# Dust deposition at a Gold Mine Village in the West Rand

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For communities found encroaching tailings storage facilities (TSFs) in the Witwatersrand, windblown dust is perceived as a health threat and an environmental challenge. The community from a gold mine village in the West Rand perceives Tailings Storage Facility number 6 and other surrounding tailings storage facilities which are partially rehabilitated to be a health and socio economic threat. Since 2013, when a gold mine in close proximity to this community was liquidated complaints about dust have been prevalent and nothing has been done in terms of rehabilitation. To validate the claims made by the community this paper reports on the dust deposition, and respiratory illnesses risk posed by wind-blown generated dust. The study conducts an air quality assessment using dispersion modelling of windblown dust. Surface material from the TSFs was sampled, analysed for silica and heavy metal content using X-ray fluorescence (XRF) and inductively coupled plasma- mass spectrometry (ICP-MS). This paper finds dust fallout, PM10, high silica and uranium content which could potentially pose health threats to the surrounding community. The paper further shows that dust deposition is the highest in July-October, with TSF6 posing a nuisance while TSF1 being a potential health threat owing to its particle size distribution for the surrounding gold mine villages.

Key words: TSFs, windblown, dust, respiratory illnesses, health, heavy metals

## INTRODUCTION

It is reported that as of 1997, South Africa has an estimated 468 million tons of mineral waste produced per annum (DWAF, 2001). Gold mining waste accounts for 221 million tons or 47% of mineral waste produced in South Africa, this makes gold mining the largest source of waste and pollution (DWAF, 2001). There are approximately 270 tailings storage facilities reported in Witwatersrand Basin, covering 400 km2, in surface area (Anglo Gold Ashanti, 2004). Tailings storage facilities (TSFs) are residue of the milling process used to extract valuable mined ores. Moreno et al. (2010) defines tailings as the crushed, sand-like by-product refuse material, generated during extraction, crushing, grinding and milling procedures of mined ore during the mining process .The Merafong Municipality which hosts the study site of this paper is estimated to have approximately 23 TSFs (Chevrel et al, 2008).

A number of these TSFs are unlined and not rehabilitated, providing a source of dust. One of the environmental challenges brought about by unrehabilitated TSFs include water contamination and air pollution by wind-blown dust. In 2013 the West Rand District Environmental Management Framework estimated approximately 21.0 ton/day particulate emissions from TSFs in the Merafong municipality, the largest emitter in the West Witwatersrand Basin (Gauteng Air Quality Assessment, 2011). The impacts further include physical and aesthetic modification of the environment, and challenges with sustainable vegetation cover as a result of soil contamination, since tailings contain toxic heavy metals (Gauteng Air Quality Assessment, 2011).

Challenges of environmental and socio- economic impacts remain a major governance problem, even though the roles of the DMR, DWS, NNR and DEA have been clarified. Furthermore, there is a lack of integration in literature of the links between legislation, the environment and key stakeholders such as the community. The various state departments have their requirements on mining companies before the official closure of a mine occurs. The main requirement involves a complete environmental management plan (EMP) and adequate financial provisions for rehabilitation before a closure certificate can be granted. Of late some mining companies have been observed to evade this requirement through the process of winding- up a company, leading to unscheduled mine closure. Banister et al (2002) assessed forty gold mining companies' EMPs and found that, most mines recognise that TSFs generate dust, however they believe that once a mine closes these facilities' impacts decrease. Munnick (2010) notes that the South African government supports mining and has a weak regulation system when it comes to enforcement in practice. This poor enforcement in legislation results in environmental degradation, thus affecting surrounding communities.

A study by Oelofse et al. (2012) note that mine closure and the increase in Acid Mine Drainage have critical consequences for mining affected communities, this is also supported by (Adler and Rascher, 2007; Warhurst and Norhona, 2000; Claassen, 2006; Ojelede et al., 2012). At the time of these studies premature mine closure was uncommon. Recently there are very few impact assessment studies linking premature mine closure with environmental impacts and socio economic impacts, often studies look at the one end of the problem. It is to the researcher's knowledge that this paper presents the first study considering premature/unscheduled mine closure (mine liquidation), linking it with environmental and socio economic impacts with a special focus on threats posed by dust from TSFs to surrounding communities.

The purpose of this paper is to conduct an air quality impact assessment on a community surrounding a liquidated gold mine. This paper aims to investigate whether the community complaints about the dust emanating from tailings storage facility 6 (TSF6) are valid; thus establish possible solutions to address the dust problem. The study considers the wind erodible particulate matter (PM10), total suspended solids and dust fallout

The primary objective of this paper is to establish a baseline air quality in the area. The study attempts to establish a causal relationship between mine liquidation, environmental degradation and community respiratory illnesses and socio economic impacts.

The secondary objectives are:

1. To quantify the amount of dust contributed by other surrounding tailings storage facilities in the vicinity of TSF 6 and Blyvoor community using AERMOD dispersion model.
2. To conduct a chemical analysis of all TSFs surrounding the Blyvoor community, to investigate

the toxicity of the dust and the health threats it poses.
3. To conduct a particle size distribution analysis to investigate the health threats posed by the dust size fraction

**CHALLENGES IN THE WEST RAND**

Since the premature mine closure occurred in 2013 due to a mining company being liquidated the community of a gold mine village in the West Rand is complaining about dust. The community specifically complains during the windy season (July, August to October), this includes surrounding business owners, school and the clinic. The community complains that the dust triggers respiratory related illnesses, thus they end up spending money to treat these illnesses. Hence the title of the paper states that this is an assessment of the air quality impacts emanating from Tailings Storage Facility 6 and the surrounding Tailings dumps. Figure 1 illustrates a windy day in the area as observed by the surrounding affected community.

*Figure 1. A windy day in a gold mine village*

**METHODOLOGY**

Various factors contribute to the dispersion, transformation and eventual removal of particles, from the atmosphere and the ground. Such factors include local meteorology, topography, land-use, source features (e.g. point, area, volume, line or pit source and source dimensions) and source strengths. A typical air quality assessment involves the assessment of measured ambient air quality data, or dispersion modelling results, somethings involves both. Total Suspended Solids (TSP), dust fallout and PM10 are particulate matter investigated in this study as pollutants of concern. The US Environmental Protection Agency (USEPA, 1998) states that approximately 50% of the TSP is emitted as PM10, especially from mining sources.

The dispersion modelling conducted in this study is guided by the, South African Regulations Regarding Air Dispersion Modelling, 2014. Reference to the British Columbia Air Quality Dispersion Modelling Guideline, (2015) and the Good Practice Guide for Atmospheric Dispersion Modelling, New Zealand (2004) is consulted as best practice to the dispersion modelling. This study considers emissions inventory for Carletonville area; a review of the regulatory requirements and health thresholds for identified key pollutants; dispersion modelling to determine the impacts on the receiving environment in the vicinity of the community; and a screening assessment to determine compliance with the National Ambient Air Quality Standards (NAAQSs) and Dust fall Control Regulations (NDCR) is undertaken. In South Africa air quality is regulated under the National Environmental Air Quality Act (Act No. 39 of 2004) (NEM: AQA), this act ensures air quality management and compliance. Other regulations considered in this study include National Ambient Air Quality Standards (NAAQS), and the National Dust Control Regulations (NDCR) shown in the appendix.

The focus of this assessment was on the wind erodible sources (calculated using an updated methodology), primarily the Tailings Storage Facilities (TSFs) which, over time, have been partially vegetated resulting in a change in the wind erosion potential of these sources. In this assessments other sources such as the main mining roads have not been included together with other sources such as crushing and screening and plant emissions. This is due to the fact that all these tailings have no current mining activities occurring since the liquidation in 2013 and the main mining road is tarred with very little traffic, thus emissions from these sources were assumed to be insignificant. The vegetated areas or portions of the TSFs were excluded from the assessment. The assumption is that no wind erosion occurs on the vegetated areas. A source apportionment was conducted on Google Earth by digitizing the various TSFs to obtain the size.

To assess the effects of dust and the state of air quality and its impacts in the study area, the AERMOD dispersion model is used. The AERMOD (AERMOD Version 09292) is used in this study since it is a recommended model for sophisticated near-source applications in all terrain types (where near-source is defined as less than 50 km from source). AERMOD, has a range uncertainty of -50% to 200%, the accuracy improves with fairly strong wind speeds and neutral atmospheric conditions. The uncertainty comes as a result of modelling the physics, input errors, and stochastic processes.

**Description of the study area**

From an air quality perspective, this particular area in the West Rand involves activities associated with the generation of fugitive particulate matter. Fugitive particulate matter includes all emissions that are uncontrolled, cannot be captured and are therefore difficult to quantify (Garbett in Brady, 2005). The study area is classified as an urban environment. It involves all areas in the vicinity of TSF6, TSF1, TSF7, Dormant AGA, Doornfontein 1, Doornfontein 2, Savuka 5 and Savuka 7. The surrounding receptor communities include the gold mine village ward 5 and ward 27, Doornfontein mine village, Wedela, Fochville, Carletonville and Khustong. The study site is located 6 km south west of Carletonville town see Figure 2.

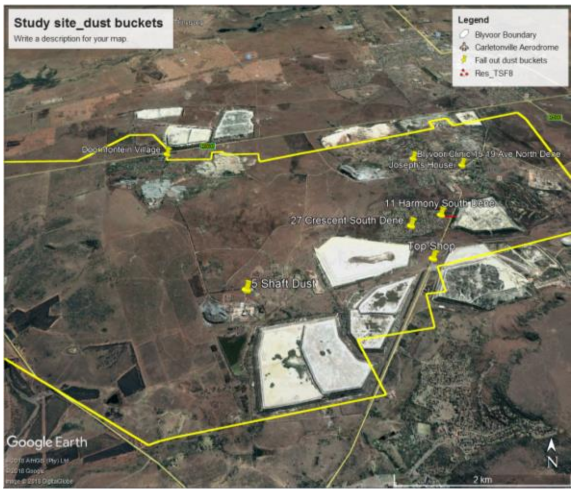



*Figure 2. Tailings Storage Facilities source material and dust sampled*

**Data collection**

***Source material-surface sampling***

Material samples were selected from eight TSFs. The samples were chosen due to their proximity (within 10 km) to the community of interest (the gold mine village). The samples were scooped from the top center surface and slope surface of each tailings dam on all side of the tailings, and that material was mixed in one sample bag as one representative sample for each of the eight tailings storage facilities. Material from the top center of the TSF represents the core deposited material as original material. Side slope material represents material eroded from the top layer by the wind and water.

***Dust fallout sampling***

The sampling of dust fallout was conducted in all the areas marked in yellow in Figure 2. Samples were collected from the dust fallout monitoring campaign conducted in 2018. The dust fallout monitoring uses a method called the American Society for Testing and Materials standard method for collection and analysis of Dustfall (ASTM-1739). A single dust bucket collects TSP, PM10 and PM2.5 particulate as it lands in the bucket. The dust data was collected to validate the dispersion modelling results and to conduct the particle size analysis and chemical content of the actual dust particles.

For each tailings storage facility and receptor location, three dust samples were collected for chemical analysis and particle size distribution analysis. The three samples each represent the duration of the windy season which covers August to October 2018 (see Appendix). The dust samples and the soil were analysed for particle size distribution; moisture content, clay content, silt content, particle density and bulk density.

**Data Analysis**

*Source material characterisation-Particle size distribution*

To characterise each TSF, the particle size distribution, moisture content, clay content, silt content, particle density and bulk density were analysed as agents of particle entrainment. The particle size distribution was undertaken by using the Malvern Master Sizer system. Particle aerodynamic diameters determines if and for how long dust remains airborne, their likelihood of being inhaled, and their site of deposition in the respiratory system. Dust concentration in the air and the aerodynamic diameter of the particles will determine the amount of material deposited, hence the dose received at the critical site (WHO, 2006).

*Meteorological data analysis*

Meteorological characteristics have impacts on the rate of emissions from fugitive dust sources, and govern the dispersion potential and eventual removal of pollutants from the atmosphere (Pasquill and Smith, 1983). To characterise the meteorological setting of the area, data from Anglo Gold Ashanti meteorological station called WW Mponeng Plant (S) was used, consisting of wind speed, precipitation, relative humidity and wind direction (see Table 2). The data obtained from the met-station, covered the period of mine liquidation which started from 2012 to 2017. Hourly data of the aforementioned period was obtained and input files were generated using AIRMET pre-processor for the dispersion simulations.

*Emissions quantification*

Preparation of input files according to the Marticorena and Bargametti (1995) model were conducted as part the windblown dust emissions quantification in the study area. Marticorena and Bargametti (1995) model accounts for variability in source erodibility through the parameterization of the erosion threshold (based on particle size distribution of the source) and roughness length of the surface. The model also takes into account soil crusting related to friction velocity, these control the horizontal and vertical movements of dust. The emission rates are determined using Airborne Dust Dispersion Model from Area Sources (ADDAS) from the entire study site. The ADDAS model uses the threshold friction velocity of the particle size and the vertically integrated horizontal dust flux (see equation 1, 2 and 3) (Marticorena and Bargametti, 1995; Burger, 2010).

$$E_i = G_i 10^{(0.134C-6)} \quad [1]$$

$$G_i = 0.261 \frac{\rho_a}{g} U_{i+1}^3 (1 + R_i)(1 - R_i) \quad [2]$$

$$R_i = \frac{U_{i+1}}{U} \quad [3]$$

Where $Ei$ = emissions rate (size catergory); $C$ = clay content (%); $\rho_a$ =air density; $Gi$ = gravitational acceleration, $U$ = frictional velocity; and $U_{i+1}$= threshold friction velocity (size category1).

ADDAS Model key inputs are summarised in Table 1. To cover the entire study area as shown in Figure 2 a 7.5km by 7.5km receptor grid with a 100m resolution was used for dispersion modelling purposes.

According to the Greece, National Pollutant Inventory (NPi) (2012) an emission factor of 0.4 kg/ha/h should be adopted for TSP and a factor of 0.2 kg/ha/h should be used for PM10. These emission factor values are supported by Environment Australia (2001). The values were used as part of data validation and improving certainty in the modelling process. The US EPA finds that the friction velocity of 5.4 m/s initiates erosion of coal from a storage pile and was used in this study (US EPA, 2006). Milan and Yanful (2003) calculated a wind speed of 9 m/s as the speed required to initiate erosion from tailings storage facilities in New Brunswick and Ontario, Canada. Table 1 summarises all the data inputs for the ADDAS model.

*Table 1. ADDAS model key inputs for dispersion modelling, moisture content and surface cover*

| Location | Density (kg/m$^3$) | Moisture (%) | Surface Cover (%) | Understurded-nonvegetation (Y/N) | Min U*t | Erodible Fraction (%) |
|---|---|---|---|---|---|---|
| TSF7 | 2640 | 0.69 | 48 | N | 5.4 | 52 |
| TSF6 | 2640 | 0.09 | 10 | Y | 5.4 | 90 |
| SAVUKA 5 | 2640 | 4.14 | 19 | N | 5.4 | 211 |
| SAVUKA7 | 2640 | 0.48 | 27 | N | 5.4 | 57.01 |
| DORMANT AGA | 2000 | 0.07 | 87 | N | 5.4 | 81 |
| TSF1 | 2000 | 0.04 | 20 | Y | 5.4 | 211 |
| DOORFONTEIN 1 | 2000 | 0.07 | 90 | N | 5.4 | 19.75 |
| DOORFONTEIN 2 | 2000 | 0.08 | 1 | N | 5.4 | 73 |

The TSFs were considered not to be active as no active mining activities were taking place in the study area at the time of data collection. The surface roughness length was considered to be the same for all tailings, the surface cover was measured through digitizing the vegetated portion of the TSFs.

*Model Validation*

All measured dust fallout data was used to compare with the dispersion simulations (see Appendix Table 3).

*Limitations and assumptions*

The vegetated areas and rock dumps were excluded from the assessment, they are assumed not to contribute to the wind-blown dust. The study relied on aerial photographs of the area as part of source data characterisation. The TSFs are the only source considered in the modelling process. The AERMOD model is known to produce inaccurate results very close to area sources.

*Chemical Analysis*

To characterise contaminants within the selected TSFs, chemical analysis was conducted for all soil samples and dust samples collected in the area. The analysis included XRF and ICP-MS analysis.

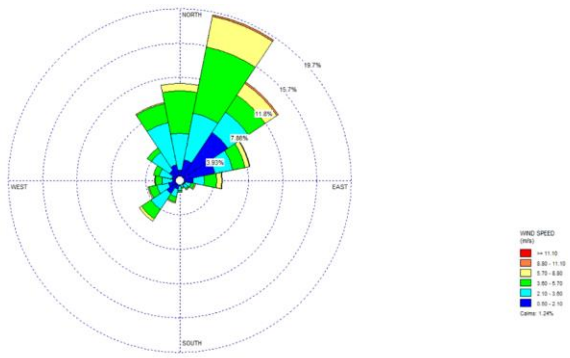
The ICP-MS analyses indicates the toxic metals which have potential to affect human health. The ICP-MS analysis followed the USEPA 3051a procedure. The X-Ray Fluorescence (XRF) analysis was also undertaken, this is a non-destructive technique used to determine elemental composition of the sampled material.

## RESULTS AND DISCUSSION

### Meteorological parameters

The extent to which pollution will accumulate or disperse in the atmosphere (atmospheric dispersion potential) depends on the meteorological factors such as wind speed, wind direction, air temperature etc. The wind speed determines the distance of downwind transport and the rate of dilution as a result of plume stretching (Liebenberg-Enslin et al., 2012). The wind speed governs the mechanical turbulence affected by surface roughness. Wind direction determines the pathway pollutants will follow and the spread of the winds (Shaw and Munn, 1971; Pasquil and Smith, 1983; Oke, 1990). Air temperature determines plume buoyancy, mixing and inversion layers. Rainfall represents the removal of pollutants from the atmosphere. Atmospheric stability determines the heating of the ground and mechanical mixing due to the friction effects from the earth’s surface. Table 2: summarizes the meteorological parameters obtained from the WW Mponeng Plant Station.

*Table 2.Meteorological parameters from the WW Mponeng Plant Station*

| **Parameter Period from January 2012 to December 2017** | | Wind Rose Diagram |
|---|---|---|
| Wind Direction | N; NE |  |
| Wind speed | 2.94 m/s | |
| Precipitation | 846 mm | |
| Relative | 54%-71% | |
| Humidity | Fairly neutral | |
| Atmospheric | 283 | |
| Stability | | |
| Solar radiation | 10-23°C | |
| Receptor grid | 7.5 km x 7.5 km | |
| Temperature | | |

The wind rose is shown in Table 2 showing an average wind speed of 2.94 m/s. The wind rose has 16 spokes, which illustrate the direction which the wind blew at specific periods. The colours used in the wind rose, reflect the different categories of wind speeds, for example, dark blue shows a range betwe0.5- 2.10 m/s , light blue shows a range of 2.10 -3.4 m/s (see Table 2). The strongest wind speeds are greater than 6 m/s which occurred mostly during spring months. The general wind direction in the study area is Northerly and North-Easterly. July to August represents the driest months with low precipitation, this provides for wind erosion to occur with ease. The average rainfall during the liquidation period was 846 mm. The study area has neutral atmospheric conditions in general (West Wits, Air Quality Assessment, 2014).

**Particle Size Distribution**

Shao (2008) explains that aerodynamic lifting of dust particles occurs when the influence of gravity and dynamic forces is diminished in small particles. The inter-cohesion of particles has more influence in this type of dust emission. Saltation bombardment where particles move because of localized movements is another mechanism of vertical dust movement. Disaggregation is when particles are released from aggregates in soil typically with high clay content. When there are strong winds, dustcoats and aggregates may disintegrate resulting in increased dust emissions. Several studies show that onset saltation occurs at wind speed 4m/s while dust generation of visible plumes occurs at wind speeds above 6m/s (Maseki et al., 2017).In Figure 3 TSF1 has bulk of its particle size distribution (80%) ranging between < 2 and 30 µm (fine material), followed by Savuka 7(60%). From the graph it is evident that TSF6 and Doornfontein 2 have primarily coarse material, while TSF7, Savuka 5, Dormant AGA and Doornfontein 1, show a mix of both fine and coarse material (see Figure 3). It is expected that TSF1 shows high contributions of PM10 while TSF6 show the highest TSP emissions (see Figure 4). TSF1 and SAVUKA 7 are the biggest health threats with high contributions of respirable fraction of particulate matter. These two TSFs surround the gold mine village, although TSF6 is partially vegetated and TSF1 is located 800 m away from the first line of houses in the Blyvoor mine village.

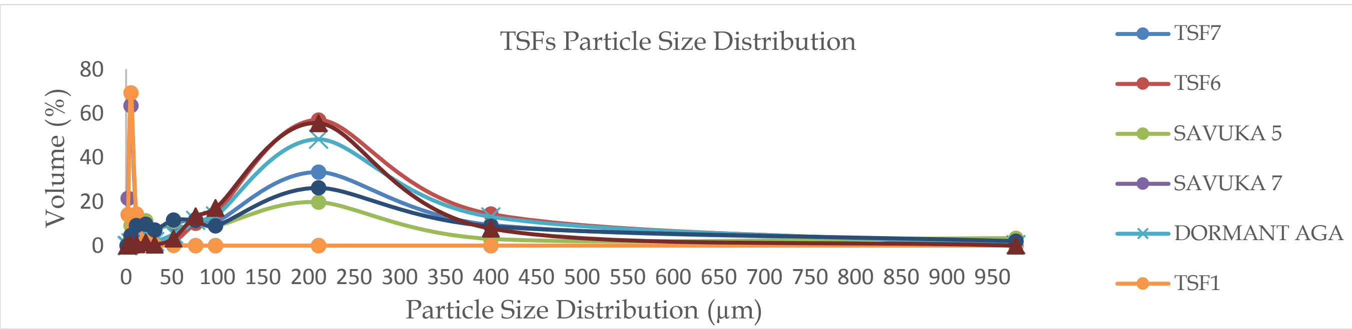



*Figure 3. Particle Size Distribution for Study site Tailings Storage Facilities*

Tegen and Fung (1994) state that global dust emissions consists of 13% of particle size ranging from 0.5 to 1 µm, while 65% in the range of 1 to 35 µm and 22% in the range of 35 to 50 µm. In this study approximately 60% of the particle size is between 2-40 µm. From the size analysis, it is clear that the community in the gold mine village is affected by PM10 and dust fall, owing to its location close to TSF1 and TSF6. Fine particulate matter is known to induce subtle health effects, mostly respiratory diseases and physiological potency (Espinosa et al., 2001; Paschoa et al., 1984).

It appears that TSF1 underwent hyperfine milling of ore during reprocessing and this resulted in fine material. TSF 6 has chiefly coarse particle sizes, this storage facility has not been reprocessed to date. For the community close to the gold mine, TSF6 contributes nuisance dust (inhalable dust) covering a distance of 60-1000 m which triggers community complaints, while TSF1 consists mainly of the respirable dust fractions.

**PM 10 and TSP emission rates**

The PM10 and TSP (in g/m²/s) average emission rates at the selected TSFs are provided in Figure 4.

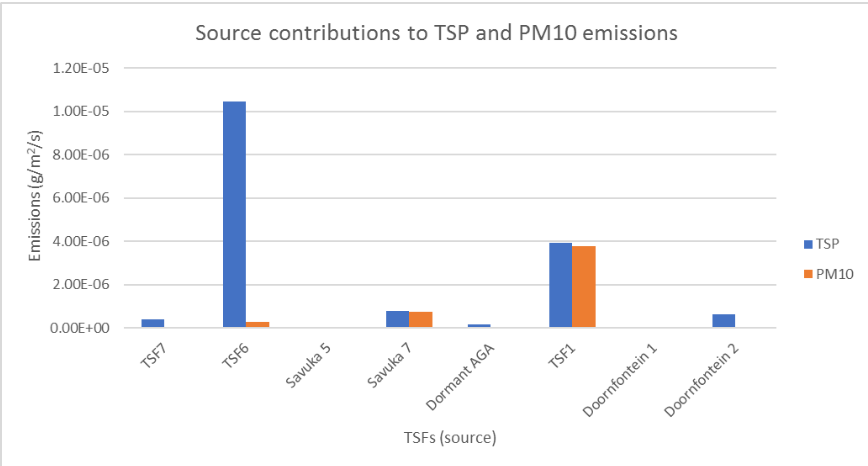



*Figure 4. Source contribution to overall emission rates TSP and PM10*

TSF 6 contributes the highest emissions and has the largest surface area (1086773 m²) while TSF1 contributes the highest PM10 emissions as illustrated in Figure 4. This is no surprise as this TSF showed the highest percentage of particle size distribution in the <2-30 µm range.

Figure 5a) and b) summarises the seasonal variation of TSP and PM10 emission rates over the different sources.

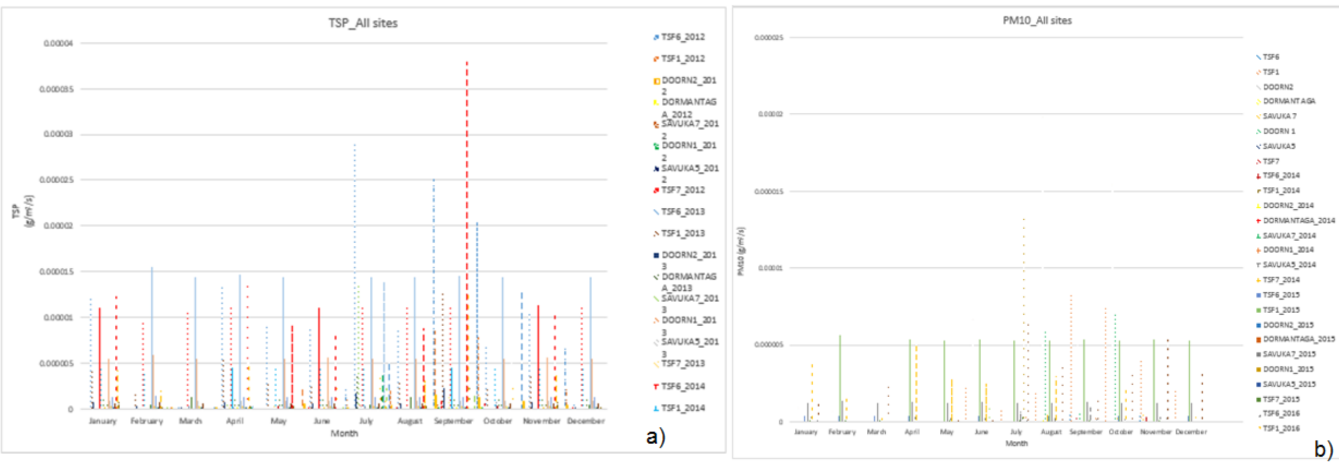



*Figure 5. Seasonal emission rates a) TSP and b) PM10*

During the spring season (August-October) the highest emission rates are calculated for TSP in TSF6 in 2016, 2013 and 2012. In all these years the gold mining company in close proximity to the community was under the supervision of the liquidator. Similarly for PM10 the highest emission rates were reached during the windy season (July-October). The highest PM10 rates are calculated at TSF1 in the year 2016 and 2014; and at Savuka 7 in 2016. The better vegetated TSFs such as Savuka 5, Dormant AGA and TSF7 show the least emission rates. This reinforces that rehabilitated TSFs are less of an environmental and human health threat.

**Dispersion simulations**

***PM 10 simulations***

The model results are the ground level concentrations (GLCs) in mg/m$^2$/day for dust fall, and µg/m$^3$ for TSP and $PM_{10}$. The results are shown as graphical presentations of isopleths shown from figure 6 to 8. The isopleth plots depict interpolated values from the concentrations simulated by AERMOD for each receptor point identified. The daily and annual averages are shown for worst cases and these are compared with the NAAQS and NDCR as shown in the Appendices. Figure 6 below shows the highest daily and hourly PM10 ground level concentrations.

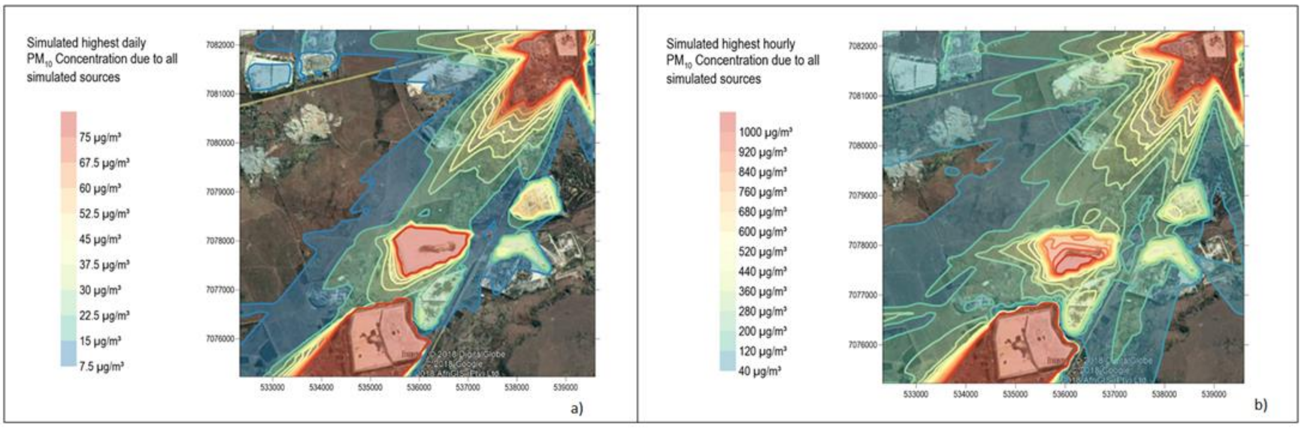



*Figure 6. Simulated highest daily $PM_{10}$ a) and Highest hourly $PM_{10}$ b) concentration due to all simulated sources*

TSF 6 and TSF 1 seem to be directly impacting on the community with no clear exceedances of the 75 µg/m$^3$ daily standard. Figure 6 b) summarizes the highest hourly ground level concentrations of PM10 in the study area. It should be noted that there is a possibility that even though a high hourly average concentration is simulated at certain locations (TSF1, TSF6 and Savuka 7), this may have been a possibility for one or two hours at a time while the 24 hour average concentrations remain in compliance with the standard. The community of Wedela (located south of Savuka 7) seems to be the most affected as it is located downwind of all the TSFs assessed in this area, this community is outside of the study area thus not shown in Figure 6. There is a major threat of impacts in the short term which could be the source of the community complaints at specific days and months. Although simulated concentrations appear to be below the daily standard, the short term exposure is a threat enough to trigger respiratory diseases. Several studies suggest that short term exposure to particulate matter is associated with health effects even at low concentrations of exposure. Adam et al. (2004) established that short-term exposure to outdoor air pollution PM10 and PM2.5 can worsen respiratory symptoms. Pope et al. (1992) studied daily mortality in relation to $PM_{10}$ in Utah and found that daily average of 365 µg/m$^3$ had recorded effects on mortality. Short term exposure to PM10 is associated with lower respiratory symptoms, medication use and small reductions in lung function (Pope and Kanner, 1993). The community of this gold mine village made mention of having to buy medication to treat respiratory related diseases during the windy season. Particulate matter is known to elicit asthma exacerbation due to cellular oxidative stress, initiated by particle produced free radicals (Li et al., 2003).

It is an interesting finding to observe that the community perceives TSF 6 as a major threat to them while this study shows that TSF6 consists mainly nuisance dust. The gold mine village is situated on the downwind side of TSF1, while TSF6 poses major health threats on the Wedela community and the OK shopping centre on the down-wind side of this TSF.

***TSP and Dust Fall simulations***

Simulated TSP for highest hourly dust fallout and TSP are shown in Figure 7 below. The TSP has implications on dust fall as it is coarse grained and is eventually deposited.

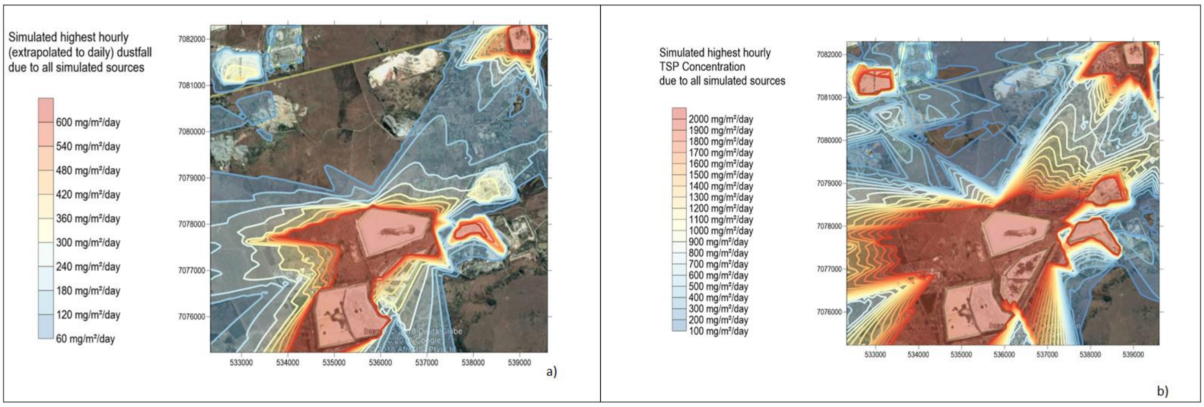



*Figure 7. a) Simulated highest hourly Dustfall and b) TSP due to all simulated sources*

The simulated highest hourly dust fall and TSP concentrations from all sources, show high short term dust fallout which is equivalent to daily dust fallout rates higher than 600 mg/m²/day. The highly affected receptors appear to be located away from the gold mine village to the South West see Figure 7 a) and b) respectively. The highest simulated concentration (GLC) is 600 mg/m²/day, from TSF1, TSF6, and Savuka 7. The highest hourly is showing very high concentrations for both dust fallout and TSP. This is another indication of high exposure in the short term. In the entire study period in August, a total of 30 hours (highest hours) were recorded of dust fall, TSP and particulate matter at high wind speeds > 5.4 m/s (see Appendix, Figure 3) for the entire study period.

The simulated highest monthly dust fall rates due to all simulated sources, are shown in Figure 8.


*Figure 8. Simulated highest monthly dust fall due to all simulated sources*

There are exceedances of the NDCR with concentrations reaching 600 mg/m²/day at TSF 1, TSF6 and Savuka 7. These exceedances however have no clear impact on the community of the gold mine village, the NDCR allows for 2 days non-sequential exceedances per year.

***Simulated results and measured data***

Simulations and measured data are expected to differ, as simulations only include emissions associated with the TSFs in the vicinity of gold mine village area as modelled. The sampled or measured dust fall concentrations include sources from areas close to the mine village (see Figure2). Table 3 in the Appendix shows the measured and the simulated results. It is evident that simulated dust fall concentrations are less than the measured this is expected due to the assumptions made and the modelling inputs.

**TSFs chemistry**

The elemental investigation, aimed at finding out whether there is any silica content, which is a major health threat for the surrounding communities. The study finds that silica is the most abundant of all the other mineral content in all the TSFs ranging from 65- 93%. Other major elements include Al, K, Fe, Mg, and Mn in small quantities. The ICP-MS results indicated the presence of As, Pb, U, Cr, Ni, Cd, Au and Se. Makgae (2011) and Maseki (2013) note that numerous mining residential areas are at risk of high radioactivity contamination. This is due the uranium content found in the tailings storage facilities, especially in the Witwatersrand Basin. To examine the potential health impacts that could be posed by the heavy metals, enrichment factors are calculated. According to Dudu et al. (2018) enrichment factor (EF) method is one way of quantifying anthropogenic pollution of a given site. The assumption made in calculating EF is that the ratio is 1 for elements not above crustal average. The EF greater than 2 shows enriched elements above crustal average, meaning additional sources have contributed to the elemental composition. In this study Au, U and As have a high enrichment factor, significantly above crustal average ranging from 72-359; 30-82 and 33-317 respectively. The TSFs, TSF7, TSF6, TSF1 and Dormant AGA were assessed as they surround the gold mine village community quite closely.

The tailings dumps elemental content is a product of the ore and materials used in the treatment and extraction processes (Ersoy et al., 2004; Mendez and Maier, 2008). The major concern is silica, and uranium which are both carcinogenic at high levels over a period of time. These are known to pose respiratory diseases and cancer. This supports the community complains and claims that the dust poses health related threats and triggers the respiratory diseases.

It is not surprising to see this trend as it was found by Maseki et al. (2017), that As, Pb, U and Au are highly enriched in the West Witwatersrand Basin. This is owing to the enhanced uranium and gold content of the Dominion Reef mined in the Basin. Studies conducted in the Witwatersrand Basin investigated airborne radioactivity levels through radiometric surveys confirmed high doses of uranium in and around TSFs (Larkin et al., 2004).

A high silica content is also recorded from the TSFs. The acute exposures to high concentrations of silica can cause cough, shortness of breath, and pulmonary alveolar lipoproteinosis (acute silicosis) provided it is fresh cut. After chronic but lower workplace exposures to silica for six to sixteen years, the small airways become obstructed as measured by pulmonary function tests (Chia *et al.*, 1992).

**CONCLUSION**

The community provided perspectives on their daily experiences of the environment and the dispersion model gives the overall scientific evidence about the status of the environment with respect to air quality. In the 21$^{st}$ century the intergration of indigenous knowledge and science cannot be overlooked and especially to provide fast monitoring and management of the environment. The community perspectives are comparable to the dispersion simulation and the emission rate calculations. The dust emissions are prevalent during the windy season and August-September are the highest months as correctly pointed out by the community. Analysis of the source material and dust samples showed the presence of particles in the respirable range in certain TSFs and these are known to be more toxic once inhaled. In the short term the PM10 modelled has potential to trigger respiratory related diseases. Ambient PM collection showed that the daily PM10 concentrations at the TSF6, TSF1 and Savuka 7 were slightly above the NDCR acceptable exposure limit. The results from the assessment reveal that strong Northerly Easterly winds blowing to the South West are more frequent compared to other wind patterns and lead to tailings dust deposition south of the TSFs. The chemical analysis show that Au, U, and As are extremely highly enriched with EF > 40 and this is due to the geochemistry of the Witwatersrand Basin and mining processes. TSF 1 is a potential health threat in the long term while TSF6 is a nuisance in the short term. To show the potential effects of the dust to human health in the community of the gold mine village, a full health risk assessment should be conducted by a qualified toxicologist.

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# APPENDIX


Figure1. Tailings sites

Table 1. National Dust Control Regulation

| RESTRICTION AREAS | DUST FALLOUT RATE (MG/M²/DAY, 30 DAYS AVERAGE) | PERMITTED FREQUENCY OF EXCEEDING DUST FALL RATE |
|---|---|---|
| Residential area | D < 600 | Two within a year, not sequential months |
| Non-residential area | 600 < D < 1200 | Two within a year, not sequential months |

Table 2.NAAQS Exposure limit PM10

| Source | Daily Average | Annual average |
|---|---|---|
| Initial NAAQS[a,b] | 120 μg/m³[d] | 50 μg/m³[e] |
| Current NAAQS [a,c] | 75 μg/m³[d] | 40 μg/m³[e] |
| WHO[f] | 50 μg/m | 20 μg/m |

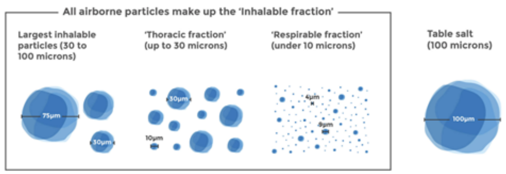


Figure2.: Particle size distribution impact

Table3. Predicted and Measured dust fallout, Highest Monthly dust deposition at all receptor

| Name | Distance from TSF6 | Highest Monthly Modelled Dustfall Rate | HIghest Monthly Measured Dustfall Rate | Measured dust deposition levels annual average | South African Ambient Air Quality Standard (μg/m³) 2015 |
|---|---|---|---|---|---|
| | m | mg/m²/day | mg/m²/day | mg/m²/day | mg/m²/day |
| No. 5 Shaft | 1408 | 68 | 450 | 193 | Dust Monthly-Residential D < 600 mg/m²/day |
| 27 Crescent South Dene | 300 | 96 | 750 | 215 | Non Residential D < 1200 mg/m²/day |
| Doornfontein Village House | 3984 | 10 | 480 | 200 | |
| 1 Harmony South Dene | 866 | 23 | 490 | 168 | |
| Top Shop | 400 | 45 | 600 | 277 | |
| Joseph | 2500 | 14 | 540 | 190 | |
| Clinic | 2315 | 24 | 500 | 184 | |

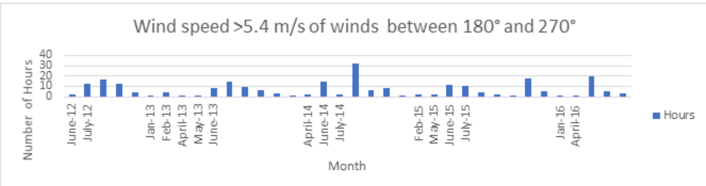


Figure3.Wind speed > 5.4 m/s