Vermiculite Covers on Mining Wastes in a Semi-Arid Environment in South Africa

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Abstract

Deposition of large quantities of mining waste can have negative impacts on surface and ground water resources. These impacts necessitate amelioration of the wastes through various measures, but primarily through a cover system. These covers are designed to restrict percolation of rain water through the waste material, and thereby restrict moving contaminants to groundwater, either through retention and subsequent evapotranspiration, or by water shedding. Cover systems in semi-arid areas require particularly careful design and performance evaluation in order to provide a sustained first defence to impacts. This study assesses the performance of covers comprising vermiculite material over waste rock and tailings.

Keywords: Mine waste covers, vermiculite covers, mine waste water balance

Introduction

Deposition of large quantities of mining waste can have negative impacts on surface and ground water resources. These impacts necessitate reclamation and amelioration of the wastes through various measures, but primarily through a first level of remediation in the placing of cover systems over the waste. These covers are designed to restrict or detain percolation of rain water through the waste material and thereby moving contaminants into the groundwater or surface water receptors. Covers also protect waste materials from water and wind erosion, thus contributing to the sustainability of vegetation, which can further restrict the ingress of rain. Moreover, cover systems located in semi-arid areas require particularly careful design and performance evaluation in order to provide a sustained first defence to impacts.

The aim of this study is to evaluate a verminculate material in a waste rock and tailings cover in a mine in the Limpopo province of South Africa, where the Mean Annual Precipitation (517 mm) is considerably less than the Mean Annual Potential Evaporation

Figure 1 *Sampling site layout*

(1774 mm). Performance of this type of material in cover systems in semi-arid environments has not been quantified heretofore. Observations include percolation fluxes in two large lysimeters in waste rock material, with a vermiculite cover as well as runoff from an automated runoff plot on the Waste Rock Dump (WRD). On a copper tailings storage facility (TSF), top surfaces and side slopes runoff was observed, together with the monitoring of soil water content and soil water tension at various depths in the cover and tailings waste. In addition, the hydraulic characteristics of the cover and waste materials were measured through in-situ and laboratory testing.

This study provides a rare set of physical observations, simulations and assessment of the water balance resulting from the use of a vermiculite material in waste covers in a semi-arid environment. The detailed observations and assessments lend value to cover design using other materials in semi-arid climates.

Methodology

Although some research has been conducted on the use of exfoliated vermiculite in hydroponics, no documented research has been discovered on un-exfoliated vermiculite in the mineral state, as a cover for mine wastes (Abate & Masini, 2005). The hydraulic characterisation of vermiculite may also be very site specific as this will depend on the mineral waste materials that were mined with the vermiculite (Van der Nest & Kuit, 1993; Wates, et al., 2006). Cover types and material properties of the covers have a specific influence on the water balance mechanisms and these need to be identified and quantified to determine an accurate water balance.

Setting

The study area is located in the North-Eastern part of the Limpopo Province of the Republic of South Africa, some 5km southeast of the town of Phalaborwa and adjacent to the Kruger National Park

Eight (8) sampling sites (fig.1) were identified that were seen as representative of the location. A Davis Weather station was used to obtain continuous climatic data at the site. Additional climatic data were also obtained from at least 2 other local weather stations. The sampling sites included 5 runoff plot sites on the TSF, with 2 Lysimeters as well as a runoff plot on a WRD. In the selection of the runoff plot sites consideration was given to slope, aspect, vegetation and cover materials. Runoff- plots 1, 2, 3 & 4 have been established on the side slopes (1:3) of the TSF. Runoff plot 5 has been established on a top surface of the TSF, whereas runoff plot 6 was established on a very steep slope of the WRD (fig. 1).

Lysimeters

Lysimeters 1 and 2 were established on the WRD on top surfaces by excavating and shaping an 8x8x2m cavity in the waste rock (fig. 2). The base and sides of the lysimeter were lined with a plastic liner and an aggregate drain was placed at the bottom centre.

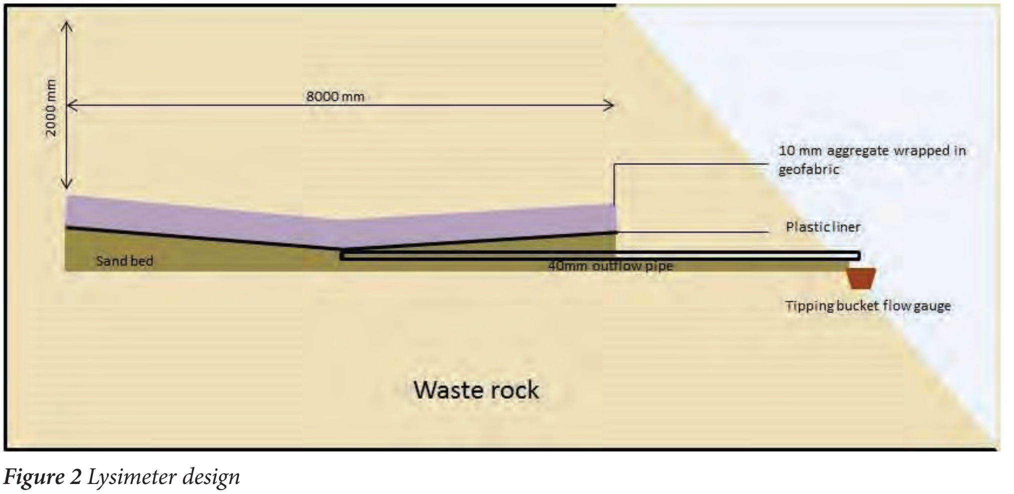

Figure 2 *Lysimeter design*

The base of the lysimeter sloped towards the centre where a drain led the seepage water to a tipping bucket approximately 6 meters away from the lysimeter. The tipping bucket was placed in an excavation lower than the drain to allow for gravity flow from the lysimeter drain to the tipping bucket (fig.2).

Soil Water Monitoring

Next to each sampling site Time Domain Reflectometry (TDR) probes were installed at 100mm, 500mm and 1000mm below the surface. These served as volumetric water content sensors which were read periodically using a TDR100 wave generator. The volumetric water content record was used to calibrate the water balance modelling and to assess water transfers between cover and waste.

Runoff Plots

Event based infiltration and run-off was measured in plots (2m wide x10 m long), isolated from surrounding runoff by sheet metal inserted into the surface. Each plot was equipped with a collection gutter at the down slope end, from which runoff was discharged into a tipping bucket and tips recorded with an event logger. The soil moisture measurements were used to assess subsequent evaporation and transpiration of the water infiltrated into the cover and waste.

Material characteristics

Cover and underlying waste hydraulic characterisation was completed in-situ using Tension Infiltrometers, Double Ring Infiltrometers as well as Guelph Permeameters and samples were extracted for laboratory water retention tests. The tests were performed on surface and at depths of 100mm, 500mm and a 1000mm at each of the eight sampling sites. The surface measurement represented the cover material, the 100mm depth observation represented the cover-waste and the 500 mm and 1000 mm measurements represented the tailings materials.

Evaporation and seepage

Potential evapotranspiration was estimated using temperature, humidity, wind speed and solar radiation data. Lysimeters were also used to estimate the actual evapo-transpiration released by vegetation and soils.

Results

Hydraulic characteristics

Typical hydraulic characteristics at two sites are compared here. The hydraulic conductivity characteristic of the materials at runoff plot 3, on a steep TSF side slope (1:3), and runoff plot 5, on a flat TSF surface, reveal significant differences between the materials (fig. 3). The hydraulic conductivity (both saturated and unsaturated) of the flat surface runoff plot 5 has unsaturated hydraulic conductivities an order of magnitude lower than at runoff plot 3, on the 1:3 side slope. The saturated hydraulic conductivities at runoff plot 5 are also lower than those at runoff plot 3, but by less than an order of magnitude. The differences in hydraulic conductivities of the tailings material may also be attributed to the method of tailings deposition. Runoff from the flat surface at plot 5 could be expected to exceed

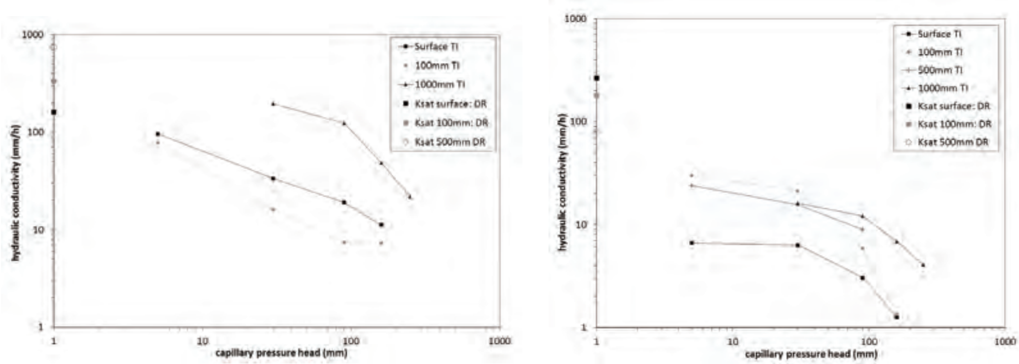

***Figure 3** Hydraulic conductivity characteristics at runoff plot 3 (left) abd runoff plot 5 (right).*

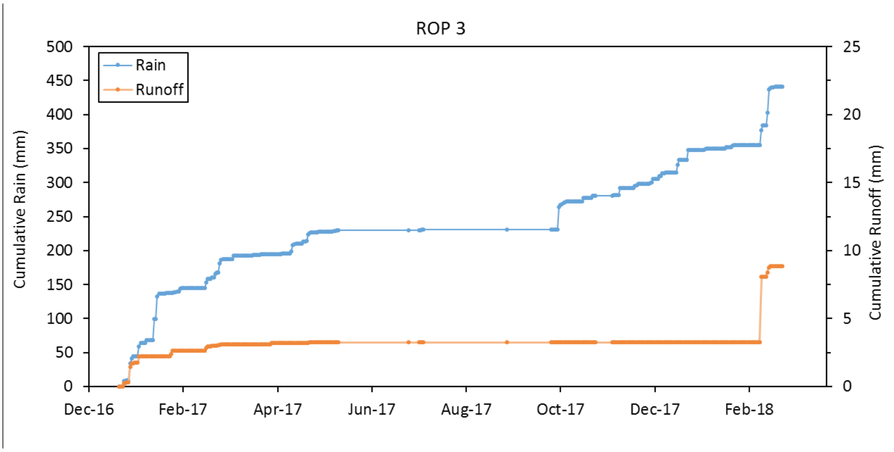

Figure 4 *Rainfall and runoff at TSF runoff plot 3 (side slope 1:3)*

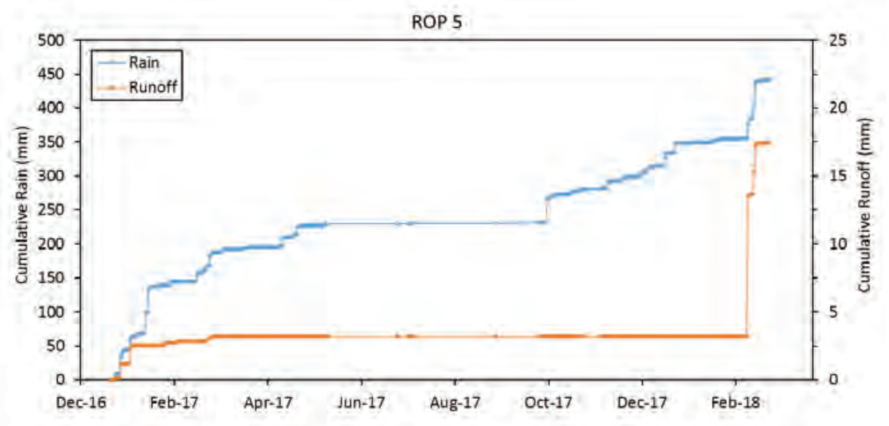

Figure 5 *Rainfall and runoff at TSF runoff plot 5 (slope ≈ 0).*

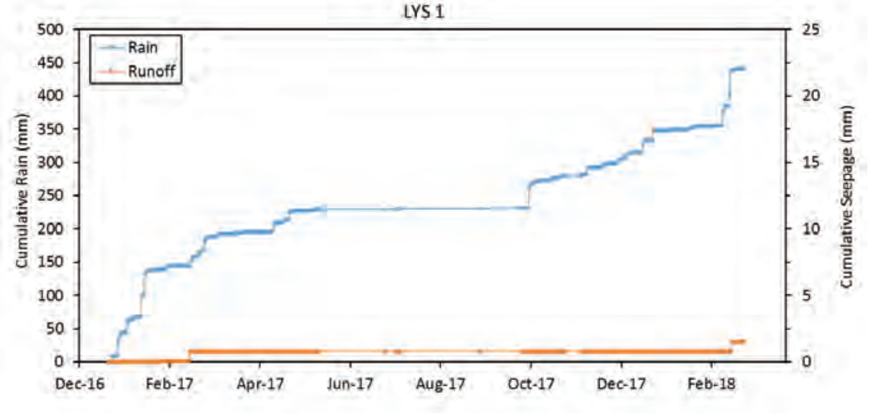

Figure 6 *Rainfall and seepage at a WRD lysimeter plot (similar for both plots)*

Table 1 Summary of the water balance

Component	Runoff Plot 3		Runoff Plot 5		WRD Lysimeter	
	(mm)	(%)	(mm)	(%)	(mm)	(%)
Rain	441.4	100	441.1	100	441.4	100
Runoff	8.8	2	17.4	4	0.0	0
Infiltration	432.6	98	424.0	96	441.4	100
Evaporation	156.9	36	156.9	36	169.3	38
Transpiration	250.9	56	250.9	56	270.7	61
Seepage	25.0	6	16.4	4	1.5	0.3

that of the sloped site due to the low hydraulic conductivities at plot 5, limiting the ingress of water. The materials in the plot 5 profile are more compacted than at the side slope site, resulting in these low conductivities.

The hydraulic conductivities within the cover materials are generally lower than in the tailings, although at the flat site (plot 5), the saturated conductivity in the cover material is higher than in the tailings, but the unsaturated characteristic of the cover material falls below the tailings material, at least on surface, and particularly at capillary pressure heads lower than 100 mm. The higher conductivities in the tailings compared to the vermiculite cover materials is indicative of the fine nature of the tailings, retaining water at low capillary pressures, while the coarser nature of the vermiculite material loses water, even at low capillary pressures, resulting in low hydraulic conductivities.

Runoff and Seepage

The time series of runoff over 14 months of observation at plot 3 (sloped), (fig. 4) and runoff plot 5 (flat), (fig. 5) reveal that the steeper slope yields less runoff (9 mm) than the flat TSF area (17 mm). This surprising difference in the runoff volumes suggests a high infiltration capacity in the side slope profile and a lack of deeper wetting, indicated by the deep soil water probes, supports the high water retention in the vermiculite cover. At the WRD lysimeters, on the other hand, the infiltration at both sites yielded just 0.7 mm of seepage at 2m below surface, indicating that the vermiculite fines in the cover and within the waste rock matrix are highly effective in retaining the ingress of rainfall (fig. 6).

Observations of the water contents over a long time series indicate that these infiltrated volumes are released to evapotranspiration demands after the events.

Water balance

The water balance in the tailings and waste rock have been estimated using a combination of simulations with the HYDRUS-2D soil physics model, (Šimůnek et al., 2006), and confirmed against the observations. The surface runoff in the TSF and the seepage in WRD were confirmed through observed fluxes.

The resultant water balance is summarised in Table 1, showing volumetric water balance components in mm and as a percentage of total rainfall during the observation period from 21 December 2016 to 2 March 2018. The total rainfall observed during the period was very low (441 mm) and produced very little runoff or seepage. This is typical of the savanna in which the site is located.

In the TSF, runoff varies from 2% (sloped surface) to 4% (flat surface) of the rainfall. Seepage varies from 6% to 4% of the rainfall for the sloped and flat surfaces, respectively, while the evapotranspiration losses comprise 92% of the rainfall.

In the WRD lysimeters, no runoff was observed, while seepage comprised only 0.3% of the rainfall recorded during the observation period. Here, the evapotranspiration is estimated to comprise over 99% of the rainfall. This is deemed feasible as rooting systems were observed in the entire 2 m of the WRD upper profile.

Conclusions

Preliminary examination of the 14 months of monitoring the tailings and waste rock sites indicate that the vermiculite cover materials over the tailings and within and over the waste rock provides an excellent medium for allowing infiltration of rainwater at the surface, but also provides an effective storage medium for later release of water to evapotranspiration demands.

Water content observations within the cover and tailings materials in the TSF sites indicate the tailings below the cover is a significant component of the store and release fluxes of the cover system.

Continued monitoring is recommended so that rainfall seasons yielding higher annual precipitation can be observed, since the 14 year observation period in this study coincided with a significantly low precipitation period.

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