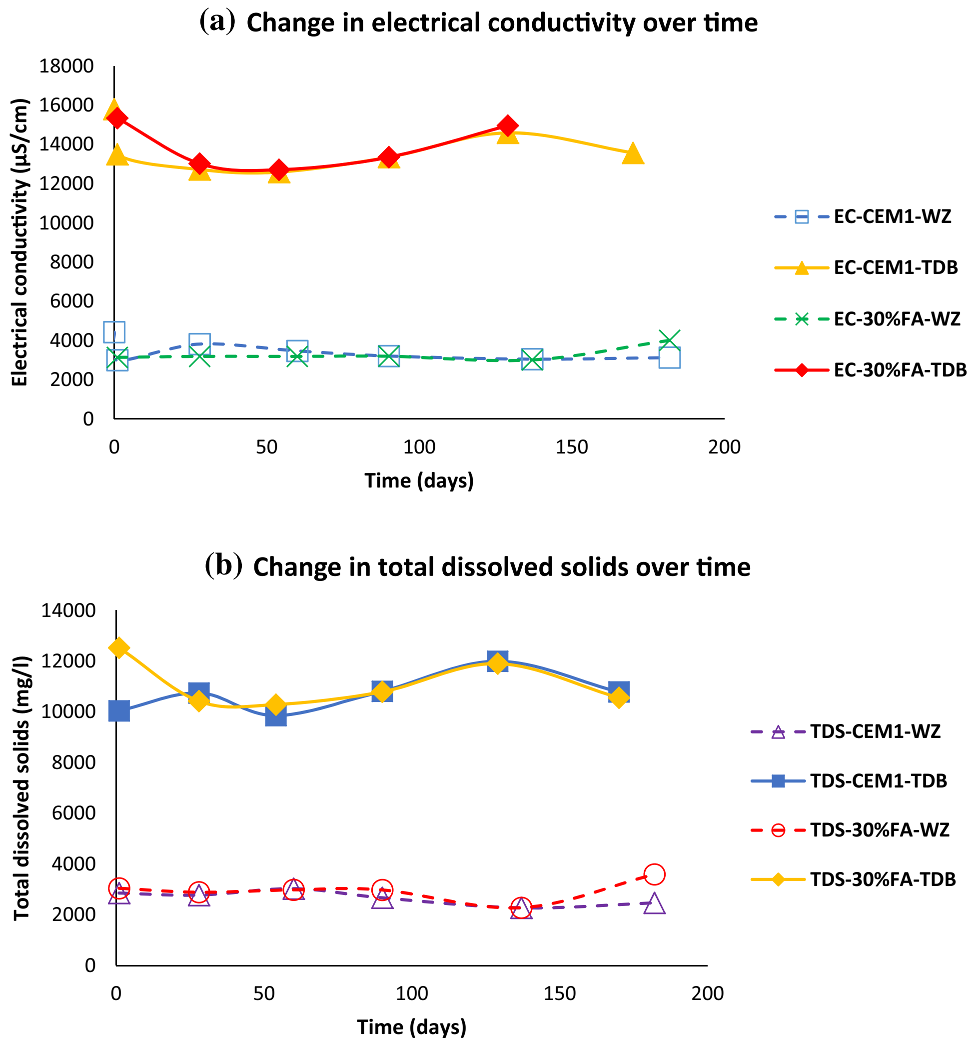

Fig. 4 Changes in **a** electrical conductivity and, **b** total dissolved solids with time during the experiment

Sodium

Na^+ is a key element in determining the suitability of irrigation water. Excessive Na^+ in irrigation water leads to highly alkaline soils that can cause physical problems and reduce soil permeability (Shakir et al. 2017). It can be seen in Table 1 that the Na^+ concentration in the treated AMD varied from 175 mg/L for WZ to 3261 mg/L for TDB. These Na^+ concentration levels are well above the required maximum levels of 70 mg/L (FAO 1992; DWA 1998).

Sodium Adsorption Ratio

Sodium adsorption ratio is one of the quality indexes for irrigation water. It is an estimation of the extent to which Na^+ can be absorbed by soil. Irrigation water having high SAR levels can lead to the build-up of high soil sodium levels over time, which in turn can adversely affect soil infiltration and percolation rates. The presence of high Na^+ concentration levels may lead to the replacement of Ca^{2+} and Mg^{2+} ions in the soil with Na^+ ions. Such changes can cause damage to the soil structure, resulting in waterlogging and poor plant growth (Shah and Mistry 2013). The typical sodium toxicity symptoms are leaf burn, scorch and dead tissue along the outside edges of leaves (Lantzke et al. 2016). Table 2 gives the guidelines for assessment of sodium hazard in irrigation water. Sodium hazard is typically evaluated in relation to SAR and EC. For the treated TDB water, the EC was found to be greater than 5.0 dS/m (5000 µS/cm) and the SAR was between 20 and 40, indicating that the water poses no sodium hazard. For the treated WZ water, the SAR and EC were found to be 0–3 and > 0.7 dS/m (700 µS/cm), respectively, also indicating the water to be safe for supplemental irrigation. These values remained consistent throughout the experiment, as shown in Fig. 5.

Kelly's Ratio

The concentration of Na^+ measured against Ca^{2+} and Mg^{2+} is taken as the KR, one of the index parameters used to rate irrigation water (Satyanarayana et al. 2016). A KR value exceeding 1.0 indicates an excessive level of Na^+ in water, making it unsuitable for irrigation. A KR value between 1.0 and 2.0 indicates marginal suitability, while values that are less than 1.0 indicate good quality water for irrigation use. The treated WZ samples had a KR value of 0.24 indicating good quality water for irrigation, as shown in Table 3. The KR value for the treated TDB samples was 6.90 indicating unsuitable water quality for irrigation. Figure 6 gives a plot of the KR values obtained for the treated TDB and WZ, showing consistency throughout the experiment.

Sodium Soluble Percentage (SSP)

This parameter classifies irrigation water according to the proportion of soluble Na^+. A value of SSP < 60 indicates good quality water, while high values > 60 shows unsafe water for irrigation. It is observed, as seen in Table 3, that the WZ samples treated with pervious concrete gave an SSP value of 19%, indicating good water quality for irrigation. The treated TDB had an SSP value of 87% showing the water to be unsafe for irrigation. It can be seen in Fig. 7 that the SSP values remained unchanged throughout the duration of the experiment, as similarly observed for the SAR and KR indicators.

Table 2 Sodium hazard for irrigation water based on SAR and EC (Ayers and Westcot 1989; FAO 1992)

	Sodium hazard		
	None	Moderate	Severe
When SAR = 0–3 and EC (dS/m)	> 0.7	0.2–0.7	< 0.2
When SAR = 3–6 and EC (dS/m)	> 1.2	0.3–1.2	< 0.3
When SAR = 6–12 and EC (dS/m)	> 1.9	0.5–1.9	< 0.5
When SAR = 12–20 and EC (dS/m)	> 2.9	1.3–2.9	< 1.3
When SAR = 20–40 and EC (dS/m)	> 5.0	2.9–5.0	< 2.9

Chloride

The most common toxicity in irrigation water comes from chloride. Chloride is not adsorbed or retained by soils. Therefore it can readily move during soil–water interaction, is taken up by crops, moves to the transpiration stream, and accumulates in the leaves. Excessive chloride concentrations in the leaves may lead to leaf burn or drying of leaf tissue (Pescod 1985). The maximum permissible limit for chloride levels in irrigation water is 142 mg/l (FAO 1992; DWA 1996). In the present study, the chloride ion concentrations in the treated WZ and TDB water were 19.7 mg/L and 103.1 mg/L, respectively, thereby meeting the permissible limits (Table 1).

Boron

Boron is a micronutrient necessary for plant growth and development. Excess boron causes plant toxicity, delayed development, inhibition of plant growth and decrease in weight, number and size of yield. The primary symptoms exhibited by plants exposed to boron toxicity are the burning of older leaf margins or tips (Shah et al. 2017). In the present study, the Boron concentration in the treated WZ sample was below detection. Boron concentrations in the treated TDB water varied from 0.58 to 0.89 mg/L, which are somehow above the maximum recommended level of 0.5 mg/L (FAO 1992; DWA 1996).

Conclusions

Acid mine drainage (AMD) collected from an abandoned gold mine (WZ) and coal mine (TDB) were treated using pervious concrete, then analyzed for various physico-chemical parameters and indices comprising Sodium Absorption Ratio (SAR), Kelly's Ratio (KR), Soluble Sodium Percentage (SSP). The treated mine water was assessed to evaluate

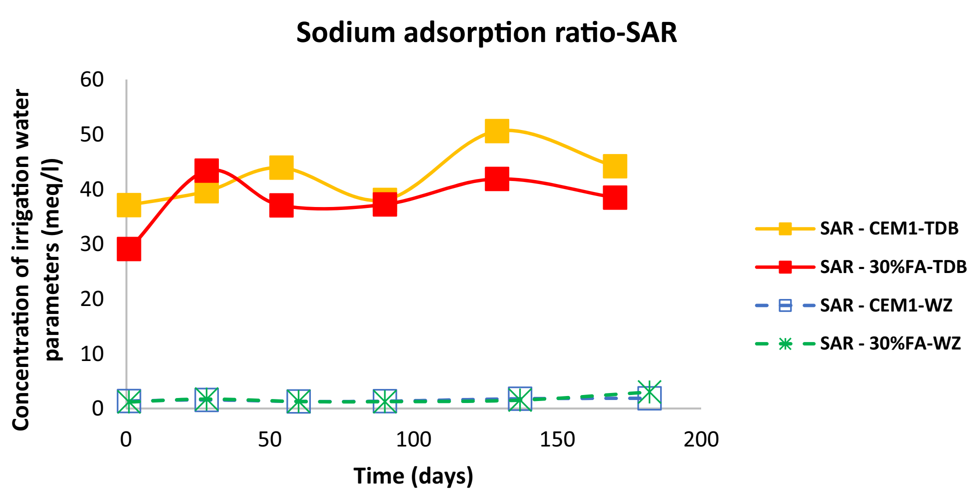

Fig. 5 Changes in the sodium adsorption ratio over time during the experiment

Table 3 Limits of some parameter indices for rating water quality and its suitability for irrigation

Parameter	WZ		TDB	
	Before treatment	After treatment	Before treatment	After treatment
KR				
< 1 unsuitable	0.14	0.24	3.22	6.90
1–2 marginal suitability				
> 1 suitable				
SSP				
< 60 safe for irrigation	12.19	19	75.77	87
> 60 unsafe for irrigation				

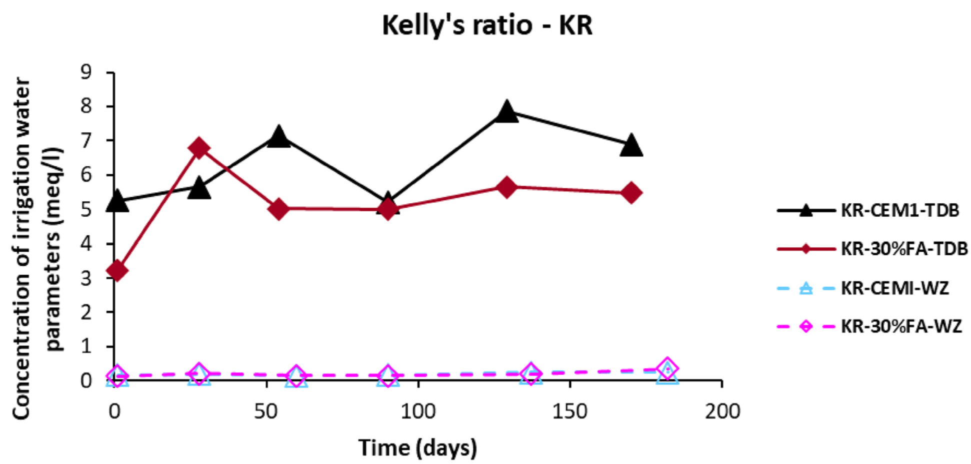

Fig. 6 Changes in Kelly's ratio with time during the column experiment

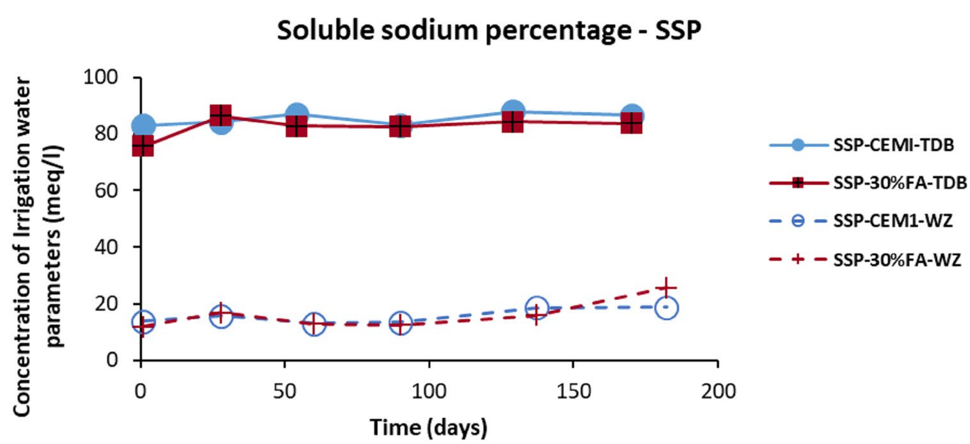

Fig. 7 Change in concentration of sodium soluble percentage with time during the experiment

its suitability for irrigation use. It was found that the treated mine water had pH levels of 9.0–11, indicating high alkalinity which exceeded permissible limits. The values of Electrical Conductivity (EC) and Total Dissolved Solids (TDS) for treated TDB water samples revealed high salinity, making the water unsuitable for irrigation while the EC and TDS values for WZ fell within the safe limits for irrigation use. Results showed that metals including Al, Co, Cr, Fe, Mn, Ni, Pb, and Zn were reduced to levels within the recommended maximum concentrations for crop production, in both the treated TDB and treated WZ. The treated TDB water had significantly high TDS, EC, SSP and KP values which made it unsuitable for irrigation purposes. The treated WZ water was found to be suitable for irrigation based on its SAR, SSP, KP contents which fell within the permissible limits for irrigation water. These findings indicate that pervious concrete technology is effective in treating mine water for irrigation use but it requires an improvement to enable attenuation of the resulting high salinity and alkalinity in the treated water.

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