THE EFFECT OF TREES ON PHYSICAL AND CHEMICAL PROPERTIES OF SUBSTRATA CONTAMINATED BY GOLD MINE WASTE DISPOSAL

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DECLARATION

I declare that this Research Report is my own, unaided work. It is being submitted for the Degree of Master of Science at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

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Signature of Candidate

Signed on 22 day of May 2015 in Johannesburg.

ABSTRACT

The Witwatersrand Basin has the world's richest deposits of gold and low-grade uranium, with South Africa being the world's leading producer of gold. In South Africa, 70% of all waste is generated by mining, mainly the gold and uranium, platinum and coal sectors. In the Witwatersrand Basin alone, there is approximately 400 km^2 of gold tailings storage facilities (TSFs) and footprints. Acid rock drainage (ARD) is one of the most severe types of mine pollution and emanates from ore being exposed to both oxygen and water, which acidifies the water leaching through the dumps. This could potentially percolate into ground water systems, and eventually river systems. ARD could lead to contamination by metals and metalloids and could affect the chemical speciation of these elements.

Phytoremediation involves using plants and soil micro flora, as well as non-living biomass to improve the quality of a substrate; as plants naturally take up metals from soil and water. Metal hyperaccumulators are of interest as they are capable of accumulating high concentrations of metals and metalloids in their tissues, thus making them highly applicable for mine remediation purposes.

The aim of the project was to assess whether two species of trees, namely *Rhus lancea* and *Tamarix usneoides*, have the potential to phytoremediate ARD by modifying the physical and chemical properties in the substrate, versus a control. For each tree species, two treatments, i.e. woodland and grassland (control) substrates were studied within two gold mine sites near Klerksdorp (on the western part of the basin), with different soil forms and conditions for the growth of trees. The results were interpreted in order to assess if either of these tree species show potential for remediation of ARD-impacted substrata.

Soil samples were collected from the two gold mine sites in the dry season of 2009. Physical analysis of the soil samples included: soil colour; carbon, hydrogen,

nitrogen and sulphur (CHNS) analysis, X-ray fluorescence (XRF); soil fertility; and soil texture of the soil samples. Chemical analysis included the initial physical-chemical soil solution measurements, the sequential extraction of the soil using the European Communities Bureau of Reference (BCR) method, and the analysis of the BCR extracts using inductively coupled plasma - optical emission spectroscopy (ICP-OES). Analysis was done for the following major nutrients: calcium, magnesium, potassium, phosphorous and sulphur, and trace elements: aluminium, arsenic, chromium, copper, iron, lead, manganese, mercury, nickel, titanium, uranium, vanadium and zinc. The statistical analysis included: descriptive statistics, percentage differences, principal components analysis (PCA), histograms, analysis of variance (ANOVA), and linear regression analysis (LRA).

The trees enhanced the physical-chemical characteristics of the soil, i.e. the pH increased by 7% due to alkalinising effects; the conductivity increased by 88% due to salt and metal hyperaccumulation from the soil; and the redox potential decreased by 15%, thus reducing the oxidation potential of the soil.

The trees also improved the phyical soil characteristics improving soil texture, due to the introduction of finer particles into the soil; i.e 18% more clay particles.

The chemical condition of the soil in the presence of the trees also bettered, as the concentration of calcium increased by 14% in the soil due to top-soil enrichment. Hence the trees have enriched the soil substrate by increasing the calcium in the soil. PCA showed that calcium, magnesium and sulphur were grouped together while phosphorous and potassium formed another grouping; indicating similar behaviour within each major nutrient group. ANOVA results suggested that the concentration of the major nutrients showed no significant difference between the woodland and the grassland treatment substrates (p = 0.388 for the first grouping and p = 0.405 for the second grouping). The linear regression results indicated that the major nutrients had a significant, linear, negative relationship with depth; hence the equation which was generated could be used in future predictions.

Nickel decreased in the presence of the trees by between 39%. The trees likely absorbed the nickel ions from the soil, causing a decrease in the soil solution.

The PCA showed three distinct groupings, namely one for mercury, vanadium, chromium, arsenic, titanium, nickel and zinc; another for aluminium, manganese, and iron; and lastly uranium and lead formed another grouping, again indicating similar behaviour in each grouping. The ANOVA results indicated that aluminium, manganese and iron showed a significant difference between the woodland and the grassland treatment substrates ($p = 0.00$), and no significant difference for the other trace elements ($p = 0.40$ and $p = 0.20$). The linear regression data indicated uranium and lead had a significant, quadratic correlation with depth ($p = 0.01$), while the other trace elements did not have a significant correlation with depth.

Distribution curves showed that aluminium, chromium, iron, phosphorous, potassium, titanium, vanadium and nickel (at the VRMP), were mainly present in the residual fraction, while calcium, magnesium, manganese and nickel (at the VRWC) were mainly present in the BCR fractions. The trees did not change the percentage distribution of aluminium, chromium, iron, phosphorous, potassium, titanium, vanadium and nickel (at the VRMP), but did change that of calcium, magnesium, manganese and nickel (at the VRWC)

The study revealed that *Rhus lancea* and *Tamarix usneoides* tree species have a great apititude for the treatment of ARD through phytoremediation, as the physical, and chemical characteristics of the mine soils improved in the presence of the trees.

The research also highlighted the differences between the sites, and it was found that the overall soil quality was better at the VRWC than at the VRMP. For example the conductivity of the soil was 168% higher, the CEC in terms of soil fertility was 129% higher, and all major nutrients were between 96% and 183% higher at the VRWC than at the VRMP.

Differences between the tree species, i.e. *Tamarix usneoides* and *Rhus lancea* were also investigated, and it was found that *Tamarix usneoides* was more effective in improving the overall quality of the soil. For example the buffer pH was 10% higher, and the conductivity 107% higher in the soil surrounding *Tamarix usneoides*, while the redox potential was 18% lower, thus improving some of the conditions which exacerbate ARD. The magnesium was 71% in the presence of *Tamarix usneoides*.

DEDICATION

My loving and supportive parents

Faried and Nazley Arendze

You have guided me well

My beloved cousin

Candice Trompetter Moon

In memory of your amazing spirit

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LIST OF ABBREVIATIONS

AGA	AngloGold Ashanti Ltd
AMD	Acid mine drainage
ANOVA	Analysis of Variance
ARD	Acid rock drainage
BCR	European Community Bureau of Reference
CCD	Charge coupled detector
CEC	Cation exchange capacity
Cedara	KwaZulu-Natal Department of Agriculture and Environmental Affairs
CHNS	Carbon, hydrogen, nitrogen and sulphur elemental analysis
CRM	Certified reference material
CT	Control
ECEC	Effective cation exchange capacity
ICP-OES	Inductively coupled plasma – Optical emission spectroscopy
NEMA	National Environmental Management Act
PCA	Principal components analysis
PVC	Poly vinyl chloride
RL	*Rhus lancea*
SPSS	Statistical Package for Social Sciences
TSF	Tailings storage facility
TX	*Tamarix usneoides*
VRMP	Vaal River Mispah

VRWC	Vaal River West Complex
XRF	X-Ray fluorescence spectroscopy

LIST OF SYMBOLS

%	percentage
µm	micrometre
µS cm^{-1}	micro-Siemens per centimetre
°C	degrees Celsius
cm	centimetre
cmol kg^{-1}	centi-mole per kilogram
Eh	redox potential
g cm^{-3}	grams per cubic centimetre
g	gram
K	kelvin
km	kilometre
km^2	kilometres squared
m	metre
M	molarity, moles per litre
mg kg^{-1}	milligrams per kilogram
mg L^{-1}	milligram per litre
mL	millilitre
mm	millimetre
mm	millimetre
mol L^{-1}	moles per litre
V	volt

ppm	parts per million
US$	US dollars