Irrigation With Witwatersrand Goldmine Waters

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Abstract

Irrigation has been proposed as a cost-effective, long-term option for managing mining-influenced waters in the Witwatersrand Goldfields. However, there are concerns about the suitability of these waters for crop production as well as the safety of the produce for consumption. To address these concerns, A glasshouse pot trial was established where crops were irrigated with untreated and HDS-treated mine water from the Eastern, Central and Western Basins of the Witwatersrand Goldfields. The findings of this study indicate that crops that are safe to consume can successfully be produced with treated mine waters from the Witwatersrand Goldfields. Furthermore, the findings suggest that untreated mine waters from these goldfields can be utilized for irrigation if soils are strategically limed.

Keywords: Irrigation, Crops, Mine water.

Introduction

Cessation of mining activities in the Witwatersrand Goldfields led to the flooding of underground mine workings, posing a risk of acid mine drainage (AMD) discharge. Since many of the mines are ownerless and derelict, the management of AMD is a taxpayer liability. In 2010, three of the basins in the Witwatersrand goldfields – the Eastern, Central, and Western Basins were identified as posing the greatest AMD discharge risk. This was after AMD from the Western Basin discharged into a nearby nature reserve, making national news and prompting emergency interventions (Coetzee *et al.* 2010). These interventions included setting environmental critical levels (ECL), which are threshold water levels that need to be maintained in the underground mine workings to prevent AMD discharge. In addition, three high-density sludge (HDS) treatment plants, one in each basin, were constructed to pump and treat approximately 185 ML/day of AMD from the Witwatersrand basins. A major concern with the AMD from the Witwatersrand basins was the acidity and the high concentration of sulfate, total dissolved solids and trace elements.

HDS treatment addresses the acidity and reduces the concentration of most trace elements. However, the sulfate and total dissolved solids in the waters remain high, resulting in an increase in the dissolved salt load to receiving water bodies. This is a major concern in the Eastern and Central basins, where an average of 140 ML/day of treated mining-influenced water is discharged into tributaries of the Vaal Barrage, which supplies water to many parts of the country (Rand Water 2024; TCTA 2024). The treated mining-influenced water from these basins reportedly contributes 2500 mg/L of total dissolved solids (TDS) to the Vaal Barrage. This increased dissolved salt load often necessitates dilution with expensive Lesotho Highlands water to maintain a TDS of 600 mg/L in the catchment (DWS 2024; Rand Water 2024). The discharge of HDS-treated mining-influenced water is, therefore, not sustainable and long-term solutions are sought. Desalination using Reverse Osmosis is the preferred long-term management option. However, this technology is expensive and energy-intensive, making it unaffordable and possibly unfeasible, considering the ongoing energy crisis. Irrigation has been proposed as a cost-effective option with opportunities for great socioeconomic benefits (Annandale et al, 2023). However, there are concerns about the productivity of crops irrigated with mine water and their safety for consumption.

Irrigation with circumneutral, Ca^{2+} and SO_4^{2}-enriched mining–influenced water has successfully been demonstrated in the Mpumalanga Coalfields. Additionally, long-term modelling by Annadale *et al.* (2023) showed that HDS-treated mining-influenced water from the Witwatersrand Goldfields is suitable for irrigation. According to Annadale *et al.* (2023), even untreated mining-influenced water can be utilized if liming materials are applied to the soil to manage acidity. The productivity of crops irrigated with mining-influenced water has not been demonstrated in the Witwatersrand Goldfields. Furthermore, the food and feed safety of crops irrigated with treated and untreated mining-influenced water from the Witwatersrand basins requires investigation. Therefore, this study aimed to investigate crop responses to irrigation with untreated and HDS-treated mining influenced water from the Witwatersrand basins and to assess the food and feed safety of the produce.

Methods

Glasshouse pot trials were established in July 2024 at the University of Pretoria Innovation Africa Experimental Farm. Oat was selected as a salt-tolerant winter crop suitable for food and feed. The oat was planted in 6 L pots filled with 8 kg of red sandy loam soil from the experimental farm. Soils irrigated with untreated mine water were limed with reagent grade $CaCO_3$ to counteract the acidity from the water. Lime application rates were determined based on the acidity of the water and seasonal crop water requirements. The trial consisted of six treatments of treated and untreated mine water collected from the three Witwatersrand treatment plants for irrigation. The mine waters were analysed three times during the trial at an accredited laboratory, and the average quality is presented in Table 1. Analysis methods are listed in the laboratory accreditation certificate (Waterlab 2024). Deionised water was used as a control treatment. Each treatment was replicated four times.

The pots were irrigated when soil water was depleted by at least 40%. A crop and water-specific leaching fraction, determined using the leaching requirement equation proposed by Ayers and Westcot (1985), was applied with each irrigation. Once a week, the crops were irrigated to field capacity with a nutrient solution instead of the treatment irrigation waters. Therefore, crops with higher water requirements received more of the nutrient solution.

The crop was harvested at maturity, and above-ground biomass and grain yield were determined. Composite samples of the stems plus leaves and the grain were analysed for elements of concern. Trace element concentrations were determined in the shoots and seeds to assess the food and feed safety of the crops. Composite samples of each water treatment were analysed to determine the effect of the mine water treatments on pH (KCl), saturated paste electrical conductivity (ECe), phosphorus (P bray 1) as well as Melich III extractable macro and micronutrients.

Statistical analyses were performed in SAS® Studio. Analysis of variance (ANOVA) was used to assess the effects of the mine water on above-ground biomass production and seed yield. Mean comparisons were performed using Tukey's Studentized Range (HSD) Test.

Results and Discussion

Effect of mine water irrigation on selected soil chemical properties

Selected soil chemical properties of soils irrigated with mine water are presented in Table 2. The pH of the soils irrigated with untreated AMD was greater than 7, indicating

Table 1 Average qualities of mine water collected from the EB (Eastern Basin), CB (Central Basin), and WB (Western Basin). Concentrations are in mg/L, acidity as mg/L CaCO3 eq., EC in mS/m and pH without units.

Parameter	EB untreated	EB HDS treated	CB untreated	CB HDS treated	WB untreated	WB HDS treated
pH	6.36	7.81	5.79	8.14	6.29	9.33
EC	283	257	384	375	342	331
Ca	328	321	538	785	616	697
Mg	112	97	162	138	94	71
Na	185	188	157	155	165	159
SO4	1328	1254	2317	2280	1882	1864
Cl	109	110	57	56	47	47
Acidity	130	9	427	5	100	5
Al	0.06	0.057	0.140	0.100	0.100	0.129
As	0.17	0.003	0.239	0.056	0.300	0.011
B	0.26	0.249	0.451	0.169	0.075	0.074
Cd	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cr	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Cu	0.010	0.021	0.010	0.010	0.010	0.010
Fe	78	0.18	276	0.69	46	0.55
Pb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mn	4.2	1.7	19	1.47	17	0.48
Hg	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mo	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
Ni	0.053	0.031	0.308	0.025	0.032	0.025
U	0.059	0.047	0.004	0.001	0.105	0.015
Zn	0.028	0.026	0.063	0.025	0.032	0.029

that the application of limestone was efficient in neutralizing the waters. Irrigation with the mine water did increase the ECe of the soils. However, the ECe of the soils was within the ideal and acceptable range as predicted by (Annandale *et al.* 2023). Melich III extractable concentrations of selected trace elements in soils irrigated with mine water were generally similar to those of the control. This is likely due to the addition of limestone in soils irrigated with untreated AMD and the generally circumneutral pH of the soils irrigated with HDS treated AMD reducing the availability of the elements.

Above-ground biomass production and grain yield of crops irrigated with mine waters

Irrigation with mine water had no substantial effect on crop biomass production except in oats irrigated with the Eastern Basin mine waters. Oats irrigated with these waters yielded substantially greater biomass than the control. There were no substantial differences in biomass between the mine water treatments except for oats irrigated with Central Basin AMD, which yielded substantially less biomass than oats irrigated with treaded Eastern Basin AMD.

Irrigation with the mine water had no substantial effect on crop yield except in oats irrigated with treated water from the Eastern and Central basins, which produced higher yields than the control. Oats irrigated with CB AMD had substantially lower yields than those irrigated with treated CB AMD.

The biomass production and yield of crops irrigated with Eastern Basin mine water are consistent with predictions made by Annandale *et al.* (2023), which indicated

Table 2 Soil pH, ECe and selected Melich III extractable elements. Concentrations are in mg/kg, ECe in mS/m and pH without unit.

Parameter	Control	EB HDS treated	CB HDS treated	WB HDS treated	EB untreated	CB AMD untreated	WB AMD untreated
pH	6.83	7.24	5.93	6.58	7.66	7.27	7.52
ECe	25.9	181	220.8	189.5	188.2	254	173.2
P	148	86	86	113	60	52	98
K	44	60	63	53	71	71	52
Ca	1309	1762	1288	2013	1742	2513	2069
Mg	127	502	626	316	700	992	508
S	26	907	1534	1369	1295	2260	1401
Na	21	264	279	229	336	384	220
Fe	64.07	61.21	48.32	60.94	60.24	108.31	65.4
Mn	145.9	54.2	40.91	74.69	69.86	89.62	102.03
Cu	4.11	4.22	3.4	3.62	3.79	3.71	3.56
Zn	8.57	5.22	4.52	5.53	5.52	5.52	5.26
B	0.33	0.9	0.33	0.34	0.87	0.56	0.41
Mo	0.5	0.66	0.55	0.37	0.21	0.42	0.35

that these waters were the most suitable for crop production. Annandale *et al.* (2023) predicted that irrigation with CB AMD could negatively affect yield. However, in this study, these waters had no significant effect on the yield. Overall, these results indicate that mine water from the Witwatersrand Goldfields can successfully be used for crop irrigation with no effect on productivity.

Food and feed safety of crops irrigated with mine waters

Local and International food and safety feed safety regulations cite As, Cd, Hg, and Pb as contaminants in food and animal feed (DAFF 2010; FAO-WHO 2023). Therefore, food and feed safety assessments focused on these elements. Uranium was also included in the analyses, as the concentration in some of the waters exceeded irrigation and drinking water quality thresholds (DWAF 1996a, 1996b).

Table 3 shows the concentration of As, Cd, Cr, Hg, Pb, Ni and Zn concentrations in the plant material compared to food and feed safety thresholds. As, Hg and Pb were below food and safety thresholds in all plant materials analysed, indicating that irrigation with the mine waters did not result in the bioaccumulation of these elements in the edible parts of oats. Cd concentrations exceeded food safety thresholds in oats irrigated with untreated WB mining-

Table 2 Mean above-ground biomass production and yield of oats. Means with the same letter are not significantly different (p-value=0.02). Units are g/pot.

Treatment	Aboveground biomass	Yield
Control	149(bc)	35 (b)
EB HDS treated	201 (a)	61(a)
EB untreated	198(a)	60 (ab)
CB HDS treated	193(ab)	73 (a)
CB untreated	138(c)	34(b)
WB HDS treated	185 (ab)	54(ab)
WB untreated	194 (ab)	51 (ab)

Table 3 *As, Cd, Cr, Hg, Pb, Ni and Zn concentrations in oats compared to food and feed safety thresholds. Units are mg/kg on a dry mass basis. Shaded cells indicate an exceedance of the relevant threshold(s).*

	As	Cd	Hg	Pb	U
Food safety threshold	—	0.1	0.1	0.2	—
Feed safety threshold	2	0.5	0.1	5	—
			Leaves and stems		
Control	<0.01	<0.01	<0.01	<0.01	<0.01
EB HDS treated	<0.01	<0.01	<0.01	<0.01	<0.01
CB HDS treated	<0.01	0.24	<0.01	<0.01	<0.01
WB HDS treated	<0.01	<0.01	<0.01	<0.01	<0.01
EB untreated	<0.01	0.14	<0.01	<0.01	<0.01
CB untreated	<0.01	<0.01	<0.01	<0.01	<0.01
WB untreated	<0.01	0.18	<0.01	<0.01	<0.01
			Grain		
Control	<0.01	<0.01	<0.01	<0.01	<0.01
EB HDS treated	<0.01	<0.01	<0.01	<0.01	<0.01
CB HDS treated	<0.01	<0.01	<0.01	<0.01	<0.01
WB HDS treated	<0.01	<0.01	<0.01	<0.01	<0.01
EB untreated	<0.01	0.09	<0.01	<0.01	<0.01
CB untreated	<0.01	<0.01	<0.01	<0.01	<0.01
WB untreated	<0.01	0.29	<0.01	<0.01	<0.01

influenced water. This suggests that irrigation with untreated mining-influenced water from the Western Basin can result in the bioaccumulation of cadmium, posing a food safety risk. Nonetheless, cadmium concentrations were below feed safety thresholds. Uranium concentrations were below the detection limit (0.01 mg/kg). However, this detection limit is greater than typical concentrations found in staple foods (0.002 mg/kg), as reported by the WHO (2001).

Although substantial amounts of As and U were added to the soil through irrigation, this did not result in the bioaccumulation of these elements in the plant material, suggesting limited mobility of these elements in soils and or limited translocation to the edible portions of the crop. In contrast, there was substantial bioaccumulation of Cd in the plant material despite the waters containing low concentrations of the element.

Cd availability is pH dependent, and the concentration of plant-available cadmium is typically higher in acidic soils (pH < 5.5)(Gu *et al.* 2022; Kicińska *et al.* 2022; Zhang *et al.* 2023). Cadmium concentrations in the mine waters were below the detection limit, and soil pH was greater than 5.5. The relatively high concentrations of Cd in the plant material may be a result of the soils containing substantial amounts of the element and/or the mine waters increasing the availability. Additionally, studies have shown that plants can accumulate substantial amounts of Cd even though the soil concentrations of the elements are low (Liu *et al.* 2016; Niu *et al.* 2023; Rolka 2015).

The food safety assessments suggest that crops irrigated with HDS-treated mining-influenced water from the Witwatersrand Basins should be safe for consumption, as predicted by Annadale et.al (2023). The food safety risk of crops irrigated with untreated WB untreated water as well as the food safety risk posed by U in the EB waters and the untreated WB untreated water require further investigation. More sensitive water and crop analyses are required to explore the magnitude of the risk.

Conclusions

Irrigation offers a mine water management option that will support water and food security, with the potential to create livelihoods. This study demonstrated that crops can successfully be produced with treated mine water from the Witwatersrand Goldfields. Furthermore, the untreated mine water from these goldfields can be utilized for irrigation if soils are strategically limed. Concentrations of major elements of concern were generally below the food and feed safety thresholds. However, food safety risks posed by Cd and U, particularly in crops irrigated with untreated mining-influenced water, require further investigation.

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