Air Quality Impact Assessment for the Navachab Gold Mine, Tailings Storage Facility 3 near Karibib in Namibia

Project done for **Environmental Compliance Consultancy (ECC)**

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Revision Record

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Abbreviations

AQG	Air Quality Guidelines
AQIA	Air Quality Impact Assessment
AQMP	Air Quality Management Plan
AQO	Air Quality Objectives
AQSRs	Air Quality Sensitive Receptors
ASTM	American Society for Testing and Materials standard method
CE	Control efficiency
CIP	Carbon-in-Pulp
CN	Cyanide
CO	Carbon monoxide
DMS	Dense-Medium-Separation
EAADT	Estimated annual average daily traffic
EC	European Community
ECC	Environmental Compliance Consultancy
EETM	Emission Estimation Technique Manual
EHS	Environmental, Health and Safety
ESIA	Environmental and Social Impact Assessment
EQOs	Environmental Quality Objectives
GIIP	Good International Industry Practice
GLCs	Ground level concentrations
IFC	International Finance Corporation
IT	Interim target
LOM	Life of mine
LMo	Obukhov length
ML	Mining License
MES	Minimum Emission Standards
NAAQS	National Ambient Air Quality Standards
NDCR	National Dust Control Regulations
NGM	Navachab Gold Mine
NOx	Oxides of nitrogen
NPI	Australian National Pollutant Inventory
PM	Particulate Matter
PM_{10}	Particulate matter with an aerodynamic diameter of less than 2.5 µm (thoracic particles)
$PM_{2.5}$	Particulate matter with an aerodynamic diameter of less than 10 µm (respirable particles)
PSD	Particle size distribution
ROM	Run-of-Mine
SA	South African
SEA	Strategic Environmental Assessment
SEMP	Strategic Environmental Management Plan
SO_2	Sulfur dioxide
TSF	Tailings Storage Facility
TSF3	Tailings Storage Facility3
TSP	Total Suspended Particulates
US EPA	United States Environmental Protection Agency
VKT/day	Vehicle kilometres travelled per day

WBG	World Bank Group
WHO	World Health Organisation
WRF	Weather Research and Forecasting

Units

°C	Degree Celsius
km	kilometre
m	metres
mm	millimetre
mg/m²/day	milligram per metre squared per day
Mm³	Million cubic metres
t	ton
tpa	tons per annum
tpm	tons per month
µm	micrometre
µg/m³	microgram per cubic metre
%	percent

Glossary

Air pollution: means any change in the composition of the air caused by smoke, soot, dust (including fly ash), cinders, solid particles of any kind, gases, fumes, aerosols and odorous substances.

Atmospheric emission: means any emission or entrainment process emanating from a point, non-point or mobile sources that result in air pollution.

Averaging period: This implies a period of time over which an average value is determined.

Dust: Solid materials suspended in the atmosphere in the form of small irregular particles, many of which are microscopic in size.

Frequency of Exceedance: A frequency (number/time) related to a limit value representing the tolerated exceedance of that limit value, i.e. if exceedances of limit value are within the tolerances, then there is still compliance with the standard.

Particulate Matter (PM): These comprise a mixture of organic and inorganic substances, ranging in size and shape and can be divided into coarse and fine particulate matter. The former is called Total Suspended Particulates (TSP), whilst PM_{10} and $PM_{2.5}$ fall in the finer fraction referred to as Inhalable particulate matter.

TSP: Total suspended particulates refer to all airborne particles and may have particle sizes as large as 150 µm, depending on the ability of the air to carry such particles. Generally, suspended particles larger than 75 to 100 micrometre (µm) do not travel far and deposit close to the source of emission.

PM_{10}: Thoracic particulate matter is that fraction of inhalable coarse particulate matter that can penetrate the head airways and enter the airways of the lung. PM_{10} consists of particles with a mean aerodynamic diameter of 10 µm or smaller, and deposit efficiently along the airways. Particles larger than a mean size of 10 µm are generally not inhalable into the lungs. These PM_{10} particles are typically found near roadways and dusty industries.

$PM_{2.5}$: Respirable particulate fraction is that fraction of inhaled airborne particles that can penetrate beyond the terminal bronchioles into the gas-exchange region of the lungs. Also known as fine particulate matter, it consists of particles with a mean aerodynamic diameter equal to or less than 2.5 µm ($PM_{2.5}$) that can be inhaled deeply into the lungs. These particles can be directly emitted from sources such as forest fires, or they can form when gases emitted from power plants, industries and automobiles react in the air.

Point sources: are discrete, stationary, identifiable sources of emissions that release pollutants to the atmosphere (International Finance Corporation (IFC), 2007).

Vehicle entrainment: This is the lifting and dropping of particles by the rolling wheels leaving the road surface exposed to strong air current in turbulent shear with the surface. The turbulent wake behind the vehicle continues to act on the road surface after the vehicle has passed.

Executive Summary

Navachab Gold Mine (NGM), located 10 km southwest of Karibib in Namibia, needs to prepare the environmental clearance application for their proposed additional tailings storage facility on the mine site (Tailings Storage Facility 3 - TSF3).

Airshed Planning Professionals (Pty) Ltd (Airshed) was appointed by Environmental Compliance Consultancy (ECC) to conduct an air quality impact assessment study as part of the environmental and social impact assessment (ESIA).

The main objective of the investigation was to quantify the potential air quality impacts resulting from the proposed TSF3 on the surrounding environment and human health. As part of the air quality assessment, a good understanding of the regional climate and local dispersion potential of the site is necessary and subsequently an understanding of existing sources of air pollution in the region and the current and potential future activities resulting in air quality related impacts.

The scope of work (SoW) included the review of technical information and legislative context relevant to Namibia. A baseline assessment was required to get an understanding of the receiving environment, looking at existing sources of air pollution and the status of air quality within the region, as well as sensitive receptors in the form of human settlements. Site specific meteorological data was only available as daily averages and WRF (Weather Research and Forecasting model) meteorological data for the period January 2020 to December 2022 was purchased to determine the dispersion potential of the site, influencing the spreading and removal of air pollution. With windblown dust the main concern from the TSF3, emissions were quantified using the in-house ADDAS model based on the dust emission scheme of Marticorena and Bergametti (1995). The United States (US) Environmental Protection Agency (EPA) AERMOD dispersion model was used to simulate the expected impacts from these emission sources, with the simulated particulate matter ground level concentrations (GLCs) and dustfall rates screened against the applicable air quality guidelines and standards to determine the significance of the project on the receiving environment. Once the significance of these impacts has been established, the main contributing sources could be identified, and mitigation measures defined to ensure reduced impacts from these activities.

Baseline Characterisation

The Project covers an area of about 18 km northeast-southwest and 8 km north-south. The terrain is hilly, with a ridge to the south of the open pit areas which serve as a barrier on the south-eastern side of the current TSF2, and a hill further south. The new TSF3 will be located between the two rock ridges, both serving as "sidewalls" and the waste rock dumps to the north serving as a buttress. There are no villages or homesteads near the project, with the closest settlement – farmhouses – 3 km to the northeast and 2.4 km to the southwest of TSF3. The town of Karibib (and Usab suburb) is located about 10 km to the northeast from the mine licence boundary.

The WRF weather data provided the following understanding of the conditions in the area:

- The wind field is dominated by winds from the southwest to south, and east to north-east, with the strongest winds from the south-west. Calm conditions prevailed 2.6% of the time. During the day, north-easterly winds prevailed with strong but less frequent winds from the south-west, and at night the wind field shifted to more frequent southerly winds with winds at lower wind speeds, followed by easterly to east-north-easterly winds and no wind from the northern or north-western sector.
- The average hourly wind speed over the period was 4.4 m/s, with a maximum wind speed of 12.6 m/s.
- Seasonal variation in the wind field showed more frequent south-westerly winds during the summer months and a shift to east to north-easterly winds in autumn, remaining such during winter but with strong "east-winds". The spring months show similar wind flow to the summer months.
- Maximum, minimum, and mean temperatures were given as 38°C, -1.3°C and 21°C respectively.

- Rainfall recorded at NGM over a 10-month period (Jan-Oct 2022) totalled 273 mm, with the highest rainfall of 161 mm recorded in February 2022.

The main pollutant of concern in the region is particulate matter (TSP; PM_{10} and $PM_{2.5}$) resulting from vehicle entrainment on the roads (paved, unpaved and treated surfaces), windblown dust, and mining and exploration activities. Gaseous pollutants such as SO_2, NOx, CO and CO_2 would result from vehicles and combustion sources, but these are expected to be at low concentrations due to the few sources in the region.

Sources of atmospheric emissions in the vicinity of the proposed Project include:

- Vehicle entrainment from roads: The national road to the north (B2) of the Project is the main road between Windhoek and Swakopmund, and one of the roads in the region with the highest traffic counts. Vehicle entrainment was estimated to be a significant contributor to the regional paved road $PM_{2.5}$ and PM_{10} emissions. The C32, is an unpaved road connecting the Karibib with the Namib Naukluft Park, and although no information was available for this road, it is expected to have very low traffic counts and low $PM_{2.5}$ and PM_{10} emissions.
- Windblown dust: Windblown particulates from natural exposed surfaces, mine waste facilities, and product stockpiles can result in significant dust emissions with high particulate concentrations near the source locations, potentially affecting both the environment and human health. Windblown dust from natural exposed surfaces around the Project site is only likely to result in particulate matter emissions under high wind speed conditions (>10 m/s), and since recorded wind speeds exceeded 10 m/s for only 0.8% over the three-year period, this source is likely to be of low significance.
- Mines and Exploration operations: Pollutants typically emitted from mining and quarrying activities are particulates, with smaller quantities associated with vehicle exhaust emissions. Mining and quarrying activities, especially open-cast mining methods, emit pollutants near ground-level over (potentially) large areas. Mines in proximity to the Project are NGM, where it is located, with the existing TSF2 directly to the west on the other side of the ridge. There are several marble quarries in the region, with one 3.5 km west, and others to the south of Karibib.
- Regional transport of pollutants: regional-scale transport of mineral dust and ozone (due to vegetation burning) from the north of Namibia is a significant contributing source to background PM concentrations.

A dustfall monitoring network comprising of 10 single dustfall units are in place at NGM, with dustfall data available for the period January 2022 to January 2023. Dustfall rates were low for the dustfall units furthest from the operations (NAQ2; NAQ3; NAQ9 and NAQ10) whereas the ones closest to the mining operations (NAQ4; NAQ7 and NAQ8) had the highest dustfall rates. NAQ4, located next to the haul road north of the existing TSF2, had the highest dustfall rates, exceeding the alert threshold (2 400 mg/m²/day) for four months and the industrial limit (1 200 mg/m²/day) for 10 months.

In order to determine the potential impacts from the Project (TSF3) cumulatively, the current mining operations at NGM were assessed though the quantification of emissions and dispersion modelling. No current mining and production rates were available, so the 2016 rates were assumed to be representative of the current mining operations at NGM.

- Estimated emissions from the operations at NGM were 596 tons per annum (tpa) for $PM_{2.5}$, 2 096 tpa for PM_{10} and 792 tpa for TSP (these exclude emissions from point sources). Based on the 2016 mining rates, the main contributing activities to $PM_{2.5}$ and PM_{10} emissions are the in-pit activities (i.e. drilling, blasting, loading of ore and waste onto haul trucks, truck movement on in pit roads), with crushing and screening the main contributing sources to TSP emissions.
- Simulated 24-hour GLCs for $PM_{2.5}$ and PM_{10} were mainly within the two Mining Licence areas (MLs), with exceedances of the adopted AQO only for a small area on the southern and south-eastern border of the MLs and

not affecting any of the AQSRs. The annual average impact areas for both $PM_{2.5}$ and PM_{10} exceeded a very small area on the south-eastern side. Daily dustfall impacts only exceeded the industrial dustfall limit for a small area outside the ML.

Impact Assessment

A quantitative air quality impact assessment was conducted for the proposed Project (TSF3). Construction, closure, and post-closure activities were assessed qualitatively. The assessment included an estimation of atmospheric emissions, the simulation of pollutant concentrations and determination of the significance of impacts.

Construction infrastructure required for the new TSF3 would be limited to vegetation clearing and TSF foundation construction. The main pollutant of concern from construction operations is particulate matter, including PM_{10}, $PM_{2.5}$ and TSP. Each of the operations associated with the construction phase has their own duration and potential for dust generation. The area to be cleared of vegetation for development of the TSF3 is 920 056 m². Applying the general construction emission factor, the emissions are 2 970 tpa for TSP, 1 158 tpa for PM_{10} and 579 tpa for $PM_{2.5}$. This is assuming construction will be for 12 months. Due to the intermittent nature of construction operations, the impacts are expected to have a small and potentially insignificant impact at the nearest AQSRs, due to the distance from the TSF and the ridge in-between. With mitigation measures in place these impacts are expected to be very low.

Operational Phase:

- Quantification of emissions for TSF3 are restricted to fugitive releases (non-point releases) i.e. windblown dust with particulates the main pollutant of concern. Wind erosion is a complex process which requires the wind speed to exceed a threshold velocity of ~8.8 m/s as determined for gold tailings. Emission quantification was done using the in-house ADDAS model based on the dust emission scheme of Marticorena and Bergametti (1995). Model input data was based on tailing samples analysed during the Air Quality Impact Assessment conducted for NGM in 2010. The particle size distribution indicated the largest portion of the particles to be within the coarse fraction (63 µm – 3 000 µm) with 30% below 41 µm. The moisture content was 2%, and the particle density 1 650 kg/m³. The quantified emissions were 237 for $PM_{2.5}$, 533 for PM_{10} and 2066 for TSP and reflected a threshold friction velocity of 7.9 m/s, which is in line with the expected 8.8 m/s.
- Dispersion modelling results for $PM_{2.5}$, PM_{10} and dustfall, unmitigated and mitigated (vegetation cover resulting in 60% CE) as a result of windblown dust from TSF3 were:
  - Modelled daily average $PM_{2.5}$ GLCs were high at and immediately around TSF3, exceeding the AQO of 37.5 µg/m³ for a small area outside the ML on the eastern side but not at any AQSR. Applying mitigation (60% CE) resulted in a slight reduction in the impact footprint, still exceeding the AQO outside the ML due to the location of TSF3 so close to the ML boundary. Over an annual average, the impacts are low and within the AQO.
  - PM_{10} daily concentrations showed exceedances of the AQO of 75 µg/m³ outside the ML on the eastern side without mitigation and with mitigation, but not at any AQSR. Similarly, the annual average concentrations are below the AQO for the unmitigated and mitigated scenarios.
  - Dustfall rates simulated as highest daily dust fallout indicated exceedances of the industrial limit of 1 200 mg/m²/day outside the ML on the eastern side, without mitigation and with mitigation. There are no exceedances of the residential limit of 600 mg/m²/day at any of the AQSRs.
- The incremental (Direct) impacts, from TSF3 only, would result in a Moderate (negative) significance.
- Cumulatively, the impact of the current mining operations in combination with TSF3 remain at a Minor (negative) significance rating since the area of exceedance outside of the ML is likely to increase only slightly, with no negative impact on any of the AQSRs.

Closure and **Post-closure** activities likely to result in dust impacts are the rehabilitation and re-vegetation of TSF3, and vehicle entrainment on unpaved road surfaces during rehabilitation.

Conclusion

The proposed Project is likely result in $PM_{2.5}$ and PM_{10} GLCs exceedances in the immediate vicinity of TSF3, with no mitigation in place but the impact area can be reduced with mitigation measures in place. Dustfall rates are also likely to exceed the limit in the immediate vicinity of the TSF3. The GLCs are however within the limits at all the AQSRs.

It is the specialist's opinion that the proposed project could be authorised provided strict enforcement of mitigation measures and the tracking of the effectiveness of these measures to ensure the lowest possible off-site impacts.

Recommendations

Based on the findings from the air quality impact assessment for the Project following recommendations are included:

- **Construction**: air quality impacts during construction would be minimised through basic control measures such as limiting the speed of haul trucks; limit unnecessary travelling of vehicles on untreated roads; reducing the area of construction where it is close to receptors; and to apply water sprays on regularly travelled, unpaved sections.
- **Operational**: TSF3 is located in between two ridges, acting as natural side walls but also as wind breaks and barriers with the only side walls to be constructed on the south-western side and against the current waste rock dumps on the north-eastern side. With the south-western side slope exposed to approaching winds, this wall will need to be continuously vegetated to reduce/minimise the potential for windblown dust. It is further important to keep the dried-out beach areas moist or to allow the material to form a crust, thus preventing disturbances. The NPI (2012) indicates the following CE for various control options for stockpiles:
    - 40% for vegetation established but not demonstrated to be self-sustaining.
    - 60% for secondary rehabilitation.
    - 90% for revegetation.
    - 100% for fully rehabilitated (release) vegetation
- **Air Quality Monitoring**: The current dustfall monitoring network, comprising of 10 single dustfall units, should be maintained with an additional unit to be located to the south of the TSF3. Monthly dustfall results should be used as indicators to tract the effectiveness of the applied mitigation measures. Dustfall collection should follow the ASTM method.

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1 INTRODUCTION

Navachab Gold Mine (NGM), located 10 km southwest of Karibib in Namibia, needs to prepare the environmental clearance application for their proposed additional tailings storage facility on the mine site (Tailings Storage Facility 3 - TSF3).

An air quality assessment is required as part of the environmental and social impact assessment (ESIA) for the Project. Airshed Planning Professionals (Pty) Ltd was appointed by Environmental Compliance Consultancy (ECC) to undertake an air quality impact assessment (AQIA) for the proposed Project. The main objective of the investigation is to quantify the potential impacts resulting from the new TSF3 on the surrounding environment and human health. As part of the air quality assessment, a good understanding of the regional climate and local dispersion potential of the site is necessary and subsequently an understanding of existing sources of air pollution in the region.

The investigation followed the methodology required for a specialist impact assessment report.

1.1 Terms of Work

The baseline assessment includes a study of the receiving environment by referring to:

- A study of legal requirements pertaining to air quality – applicable international legal guidelines and limits and dust control regulations.
- Desktop review of all available project and associated data, including meteorological data, previous air quality assessments, ESIAs and technical air quality data and modelled results.
- A study of atmospheric dispersion potential by referring to available on-site weather records for a period of at least one year (required for dispersion modelling), land use and topography data.
  - Details on the physical environment i.e. meteorology (atmospheric dispersion potential), land use and topography.
  - Identification of existing air pollution sources (other mines; industries; commercial operations, etc.).
  - Identification of air quality sensitive receptors (AQSRs), including any nearby residential dwellings and proposed receptors (temporary or permanent workers accommodation site(s)) in the vicinity of the mine.
  - Any freely available ambient air quality data, specifically Particulate Matter (PM).
- An impact assessment, including:
  - Identify all current sources of air pollution in the area (other mines; wildfires; domestic fuel burning; etc.).
  - The compilation of a comprehensive emissions inventory including the identification and quantification of all emissions associated with the proposed Project (TSF3).
  - Atmospheric dispersion modelling to simulate ambient air pollutant concentrations and dustfall rates from the project activities.
  - The screening of simulated ambient pollutant concentration levels and dust fallout against ambient air quality guidelines and standards.
- Assessment of the potential air quality impacts on human health and the environment.
- The identification and recommendation of suitable mitigation measures and monitoring requirements.
- The preparation of a comprehensive specialist air AQIA report.

1.2 Project Description

The current mining process consists of open pit operations, with continuous drilling and blasting twice weekly. Material handling includes various transfer points such as loading within the pit, where the ore and waste rock are placed in trucks for transport out of the pit. The waste material is deposited on several waste rock dumps, while the ore is temporarily stored on the Run of Mine (ROM) storage facility before being transferred to the crusher. The crushed ore is transported to the processing facility via conveyor belt, where a Carbon-In-Pulp process (CIP) process is used to extract the gold from the ore. Primary extraction through electrowinning is then conducted to separate the gold from other material. The tailings are deposited on the existing tailings storage facility (TSF). Simultaneously there is a Dense-Medium-Separation (DMS) plant in operation with three semi-mobile crushers which can access minor or secondary ore deposits. Other facilities at the mine include workshops for the maintenance of equipment, an oxygen generation plant, laboratories used by the exploration geologists and an incineration facility where open burning of packing material is conducted. These activities and sources are all capable of emissions to the atmosphere.

The proposed project will include the construction of a 20 million cubic metre (Mm^3) TSF, to be called TSF3. TSF3 will allow NGM to continue operations for the rest of the life of the mine (LOM) while ensuring the safe disposal of tailings from the CIP plant. The mine layout plan is provided in Figure 1.

1.2.1 Air pollution activities associated with the proposed Project

With the focus of this assessment on air quality impacts from the proposed TSF3 on the surrounding environment, the subsequent discussion is intended to provide an indication of the likely source activities associated with the different phases of the TSF3, i.e. the construction-, operational-, closure- and post-closure phases.

1.2.1.1 Construction

The location of TSF3 is on the mine site to the east of TSF2, between two rock ridges and buttressed to the north by waste rock dumps. Vegetation clearing will be required for site construction of the new TSF3, and it will be built with the coarse fraction of the sandy tailings from cyclones as well as run of mine, non-mineralized mine waste rock. Existing pipelines and roads will be used. Construction activities were given to take place from 07:00 to 18:00.

1.2.1.2 Operations

The new TSF3 will be operated similar to the existing TSFs, with the gold processing fine waste, or tailings, to be piped to the storage facility in existing pipelines and along existing routes. Tailings slurry will be discharged and stored within the facility. As part of the gold recovery process, the slurry will have elevated concentrations of cyanide (CN). CN destruction will take place within the pipeline and within the facility, typically by oxidation. The water fraction of the slurry will naturally decant and separate from the tailing's sands. It will pond against the western rock ridge from which the water will be pumped back to the processing facility for reuse.

For project operational activities, pumps were assumed to operate 24 hours per day, with light duty vehicles and backactor activities assumed to take place during daytime (07:00 – 22:00) only.

The main activity resulting in air pollution during the operational phase is wind erosion from the TSF3 side slopes and surface, and the associated pollutants are primarily PM.

1.2.1.3 Closure and post-closure

Closure and post-closure activities typically include rehabilitation of the site infrastructure – demolition of infrastructure and vegetation of TSF. These activities mainly result in PM emissions with gaseous emissions from equipment and trucks.

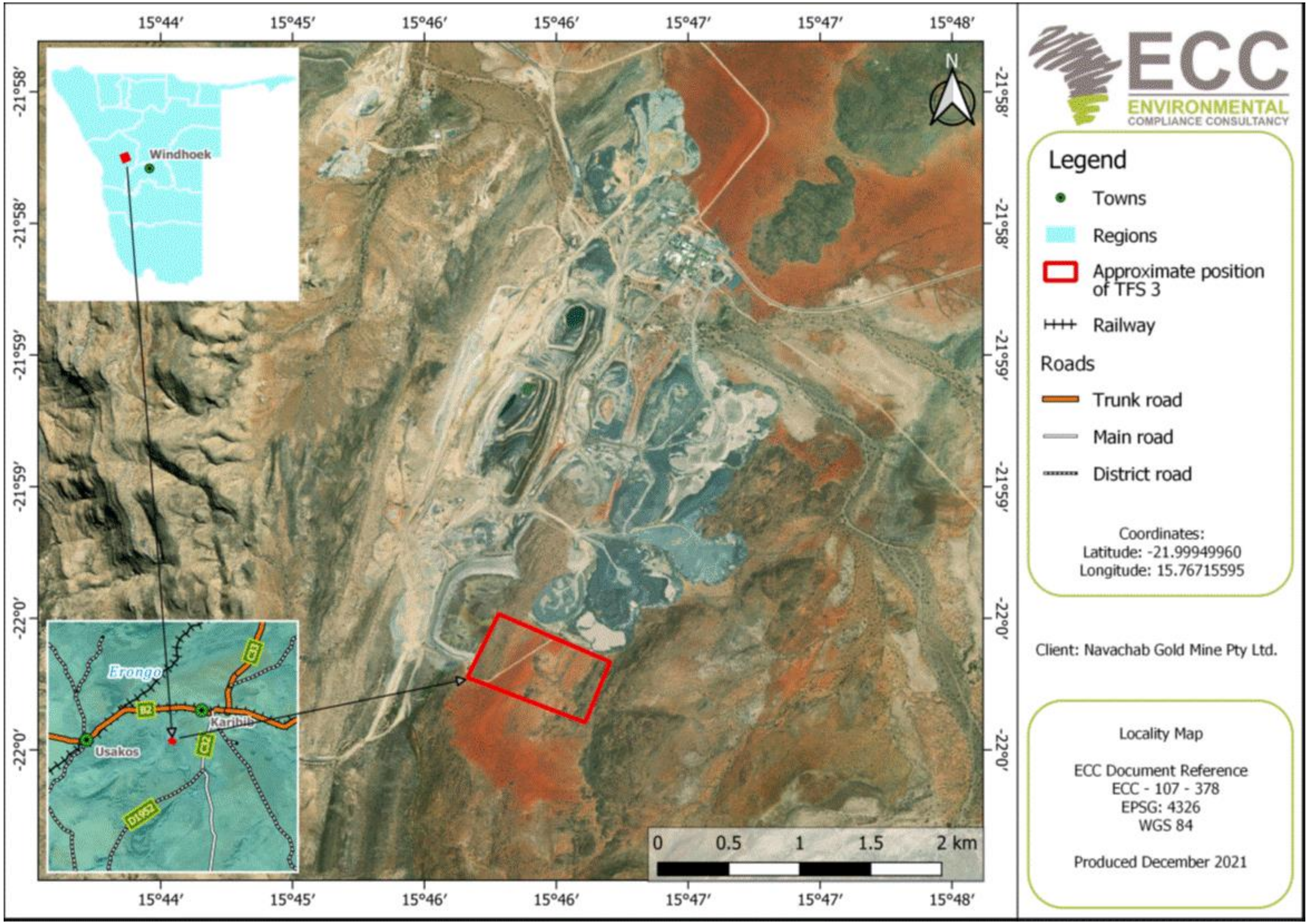


Figure 1: Navachab Gold Mine and proposed Project layout

1.2.2 Pollutants of concern

The primary pollutant of concern is particulate matter (PM), in the form of PM_{10} (particulate matter less than 10 µm in diameter) and $PM_{2.5}$ (particulate matter less than 2.5 µm in diameter) which due to its small size can penetrate deep into lungs and therefore has important health implications. TSP (total suspended particulates, represents the coarse fraction >10 µm), which is associated with dust fallout, is an important pollutant due to the nuisance that it creates. Gaseous emissions, such as sulfur dioxide (SO_2), oxides of nitrogen (NO_x) and carbon monoxide (CO) were not evaluated since the focus of the study is on windblown dust (PM) from the TSF3.

The impact of particles on human health is largely dependent on: (i) particle characteristics, particularly particle size and chemical composition; and (ii) the duration, frequency and magnitude of exposure. The potential of particles to be inhaled and deposited in the lung is a function of the particle size, shape and density. The deposition of particles in different regions of the respiratory system depends on the size – the nasal openings permit very large dust particles to enter the nasal region, along with much finer airborne particulates.

Air quality guidelines for airborne particulates are given for various particle size fractions, including total suspended particulates (TSP), and thoracic (PM_{10}) and respirable ($PM_{2.5}$) particulates (see Section 2.2).

2 PROJECT APPROACH AND METHODOLOGY

The approach and methodology followed in the completion of tasks included in the scope of work are discussed below.

2.1 Project Information and Activity Review

A review of gold mining and ore processing operations at NGM from an air quality perspective was conducted. In the assessment extensive reference was made to the following:

- The Australian National Pollutant Inventory (NPI) Emission Estimation Technique Manual (EETM) for surface mining (NPI, 2012);
- Background information document from ECC;
- The air quality impact assessment conducted by Airshed in July 2010 (Liebenberg-Enslin, et al., 2010), and
- The Air Quality Management Plan (AQMP) developed as part of the Strategic Environmental Management Plan (SEMP) for the Erongo region (Liebenberg-Enslin, et al., 2019).

An information requirements list was sent to ECC at the onset of the project. In response to the request, the following information was supplied:

- Layout maps;
- Process descriptions;
- Mining and production rates; and
- Project equipment details.

2.2 The Identification of Regulatory Requirements and Screening Criteria

In the evaluation of ambient air quality impacts and dustfall rates reference was made to:

- South African National Ambient Air Quality Standards (SA NAAQS) and National Dust Control Regulations (SA NDCR) as set out in the National Environmental Management Air Quality Act (Act No. 39 of 2004) (NEM:AQA);
- Air Quality Guidelines (AQGs) published by the World Health Organisation (WHO); and
- Namibian legislation and Best Practice Criteria.

2.3 Study of the Receiving Environment

It is important to have a good understanding of the meteorological parameters governing the rate and extent of dilution and transportation of air pollutants that are generated by the proposed project. The primary meteorological parameters to obtain from measurement include wind speed, wind direction and ambient temperature. Other meteorological parameters that influence the air concentration levels include rainfall (washout) and a measure of atmospheric stability. The latter quantities are normally not measured and are derived from other parameters such as the vertical height temperature difference or the standard deviation of wind direction. The depth of the atmosphere in which the pollutants are able to mix is similarly derived from other meteorological parameters by means of mathematical parameterizations. Hourly average meteorological data is needed to draw wind roses and as input to the dispersion model. NGM operates an on-site weather station, but only daily average data was provided and could not be used in the study. Simulated WRF (Weather Research and Forecasting) meteorological data for the period January 2020 to December 2022 was purchased for use in the study.

Potential air quality sensitive receptors (AQSR) within the study area were identified for consideration during the impact assessment. AQSRs primarily relate to where people reside.

2.4 Determining the Impact of the Project on the Receiving Environment

2.4.1 Emissions Inventory

The establishment of a comprehensive emission inventory formed the basis for the assessment of the air quality impacts from the Project's emissions on the receiving environment. In the quantification of emissions, use was made of emission factors which associate the quantity of release of a pollutant to the related activities. Emissions were calculated using emission factors and equations published by the United States Environmental Protection Agency (US EPA) and Environment Australia in their National Pollutant Inventory (NPI) Emission Estimation Technique Manuals.

2.4.2 Atmospheric Dispersion modelling

The US EPA approved AERMOD atmospheric dispersion modelling suite was used for the simulation of ambient air pollutant concentrations and dustfall rates. AERMOD is a Gaussian plume model, best used for near-field applications where the steady-state meteorology assumption is most likely to apply. The AERMOD model is one of the most widely used Gaussian plume model. AERMOD is a model developed with the support of the AMS/EPA Regulatory Model Improvement Committee (AERMIC), whose objective was to include state-of the-art science in regulatory models (Hanna, Egan, Purdum, & Wagler, 1999). AERMOD is a dispersion modelling system with three components, namely: AERMOD (AERMIC Dispersion Model), AERMAP (AERMOD terrain pre-processor), and AERMET (AERMOD meteorological pre-processor).

AERMOD is an advanced new-generation model. It is designed to predict pollution concentrations from continuous point, flare, area, line, and volume sources. AERMOD offers new and potentially improved algorithms for plume rise and buoyancy, and the computation of vertical profiles of wind, turbulence, and temperature. However, retains the single straight-line trajectory limitation. AERMET is a meteorological pre-processor for AERMOD. Input data can come from hourly cloud cover observations, surface meteorological observations and twice-a-day upper air soundings. Output includes surface meteorological observations and parameters and vertical profiles of several atmospheric parameters. AERMAP is a terrain pre-processor designed to simplify and standardise the input of terrain data for AERMOD. Input data includes receptor terrain elevation data which may be in the form of digital terrain data. The output includes, for each receptor, location and height scale, which are elevations used for the computation of air flow around hills. A disadvantage of the model is that spatially varying wind fields, due to topography or other factors cannot be included. Input data types required for the AERMOD model includes source data, meteorological data (pre-processed by the AERMET model), terrain data (pre-processed by the AERMAP model) and information on the nature of the receptor grid.

The components of the AERMOD modelling suite are summarised in Table 1; however, only AERMOD contain the simulation engines to calculate the dispersion and removal mechanisms of pollutants released into this boundary layer. The other codes are mainly used to assist with the preparation of input and output data. Table 1 also includes the development versions of each of the codes used in the investigation.

Table 1: Summary description of AERMOD model suite with versions used in the investigation

Module	Interface Version	Executable	Description
AERMOD	Breeze v10.0.0.15	(US) EPA 21112	Gaussian plume dispersion model.
AERMET	Breeze v9.0.0.4	(US) EPA 21112	Meteorological pre-processor for creating AERMOD compatible formats.
AERMAP	Breeze v10.0.0.15	(US) EPA 21112	Topographical pre-processor for creating digital elevation data in a format compatible with the AERMOD control file.

The execution phase (i.e. dispersion modelling and analyses) involves gathering specific information regarding the emission source(s) and site(s) to be assessed, and subsequently the actual simulation of the emission sources and determination of impact significance. The information gathering included:

- Source information: emission rate, source extents and release height;
- Site information: site layout, terrain information, and land use data;
- Meteorological data: a minimum of wind speed, wind direction, temperature, and sensible heat flux or Monin-Obukhov length; and
- Receptor information: locations using discrete receptors and/or gridded receptors.

2.4.2.1 Meteorological Requirements

An understanding of the atmospheric dispersion potential of the area is essential to an air quality impact assessment. WRF modelled meteorological data was used. The WRF model domain covered a 50 km (east-west) by 50 km (north-south) area with a 12 km resolution. The modelled meteorological data for a point at NGM was extracted for the period from January 2020 to December 2022.

2.4.2.2 Topographical and Land Use Data

Readily available terrain and land use data was obtained from the United States Geological Survey (USGS) via the Earth Explorer website (U.S. Department of the Interior, U.S. Geological Survey, 2018). Use was made of Shuttle Radar Topography Mission (SRTM) (30 m, 1 arc-sec) data and Global Land Cover Characterisation (GLCC) data for Africa.

2.4.2.3 Receptors

The dispersion of pollutants expected to arise from proposed operations was simulated for an area covering 21.5 km (east-west) by 11.2 km (north-south). The area was divided into a grid matrix with a resolution of 200 m. AERMOD calculates ground-level concentrations and deposition rates at each grid point and discrete receptor.

2.4.2.4 Dispersion results

The dispersion model uses the specific input data to run various algorithms to estimate the dispersion of pollutants between the source and receptor. The model output is in the form of a simulated time-averaged concentration at the receptor. These simulated concentrations are added to suitable background concentrations and compared with the relevant ambient air quality standard or guideline. The post-processing of air concentrations at discrete receptors as well as the regular grid points includes the calculation of various percentiles, specifically the 99th percentile, which corresponds to the requirements of the NAAQS.

Ground level concentration (GLC) isopleth plots presented in this report depict interpolated values from the concentrations simulated by AERMOD for each of the receptor grid points specified. Plots reflecting daily averaging periods contain only the 99th percentile of simulated ground level concentrations, for those averaging periods, over the entire period for which simulations were undertaken. It is therefore possible that even though a high daily average concentration is simulated at certain locations, this may only be true for one day during the period. Typically, NAAQS apply to areas where the Occupational Health and Safety regulations do not apply, thus outside the mine property or lease area. Ambient air quality guidelines and standards are therefore not occupational health indicators but applicable to areas where the public has access i.e. off-site.

2.4.2.5 Uncertainty of Modelled Results

There will always be some error in any geophysical model; however, modelling is recognised as a credible method for evaluating impacts. It is desirable to structure the model in such a way to minimise the total error. A model represents the most likely outcome of an ensemble of experimental results. The total uncertainty can be thought of as the sum of three components: the uncertainty due to errors in the model physics; the uncertainty due to data errors; and the uncertainty due to stochastic processes (turbulence) in the atmosphere.

The stochastic uncertainty includes all errors or uncertainties in data such as source variability, observed concentrations, and meteorological data. Even if the field instrument accuracy is excellent, there can still be large uncertainties due to unrepresentative placement of the instrument (or taking of a sample for analysis). Model evaluation studies suggest that the data input error term is often a major contributor to total uncertainty. Even in the best tracer studies, the source emissions are known only with an accuracy of ±5%, which translates directly into a minimum error of that magnitude in the model predictions. It is also well known that wind direction errors are the major cause of poor agreement, especially for relatively short-term predictions (minutes to hours) and long downwind distances. All the above factors contribute to the inaccuracies not associated with the mathematical models themselves.

A disadvantage of the model is that spatial varying wind fields, due to topography or other factors cannot be included. Although the model has been shown to be an improvement on the ISC model, especially short-term predictions, the range of uncertainty of the model predictions is -50% to 200%. The accuracy improves with fairly strong wind speeds and during neutral atmospheric conditions.

In quantifying the uncertainty of the modelled results for this assessment, measured ambient data was required which was not available for this study.

2.5 Impact Assessment

The significance of the GLC impacts was assessed by comparing simulated ambient particulate pollutant concentrations ($PM_{2.5}$ and PM_{10}) and dustfall rates to selected ambient air quality and dustfall criteria (see Section 2.5). The significance of the impacts was assessed using the prescribed ECCs impact rating methodology (Appendix C).

2.6 Managing Uncertainties

This portion of the study and the impact assessment portion is and will be based on a few assumptions and is subject to certain limitations, which should be borne in mind when considering information presented in this report. The validity of the findings of the study is not expected to be affected by these assumptions and limitations:

- Meteorological and ambient data:
    - On-site meteorological data was available for a period of 12-months (12 June 2021 to 4 November 2021) but only provided as daily averages and could therefore not be used in the study. WRF simulated data for a location at NGM for the most recent three-year period was used.
    - Dust fallout data was available for the site for the period January 2022 to January 2023, but with no data for two months (February 2022 and April 2022). A general description of the air quality within the greater Erongo Region was obtained from the AQMP conducted as part of the SEMP. A limitation is that Karibib is located on the eastern boundary of the area assessed as part of the SEMP AQMP.
- Emissions:
    - Emission quantification of the current sources of emission at NGM was based on the 2016 mining and production rates, used in the SEMP study, since no recent mining rates were be provided. The previous air quality assessment conducted for the mine in 2010 is regarded outdated and could not be used to establish the baseline emission inventory for the mine. Although other background sources were identified, such as emissions from roads and other mines and quarries, these could not be quantified and did not form part of the scope of work.
    - Emissions for the proposed Project (TSF3) mainly include construction activities and windblown dust once TSF3 is in operation. For wind erosion to occur, the wind speed must exceed a certain threshold in order

to lift and entrain the fine loose tailings material. An estimated wind speed threshold for gold tailings is 8.8 m/s (Liebenberg-Enslin, 2014), and this was applied to the wind erosion potential from TSF3. The TSF3 design was provided. Particle size fractions (PSD) determined for TSF2 were assumed to be representative of the TSF3 material.

- Impact Assessment:
    - Impacts due to the operational phase were assessed quantitatively, whilst the construction, closure and decommissioning phases were assessed qualitatively.
    - The impact assessment was limited to airborne particulates (including TSP, PM_{10} and $PM_{2.5}$) since these represent the main pollutants of concern. Whereas gaseous emissions will derive from vehicle exhaust and other mining equipment, these impacts are usually localized and unlikely to exceed health screening limits outside the mining license (ML) area. Emissions from point-source releases at the Dense Medium Separation (DMS) plant could not be determined due to insufficient information on the design parameters.
    - Since it is a difficult task to calculate real-life variations in impacts due to the variability of the operation, design maximum mining rates were utilized in the simulations. Though the nature of the mining operations will change over the life of mine, the proposed sources were modelled to reflect the worst-case conditions (i.e. resulting in the highest impacts and/or closest to AQSRs). For this reason, the future TSF3 operations were modelled for a no mitigation scenario, and one where mitigation is applied.
    - There will always be some degree of uncertainty in any geophysical model, but it is desirable to structure the model in such a way to minimize the total error. A model represents the most likely outcome of an ensemble of experimental results. The total uncertainty can be thought of as the sum of three components: the uncertainty due to errors in the model physics; the uncertainty due to data errors; and the uncertainty due to stochastic processes (turbulence) in the atmosphere. Nevertheless, dispersion modelling is generally accepted as a necessary and valuable tool in air quality management.

3 LEGAL OVERVIEW

Air quality guidelines and standards are fundamental to effective air quality management, providing the link between the source of atmospheric emissions and the user of that air at the downstream receptor site. Air quality guidelines and standards are based on benchmark concentrations that normally indicate safe daily exposure levels for the majority of the population, including the very young and the elderly, throughout an individual's lifetime. Benchmark concentrations could therefore be based on health effects, such as SO_2, or carcinogenic consequences, such as benzene.

Air quality guidelines and standards are normally given for specific averaging or exposure periods and are evaluated as the observed air concentration expressed as a fraction of a benchmark concentration. A standard, as opposed to a benchmark concentration only, is a set of instructions which include a limit value and may contain a set of conditions to meet this limit value. Standards are normally associated with a legal requirement as implemented by the country's relevant authority; however, organisations such as the World Bank Group (WBG) International Finance Corporation (IFC) and private companies also issue standards for internal compliance. The benchmark concentrations issued by the World Health Organisation (WHO), on the other hand, are not standards, but rather guidelines that may be considered for use as limit values in standards.

A common condition included in a standard is the allowable frequency of exceedances of the limit value. The frequency of exceedances recognises the potential for unexpected meteorological conditions coupled with emission variations that may result in outlier air concentrations and would normally be based on a percentile, typically the 99^{th} percentile.

Standards are normally issued for criteria pollutants, i.e. those most commonly emitted by industry including SO_2, NO_2, CO, PM_{10} and $PM_{2.5}$, but may also include secondary pollutants such as O_3. Some countries include other pollutants, specifically when these are considered to be problematic emissions.

In addition to ambient air quality standards or guidelines, emission limits aim to control the amount of pollution from a point source[1]. Emissions to air should be avoided or controlled according to Good International Industry Practice (GIIP) applicable to the specific industry sector (IFC, 2007a).

Namibia does not have air quality guidelines or limits and reference is usually made to international ambient air quality guidelines and standards. The WHO is widely referenced, as well as countries in the region who have air quality standards. As part of the AQMP developed for the SEMP update, ambient guidelines for PM_{10} and $PM_{2.5}$ were determined to provide the necessary performance indicators for mines and industries within the Erongo Region. These guidelines are regarded applicable to the current study and discussed in one of the following sub sections.

3.1 Namibian Legislation

The Atmospheric Pollution Prevention Ordinance (No. 11 of 1976) deals with the following:

Part I	:	Appointment and powers of officers;
Part II	:	Control of noxious or offensive gases;
Part III	:	Atmospheric pollution by smoke;
Part IV	:	Dust control;
Part V	:	Pollution of the atmosphere by gases emitted by vehicles;
Part IV	:	General provisions; and
Schedule 2:		Scheduled processes.

[1] Point sources are discrete, stationary, identifiable sources of emissions that release pollutants to the atmosphere (IFC, 2007).

The Ordinance does not include any ambient air standards with which to comply, but opacity guidelines for smoke are provided under Part III. It is implied that the Director[2] provides air quality guidelines for consideration during the issuing of Registration Certificates, where Registration Certificates may be issued for "Scheduled Processes" which are processes resulting in noxious or offensive gases and typically pertain to point source emissions. To our knowledge no Registration Certificates have been issued in Namibia. However, an Environmental Clearance Certificate is required for any activity entailing a scheduled process as referred to in the Atmospheric Pollution Prevention Ordinance, 1976.

Also, the Ordinance defines a range of pollutants as noxious and offensive gases, but no ambient air quality guidelines or standards or emission limits are provided for Namibia.

Part II of the Ordinance pertains to the regulation of noxious or offensive gases. The Executive Committee may declare any area a *controlled area* for the purpose of this Ordinance by notice in the Official Gazette. Any scheduled process carried out in a *controlled area* must have a current registration certificate authorising that person to carry on that process in or on that premises.

The published Public and Environmental Health Act 1 of 2015 provides "a framework for a structured uniform public and environmental health system in Namibia; and to provide for incidental matters". The act identifies health nuisances, such as chimneys sending out smoke in quantities that can be offensive, injurious, or dangerous to health and liable to be dealt with.

3.1.1 Best Practice Guide for the Mining Sector in Namibia

A Best Practice Guide for the Mining Sector in Namibia was published in July 2020 (NCE, 2020). The document serves as a guiding framework during all mining phases to effectively assess aspects such as environmental and social impacts.

The report lists air quality as an environmental risk. It provides examples of sources and activities that would result in particulate and gaseous emissions and gives guidance on management and control of these source activities. Aspects relevant to the Project can be summarised as follows:

- The benefits of the SEMP for industry are highlighted and the SEMP Environmental Quality Objectives (EQOs) require as a minimum management objective that "any change to the environment must be within acceptable limits, and that pro-active intervention will be triggered by the responsible party to avoid unwanted changes that breach a specific threshold." All mining companies within the region submit reports annually as part of the SEMP annual report which is available in the public domain.
- Section 3 provides requirements for Baseline Studies where air quality is listed as one of the most important aspects where background conditions of dust, gaseous and nuisance emissions and in some cases fumes and odours are required. Dust and gaseous emissions require immediate monitoring, as well as the establishment of a network of meteorological measuring points. Dust requires the monitoring of particulate matter (PM), in PM_{10}–format, but the monitoring program may require simultaneous measurement of TSP or $PM_{2.5}$ as well.
- Applicable ambient air quality guidelines are listed in Section 3 of the report. It states that Namibia does not have ambient air quality standards or guidelines and references the SEMP AQMP (Liebenberg-Enslin, et al., 2019) guidelines which were determined to provide the necessary performance indicators for the region. These are discussed in more detail under Section 2.5.
- Recommendations in Section 3 include: Dust Management Plans for all operational sites (mines, exploration sites and quarries); annual reporting of dust fall levels and PM_{10} concentrations to the authorities; dust suppression at

[2] *Director* means the Director of Health Services of the Administration, and, where applicable, includes any person who, in terms of any authority granted to him under section 2(2) or (3) of the Ordinance.

construction sites (as well as annual reporting on dust mitigation measures); update and improvement of the current emissions inventory; establishing a monitoring regime to enhance source apportionment of PM concentrations and sodium content; and continuation with PM_{10} and meteorological monitoring.

- Section 4 indicates that once mines are operational, an air quality management plan is essential for dealing with issues that can potentially have an adverse impact on operations. In addition to dust, an air quality plan needs to incorporate the management of emissions (release of pollutants and particulates) and fumes as well. All mines must, as a minimum requirement of an air quality management plan, manage dust.
- Requirements for air quality monitoring during the operational phase is provided and reference is made again to the SEMP guidelines as performance indicators for the region. All the uranium mines in Namibia are in the Erongo Region and all these mines have extensive air quality monitoring programmes in place.
- The report further provides guidance on closure and maintenance where management and monitoring of erosion is one of the essential aspects.

3.2 International Criteria

Typically, when no local ambient air quality criteria exist, or are in the process of being developed, international criteria are referenced. This serves to provide an indication of the severity of the potential impacts from proposed activities. The most widely referenced international air quality criteria are those published by the WBG, the WHO, and the European Community (EC). The South African (SA) National Ambient Air Quality Standards (NAAQS) are also referenced since it is regarded representative indicators for Namibia due to the similar environmental and socio-economic characteristics between the two countries. The PM guidelines selected as part of the SEMP AQMP for the Erongo Region were based on these international guidelines and standards, and the following subsections provide the relevant background.

3.2.1 WHO Air Quality Guidelines

Air Quality Guidelines (AQGs) were published by the WHO in 1987 and revised in 1997. Since the completion of the second edition of the AQGs for Europe, which included new research from low-and middle-income countries where air pollution levels are at their highest, the WHO has undertaken to review the accumulated scientific evidence and to consider its implications for its AQGs. The result of this work is documented in *'Air Quality Guidelines – Global Update 2005'* in the form of revised guideline values for selected criteria air pollutants, which are applicable across all WHO regions (WHO, 2005).

Given that air pollution levels in developing countries frequently far exceed the recommended WHO AQGs, interim target (IT) levels were included in the update. These are more lenient than the WHO AQGs with the purpose to promote steady progress towards meeting the WHO AQGs (WHO, 2005). There are two or three interim targets depending on the pollutant, starting at WHO interim target-1 (IT-1) as the most lenient and IT-2, IT-3 and IT-4 as more stringent targets before reaching the AQGs. The SA NAAQS are, for instance, in line with IT-1 for SO_2 and IT-3 for PM_{10} and $PM_{2.5}$. It should be noted that the WHO permits a frequency of exceedance of 1% per year (4 days per year) for 24-hour average PM_{10} and $PM_{2.5}$ concentrations. In the absence of interim targets for NO_2, reference is made to the AQG value. These are provided in Table 2 for the pollutants considered in this study.

3.2.2 SA National Ambient Air Quality Standards

NAAQSs for SA were determined based on international best practice for SO_2, NO_2, $PM_{2.5}$, PM_{10}, O_3, CO, Pb and benzene. These standards were published in the Government Gazette on 24 of December 2009 and included a margin of tolerance (i.e. frequency of exceedance) and with implementation timelines linked to it. SA NAAQSs for $PM_{2.5}$ were published on 29 July 2012. As mentioned previously, SA NAAQS closely follow WHO interim targets, which are targets for developing countries, for $PM_{2.5}$, PM_{10} and SO_2. With the main focus of this assessment on PM, only SA NAAQSs for $PM_{2.5}$, PM_{10} are provided in Table 2.

Table 2: International assessment criteria for criteria pollutants

Pollutant	Averaging Period	WHO Guideline Value (µg/m³)	South Africa NAAQS (µg/m³)
Particulate Matter (PM_{10})	1-year	70 (IT1) 50 (IT2) 30 (IT3) 20 (IT4) 15 (AQG)	40 (b) (a)
	24-hour	150 (IT1) 100 (IT2) 75 (IT3) 50 (IT4) 45 (AQG)	75 (b)
Particulate Matter ($PM_{2.5}$)	1-year	35 (IT1) 25 (IT2) 15 (IT3) 10 (IT4) 5 (AQG)	25 (f) 20 (d) 15 (e)
	24-hour	75 (IT1) 50 (IT2) 37.5 (IT3) 25 (IT4) 15 (AQG)	65 (c) 40 (d) 25 (e)

Notes:

(a) 4 permissible frequencies of exceedance per year
(b) Applicable from 1 January 2015.
(c) Applicable immediately to 31 December 2015.
(d) Applicable 1 January 2016 to 31 December 2029.
(e) Applicable 1 January 2030.

3.2.3 Dustfall Limits

Air quality standards are not defined by all countries for dust deposition, although some countries may make reference to annual average dust fall thresholds above which a 'loss of amenity' may occur. In the southern African context, widespread dust deposition impacts occur as a result of windblown dust from mine tailings and natural sources, from mining operations and other fugitive dust sources.

South Africa has published the National Dust Control Regulations (NDCR) on the 1st of November 2013 (Government Gazette No. 36974). The purpose of the regulations is to prescribe general measures for the control of dust in all areas including residential and light commercial areas. Similarly, Botswana published dust deposition evaluation criteria (BOS 498:2013). According to these limits, an enterprise may submit a request to the authorities to operate within the Band 3 (action band) for a limited period, providing that this is essential in terms of the practical operation of the enterprise (for example the final removal of a tailings deposit) and provided that the best available control technology is applied for the duration. No margin of tolerance will be granted for operations that result in dustfall rates in the Band 4 (alert band). This four-band scale is presented in Table 3.

Table 3: Bands of dustfall rates

Band Number	Band Description	30 Day Average Dustfall Rate (mg/m^2-day)	Comment
1	Residential	Dustfall rate < 600	Permissible for residential and light commercial
2	Industrial	600 < Dustfall rate < 1 200	Permissible for heavy commercial and industrial
3	Action	1 200 < Dustfall rate < 2 400	Requires investigation and remediation if two sequential months lie in this band, or more than three occur in a year.
4	Alert	2 400 < Dustfall rate	Immediate action and remediation required following the first exceedance. Incident report to be submitted to relevant authority.

3.3 International Conventions

The technical reference documents published in the IFC Environmental, Health and Safety (EHS) Guidelines provide general and industry specific examples of Good International Industry Practice (GIIP). The General EHS Guidelines are designed to be used together with the relevant Industry Sector EHS Guidelines (IFC, 2007).

The IFC EHS Guidelines provide a general approach to air quality management for a facility, including the following:

- Identifying possible risks and hazards associated with the project as early on as possible and understanding the magnitude of the risks, based on:
  - the nature of the project activities; and,
  - the potential consequences to workers, communities, or the environment if these hazards are not adequately managed or controlled.
- Preparing project- or activity-specific plans and procedures incorporating technical recommendations relevant to the project or facility;
- Prioritising the risk management strategies with the objective of achieving an overall reduction of risk to human health and the environment, focusing on the prevention of irreversible and / or significant impacts;
- When impact avoidance is not feasible, implementing engineering and management controls to reduce or minimise the possibility and magnitude of undesired consequence; and,
- Continuously improving performance through a combination of ongoing monitoring of facility performance and effective accountability.

Significant impacts to air quality should be prevented or minimised by ensuring that:

- Emissions to air do not result in pollutant concentrations exceeding the relevant ambient air quality guidelines or standards. These guidelines or standards can be national guidelines or standards or in their absence WHO AQGs or any other international recognised sources.
- Emissions do not contribute significantly to the relevant ambient air quality guidelines or standards. It is recommended that 25% of the applicable air quality standards are allowed to enable future development in a given airshed. Thus, any new development should not result in ground level concentrations exceeding 25% of the guideline value.
- The EHS recognises the use of dispersion models to assess potential ground level concentrations. The models used should be internationally recognised or comparable.

3.3.1 Degraded Airsheds or Ecological Sensitive Areas

The IFC provides further guidance on projects located in degraded airsheds (IFC, 2007), i.e. areas where the national/ WHO/ other recognised international Air Quality Guidelines are significantly exceeded or where the project is located next to areas regarded as ecological sensitive such as national parks. The Project is not located in an ecologically sensitive area, and the airshed is not regarded to be degraded.

3.3.2 Fugitive Source Emissions

According to the IFC (IFC, 2007), fugitive source emissions refer to emissions that are distributed spatially over a wide area and confined to a specific discharge point. These sources have the potential to result in more significant ground level impacts per unit release than point sources. It is therefore necessary to assess this through ambient quality assessment and monitoring practices.

3.4 Air Emission Standards

An ambient standard is a never-exceed level for a pollutant in the ambient environment, whereas emission standards are never-exceed levels applied directly to the quantities of emissions coming from pollution sources.

Only the current operations, i.e. gold processing, fall under the list of "Scheduled Process" in the Ordinance. To the author's knowledge, no registration certificate has been issued for any "Scheduled Process" in Namibia. Since Namibia does not have any emission limits or guidelines, the international IFC and SA Minimum Emission Standards (MES) are typically referenced.

Since the stack emissions could not be quantified, and the proposed Project would not influence the DMS processing, these sources are not included in the current study.

3.5 Recommended Guidelines and Objectives

The IFC references the WHO guidelines but indicates that any other internationally recognized criteria can be used such as the United States Environmental Protection agency (US EPA) or the EC. It was, however, found that merely adopting the WHO guidelines would result in exceedances of these guidelines in many areas due to the arid environment in the country, and specifically in Namibia. The WHO states that these AQG and interim targets should be used to guide standard-setting processes and should aim to achieve the lowest concentrations possible in the context of local constraints, capabilities, and public health priorities. These guidelines are also aimed at urban environments within developed countries (WHO, 2005). For this reason, the South African NAAQS are also referenced since these were developed after a thorough review of all international criteria and selected based on the socio, economic and ecological conditions of the country.

In the absence of guidelines on ambient air concentrations for Namibia, reference is made to the Air Quality Objectives (AQO) recommended as part of the SEMP AQMP (Liebenberg-Enslin, et al., 2019). These objectives are based on the WHO interim targets and SA NAAQS (Table 2). The criteria were selected on the following basis:

- The WHO IT3 was selected for particulates since these limits are in line with the SA NAAQSs, and the latter are regarded feasible limits for the arid environment of Namibia.
- Even though $PM_{2.5}$ emissions are mainly associated with combustion sources and mainly a concern in urban environments, it is regarded good practice to include as health screening criteria given the acute adverse health effects associated with this fine fraction. Also, studies found that desert dust with an aerodynamic diameter 2.5 µm cause premature mortality (Giannadaki, et al., 2014).

- The Botswana and South African criteria for dust fallout are the same and with limited international criteria for dust fallout, these were regarded applicable.

The AQOs as set out in Table 4 are intended to be used as indicators during the impact assessment.

Table 4: Adopted Air Quality Objectives for the Project

Pollutant	Averaging Period	Criteria	Reference
Particulate matter (PM_{10})	24-hour average (µg/m³)	75[a]	WHO IT3 & SA NAAQS (as per SEMP AQMP)
	Annual average (µg/m³)	40	SA NAAQS (as per SEMP AQMP)
Particulate matter ($PM_{2.5}$)	24-hour average (µg/m³)	37.5[a]	WHO IT3 (as per SEMP AQMP)
	Annual average (µg/m³)	15	WHO IT3 & SA NAAQS (as per SEMP AQMP)
Dustfall	30-day average (mg/m²/day)	600[b]	SA NDCR & Botswana residential limit
		1 200[b]	SA NDCR & Botswana industrial limit
		2 400	Botswana Alert Threshold

Notes: [a] Not to be exceeded more than 4 times per year (SA)

[b] Not to be exceeded more than 3 times per year or 2 consecutive months

4 DESCRIPTION OF THE BASELINE ENVIRONMENT

4.1 Site Description and Sensitive Receptors

The proposed Project is located just outside of Karibib (approximately 10 km), in the eastern part of the Erongo Region of Namibia. This region is characterised by low rainfall, extreme temperature ranges and unique climatic factors influencing the natural environment and biodiversity (Goudie, 2009). Episodic dust storms associated with strong easterly winds occur during the autumn and winter months, giving rise to dust emissions from natural and anthropogenic sources under conditions of high wind speeds (MME, 2010).

The two Mining Licence (ML) areas (ML31 and ML180) cover an area with dimensions of about 18 km northeast-southwest and 8 km north-south. The current mining operations, as well as the proposed TSF3, fall within ML31. The terrain is hilly, with a ridge to the south of the open pit areas which serve as a barrier on the south-eastern side of the current TSF2, and a hill further south. The new TSF3 will be located between the two rock ridges, both serving as “sidewalls” and the waste rock dumps to the north serving as a buttress.

AQSRs primarily relate to where people reside. There are no villages or homesteads near the project, with the closest settlement – homesteads – 3 km to the northeast and 2.4 km to the southwest. The town of Karibib is located about 10 km to the northeast from the operations. All identified AQSRs are shown in providing the spatial context for the closest AQSRs (Figure 2).

Main (national) roads in close proximity to the Project are the B2, approximately 3 km to the north of the mine and the C32, about 5.5 km to the east.

4.2 Atmospheric Dispersion Potential

Meteorological mechanisms govern the dispersion, transformation, and eventual removal of pollutants from the atmosphere. The extent to which pollution will accumulate or disperse in the atmosphere is dependent on the degree of thermal and mechanical turbulence within the earth’s boundary layer. Dispersion comprises vertical and horizontal components of motion. The stability of the atmosphere and the depth of the surface-mixing layer define the vertical component. The horizontal dispersion of pollution in the boundary layer is primarily a function of the wind field. The wind speed determines both the distance of downwind transport and the rate of dilution as a result of plume ‘stretching’. The generation of mechanical turbulence is similarly a function of the wind speed, in combination with the surface roughness. Pollution concentration levels therefore fluctuate in response to changes in atmospheric stability, to concurrent variations in the mixing depth, and to shifts in the wind field.

Meteorological data for NGM was provided for the period 12 June 2021 to 4 November 2022, however these were daily records where hourly average data is required to compile wind roses and for the dispersion modelling. Reference was therefore made to WRF modelled meteorological data for the NGM study area for the period 1 January 2020 to 31 December 2022.

A description of the wind field, temperature, precipitation, and atmospheric stability is provided in the following sections.

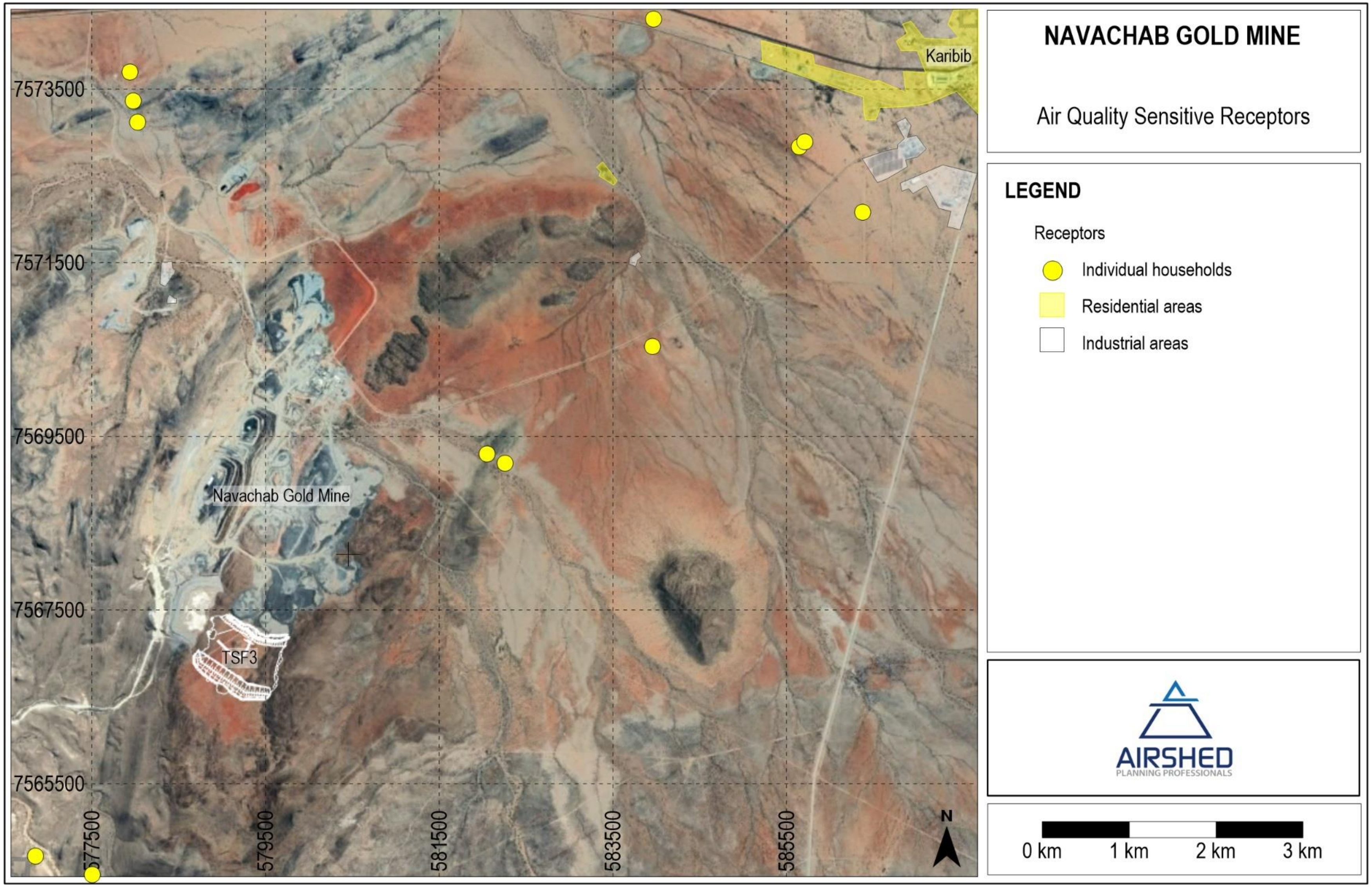


Figure 2: Air Quality Sensitive Receptors in the vicinity of Navachab Gold Mine

4.2.1 Surface Wind Field

The wind direction, and the variability in wind direction, determines the general path that air pollutants will follow, and the extent of crosswind spreading. Wind roses comprise 16 spokes, which represent the directions from which winds blew during the period. The colours used in the wind roses below, reflect the different categories of wind speeds; the red area, for example, representing winds between higher than 7 m/s. The dotted circles provide information regarding the frequency of occurrence of wind speed and direction categories. The frequency with which calms occurred refers to periods during which the wind speed was below 1 m/s.

Period, daytime and night-time wind roses for the study area, based on the WRF meteorological data for the three-year period (2020 – 2022), are depicted in Figure 3, with monthly wind roses for the same period shown in Figure 4.

The wind field is dominated by winds from the southwest to south, and east to north-east, with the strongest winds from the southwest. Calm conditions prevailed 2.6% of the time. During the day, north-easterly winds prevailed with strong but less frequent winds from the southwest, and calm conditions for 2.5%. At night, the wind field shifted to more frequent southerly winds with winds at lower wind speeds, followed by easterly to east-north-easterly winds and no wind from the northern or north-western sector (Figure 3).

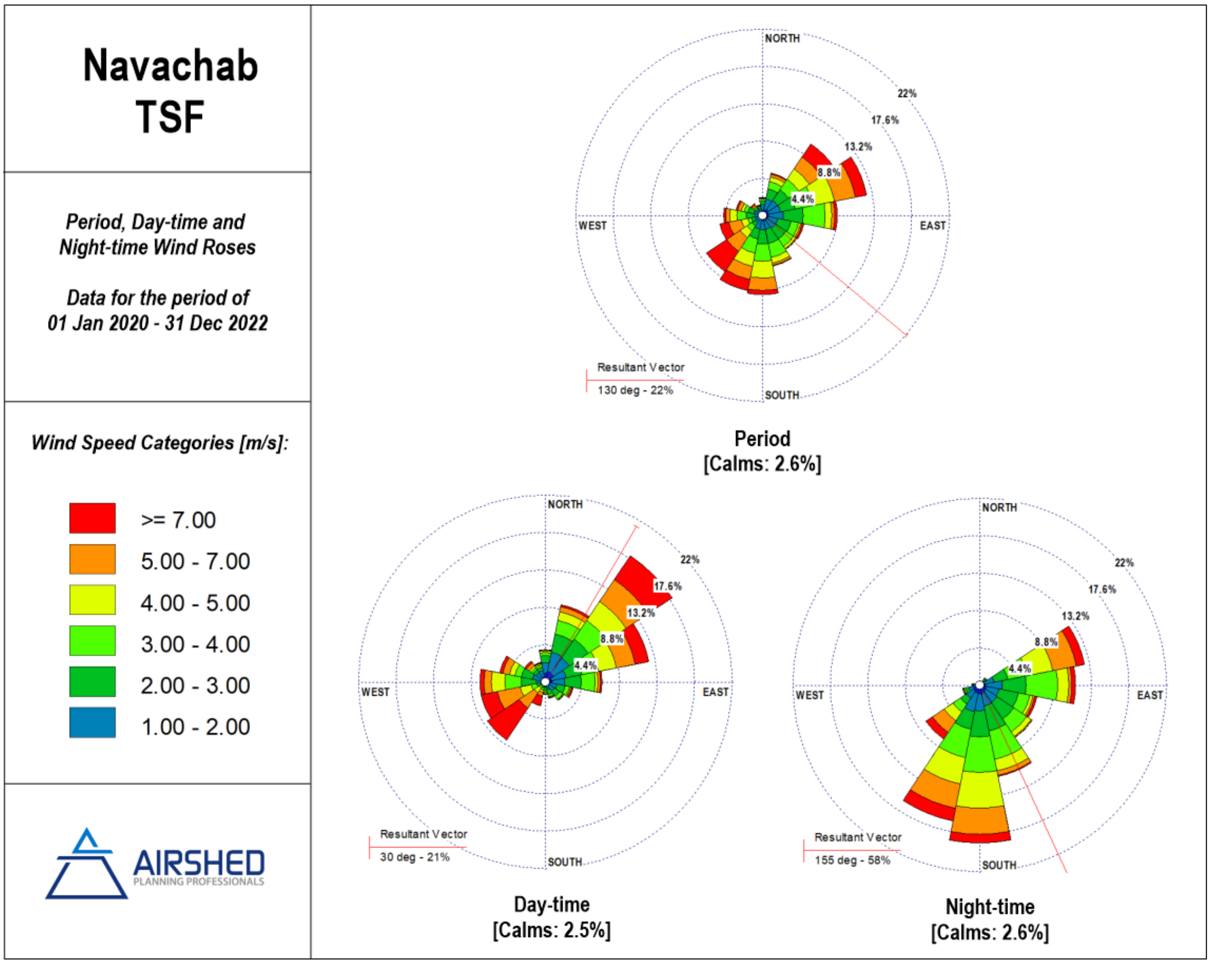


Figure 3: Period, day- and night-time wind roses for Navachab Gold Mine (WRF data: 2020 – 2022)

Seasonal variation in the wind field is shown in Figure 4. During the summer months, the south-westerly winds dominate with infrequent weak winds from the northeast. The wind field shifts to dominant east to north-easterly winds during autumn and less frequent south-westerly winds. The wind field remains similar during winter months but associated with much stronger winds; the so called "East wind conditions". The spring months start showing similar wind flow to the summer months, but with more frequent easterly winds.

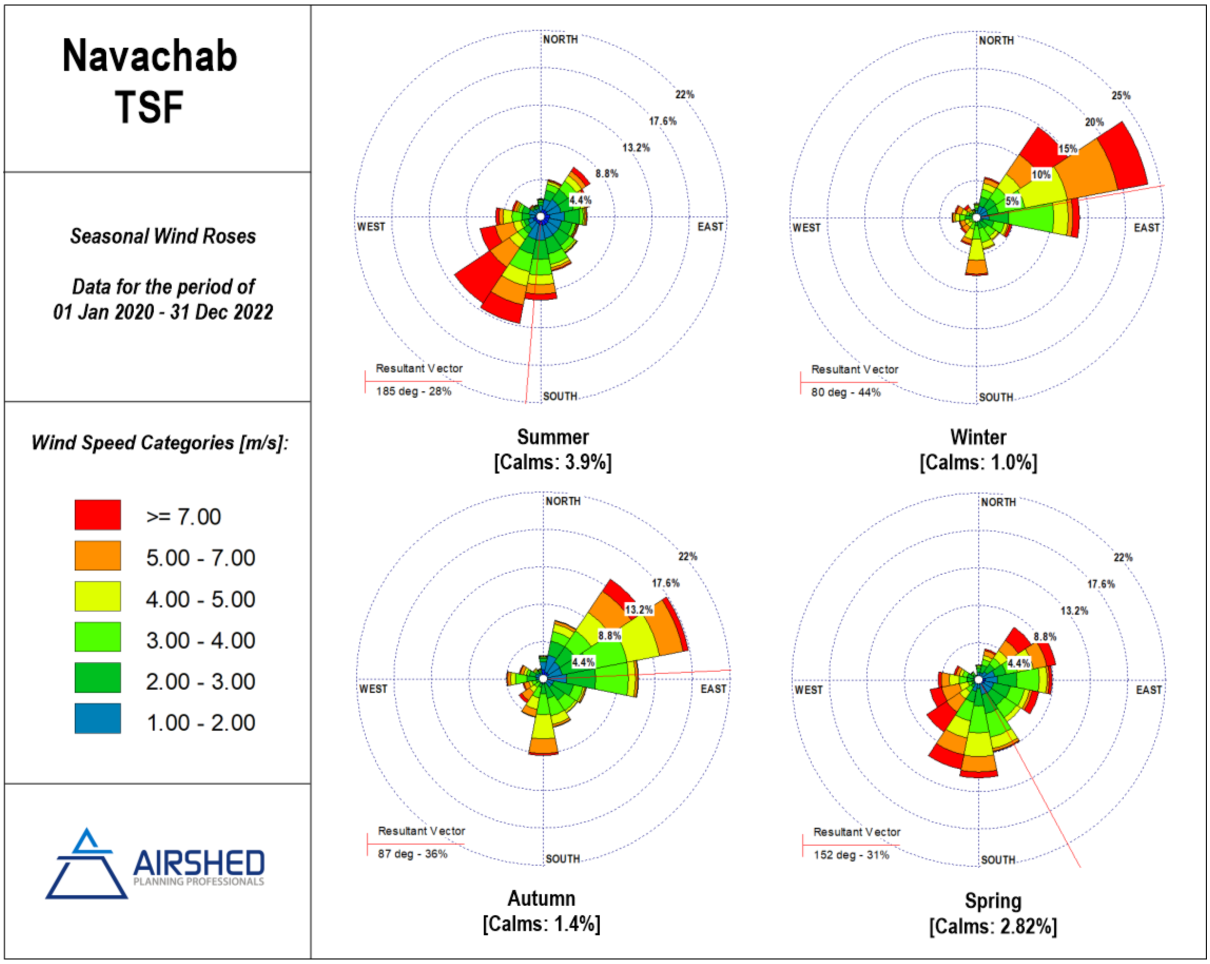


Figure 4: Seasonal wind roses for Navachab Gold Mine (WRF data: 2020 – 2022)

According to the Beaufort wind force scale (https://www.metoffice.gov.uk/guide/weather/marine/beaufort-scale), wind speeds between 6-8 m/s equate to a moderate breeze, with wind speeds between 14-17 m/s near gale force winds. Based on the WRF data for the period 2020 – 2022, wind speeds fell mostly in the 5-8 m/s category (30% of time) with winds exceeding 8 m/s for 7% of the time (Figure 5). Winds exceeding 5 m/s occurred for 37% of the time, with a maximum wind speed of 12.6 m/s. The average wind speed over the period was 4.4 m/s. The likelihood for wind erosion to occur from open and exposed surfaces, with loose fine material, but taking into account that the natural surfaces are crusted, was estimated when the wind speed exceeds 10 m/s (Liebenberg-Enslin, et al., 2019), whereas the estimated wind speed threshold for gold tailings is 8.8 m/s (Liebenberg-Enslin, 2014). Wind speeds exceeding 10 m/s occurred for 0.8% over the period.

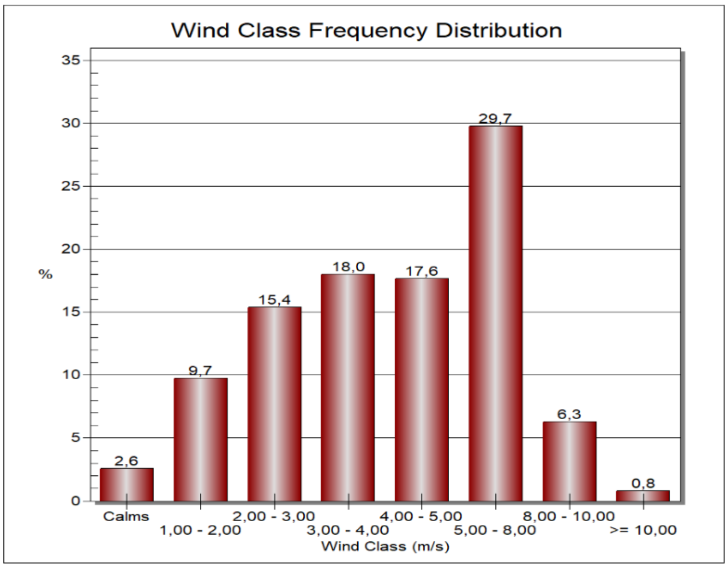
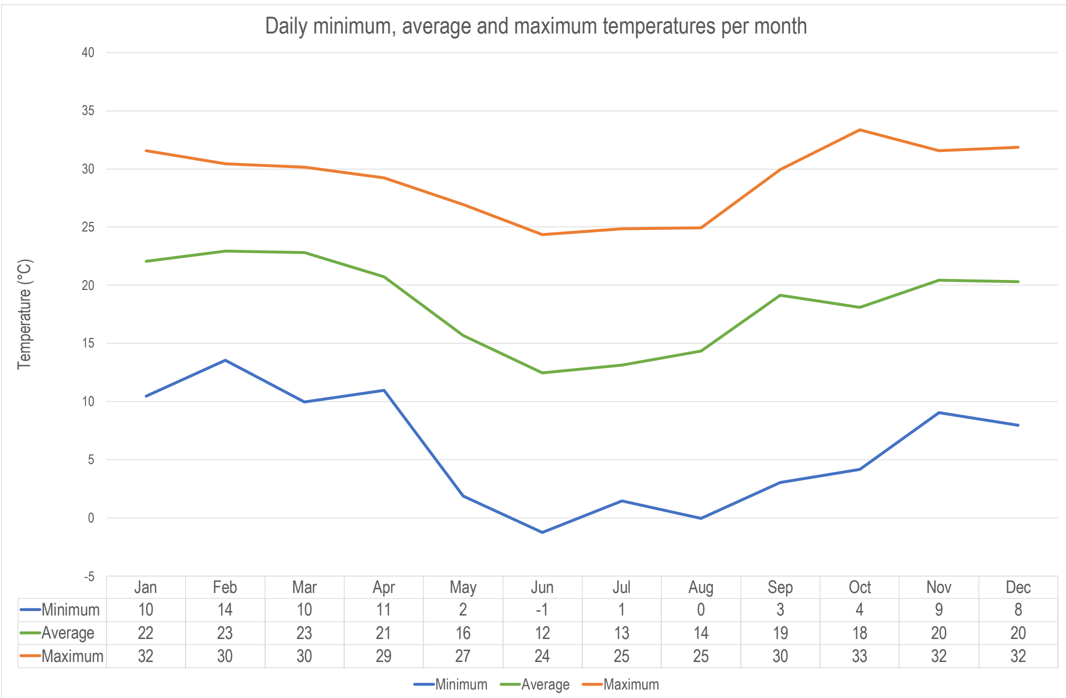


Figure 5: Wind speed categories for Navachab Mine (WRF data: 2020 – 2022)

4.2.2 Temperature

Air temperature is important, both for determining the effect of plume buoyancy (the larger the temperature difference between the plume and the ambient air, the higher the plume can rise), and determining the development of the mixing and inversion layers.

Minimum, average, and maximum hourly temperatures for the study area are given as -1.3°C, 21°C and 38°C respectively. The minimum, average, and maximum daily temperatures for the period 2020 – 2023 is provided in Figure 6.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum	10	14	10	11	2	-1	1	0	3	4	9	8
Average	22	23	23	21	16	12	13	14	19	18	20	20
Maximum	32	30	30	29	27	24	25	25	30	33	32	32

Figure 6: Daily minimum, average, and maximum temperatures for Navachab Gold Mine (WRF data: 2020 – 2022)

4.2.3 Precipitation

Precipitation is important to air pollution studies since it represents an effective removal mechanism for atmospheric pollutants and inhibits dust generation potentials. Monthly average rainfall figures obtained from the NGM weather station data for January 2022 to October 2022 are illustrated in Figure 7. Annual rainfall for 2022 is 273 mm, with the highest rainfall of 161 mm recorded in February 2022. No rainfall was reported for 2021.

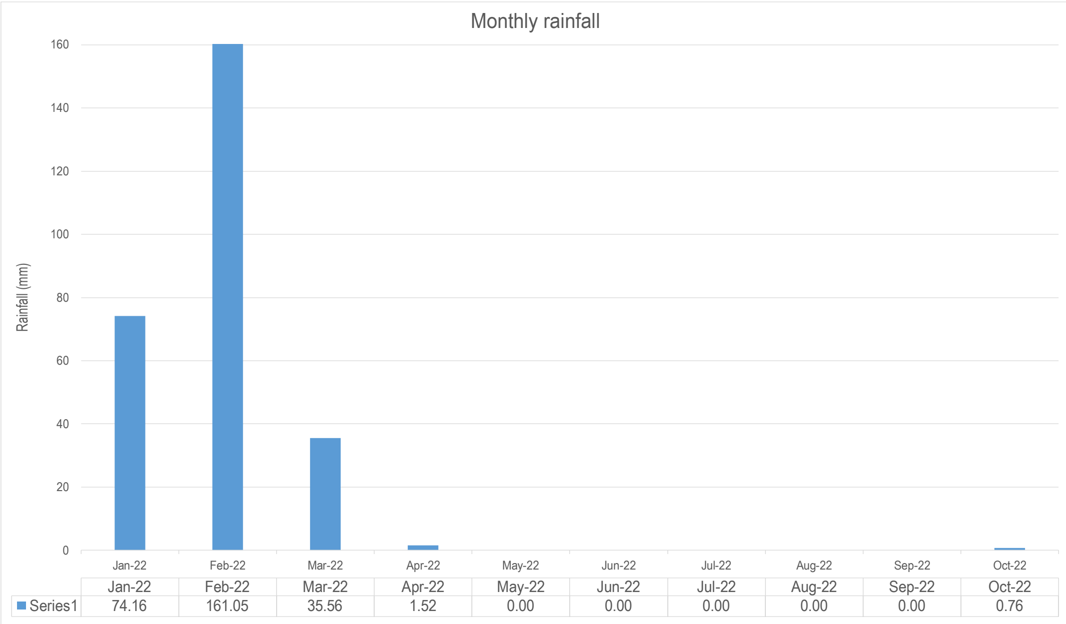


Figure 7: Average rainfall for Navachab Gold Mine (on-site data 2022)

4.2.4 Atmospheric Stability

The new generation air dispersion models differ from the models traditionally used in several aspects, the most important of which are the description of atmospheric stability as a continuum rather than discrete classes. The atmospheric boundary layer properties are therefore described by two parameters: the boundary layer depth and the Obukhov length, rather than in terms of the single parameter Pasquill Class. The Obukhov length (LMo) provides a measure of the importance of buoyancy generated by the heating of the ground and mechanical mixing generated by the frictional effect of the earth's surface. Physically, it can be thought of as representing the depth of the boundary layer within which mechanical mixing is the dominant form of turbulence generation (CERC, 2004)..

The atmospheric boundary layer constitutes the first few hundred metres of the atmosphere. During the daytime, the atmospheric boundary layer is characterised by thermal turbulence due to the heating of the earth's surface and the predominance of an unstable layer. In unstable conditions, ground level pollution is readily dispersed thereby reducing ground level concentrations. Elevated emissions, however, such as those released from a chimney, are returned more readily to ground level, leading to higher ground level concentrations.

Night times are characterised by weak vertical mixing and the predominance of a stable layer. These conditions are normally associated with low wind speeds and less dilution potential. During windy and/or cloudy conditions, the atmosphere is normally neutral (which causes sound scattering in the presence of mechanical turbulence). For low level releases, the highest ground level concentrations would occur during weak wind speeds and stable (night-time) atmospheric conditions.

Atmospheric stability is frequently categorised into one of six stability classes – these are briefly described in Table 5 with the percentage time each class occurred during the three-year period. For low level releases, such as mining operations, the highest ground level concentrations would occur during weak wind speeds and stable (night-time) atmospheric conditions (Category E), which relates to on average 7% of the time at the proposed Project site. However, windblown dust is likely to occur under high winds (neutral conditions – Category D) which accounted for 5% of the time, on average.

Table 5: Atmospheric stability classes: Frequency of occurrence for the period 2020 – 2023

Designation	Stability Class	Atmospheric Condition	Frequency of occurrence
A	Very unstable	calm wind, clear skies, hot daytime conditions	3%
B	Moderately unstable	clear skies, daytime conditions	7%
C	Unstable	moderate wind, slightly overcast daytime conditions	13%
D	Neutral	high winds or cloudy days and nights	5%
E	Stable	moderate wind, slightly overcast night-time conditions	7%
F	Very stable	low winds, clear skies, cold night-time conditions	65%

4.3 Current Ambient Air Quality

4.3.1 Existing Sources of Atmospheric Emissions in the Area

The Project falls within the eastern part of the Erongo Region. The main air pollution sources within the region, as identified during the 2019 air quality study as part of the SEMP AQMP (Liebenberg-Enslin, et al., 2019), include current mining and quarry operations, exploration activities, public roads (paved, unpaved and salt/treated), and natural exposed areas prone to wind erosion. In addition, there are several other sources emitting PM such as small boilers and incinerators, commercial activities, charcoal packaging, construction activities (roads, buildings, etc.), and marine aerosols (sea salts and organic matter originating from the Atlantic Ocean).

The main pollutant of concern would be particulate matter (TSP; PM_{10} and $PM_{2.5}$) resulting from vehicle entrainment on the roads (paved, unpaved, and treated surfaces), windblown dust, and mining and exploration activities. Gaseous pollutants such as SO_2, NOx, CO and CO_2 would result from vehicles and combustion sources, but these are expected to be at low concentrations due to the few combustion sources in the region.

4.3.1.1 Vehicle entrainment from roads

Particulate emissions from roads occur when the force of the wheels on the road surface grinds the surface material into finer particles which are then lifted by the rolling wheels and kept in suspension due to the turbulent wake behind the vehicle (U.S. EPA, 2011). Dust emissions from paved and unpaved roads varies linearly with the volume of traffic. In addition, a number of parameters influence the surface condition of a particular road, such as average vehicle speed, mean vehicle weight, silt content of road material, and road surface moisture, and these will thus impact on dust emissions (U.S. EPA, 2006).

The national road to the north (B2) of NGM is a paved road and one of the main routes from Windhoek to Swakopmund, resulting in one of the road sections with the highest traffic in the region. During the SEMP AQMP, the emissions from these roads were quantified based on vehicle estimated annual average daily traffic (EAADT) figures, as provided by the Namibian Roads Authority (RA) for the year 2016. The vehicle kilometres travelled per day (VKT/day) on the paved B2 were calculated to be 224,722. Vehicle entrainment from the B2 was calculated to be a significant contributor at 29% to the regional paved road $PM_{2.5}$ and PM_{10} emissions. The C32, is an unpaved road connecting the Karibib with the Namib Naukluft Park. This road was not accounted for in the SEMP study but is assumed to have very low traffic counts[3].

[3] This will be confirmed with the Traffic Specialist to include in the impact assessment phase.

Dispersion modelling was conducted to identify the main contributing sources to the measured PM_{10} and $PM_{2.5}$ concentrations. Modelled results indicated that vehicle entrainment from roads (paved, unpaved, and salt/treated surfaces) are the main contributing sources of PM_{10} and $PM_{2.5}$ emissions, but mostly affecting receptors close to the roads. Vehicle entrained emissions from the paved B2 are likely to be a significant background source of PM_{10} and $PM_{2.5}$ concentrations at the Project.

4.3.1.2 Windblown dust

Windblown particulates from natural exposed surfaces, mine waste facilities, and product stockpiles can result in significant dust emissions with high particulate concentrations near the source locations, potentially affecting both the environment and human health.

Wind erosion is a complex process, including three different phases of particle entrainment, transport, and deposition. For wind erosion to occur, the wind speed needs to exceed a certain threshold, called the friction velocity. This relates to gravity and the inter-particle cohesion that resists removal. Surface properties such as soil texture, soil moisture and vegetation cover influence the removal potential. For a natural environment such as the gravel plains of the Erongo Region, the threshold friction velocity was estimated to be 10 m/s and above due to the crusting effect of the soil surface.

In the quantification of windblown fugitive PM, use was made of the Airshed inhouse ADDAS model taking into account the particle size distribution (PSD); moisture content; particle density and friction threshold velocity. Windblown dust from natural exposed areas within the entire Erongo Region regarded to be prone to wind erosion (16,170 km²), resulted in high emissions ranging between 11 g/m²/year for $PM_{2.5}$ and 15 g/m²/year for PM_{10}. When reported as a soil (PM) loss per square metre (m²), the erosion losses seem reasonable when compared to other reported soil/PM_{10} losses due to wind erosion (Pi et al., 2018; Schepanski, 2018). The percentage hours where emissions occurred ranged between 0.1% and 2.1%, which is in line with wind speeds exceeding 10 m/s. Wind speeds at NGM (based on WRF data) exceed 10 m/s for 0.8% of the time. Windblown dust from natural exposed surfaces at and around the Project is regarded to be an insignificant source of particulate matter.

4.3.1.3 Mines and Exploration operations

Pollutants typically emitted from mining and quarrying activities are particulates, with smaller quantities associated with vehicle exhaust emissions. Mining and quarrying activities, especially open-cast mining methods, as well as exploration activities, emit pollutants near ground-level over (potentially) large areas. Source activities resulting in significant dust emissions include: drilling and blasting; materials handling (loading, unloading, and tipping); crushing and screening; windblown dust (from the sources as described above); access roads; and plant stack emissions.

Mines in proximity to the Project[4] are NGM, where it is located, with the existing TSF2 directly to the west on the other side of the ridge. There are a number of marble quarries in the region, with one 3.5 km west, and others to the south of Karibib.

Emissions quantified for the various mines in the region as part of the SEMP AQMP (Liebenberg-Enslin, et al., 2019), indicated vehicle entrained dust from on-site haul roads and access roads (combination of paved and unpaved road surfaces) to be the main contributing source to PM_{10} emissions. The largest source of $PM_{2.5}$ emissions was windblown dust mainly derived from the mining TSFs. Crushing and screening operations were identified as the third largest source of PM emissions followed by materials handling.

From the regional dispersion model, mining and quarry operations were the second highest dust sources. The impact range of these sources were a few kilometres from the mining operations, primarily within an east-west (or east-northeast and west-southwest) direction, not affecting the coastal towns but the nearby settlements.

[4] The Project is the proposed TSF3

4.3.1.4 Regional transportation of pollutants

Another source of air pollution is aerosols as a result of regional-scale transport of mineral dust and ozone (due to vegetation burning) from the north of Namibia (http://www.fao.org/docrep/005/x9751e/x9751e06.htm). Biomass burning is an incomplete combustion process (Cachier, 1992), with carbon monoxide, methane and nitrogen dioxide gasses being emitted. Approximately 40% of the nitrogen in biomass is emitted as nitrogen, 10% is left in the ashes, and it may be assumed that 20% of the nitrogen is emitted as higher molecular weight nitrogen compounds (Held, et al., 1996). The visibility of the smoke plumes is attributed to the aerosol (particulate matter) content. Formenti et al., (2018) attributed the recording of black carbon at Henties Bay to contributions from biomass burning and even from the SA highveld's coal fired power stations.

Evaporation of sea spray are also sources of airborne particles, whereas pollen grains, mould spores and plant and insect parts all contribute to the atmospheric particulate load. Marine aerosols may include sea salt as well as organic matter (O'Dowd, 2007). Sea salt is a major atmospheric aerosol component on a global scale, with a significant impact on PM concentrations (O'Dowd, 2007; (Athanasopoulou, 2008)., (Kelly, 2010); (Karaguliun, 2015)). Aside from the primary contribution from sea salt, recent interest is on its role in chemical reactions (with gaseous emission) and on climate change (O'Dowd, 2007; Kelly *et al.*, 2010). One of the findings from the SEMP AQMP was the contribution from the ocean (westerly sector) to PM_{10} concentrations at Swakopmund and Walvis Bay. The contribution from sea salts in the PM_{10} filters was confirmed through chemical analyses (Liebenberg-Enslin, et al., 2019). How far these sea salts can be transported inland is not known.

4.3.2 Measured Ambient Air Pollutant Concentrations at Navachab Gold Mine

There is a dustfall monitoring network in place at NGM comprising of 10 single dustall units, but no ambient PM (PM_{10} and $PM_{2.5}$) monitoring network. The dustfall locations are shown in Figure 8.

PM concentrations measured as part of the SEMP AQMP monitoring network were limited to the coastal towns of Swakopmund, Walvis Bay and Henties Bay with a station in the central western part of the region on the farm Jakalswater. None of these locations are representative of the air quality in the Karibib area.

The dustfall monitoring network was modified at the beginning of 2022 by relocating some of the dustfall units to be more representative of the current mining operations. The network comprises of 10 single dustfall units, and dustfall data is provided for 13 months (Jan'2022 to Jan'2023), but with no data for Feb'2022 and Apr'2022. Dustfall rates vary over the 11 data months and across the network, with the lowest dustfall rate recorded of 29 mg/m²/day and the highest of 7 775 mg/m²/day. On average, the highest dustfall was recorded in Jan'2022 followed by May'2022, with the lowest on average during Jun'2022. NAQ4, located next to the haul road north of the existing TSF2, had the highest dustfall rates over the reporting period, exceeding the alert threshold (2 400 mg/m²/day) for four months and the industrial limit (1 200 mg/m²/day) for 10 months. NAQ2, NAQ9 and NAQ10 had dustfall rates below the residential limit (600 mg/m²/day) for the entire period, with only a single exceedance at NAQ3 and NAQ6. Aside from NAQ4, the industrial limit (1 200 mg/m²/day) was exceeded for three consecutive months at NAQ8, located to the northeast of the northern waste rock dump. The dustfall units furthest from the operations (NAQ2; NAQ3; NAQ9 and NAQ10) had lower dustfall rates and the ones closest to the mining operations (NAQ4; NAQ7 and NAQ8) the highest. NAQ2 and NAQ9 had the lowest dustfall rates below 100 mg/m²/day, followed by NAQ3and NAQ10 with dustfall rates below 250 mg/m²/day. The dustfall rates are shown in Figure 9.

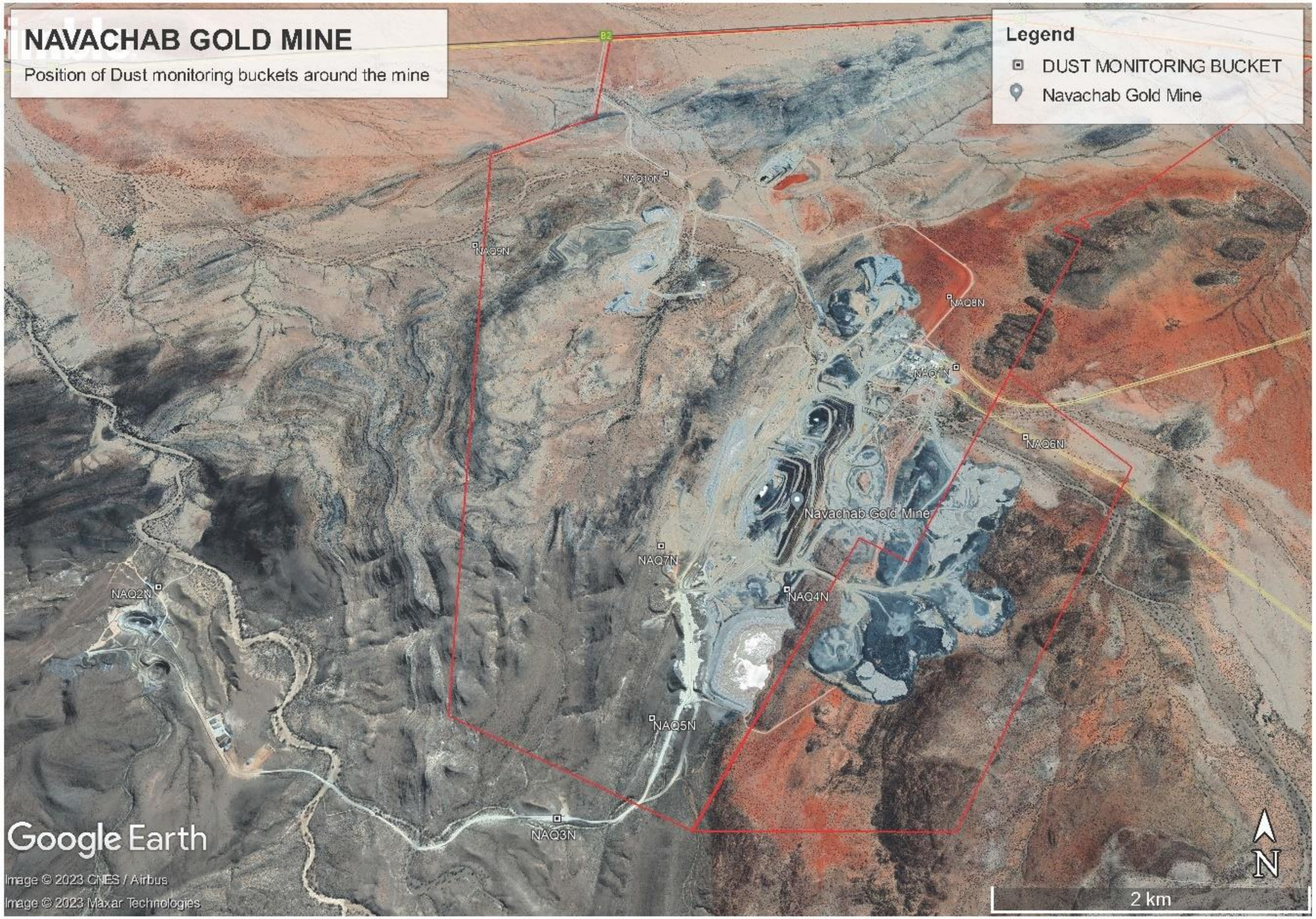


Figure 8: Navachab Gold Mine dustfall monitoring network

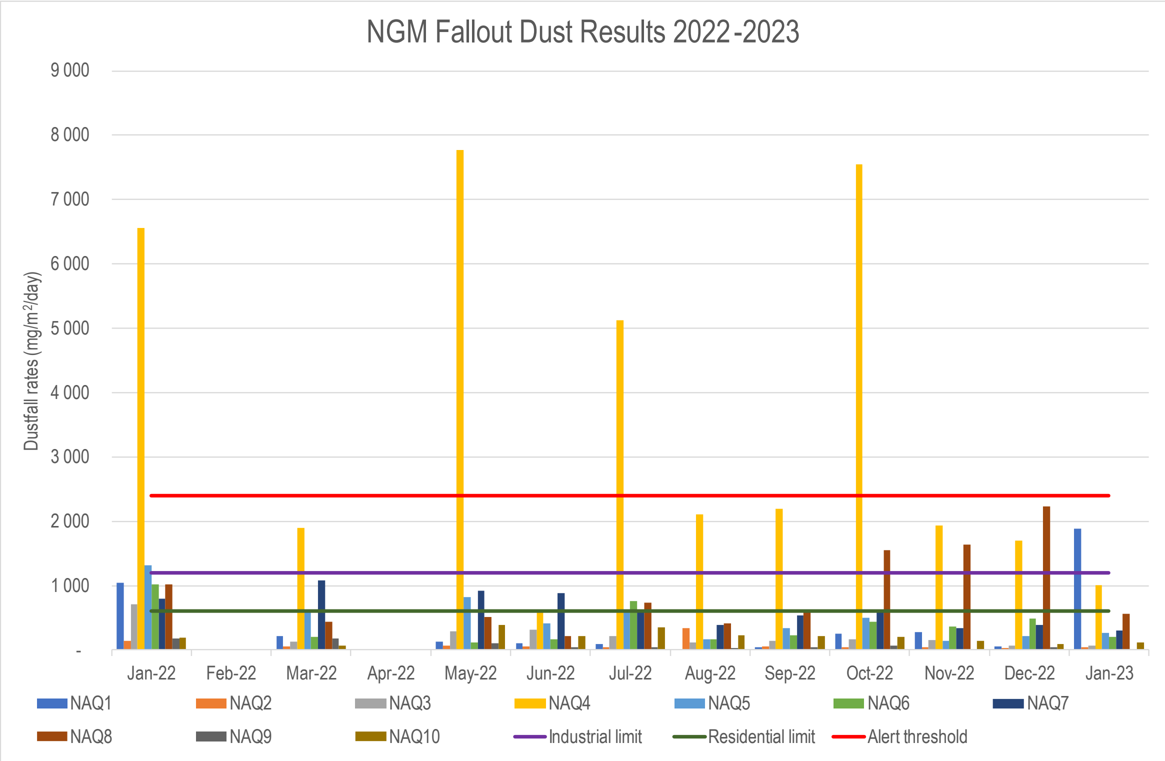


Figure 9: Dustfall rates for Navachab Gold Mine monitoring network (Jan 2022 – Jan 2023)

4.3.3 Simulated Ambient Air Pollutant Concentrations of the current operations at Navachab Gold Mine

In order to determine the potential impacts from the Project (TSF3) cumulatively, the current mining operations at NGM needs to be assessed. The current mining and production rates were not available at the time of the study, and reference is made to the assessment done as part of the 2019 SEMP report (Liebenberg-Enslin, et al., 2019). For the SEMP study the 2016 mining and production rates were used to quantify emission rates for the various mine. The total 2016 mining rate for NGM was given as 16 054 081 tons per annum (tpa) (ore is 3 886 117 tpa, and waste is 12 167 964 tpa). For this assessment, these 2016 rates were assumed to be representative of the current mining operations at NGM.

4.3.3.1 Emissions Quantification

In the quantification of fugitive dust emissions, emission factors were used that associate the quantity of a pollutant to the activity associated with the release of that pollutant. Due to the absence of locally generated emission factors, use was made of the comprehensive set of emission factors published by the US EPA in its AP-42 document compilation of Air Pollution Emission Factors (U.S. EPA, 1998a) and the NPI for mining operations (NPI, 2012). The US EPA AP-42 emission factors are of the most widely used in the field of air pollution and most of the NPI emission factors are based on these. Empirically derived predictive emission factor equations are available for vehicle-entrained dust from roadways, materials handling operations, and for crushing and screening. Single-valued emission factors are also available for general surface preparation, stone crushing, fines screening, and conveyor transfer points. The U.S. EPA emission factors facilitate the quantification of various particle size fractions. This is important given that ambient air quality standards make a distinction between TSP, PM_{10}, and $PM_{2.5}$. The estimated emissions from the various sources at NGM for 2016 are provided in Table 6, with the emission equations used provided in Appendix A.

Table 6: Source group contribution from the activities at Navachab Gold Mine for the year 2016

Source Group	2016 Total (tpa)(b)			Percent contribution		
	$PM_{2.5}$	PM_{10}	TSP	$PM_{2.5}$	PM_{10}	TSP
In-pit sources (a)	266	859	1 362	45%	41%	20%
Materials handling & transfer points	78	500	1 055	13%	24%	16%
Crushing & screening	113	226	3 099	19%	11%	46%
Wind erosion	138	500	1 220	23%	24%	18%
On-site & access roads	1	10	57	0%	0%	1%
TOTAL	**595.94**	**2 095.55**	**6 792.02**			

Notes: (a) Includes all in-pit activities i.e. drilling, blasting, material transfer, in-pit roads.
(b) excludes emissions from point sources (stacks).

Based on the 2016 mining rates, the main contributing activities to $PM_{2.5}$ and PM_{10} emissions are the in-pit activities (i.e. drilling, blasting, loading of ore and waste onto haul trucks, truck movement on in pit roads), with crushing and screening the main contributing source to TSP emissions.

4.3.3.2 Dispersion Modelling Results

Dispersion modelling was undertaken to determine highest daily and annual average $PM_{2.5}$ and PM_{10} ground level concentrations (GLC) as well as dustfall rates for each of the pollutants considered in the study. Averaging periods were selected to facilitate the comparison of predicted pollutant concentrations to relevant ambient air quality and inhalation health criteria as well as dustfall regulations.

Dispersion modelling results are provided based on the emission rates quantified in Table 6. Short-term (daily) concentrations were extracted for the 99^{th} percentile, to account for the number of exceedances allowed by the recommended and prescribed guidelines and targets. A visual reference of the impact areas is shown in the subsequent isopleth plots that represent pollutant dispersion.

Both $PM_{2.5}$ (Figure 10) and PM_{10} (Figure 12) 24-hour GLCs fall mainly within the two MLs with exceedances of the AQO on the southern and south-eastern border of the MLs. These exceedances are however for a small area and not affecting any of the AQSRs. The annual average impact areas for both $PM_{2.5}$ (Figure 11) and PM_{10} (Figure 13) exceed for a very small area on the south-eastern side.

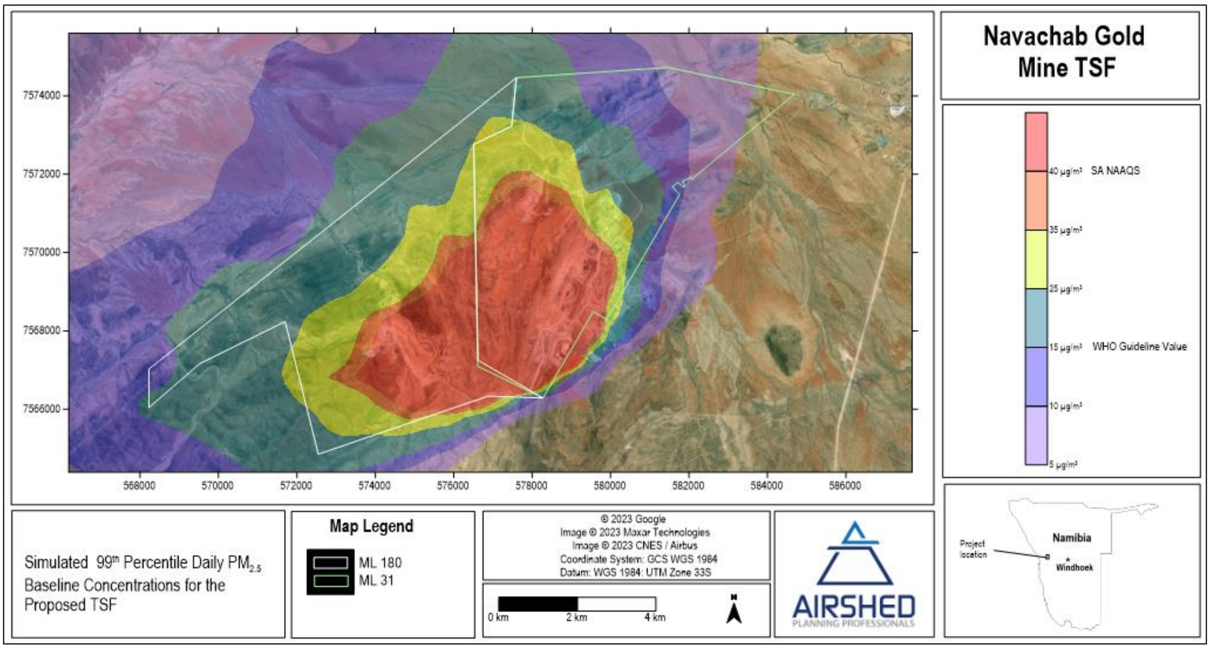


Figure 10: $PM_{2.5}$ 24-hour average ground level concentrations for the 2016 Navachab Gold Mine operations (excluding stack emissions)

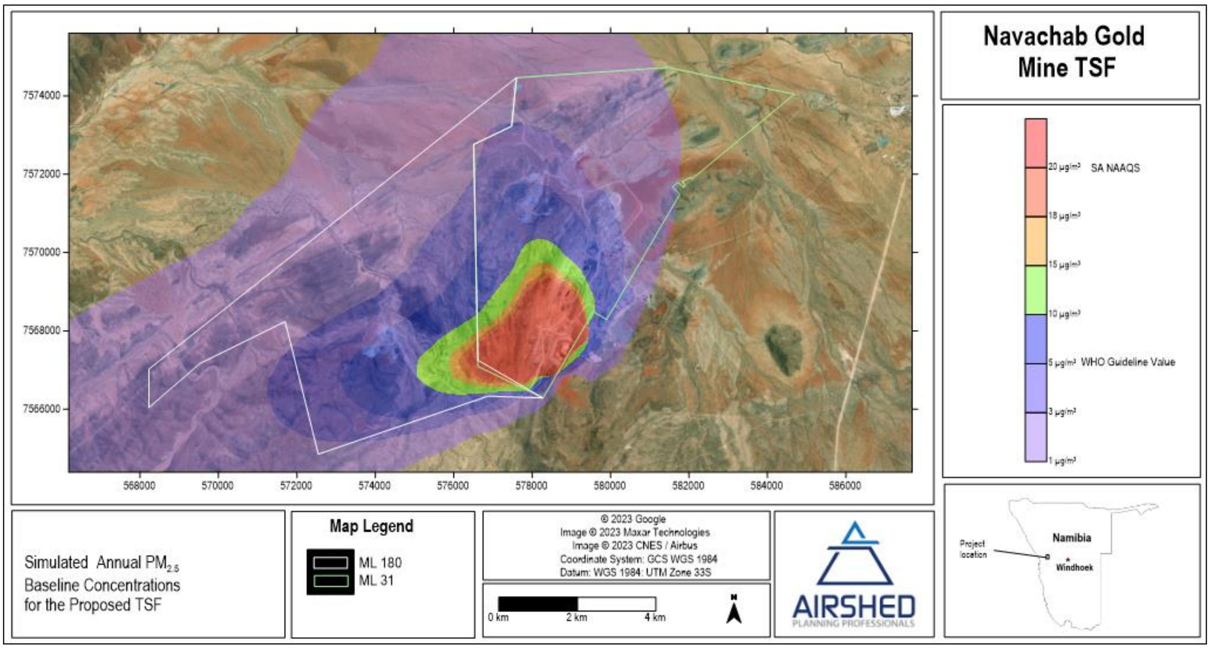


Figure 11: $PM_{2.5}$ annual average ground level concentrations for the 2016 Navachab Gold Mine operations (excluding stack emissions)

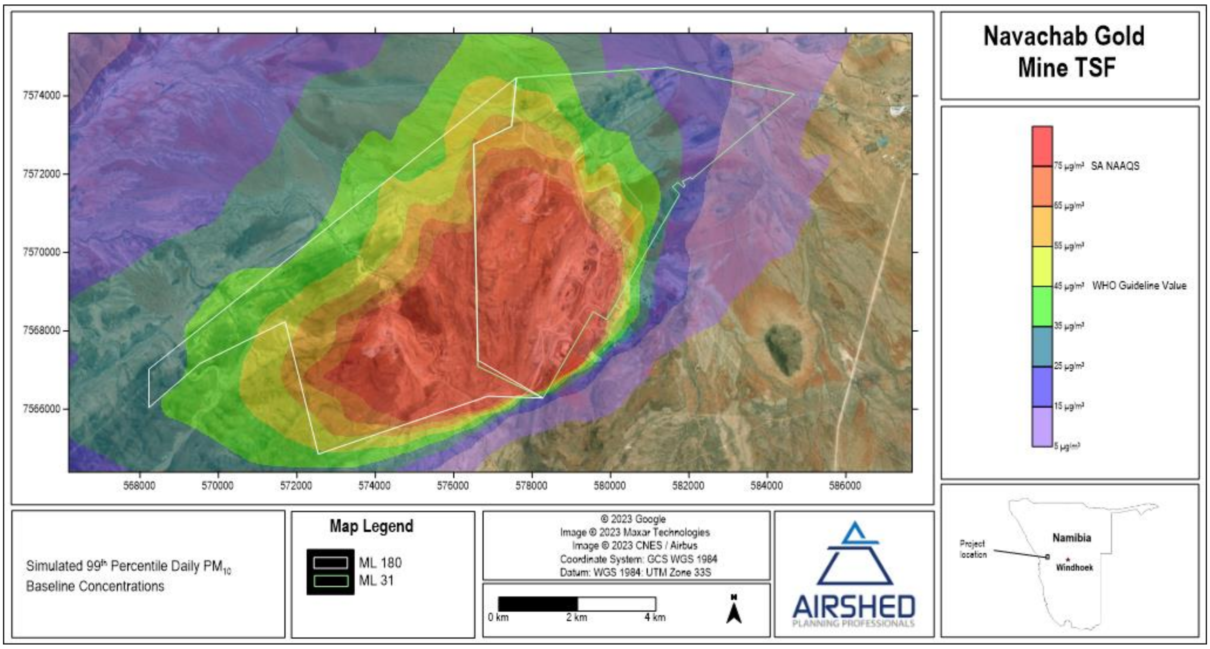


Figure 12: PM_{10} 24-hour average ground level concentrations for the 2016 Navachab Gold Mine operations (excluding stack emissions)

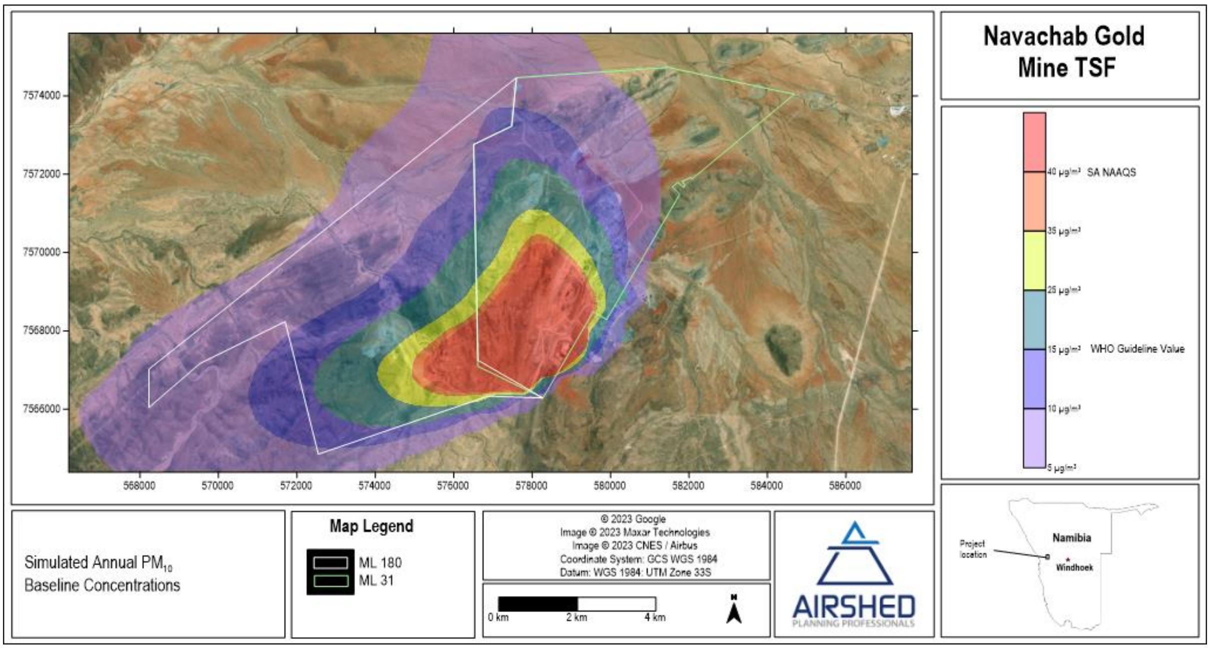


Figure 13: PM_{10} annual average ground level concentrations for the 2016 Navachab Gold Mine operations (excluding stack emissions)

Daily dustfall impacts are primarily over the existing TSF, and only exceeding the industrial dustfall limit for a small area outside the ML as shown in Figure 14.

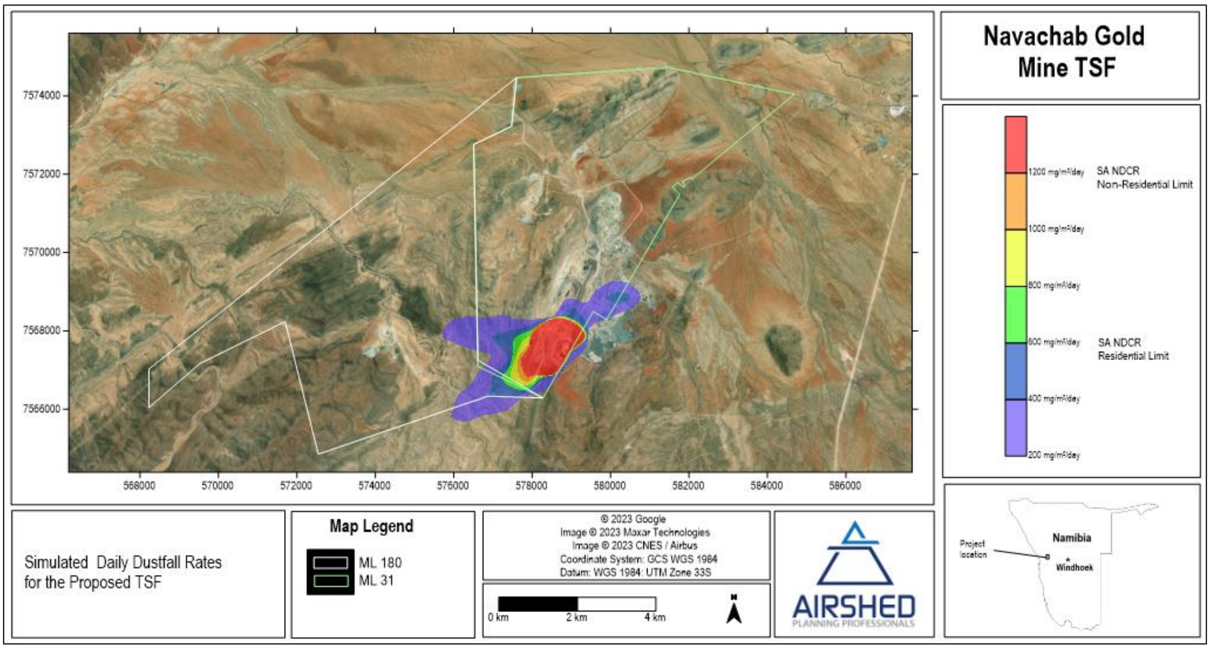


Figure 14: Daily dustfall rates for the 2016 Navachab Gold Mine operations

5 Impact Assessment

The emissions inventory, dispersion modelling and results for the Project only are discussed in Section 5.1, 5.2 and 5.3 respectively.

5.1 Atmospheric Emissions

5.1.1 Construction Phase

Construction normally comprises a series of different operations including land clearing, topsoil removal, material loading and hauling, stockpiling, grading, bulldozing, compaction, etc. Infrastructure required for the new TSF3 would be limited to vegetation clearing and TSF foundation construction.

The main pollutant of concern from construction operations is particulate matter, including PM_{10}, $PM_{2.5}$ and TSP. PM_{10} and $PM_{2.5}$ concentrations are associated with potential health impacts due to the size of the particulates being small enough to be inhaled. Nuisance effects are caused by the TSP fraction (20 µm to 75 µm in diameter) resulting in soiling of materials and visibility reductions. This could in effect also have financial implications due to the requirement for more cleaning materials.

Each of the operations associated with the construction phase has their own duration and potential for dust generation. It is therefore often necessary to estimate area wide construction emissions, without regard to the actual plans of any individual construction process. Quantified construction emissions are usually lower than operational phase emissions and due to their temporary nature and duration, and the likelihood that these activities will not occur concurrently at all portions of the site; dispersion simulation was not undertaken for construction emissions.

The US EPA documents emission factors which aim to provide a general rule-of-thumb as to the magnitude of emissions which may be anticipated from construction operations (US EPA, 2006). The quantity of dust emissions is assumed to be proportional to the area of land being worked and the level of construction activity. The approximate emission factors for general construction activity operations are given as:

E = 2.69 Mg/hectare/month of activity (269 g/m²/month)

The PM_{10} fraction is given as ~39% of the US EPA total suspended particulate factor. These emission factors are most applicable to construction operations with (i) medium activity levels, (ii) moderate silt contents, and (iii) semiarid climates. The emission factor for TSP considers 42 hours of work per week of construction activity. Test data were not sufficient to derive the specific dependence of dust emissions on correction parameters, and because the above emission factor is referenced to TSP, use of this factor to estimate PM_{10} emissions will result in conservatively high estimates. Also, because derivation of the factor assumes that construction activity occurs 30 days per month, the above estimate is somewhat conservatively high for TSP as well.

The area to be cleared of vegetation for development of the TSF3 is 920 056 m². Applying the general construction emission factor, the resulting emission estimates are 2 970 tpa for TSP, 1 158 tpa for PM_{10} and 579 tpa for $PM_{2.5}$. This is assuming construction will be for 12 months.

5.1.2 Operational Phase

Quantification of emissions from the proposed Project are restricted to fugitive releases (non-point releases) i.e. windblown dust. Particulates are the main pollutant of concern from windblown dust. Gaseous emissions (i.e. SO_2, NO_x, CO and VOCs) will primarily result from diesel combustion, mainly from maintenance vehicles and pumps.

As mentioned under Section 4.3.1.2, wind erosion is a complex process which requires the wind speed needs to exceed the threshold velocity. The US EPA indicates a friction velocity of 5.4 m/s to initiate erosion from a coal storage piles (US EPA, 2006) and Mian & Yanful (2003) calculated a wind speed in excess of 9 m/s is required to initiate wind erosion from two tailings storage facilities in in New Brunswick and Ontario, Canada. A study conducted by Liebenberg-Enslin (2014) set out to establish a best practice prescription for modelling aeolian dust emissions from mine tailings storage facilities and ash dumps determined a threshold velocity of 8.8 m/s for gold tailings. Thus, the likelihood exists for wind erosion to occur from TSF3, with loose fine material, when the wind speed exceeds at least 8.8 m/s.

Emission quantification was done using the in-house ADDAS model (Burger *et al*., 1997; Burger, 2010, Liebenberg-Enslin, 2014). This model is based on the dust emission scheme of Marticorena and Bergametti (1995) referred to as MB95 (from this point forward) and Shao *et al*. (2011) (referred to as SH11), which was tested in the study conducted by Liebenberg-Enslin (2014). Site specific particle size distribution data, bulk density and moisture content were used in the dust flux schemes of MB95, and SH11 to test the effects on a local scale. This was done by coupling these schemes with the US EPA regulatory Gaussian plume AERMOD dispersion model for the simulation of ground level concentrations resulting from aeolian dust from mine tailings facilities and two ash dumps. Simulated ambient near surface concentrations were validated with ambient monitoring data for the same period as used in the model. Coupling the dust flux schemes with a regulatory Gaussian plume model provided simulated ground level PM_{10} concentrations in good agreement with measured data.

For this study, the MB95 dust flux model, as schematically represented in Figure 15, is used. The model inputs include material particle density, moisture content, PSD, and site-specific surface characteristics such as an active or undisturbed source. All input parameters not measured as part of this work, have been drawn from or calculated using referenced methodologies (Liebenberg-Enslin, 2014). Tailings sample analysis was done as part of the 2010 study (Liebenberg-Enslin, et al., 2010), and the PSD, moisture content and particle density were assumed to be similar for TSF3. The moisture content was 2%, and the particle density 1 650 kg/m³. The PSD analysis in provided in Figure 16 for the TSF, showing the largest portion to be within the coarse fraction (63 µm – 3 000 µm) with 30% below 41 µm. The parameters used in the wind erosion quantification are provided in Table 7. Clay, silt, and sand fractions are in accordance with the typical soil classification provided by Friedman & Sanders (1978), where clay is defined as d < 2 µm. The TSF sample had low clay content, and a large percentage sand content (59%).

Table 7: Parameters applied for TSF3, including particle size distribution

Project	Area	Moisture content	Particle density	Clay content	Silt content	Sand content
	(m²)	(%)	(kg/m³)	(<2 µm)	(2-63 µm)	(63-3000 µm)
TSF3	920 056	2	1 650	4%	37%	59%

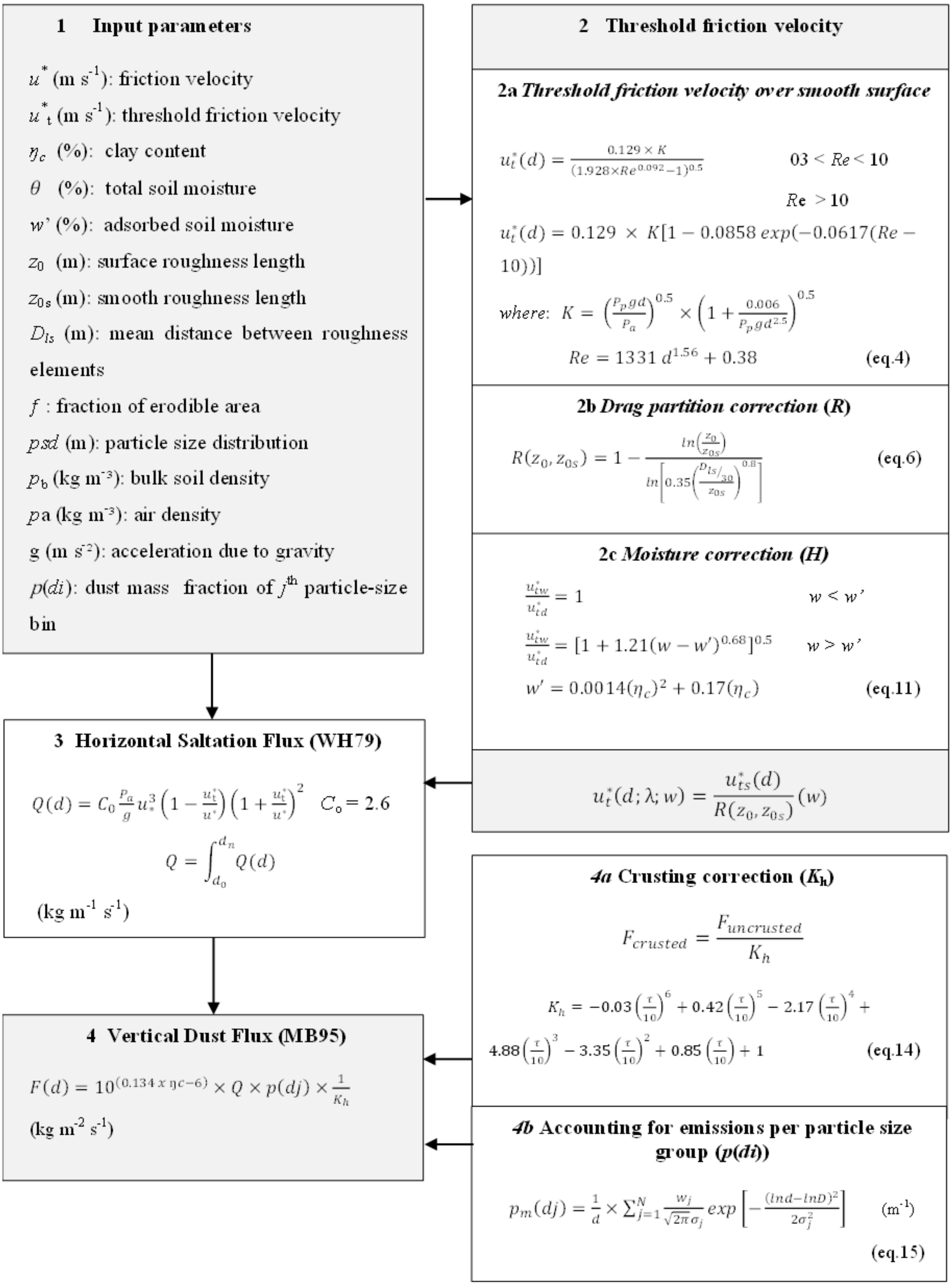


Figure 15: Schematic diagram of parameterisation options and input parameters for the Marticorena and Bergametti (1995) dust-flux scheme (Liebenberg-Enslin, 2014)

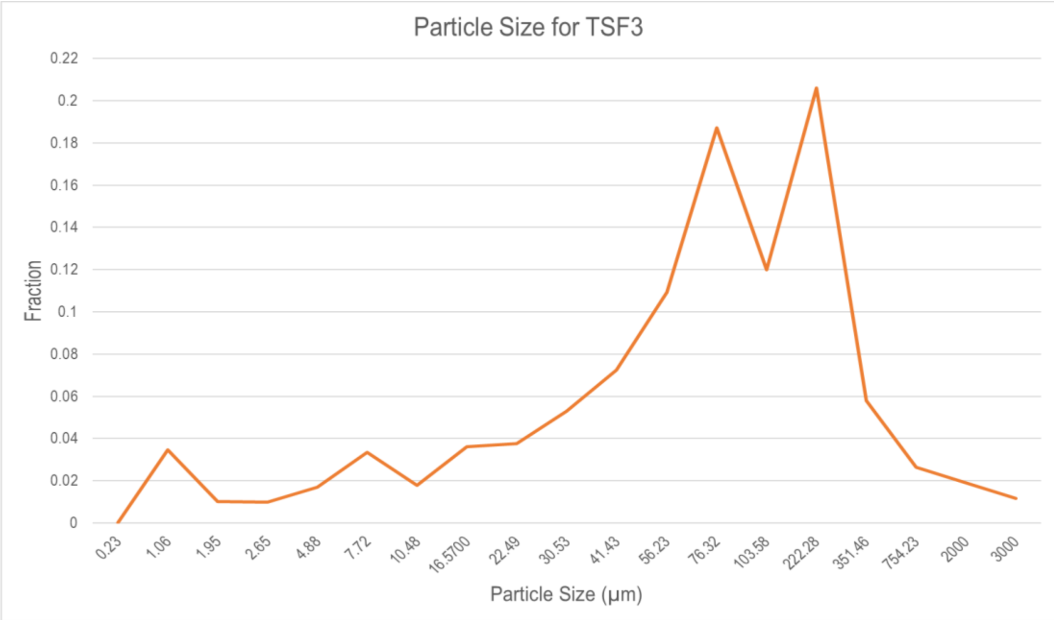


Figure 16: Particle size distribution of the sample from the Navachab Gold Mine existing TSF

Quantified emission rates are provided in Table 8. The emissions reflected a threshold friction velocity of 7.9 m/s, which is in line with the expected 8.8 m/s. Wind speeds exceeding 7.9 m/s occurred for 7.3% of the time. The estimated emission rates from TSF3 would add on average 24% to the total fugitive emissions (excluding emissions from point sources).

Table 8: Quantified emissions from TSF3

Project	Emission Rates (tpd)			Threshold friction velocity
	$PM_{2.5}$	PM_{10}	PM_{75}	(m/s)
TSF3	237	533	2 066	7.9

5.1.3 Closure and Decommissioning Phase

It is assumed that all the operations will have ceased by the closure phase of the project. The potential for impacts during this phase will depend on the extent of rehabilitation efforts during closure. Aspects and activities associated with the closure phase of the proposed TSF3 would depend on the rehabilitation efforts during the operational phase i.e. continuous vegetation ore rock cladding of the exposed side walls. During closure the surface area would need to be vegetated to reduce the potential for windblown dust. There is also the potential for dust generation due to the rehabilitation efforts such as dust entrainment from equipment and vehicles.

5.2 Atmospheric Dispersion Modelling

The impact assessment of the Project's operations on the environment is discussed in this section. To assess impact on human health and the environment the following important aspects need to be considered:

- The criteria against which impacts are assessed (Section 3.5);
- The potential of the atmosphere to disperse and dilute pollutants emitted by the project (Section 4.24.2); and
- The AQSRs in the vicinity of the proposed mine (Section 4.1).

Dispersion modelling was undertaken to determine highest daily and annual average ground level concentrations for unmitigated and mitigated emissions from TSF3. Mitigation in the form of vegetation and secondary rehabilitation could result in up to 60% control efficiency (CE) for non-sustaining vegetation (NPI, 2012)[5]. Averaging periods were selected to facilitate the comparison of predicted pollutant concentrations to relevant ambient air quality and inhalation health criteria as well as dustfall regulations (see Table 4).

Pollutants with the potential to result in human health impacts which are assessed in this study include $PM_{2.5}$ and PM_{10}. Dustfall is assessed for its nuisance potential. Results are primarily provided in form of isopleths to present areas of exceedance of assessment criteria. GLCs or dustfall isopleths presented in this section depict interpolated values from the concentrations simulated by AERMOD for each of the receptor grid points specified.

5.2.1 Dispersion Model Results

Isopleth plots reflect the incremental GLCs for unmitigated and mitigated $PM_{2.5}$ as a result of windblown dust from TSF3 are provided in Figure 17 to Figure 20, for 24-hour and annual averages. Isopleth plots for unmitigated and mitigated PM_{10} GLCs are provided in Figure 21 to Figure 24 for 24-hour and annual averages. The impact area from dustfall rates is provided in Figure 25 (unmitigated) and Figure 26 (mitigated). The findings are:

- Modelled daily average $PM_{2.5}$ concentrations are high at and immediately around TSF3, exceeding the AQO of 37.5 µg/m³ outside the ML on the eastern side (Figure 17) but not at any of the AQSRs. Mitigation (60% CE) would result in a slight reduction in the impact footprint, still exceeding the AQO outside the ML due to the location of TSF3 so close to the ML boundary (Figure 18). Over an annual average, the impacts are low and within the AQO (Figure 19 and Figure 20).
- PM_{10} daily concentrations show similar impact area to $PM_{2.5}$, with exceedances of the AQO of 75 µg/m³ outside the ML on the eastern side without mitigation (Figure 21) and with mitigation (Figure 22). Similarly, the annual average concentrations are below the AQO for the unmitigated (Figure 23) and mitigated scenarios (Figure 24).
- Dustfall rates simulated as highest daily dust fallout indicate exceedances of the industrial limit of 1 200 mg/m²/day outside the ML on the eastern side, without mitigation (Figure 25) and with mitigation (Figure 26). There are no exceedances of the residential limit of 600 mg/m²/day at any of the AQSRs.

[5] Any binding properties would reduce the potential for wind erosion. One of the most effective measures of minimizing wind erosion emissions from tailings storage facilities is re-vegetation. The control efficiency of vegetation is given as 40% for non-sustaining vegetation and 90% for re-vegetation. Secondary rehabilitation would up the control efficiency to 60% for non-sustaining vegetation (NPI, 2012).

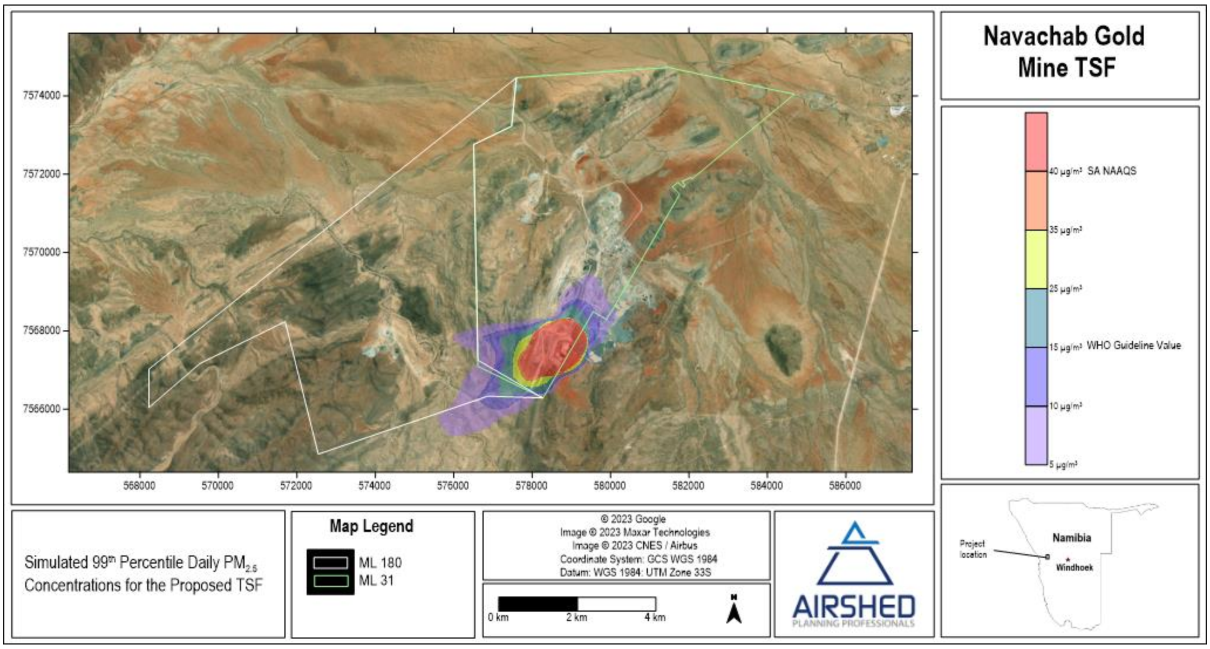


Figure 17: PM$_{2.5}$ 24-hour average ground level concentrations for TSF3 (unmitigated)

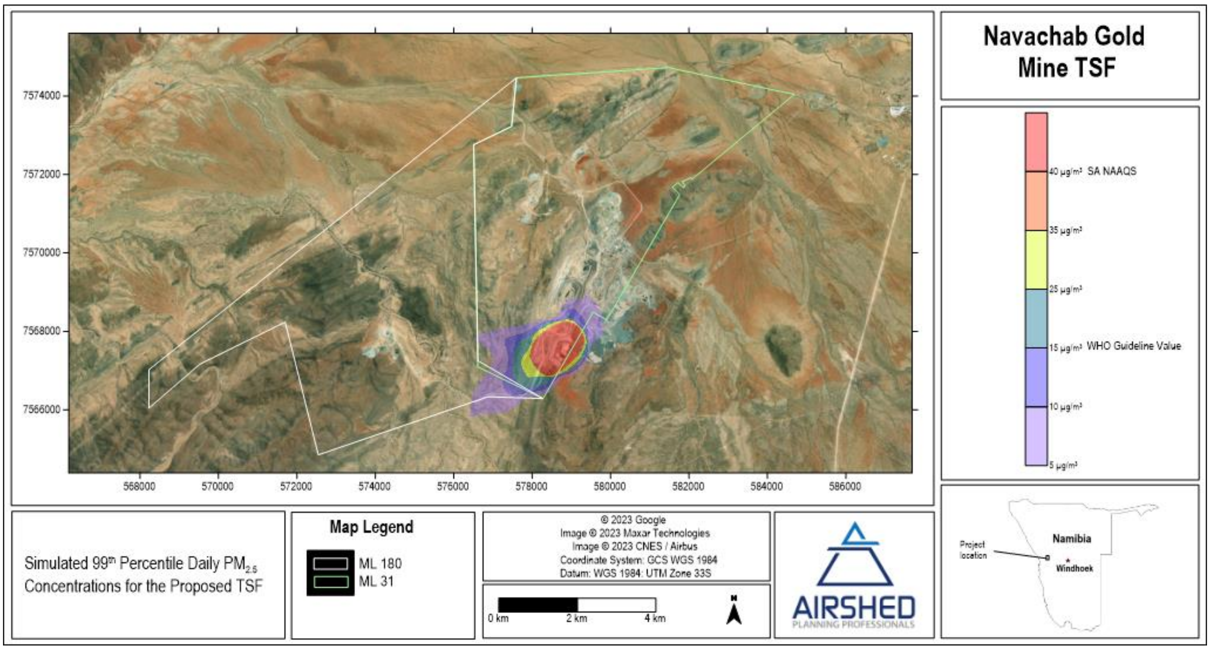


Figure 18: PM$_{2.5}$ 24-hour average ground level concentrations for TSF3 (mitigated)

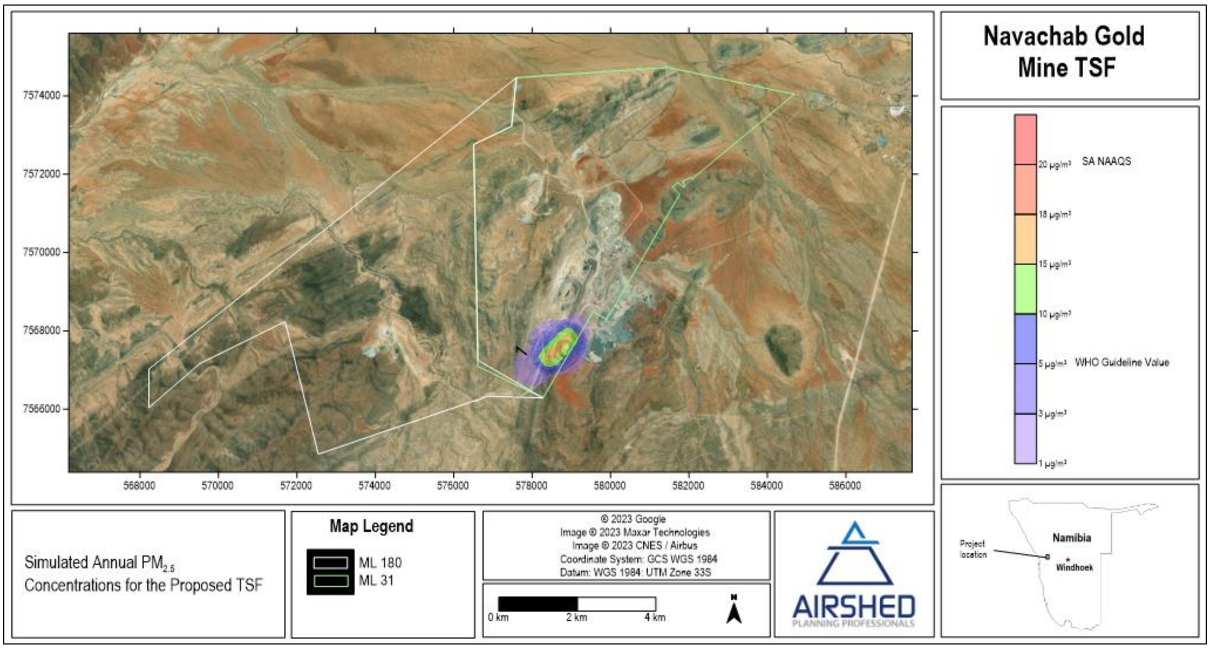


Figure 19: $PM_{2.5}$ annual average ground level concentrations for TSF3 (unmitigated)

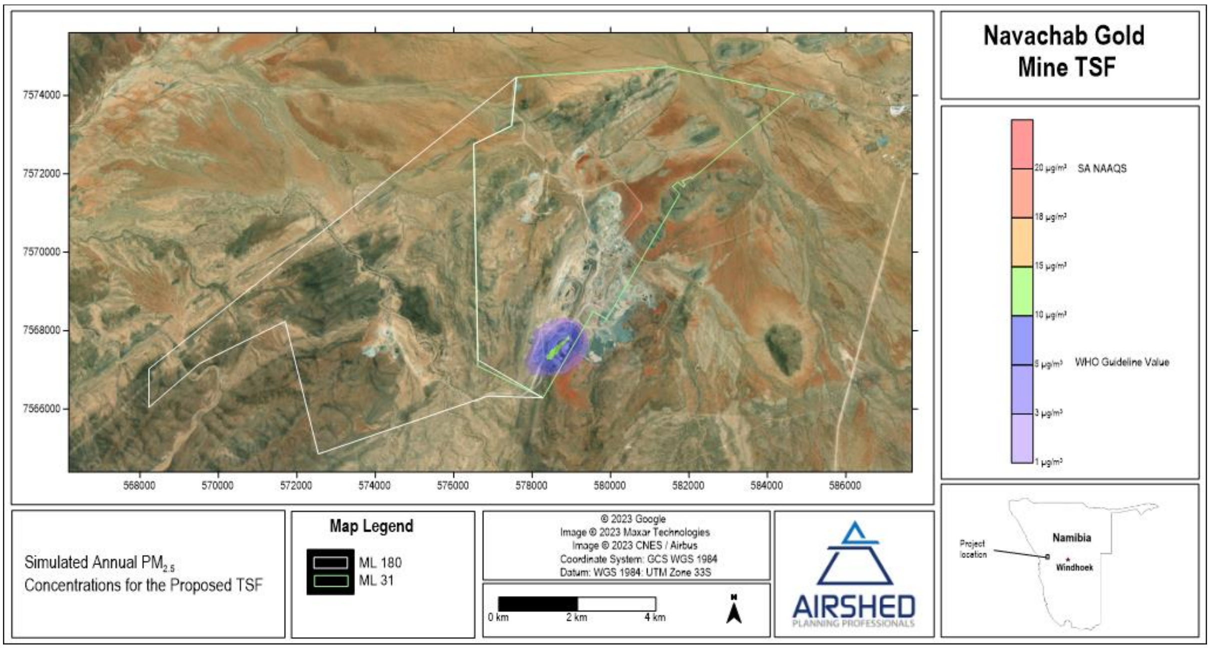


Figure 20: $PM_{2.5}$ annual average ground level concentrations for TSF3 (mitigated)

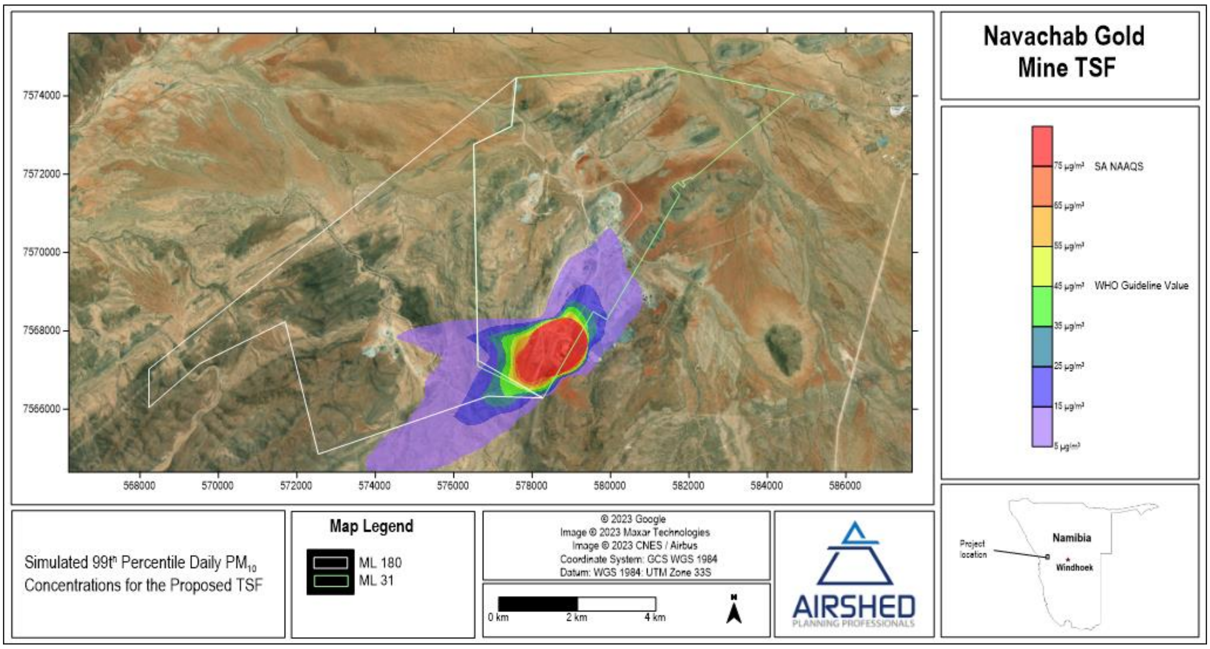


Figure 21: PM_{10} 24-hour average ground level concentrations for TSF3 (unmitigated)

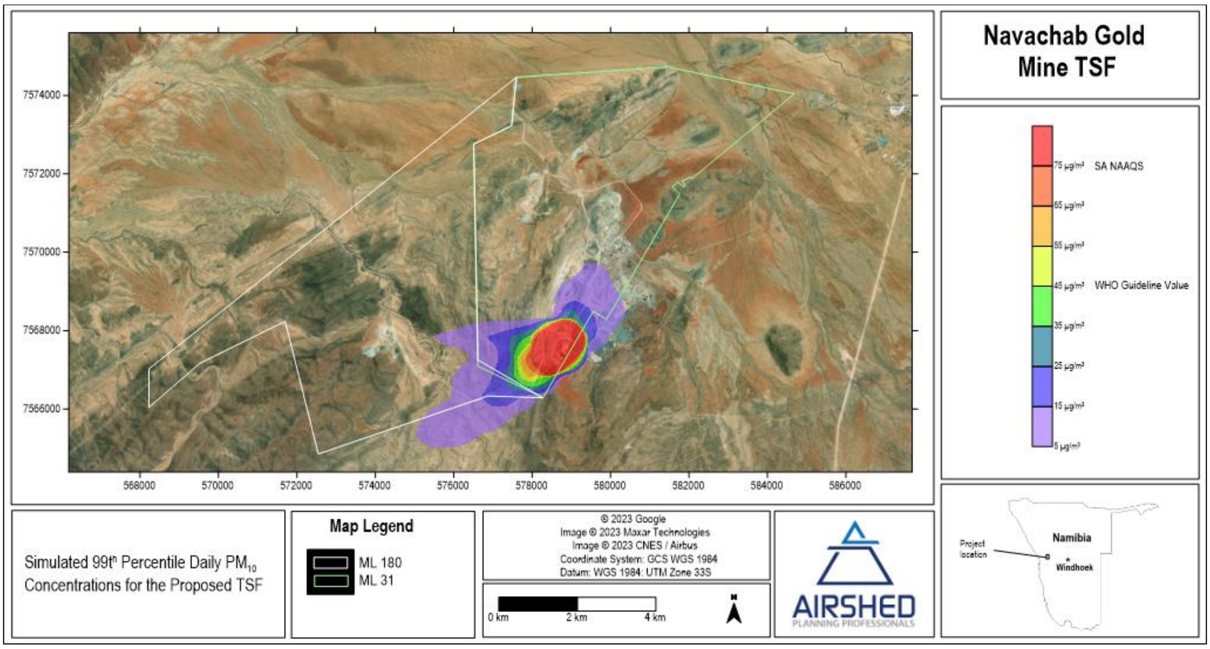


Figure 22: PM_{10} 24-hour average ground level concentrations for TSF3 (mitigated)

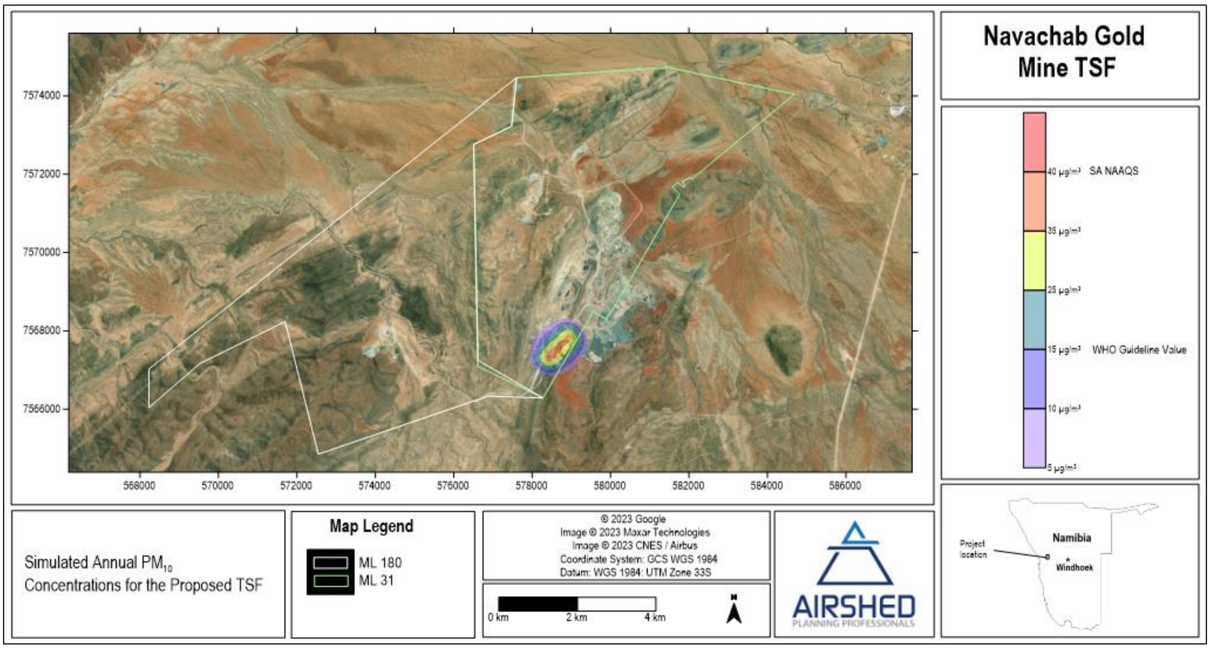


Figure 23: PM_{10} annual average ground level concentrations for TSF3 (unmitigated)

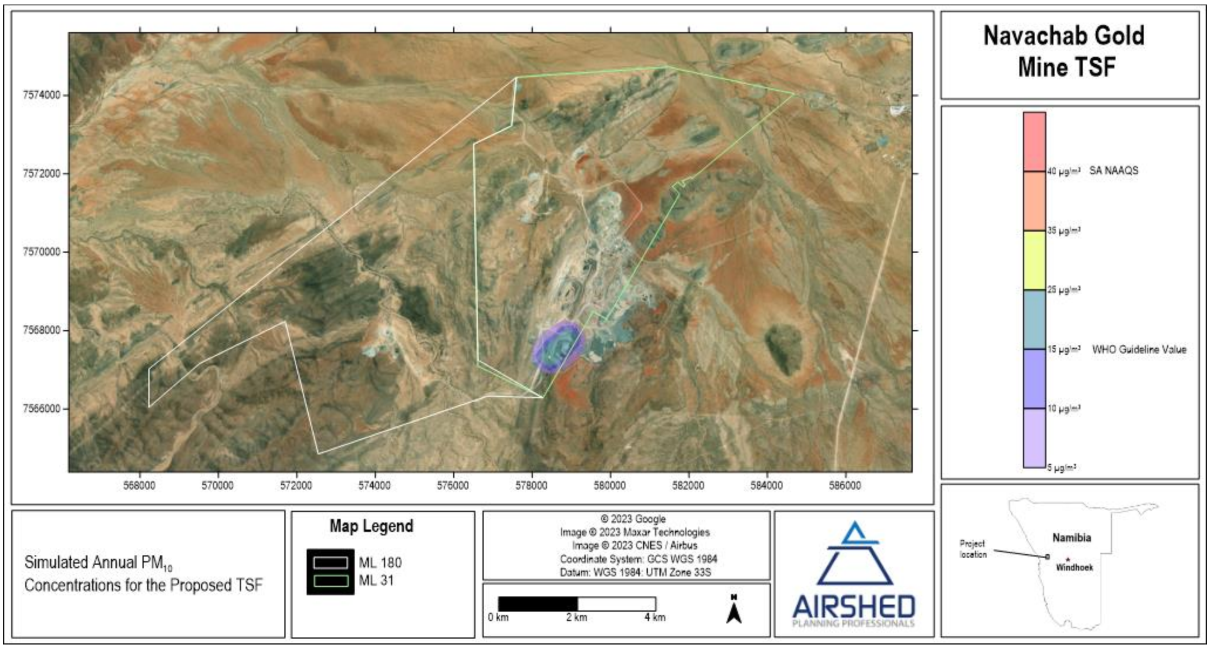


Figure 24: PM_{10} annual average ground level concentrations for TSF3 (mitigated)

Daily dustfall impacts are primarily over the existing TSF, and only exceeding the industrial dustfall limit for a small area outside the ML as shown in Figure 25 (unmitigated) and Figure 26 (mitigated).

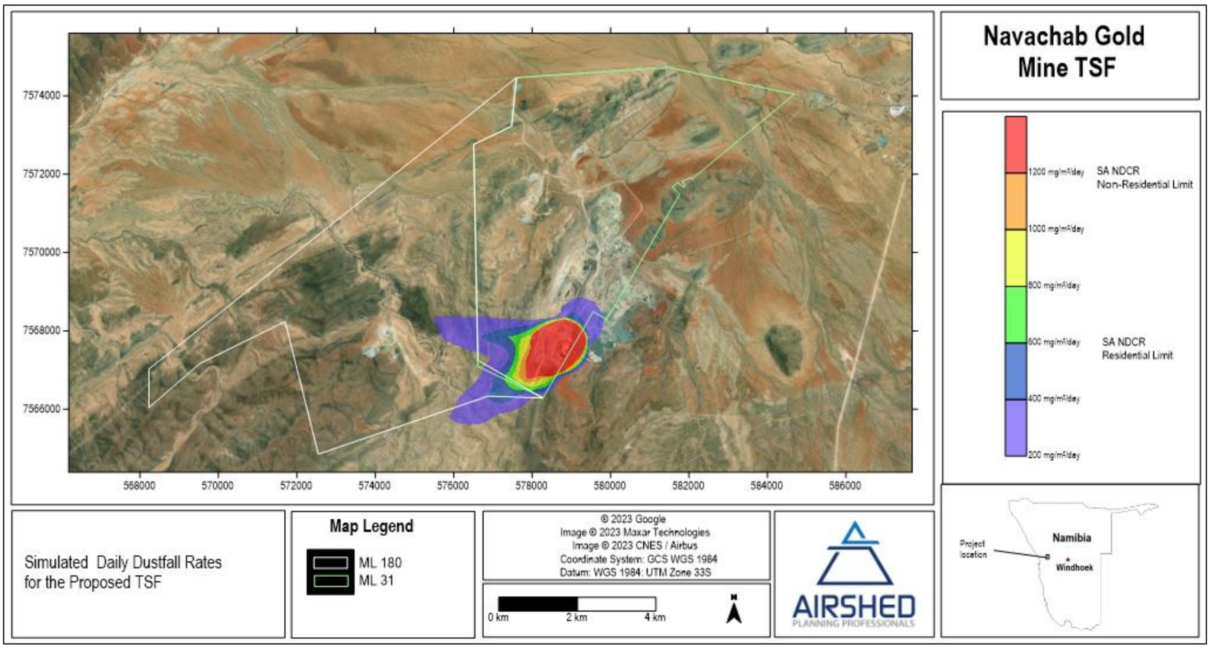


Figure 25: Daily dustfall rates for TSF3 (unmitigated)

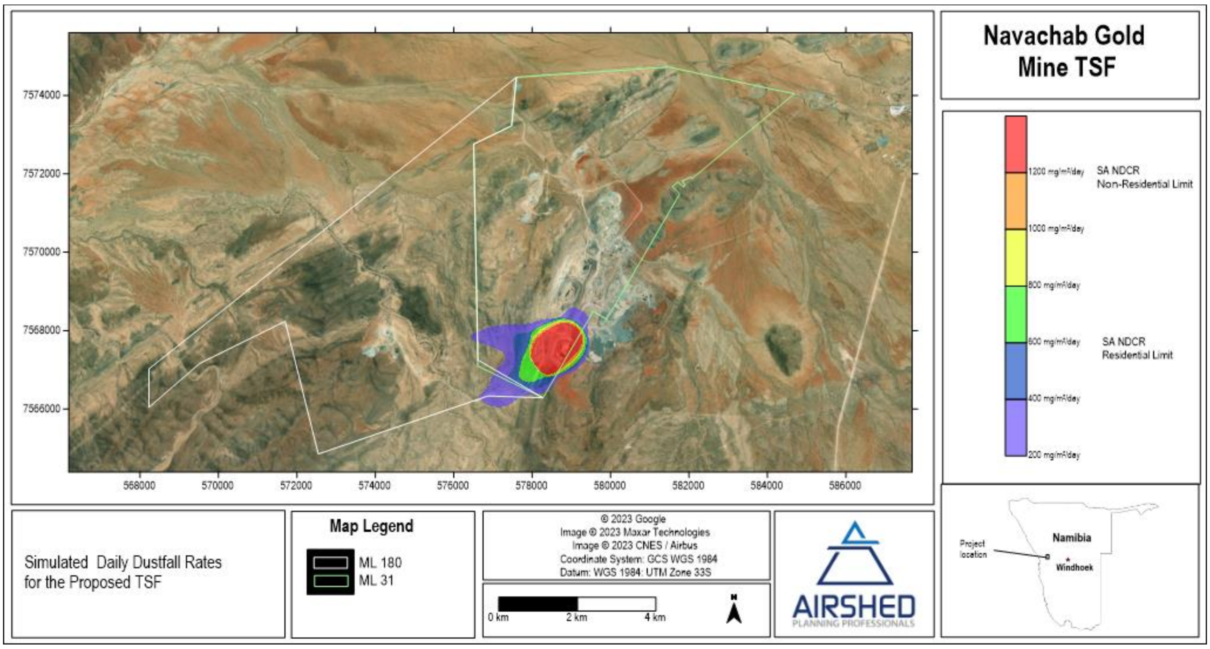


Figure 26: Daily dustfall rates for TSF3 (mitigated)

6 SIGNIFICANCE RATING OF IMPACTS

The significance of the air quality impacts was assessed according to the methodology adopted by ECC. The definitions of the significance ratings and EIA ratings matrix are provided in Appendix B.

The incremental (*Direct*) impacts, from TSF3 only, would result in a Moderate (negative) significance. These impacts are considered *Reversable* with a Low/Minor *Biophysical Environmental* impact and Low/Minor *Social Environmental* impact. The *Duration* is regarded medium-term (impacts that are likely to continue after the activity causing the impact and are recoverable (5-15 years)) and it is over a *Local* extent since the exceedances are limited to a small area outside the ML, with no regional impact. The *Probability* that these impacts would occur, is however high.

Cumulatively, the impact of the current mining operations in combination with TSF3 remain at a Moderate (negative) significance rating since the area of exceedance outside of the ML is likely to increase only slightly, with no negative impact on any of the AQSRs.

A Moderate (negative) impact is one within accepted limits and standards. The emphasis for moderate impacts is on demonstrating that the impact has been reduced to a level as low as reasonably practicably. This does not necessarily mean that 'moderate' impacts have to be reduced to 'minor' impacts, but that moderate impacts are being managed effectively and efficiently. Impacts are long-term, but reversible and/or have regional significance.

7 AIR QUALITY MANAGEMENT MEASURES

In the light of potentially high impacts from the proposed Project, specifically from PM_{10} and $PM_{2.5}$ concentrations, it is recommended that the project proponent commit to adequate air quality management planning throughout the life of the mine. An air quality management plan provides options on the control of particulate matter at the main sources, while the monitoring network is designed to track the effectiveness of the mitigation measures.

Based on the findings of the impact assessment, the following mitigation, management, and monitoring recommendations are proposed following a hierarchy of: **Avoidance > Minimisation > Rehabilitation > Offset**.

7.1 Air Quality Management Objectives

The main objective of the proposed air quality management measures for the project is to ensure that operations result in ambient air concentrations (specifically $PM_{2.5}$ and PM_{10}) and dustfall rates that are within the selected AQOs (Section 3.5) outside the ML boundary and at AQSRs. In order to define site specific management objectives, the main sources of pollution need to be identified. Once the main sources have been identified, target control efficiencies for each source can be defined to **minimise** dust emissions and ensure acceptable cumulative ground level concentrations.

7.1.1 Ranking of Sources

The ranking of sources serves to confirm the current understanding of the significance of specific sources, and to evaluate the emission reduction potentials required for each. Sources ranking can be established on:

- Emissions ranking: based on the comprehensive emissions inventory established for the operations (Section 5.1); and
- Impact ranking; based on the simulated pollutant GLCs (Section 5.2).

Since the Project relates to a single source (TSF3) this is the main contribution **emission** source, and the only direct **impacting** source. Management recommendations are thus focussed on minimising the potential for windblown dust from the TSF3.

For construction the main contributing sources would likely be dust generation from scraping and grading (land clearing) and vehicle entrained dust on-site.

Closure and Post-closure activities likely to result in dust impacts are the rehabilitation and re-vegetation of TSF3, and vehicle entrainment on unpaved road surfaces during rehabilitation.

7.2 Proposed Mitigation and Management Measures

7.2.1 Proposed Mitigation Measures and/or Target Control Efficiencies

Construction Phase: air quality impacts during construction would be minimised through basic control measures such as limiting the speed of haul trucks; limit unnecessary travelling of vehicles on untreated roads; reducing the area of construction where it is close to receptors; and to apply water sprays on regularly travelled, unpaved sections.

Operational Phase: TSF3 is located in between two ridges, acting as natural side walls but also as wind breaks and barriers with the only side walls to be constructed on the south-western side and against the current waste rock dumps on the north-eastern side. Wind speeds are highest at the crest of a TSF or dump, increasing the potential for wind erosion to occur. Thus with only one (south-western) side slope exposed to approaching winds, this potential for wind erosion is reduced. It should be noted that the south-westerly winds during daytime is associated with high wind speeds (Figure 3) and these are more prevalent during the summer and spring months (Figure 4). It is assumed that the north-eastern side wall will be "protected" by the existing waster rock dumps, but the south-eastern wall needs to be continuously vegetated to reduce/minimise the potential for windblown dust. It is further important to keep the dried-out beach areas moist or to allow the material to form a crust, thus preventing disturbances. The NPI (2012) indicates the following CE for various control options for stockpiles:

- 40% for vegetation established but not demonstrated to be self-sustaining.
- 60% for secondary rehabilitation.
- 90% for revegetation.
- 100% for fully rehabilitated (release) vegetation.

With the south-western side wall on the windwards side facing the strongest winds, a vegetation barrier could be considered. Literature (Gonzales *et al*., 2018) indicates on average a CE of 33% for $PM_{2.5}$, 39% for PM_{10}, and 38% for TSP as a result of well-established trees and shrubs. These results were based on a single row of Osage orange trees which removed 15% to 54% of $PM_{2.5}$, 23% to 65% of PM_{10}, and 26% to 63% of TSP from the generated dust. These reductions varied at heights ranging between 1.5 m (lower CE) to 4.5 m (higher CE). This is in line with other studies that indicate 30% to 38% reduction in PM_{10} from unspecified Hawthorn hedge species (Tiwary *et al*.,2008) and reduction in dust (assumed to be TSP) of between 54% to 71% due to a wind fence (Grantz *et al*., 1998). A study by DEFRA (2018) indicated vegetation as a barrier close to a source could reduce concentrations immediately behind the barrier by 50%, but this depends on the type of vegetation. The effectiveness of these trees as screens would need to be monitored and, if needed, the tree density (spacing between the trees) may have to increase.

Closure and Post-closure: the open exposed areas prone to wind erosion should be either covered with surface material and rehabilitated (vegetated or compacted) to ensure the surfaces form a hard crust and/or gladded with waste rock.

7.2.2 Performance Indicators

Key performance indicators against which progress of implemented mitigation and management measures may be assessed, form the basis for all effective environmental management practices. In the definition of key performance indicators careful attention is usually paid to ensure that progress towards their achievement is measurable, and that the targets set are achievable given available technology and experience.

Performance indicators are usually selected to reflect both the source of the emission directly (source monitoring) and the impact on the receiving environment (ambient air quality monitoring). Ensuring that no visible evidence of windblown dust exists represents an example of a source-based indicator, whereas maintaining off-site dustfall levels, at the identified AQSRs, to below 600 mg/m²-day represents an impact- or receptor-based performance indicator.

Except for vehicle/equipment emission testing, source monitoring at mining activities can be challenging due to the fugitive and wind-dependant nature of particulate emissions. The focus is therefore rather on receptor-based performance indicators i.e. compliance with ambient air quality standards and dustfall regulations.

7.2.3 Ambient Air Quality Monitoring

Ambient air quality monitoring can serve to meet various objectives, such as:

- Compliance monitoring;
- Validate dispersion model results;
- Use as input for health risk assessment;
- Assist in source apportionment;
- Temporal and spatial trend analysis;
- Source quantification; and,
- Tracking progress made by control measures.

It is recommended that the current dustfall monitoring network, comprising of 10 single dustfall units, be maintained and the monthly dustfall results used as indicators to tract the effectiveness of the applied mitigation measures. It is further recommended that an additional unit be placed to the south of the proposed TSF3, just outside the ML. Dustfall collection should follow the American Society for Testing and Materials (ASTM) standard method for collection and analysis of dustfall (ASTM D1739-98). The ASTM method covers the procedure of collection of dustfall and its measurement and employs a simple device consisting of a cylindrical container exposed for one calendar month (30 ±2 days). The method provides for a dry bucket, which is advisable in the dry environment.

7.2.4 Periodic Inspections and Audits

Periodic inspections and external audits are essential for progress measurement, evaluation and reporting purposes. It is recommended that site inspections and progress reporting be undertaken at regular intervals (at least quarterly), with annual environmental audits being conducted. Annual environmental audits should be continued at least until closure. Results from site inspections and monitoring efforts should be combined to determine progress against source- and receptor-based performance indicators. Progress should be reported to all interested and affected parties, including authorities and persons affected by pollution.

The criteria to be taken into account in the inspections and audits must be made transparent by way of minimum requirement checklists included in the management plan. Corrective action or the implementation of contingency measures must be proposed to the stakeholder forum in the event that progress towards targets is indicated by the quarterly/annual reviews to be unsatisfactory.

7.2.5 Liaison Strategy for Communication with I&APs

Stakeholder forums provide possibly the most effective mechanisms for information dissemination and consultation. Management plans should stipulate specific intervals at which forums will be held and provide information on how people will be notified of such meetings. Given the proximity of the mine to Karibib, it is recommended that such meetings be scheduled and held at least on a bi-annual basis. A complaints register must be kept at all times.

7.2.6 Financial Provision

The budget should provide a clear indication of the capital and annual maintenance costs associated with dust control measures, dust monitoring plans and rehabilitation. It may be necessary to make assumptions about the duration of aftercare prior to obtaining closure. Costs related to inspections, audits, environmental reporting and Interested and Affected Parties liaison should also be indicated where applicable. Provision should also be made for capital and running costs associated with dust control contingency measures and for security measures. The financial plan should be audited by an independent consultant, with reviews conducted on an annual basis.

8 Findings and Recommendations

A quantitative air quality impact assessment was conducted for the operational phase activities of the proposed Project. Construction, closure, and post-closure activities, as well as cumulative impacts, were assessed qualitatively. The assessment included an estimation of atmospheric emissions, the simulation of pollutant concentrations and determination of the significance of impacts. The main concern is the potential air quality impacts from the proposed Project on the receiving environment and human health.

8.1 Main Findings

8.1.1 Baseline Assessment

The main findings from the baseline assessment can be summarised as follows:

- The Project is located approximately 10 km southwest of the town of Karibib, in the eastern part of the Erongo Region of Namibia and the Project covers an area of about 18 km northeast-southwest and 8 km north-south.
- The terrain is hilly, with a ridge to the south of the open pit areas which serve as a barrier on the south-eastern side of the current TSF2, and a hill further south. The new TSF3 will be located between the two rock ridges, both serving as "sidewalls" and the waste rock dumps to the north serving as a buttress.
- There are no villages or homesteads near the project, with the closest settlement – homesteads – 3 km north-east and 2.4 km south-west of the TSF3. The town of Karibib is located about 10 km to the northeast from the Project.
- On-site weather data was only available as daily averages as use was made of WRF data for the period 2020 – 2022. The wind field is dominated by winds from the southwest to south, and east to north-east, with the strongest winds from the south-west. Calm conditions prevailed 2.6% of the time. During the day, north-easterly winds prevailed with strong but less frequent winds from the southwest, and at night the wind field shifted to more frequent southerly winds at lower wind speeds, followed by easterly to east-north-easterly winds and no wind from the northern or north-western sector.
- The average hourly wind speed over the period was 4.4 m/s, with a maximum wind speed of 12.6 m/s.
- Seasonal variation in the wind field showed more frequent south-westerly winds during the summer months and a shift to east to north-easterly winds in autumn, remaining such during winter but with strong "east-winds". The spring months show similar wind flow to the summer months.
- Maximum, minimum, and mean temperatures were given as 38°C, -1.3°C and 21°C respectively.
- Rainfall recorded at NGM over a 10-month period (Jan-Oct 2022) totalled 273 mm, with the highest rainfall of 161 mm recorded in February 2022.
- The main pollutant of concern in the region is particulate matter (TSP; PM_{10} and $PM_{2.5}$) resulting from vehicle entrainment on the roads (paved, unpaved and treated surfaces), windblown dust, and mining and exploration activities. Gaseous pollutants such as SO_2, NOx, CO and CO_2 would result from vehicles and combustion sources, but these are expected to be at low concentrations due to the few sources in the region.
- Sources of atmospheric emissions in the vicinity of the proposed Project include:
    - Vehicle entrainment from roads: The national road to the north (B2) of the Project is the main road between Windhoek and Swakopmund, and one of the roads in the region with the highest traffic counts. Vehicle entrainment was estimated to be a significant contributor to the regional paved road $PM_{2.5}$ and PM_{10} emissions. The C32, is an unpaved road connecting the Karibib with the Namib Naukluft Park, and although no information was available for this road, it is expected to have very low traffic counts and low $PM_{2.5}$ and PM_{10} emissions.
    - Windblown dust: Windblown particulates from natural exposed surfaces, mine waste facilities, and product stockpiles can result in significant dust emissions with high particulate concentrations near the source

locations, potentially affecting both the environment and human health. Windblown dust from natural exposed surfaces in and at the Project is only likely to result in particulate matter emissions under high wind speed conditions (>10 m/s), and since recorded wind speeds only exceeded 10 m/s for only 0.8% over the three-year period, this source is likely to be of low significance.

  - Mines and Exploration operations: Pollutants typically emitted from mining and quarrying activities are particulates, with smaller quantities associated with vehicle exhaust emissions. Mining and quarrying activities, especially open-cast mining methods, emit pollutants near ground-level over (potentially) large areas. Mines in proximity to the Project are NGM, where it is located, with the existing TSF2 directly to the west on the other side of the ridge. There are several marble quarries in the region, with one 3.5 km west, and others to the south of Karibib.
  - Regional transport of pollutants: regional-scale transport of mineral dust and ozone (due to vegetation burning) from the north of Namibia is a significant contributing source to background PM concentrations.

- A dustfall monitoring network comprising of 10 single dustfall units are in place at NGM, with dustfall data available for the period January 2022 to January 2023. Dustfall rates were low for the dustfall units furthest from the operations (NAQ2; NAQ3; NAQ9 and NAQ10) whereas the ones closest to the mining operations (NAQ4; NAQ7 and NAQ8) had the highest dustfall rates. NAQ4, located next to the haul road north of the existing TSF2, had the highest dustfall rates, exceeding the alert threshold (2 400 mg/m²/day) for four months and the industrial limit (1 200 mg/m²/day) for 10 months.
- In order to determine the potential impacts from the Project (TSF3) cumulatively, the current mining operations at NGM were assessed though the quantification of emissions and dispersion modelling. No current mining and production rates were available, so the 2016 rates were assumed to be representative of the current mining operations at NGM.
  - Estimated emissions from the operations at NGM were 596 tpa for $PM_{2.5}$, 2 096 tpa for PM_{10} and 792 tpa for TSP (these exclude emissions from point sources). Based on the 2016 mining rates, the main contributing activities to $PM_{2.5}$ and PM_{10} emissions are the in-pit activities (i.e. drilling, blasting, loading of ore and waste onto haul trucks, truck movement on in pit roads), with crushing and screening the main contributing sources to TSP emissions.
  - Simulated 24-hour GLCs for $PM_{2.5}$ and PM_{10} were mainly within the two MLs, with exceedances of the adopted AQO only for a small area on the southern and south-eastern border of the MLs and not affecting any of the AQSRs. The annual average impact areas for both $PM_{2.5}$ and PM_{10} exceeded a very small area on the south-eastern side. Daily dustfall impacts only exceeded the industrial dustfall limit for a small area outside the ML.

8.1.2 Impact Assessment

The findings from the impact assessment can be summarised as follows:

Construction infrastructure required for the new TSF3 would be limited to vegetation clearing and TSF foundation construction. The main pollutant of concern from construction operations is particulate matter, including PM_{10}, $PM_{2.5}$ and TSP. Each of the operations associated with the construction phase has their own duration and potential for dust generation. The area to be cleared of vegetation for development of the TSF3 is 920 056 m². Applying the general construction emission factor, the emissions are 2 970 tpa for TSP, 1 158 tpa for PM_{10} and 579 tpa for $PM_{2.5}$. This is assuming construction will be for 12 months. Due to the intermittent nature of construction operations, the impacts are expected to have a small and potentially insignificant impact at the nearest AQSRs, due to the distance from the TSF and the ridge in-between. With mitigation measures in place these impacts are expected to be very low.

Operational Phase:

- Quantification of emissions for TSF3 are restricted to fugitive releases (non-point releases) i.e. windblown dust with particulates the main pollutant of concern. Wind erosion is a complex process which requires the wind speed to exceed a threshold velocity of ~8.8 m/s as determined for gold tailings. Emission quantification was done using the in-house ADDAS model based on the dust emission scheme of Marticorena and Bergametti (1995). Model input data was based on tailing samples analysed during the 2010 study. The PSD indicated the largest portion of the particles to be within the coarse fraction (63 µm – 3 000 µm) with 30% below 41 µm. The moisture content was 2%, and the particle density 1 650 kg/m³. The quantified emissions were 237.46 for $PM_{2.5}$, 533 for PM_{10} and 2 066 for TSP and reflected a threshold friction velocity of 7.9 m/s, which is in line with the expected 8.8 m/s.
- Dispersion modelling results for $PM_{2.5}$, PM_{10} and dustfall, unmitigated and mitigated (vegetation cover resulting in 60% CE) as a result of windblown dust from TSF3 were:
    - Modelled daily average $PM_{2.5}$ GLCs were high at and immediately around TSF3, exceeding the AQO of 37.5 µg/m³ for a small area outside the ML on the eastern side but not at any AQSR. Applying mitigation (60% CE) resulted in a slight reduction in the impact footprint, still exceeding the AQO outside the ML due to the location of TSF3 so close to the ML boundary. Over an annual average, the impacts are low and within the AQO.
    - PM_{10} daily concentrations showed exceedances of the AQO of 75 µg/m³ outside the ML on the eastern side without mitigation and with mitigation, but not at any AQSR. Similarly, the annual average concentrations are below the AQO for the unmitigated and mitigated scenarios.
    - Dustfall rates simulated as highest daily dust fallout indicated exceedances of the industrial limit of 1 200 mg/m²/day outside the ML on the eastern side, without mitigation and with mitigation. There are no exceedances of the residential limit of 600 mg/m²/day at any of the AQSRs.
- The incremental (Direct) impacts, from TSF3 only, would result in a Moderate (negative) significance.
- Cumulatively, the impact of the current mining operations in combination with TSF3 remain at a Minor (negative) significance rating since the area of exceedance outside of the ML is likely to increase only slightly, with no negative impact on any of the AQSRs.

Closure and **Post-closure** activities likely to result in dust impacts are the rehabilitation and re-vegetation of TSF3, and vehicle entrainment on unpaved road surfaces during rehabilitation.

8.2 Conclusion

The proposed Project is likely result in $PM_{2.5}$ and PM_{10} GLCs exceedances in the immediate vicinity of TSF3, with no mitigation in place, but the impact area can be reduced with mitigation measures in place. Dustfall rates are also likely to exceed the limit in the immediate vicinity of the TSF3. The GLCs are however within the limits at all the AQSRs.

It is the specialist's opinion that the proposed project could be authorised provided strict enforcement of mitigation measures and the tracking of the effectiveness of these measures to ensure the lowest possible off-site impacts.

8.3 Recommendations

Based on the findings from the air quality impact assessment for the Project following recommendations are included:

- **Construction**: air quality impacts during construction would be minimised through basic control measures such as limiting the speed of haul trucks; limit unnecessary travelling of vehicles on untreated roads; reducing the area of construction where it is close to receptors; and to apply water sprays on regularly travelled, unpaved sections.

- **Operational**: TSF3 is located in between two ridges, acting as natural side walls but also as wind breaks and barriers with the only side walls to be constructed on the south-western side and against the current waste rock dumps on the north-eastern side. With the south-western side slope exposed to approaching winds, this wall will need to be continuously vegetated to reduce/minimise the potential for windblown dust. It is further important to keep the dried-out beach areas moist or to allow the material to form a crust, thus preventing disturbances. The NPI (2012) indicates the following CE for various control options for stockpiles:
    - 40% for vegetation established but not demonstrated to be self-sustaining.
    - 60% for secondary rehabilitation.
    - 90% for revegetation.
    - 100% for fully rehabilitated (release) vegetation
- **Air Quality Monitoring**: The current dustfall monitoring network, comprising of 10 single dustfall units, should be maintained with an additional unit to be located to the south of the TSF3. Monthly dustfall results should be used as indicators to tract the effectiveness of the applied mitigation measures. Dustfall collection should follow the ASTM method.

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10 APPENDIX A – BASELINE EMISSIONS QUANTIFICATION METHODOLOGY

Table 9: Emission equations used to quantify fugitive dust emissions from Navachab Gold Mine current operations

<table>
<tr><th>Activity</th><th>Emission Equation</th><th>Source</th></tr>
<tr><td>Drilling</td><td>Emission factors
<table>
<tr><th>TSP</th><th>PM_{10}</th><th>$PM_{2.5}$(</th><th>Unit</th></tr>
<tr><td>0.59</td><td>0.31</td><td>0.31</td><td>kg/hole drilled</td></tr>
</table></td><td>NPI Section: Mining (NPI, 2012)</td></tr>
<tr><td>Blasting</td><td>$$E = 0.00022 \cdot (A)^{1.5}$$
Where,
E = Emission factor (kg dust / t transferred)
A = Blast area (m²)

The $PM_{2.5}$, PM_{10} and TSP fraction of the emission factor is 5.3%, 35% and 74% respectively.</td><td>NPI Section: Mining (NPI, 2012)</td></tr>
<tr><td>Materials handling</td><td>$$E = 0.0016 \frac{\left(U/_{2.2}\right)^{1.3}}{\left(M/_{2}\right)^{1.4}}$$
Where,
E = Emission factor (kg dust / t transferred)
U = Mean wind speed (m/s)
M = Material moisture content (%)

The $PM_{2.5}$, PM_{10} and TSP fraction of the emission factor is 5.3%, 35% and 74% respectively.</td><td>US-EPA AP42 Section 13.2.4 (US EPA, 2006)</td></tr>
<tr><td>Vehicle entrainment on unpaved surfaces (mine roads)</td><td>$$E = k\left(\frac{s}{12}\right)^{a}\left(\frac{W}{3}\right)^{b} \cdot 281.9$$
Where,
E = particulate emission factor in grams per vehicle km travelled (g/VKT)
k = basic emission factor for particle size range and units of interest
s = road surface silt content (%)
W = average weight (tons) of the vehicles travelling the road

The particle size multiplier (k) is given as 0.15 for $PM_{2.5}$ and 1.5 for PM_{10}, and as 4.9 for TSP

The empirical constant (a) is given as 0.9 for $PM_{2.5}$ and PM_{10}, and 4.9 for TSP

The empirical constant (b) is given as 0.45 for $PM_{2.5}$, PM_{10} and TSP</td><td>US-EPA AP42 Section 13.2.2 (U.S. EPA, 2006)</td></tr>
<tr><td>Crushing and screening</td><td>Emission factors
<table>
<tr><th>Crushing</th><th>TSP</th><th>PM_{10}</th><th>$PM_{2.5}$(a)</th><th>Unit</th></tr>
<tr><td>Primary</td><td>0.2</td><td>0.02</td><td>0.01</td><td>kg/ton</td></tr>
<tr><td>Secondary</td><td>0.6</td><td>0.04</td><td>0.02</td><td>kg/ton</td></tr>
<tr><td>Tertiary</td><td>1.4</td><td>0.08</td><td>0.04</td><td>kg/ton</td></tr>
</table>
Notes: (a) Fraction of $PM_{2.5}$ taken from US-EPA crushed stone emission factor ratio for tertiary crushing.</td><td>NPI Section: Mining (NPI, 2012)</td></tr>
</table>

Activity	Emission Equation	Source
	Where, E = Default emission factor for low moisture content ore (moisture < 4%)	
Wind Erosion	$$E(i) = G(i)10^{(0.134(\%clay)-6)}$$ For $$G(i) = 0.261\left[\frac{P_a}{g}\right]u^{*3}(1+R)(1-R^2)$$ And $$R = \frac{u_t^*}{u^*}$$ where, $E_{(i)}$ = emission rate (g/m²/s) for particle size class i P_a = air density (g/cm³) G = gravitational acceleration (cm/s³) u^*_t = threshold friction velocity (m/s) for particle size i u^* = friction velocity (m/s)	(Marticorena & Bergametti, 1995)

11 APPENDIX B – IMPACT SIGNIFICANCE RATING METHODOLOGY

The significance of air quality related impacts was assessed using the risk rating matrix provided by ECC (Table 11). Significance definitions are provided below (Table 10). The numbers corresponding to each significance category are calculated by multiplying the sensitivity of the receptor with the significance of the impact.

Table 10: Definitions of significance ratings

7 to 12	**Major**	An impact of major significance is one where an accepted limit or standard may be exceeded, or large magnitude impacts occur to highly valued/sensitive resource/receptors. A goal of the EIA process is to get to a position where the Project does not have any major residual impacts, certainly not ones that would endure into the long term or extend over a large area. However, for some aspects there may be major residual. Impacts are expected to be permanent and non-reversible on a national scale and/or have international significance or result in legislative non-compliance.
4 to 6	**Moderate**	An impact of moderate significance is one within accepted limits and standards. The emphasis for moderate impacts is on demonstrating that the impact has been reduced to a level as low as reasonably practicably. This does not necessarily mean that 'moderate' impacts have to be reduced to 'minor' impacts, but that moderate impacts are being managed effectively and efficiently. Impacts are long-term, but reversible and/or have regional significance.
3 to 4	**Minor**	An impact of minor significance is one where an effect will be experienced, but the impact magnitude is sufficiently small (with and without mitigation) and well within accepted standards, and/or the receptor is of low sensitivity/value. Impacts are considered to be short-term, reversible and/or localised in extent.
1 to 2	**Low**	An impact of low significance (or an insignificant impact) is where a resource or receptor (including people) will not be affected in any way by a particular activity, or the predicted effect is deemed to be 'negligible' or 'imperceptible' or is indistinguishable from natural background variations.

Table 11: EIA significance matrix

				Significance of Impact			
			Significance of Impact	Impacts are considered to be local factors that are unlikely to be critical to decision-making.	Impacts are considered to be important factors but are unlikely to be key decision-making factors. The impact will be experienced, but the impact magnitude is sufficiently small (with and without mitigation) and well within accepted standards, and/or the receptor is of low sensitivity/value. Impacts are considered to be short-term, reversible and/or localised in extent.	Impacts are considered within acceptable limits and standards. Impacts are long-term, but reversible and/or have regional significance. These are generally (but not exclusively) associated with sites and features of national importance and resources/features that are unique and which, if lost, cannot be replaced or relocated.	Impacts are considered to be key factors in the decision-making process that may have an impact of major significance, or large magnitude impacts occur to highly valued/sensitive resource/receptors. Impacts are expected to be permanent and non-reversible on a national scale and/or have international significance or result in legislative non-compliance.
	Biophysical	**Social**		**Low (1)**	**Minor (2)**	**Moderate (3)**	**Major (4)**
Sensitivity	A biophysical receptor that is protected under legislation or international conventions listed as rare threatened or endangered IUCN species. Highly valued/sensitive resource/receptors.	Those affected people/communities will not be able to adapt to changes or continue to maintain pre-impact livelihoods.	**High (3)**	**Minor (3)**	**Moderate (6)**	**Major (9)**	**Major (12)**
	Of value, importance or rarity on a regional scale, and with limited potential for substitution; and/or not protected or listed globally but may be a rare or threatened species in country; with little resilience to ecosystem changes, important to ecosystem functions, or one under threat or population decline.	Able to adapt with some difficulty and maintain preimpact status but only with a degree of support.	**Medium (2)**	**Low (2)**	**Minor (4)**	**Moderate (6)**	**Major (8)**
	Not protected or listed as common/abundant; or not critical to other ecosystems functions	Those affected are able to adapt with relative ease and maintain preimpact status. There is no perceptible change to people's livelihood.	**Low (1)**	**Low (1)**	**Low (2)**	**Minor (3)**	**Moderate (4)**

12 APPENDIX C – SPECIALIST CURRICULUM VITAE

CURRICULUM VITAE	HANLIE LIEBENBERG-ENSLIN

FULL CURRICULUM VITAE

Name of Firm	Airshed Planning Professionals (Pty) Ltd
Name of Staff	Hanlie Liebenberg-Enslin
Profession	Managing Director / Air Quality Scientist
Date of Birth	09 January 1971
Years with Firm/ entity	21 years
Nationalities	South African

MEMBERSHIP OF PROFESSIONAL SOCIETIES

- International Union of Air Pollution Prevention and Environmental Protection Associations (IUAPPA) – President 2010–2013, Board member 2013-present
- Member of the National Association for Clean Air (NACA) - President 2008-2010, NACA Council member 2010 –2014

KEY QUALIFICATIONS

Hanlie Liebenberg-Enslin started her professional career in Air Quality Management in 2000 when she joined Environmental Management Services (EMS) after completing her Master's Degree at the University of Johannesburg (then Rand Afrikaans University) in the same field. She is one of the founding members of Airshed Planning Professionals in 2003 where she has worked as a company Director until May 2013 when she was appointed as Managing Director. She has extensive experience on the various components of air quality management including emissions quantification for a range of source types, simulations using a range of dispersion models, impacts assessment and health risk screening assessments. She has worked all over Africa and has an inclusive knowledge base of international legislation and requirements pertaining to air quality.

She has developed technical and specialist skills in various modelling packages including the industrial source complex models (ISCST3 and SCREEN3), EPA Regulatory Models (AERMOD and AERMET), UK Gaussian plume model (ADMS), EPA Regulatory puff based model (CALPUFF and CALMET), puff based HAWK model and line based models such as CALINE. Her experience with emission models includes Tanks 4.0 (for the quantification of tank emissions) and GasSim (for the quantification of landfill emissions).

Having worked on projects throughout Africa (i.e. South Africa, Mozambique, Botswana, Namibia, Malawi, Kenya, Mali, Democratic Republic of Congo, Tanzania, Madagascar, Guinea and Mauritania) Hanlie has developed a broad experience base. She has a good understanding of the laws and regulations associated with ambient air quality and emission limits in South Africa and various other African countries, as well as the World Bank Guidelines, European Community Limits and World Health Organisation.

Being an avid student, she received her PhD in 2014, specialising in Aeolian dust transport. Hanlie is also actively involved in the National Association for Clean Air and is their representative at the International Union of Air Pollution Prevention and Environmental Protection Associations.

RELEVANT EXPERIENCE

Air Quality Management Plans and Strategies

Vaal Triangle Airshed Priority Area Draft Second Generation Air Quality Management Plan (AQMP)(Aug 2017 – Jun 2020); Advanced Air Quality Management for the Strategic Environmental Management Plan for the Uranium and Other Industries in the Erongo Region (May 2016 – Feb 2019); City of Johannesburg AQMP (2016-2019); Air Quality Monitoring and Management for the Al Madinah Al Munawarah Development Authority (MDA) in Saudi Arabia (2016-2017). Provincial Air Quality Management Plan for the Limpopo Province (March 2013); Mauritius Road Development Agency Proposed Road Decongestion Programme (July 2013); Transport Air Quality Management Plan for the Gauteng Province (February 2012); Gauteng Green Strategy (2011); Air Quality and Radiation Assessment for the Erongo Region Namibia as part of a Strategic Environmental Assessment (June, 2010); Vaal Triangle Airshed Priority Area AQMP (March, 2009); Gauteng Provincial AQMP (January 2009); North West Province AQMP (2008); City of Tshwane AQMP (April 2006); North West Environment Outlook 2008 (December 2007); Ambient Monitoring Network for the North West Province (February 2007); Spatial Development Framework Review for the City of uMhlathuze (August 2006); Ambient Particulate Pollution Management System (Anglo Platinum Rustenburg).

Hanlie has also been the Project Director on all the listed Air Quality Management plan developments.

Mining and Ore Handling

Hanlie has undertaken numerous air quality impact assessments and management plans for coal, platinum, uranium, copper, cobalt, chromium, fluorspar, bauxite and mineral sands mines. These include air quality impact assessments for: Namibia – Husab Uranium Mine, Trekkopje Uranium Mine; Bannerman Uranium Project; Langer Heinrich Uranium Mine, Valencia Uranium Mine, Rössing Uranium Mine; and B2Gold Otjikoto Gold Mine. South Africa – Sishen Iron Ore Mine; Tshipi Borwa Manganese Mine; Mamatwan Manganese Mine; Kolomela Iron Ore Mine; Thabazimbi Iron ore Mine; UKM Manganese Mine; Everest Platinum Mine; Impala Platinum Mine; Anglo Platinum Mines; Abglo Gold Ashanti MWS, Vaal River and West Wits complexes, Harmony Gold, Glencore Coal Mines, South32 and Anglo Coal; Tselentis Coal mine (Breyeton); Lime Quarries (De Hoek, Dwaalboom, Slurry); Beesting Colliery (Ogies); Anglo Coal Opencast Coal Mine (Heidelberg); Klippan Colliery (Belfast); Beesting Colliery (Ogies); Xstrata Coal Tweefontein Mine (Witbank); Xstrata Coal Spitskop Mine (Hendrina); Middelburg Colliery (Middelburg); Klipspruit Project (Ogies); Rustenburg Platinum Mine (Rustenburg); Impala Platinum (Rustenburg); Buffelsfontein Gold Mine (Stilfontein); Kroondal Platinum Mine (Kroondal); Lonmin Platinum Mine (Mooinooi); Rhovan Vanadium (Brits); Macauvlei Colliery (Vereeniging); Voorspoed Gold Mine (Kroonstad); Pilanesberg Platinum Mine (Pilanesberg); Kao Diamond Mine (Lesotho); Modder East Gold Mine (Brakpan); Modderfontein Mines (Brakpan); Zimbiwa Crusher Plant (Brakpan); RBM Zulti South Titanium mining (Richards Bay); Premier Diamond Mine (Cullinan). Botswana – Jwaneng Diamond Mine and Debswana Mining Company. Zimbabwe – Murowa Diamond Mine. Other mining projects include Sadiola Gold Mine (Mali); North Mara Gold Mine (Tanzania); Bulyanhulu North Mara Gold Mine (Tanzania).

Metal Recovery

Air quality impact assessments have been carried out for Smelterco Operations (Kitwe, Zimbia); Waterval Smelter (Amplats, Rustenburg); Hernic Ferrochroime Smelter (Brits); Rhovan Ferrovanadium (Brits); Impala Platinum (Rustenburg); Impala Platinum (Springs); Transvaal Ferrochrome (now IFM, Mooinooi), Lonmin Platinum (Mooinooi); Xstrata Ferrochrome Project Lion (Steelpoort); ArcelorMittal South Africa (Vandebijlpark, Vereeniging, Pretoria, Newcastle, Saldanha); Hexavalent Chrome Xstrata (Rustenburg); Portland Cement Plant (DeHoek, Slurry, Dwaalboom, Hercules, Port Eelizabeth); Vantech Plant (Steelpoort); Bulyanhulu Gold Smelter (Tanzania), Sadiola Gold Recovery Plant (Mali); RBM Smelter Complex (Richards Bay); Chibuto Heavy Minerals Smelter (Mozambique); Moma Heavy Minerals Smelter (Mozambique); Boguchansky Aluminium Plant (Russia); Xstrata Chrome CMI Plant (Lydenburg); SCAW Metals (Germiston).

Chemical Industry

Comprehensive air quality impact assessments have been completed for AECI (Pty) Ltd Operations (Modderfontein); Kynoch Fertilizer (Potchefstroom), Foskor (Richards Bay) and Omnia (Rustenburg).

Petrochemical Industry

Numerous air quality impact assessments have been completed for SASOL operations (Sasolburg); Sapref Refinery (Durban); Health risk assessment of Island View Tank Farm (Durban Harbour).

Pulp and Paper Industry

Air quality studies have been undertaken or the expansion of Mondi Richards Bay, Multi-Boiler Project for Mondi Merebank (Durban), impact assessments for Sappi Stanger, Sappi Enstra (Springs), Sappi Ngodwana (Nelspruit) and Pulp United (Richards Bay).

Power Generation

Air quality impact assessments have been completed for numerous Eskom coal fired power station studies including the Coal 3 Power Project near Lephalale, Komati Power Station and Lethabo Power Stations. In addition to Eskom's coal fired power stations, projects have been completed for the proposed Mmamabula Energy Project (Botswana); Morupule Power Plant (Botswana), NamPower Erongo Power Project (Namibia), NamPower Van Eck Power Station (Namibia) and NamPower Biomass Power Plant (Namibia).

Apart from Eskom projects, heavy fuel oil power station assessments have also been completed in Kenya (Rabai Power Station) and Namibia (Arandis Power Plant).

Green energy projects included several Solar Photovoltaic Projects (Mulilo and Enertrag South Africa (Pty) Ltd) and assessing potential particulate matter impacts from Wind Farms near the South African Large Telescope (SALT)

Waste Disposal

Air quality impact assessments, including odour and carcinogenic and non-carcinogenic pollutants were undertaken for the proposed Coega Waste Disposal Facility (Port Elizabeth); Boitshepi Waste Disposal Site (Vanderbijlpak); Umdloti Waste Water Treatment Plant (Durban).

Cement Manufacturing

Impact assessments for ambient air quality have been completed for the PPC Cement Alternative Fuels Project (which included the assessment of the cement manufacturing plants in the North West Province, Gauteng and Western).

Vehicle emissions

Transport Air quality Management Plan for the Gauteng Department of Roads and Transport (Feb 2012); Platinum Highway (N1 to Zeerust); Gauteng Development Zone (Johannesburg); Gauteng Department of Roads and Transport (Transport Air Quality Management Plan); Mauritius Road Development Agency (Proposed Road Decongestion Programme); South African Petroleum Industry Association (Impact Urban Air Quality).

Government and International Strategy Projects

Hanlie in one of the Lead Authors of Section 1.1: Africa's Development: Challenges, Drivers and key objectives, of the United Nations Environment Programme (UNEP), Climate and Clean Air Coalition (CCAC) and Stockholm Environment Institute (SEI) coordinated 'Integrated Assessment of Air Pollution and Climate Change for Africa Report. She was also the Terminal Reviewer of the UNEP/UNDA project "Air quality data for health and environment policies in Africa and the Asia-Pacific region"

(May 2020). Hanlie was also the project Director on the APPA Registration Certificate Review Project for Department of Environmental Affairs (DEA); Green Strategy for Gauteng (2011).

EDUCATION

Ph.D Geography	University of Johannesburg, RSA (2014) Title: *A functional dependence analysis of wind erosion modelling system parameters to determine a practical approach for wind erosion assessments*
M.Sc Geography and Environmental Management	University of Johannesburg, RSA (1999) Title: *Air Pollution Population Exposure Evaluation in the Vaal Triangle using GIS*
B.Sc Hons. Geography	University of Johannesburg, RSA (1995) GIS & Environmental Management
B.Sc Geography and Geology	University of Johannesburg, RSA (1994) Geography and Geology

ADDITIONAL COURSES AND ACADEMIC REVIEWS

External Examiner (February 2021)	PhD Candidate: Ms NM Walton Aerosol source apportionment in southern Africa Faculty of Natural and Agricultural Sciences, North-West University
External Examiner (May 2018)	MSc Candidate: Ms A Quta Characterisation of Particulate Matter and Some Pollutant Gasses in the City of Tshwane Department of Environmental Sciences, University of South Africa
External Examiner (December 2017)	MSc Candidate: Ms B Wernecke Ambient and Indoor Particulate Matter Concentrations on the Mpumalanga Highveld Faculty of Natural and Agricultural Sciences, North-West University
External Examiner (January 2016)	MSc Candidate: Ms M Grobler Evaluating the costs and benefits associated with the reduction in SO_2 emissions from Industrial activities on the Highveld of South Africa Department of Chemical Engineering, University of Pretoria
External Examiner (August 2014)	MSc Candidate: Ms Seneca Naidoo Quantification of emissions generated from domestic fuel burning activities from townships in Johannesburg Faculty of Science, University of the Witwatersrand
Air Quality Law– Lecturer (2012 - 2016)	Environmental Law course: Centre of Environmental Management.
Air Quality law for Mining – Lecturer (2014)	Environmental Law course: Centre of Environmental Management.
Air Quality Management – Lecturer (2006 -2012)	Air Quality Management Short Course: NACA and University of Johannesburg, University of Pretoria and University of the North-West.

ESRI SA (1999)	ARCINFO course at GIMS: Introduction to ARCINFO 7 course
ESRI SA (1998)	ARCVIEW course at GIMS: Advanced ARCVIEW 3.1 course

COUNTRIES OF WORK EXPERIENCE

South Africa, Mozambique, Botswana, Namibia, Malawi, Mauritius, Kenya, Mali, Zimbabwe, Democratic Republic of Congo, Tanzania, Zambia, Madagascar, Guinea, Russia, Mauritania, Morocco, and Saudi Arabia.

EMPLOYMENT RECORD

March 2003 - Present

Airshed Planning Professionals (Pty) Ltd, Managing Director and Principal Air Quality Scientist, Midrand, South Africa.

January 2000 – February 2003

Environmental Management Services CC, Senior Air Quality Scientist.

May 1998 – December 1999

Independent Broadcasting Authority (IBA), GIS Analyst and Demographer.

February 1997 – April 1998

GIS Business Solutions (PQ Africa), GIS Analyst

January 1996 – December 1996

Annegarn Environmental Research (AER), Student Researcher

LANGUAGES

	Speak	Read	Write
English	Excellent	Excellent	Excellent
Afrikaans	Excellent	Excellent	Excellent

CONFERENCE AND WORKSHOP PRESENTATIONS AND PAPERS

- Dust and radon levels on the west coast of Namibia – What did we learn? Hanlie Liebenberg-Enslin, Detlof von Oertzen, and Norwel Mwananawa. Atmospheric Pollution Research, 2020. https://doi.org/10.17159/caj/2020/30/1.8467

- Understanding the Atmospheric Circulations that lead to high particulate matter concentrations on the west coast of Namibia. Hanlie Liebenberg-Enslin, Hannes Rauntenbach, Reneé von Gruenewaldt, and Lucian Burger. Clean Air Journal, 27, 2, 2017, 66-74.

- Cooperation on Air Pollution in Southern Africa: Issues and Opportunities. SLCPs: Regional Actions on Climate and Air Pollution. Liebenberg-Enslin, H. 17th IUAPPA World Clean Air Congress and 9th CAA Better Air Quality Conference. Clean Air for Cities - Perspectives and Solutions. 29 August - 2 September 2016, Busan Exhibition and Convention Center, Busan, South Korea.

- A Best Practice prescription for quantifying wind-blown dust emissions from Gold Mine Tailings Storage Facilities. Liebenberg-Enslin, H., Annegarn, H.J., and Burger, L.W. VIII International Conference on Aeolian Research, Lanzhou, China. 21-25 July 2014.

- Quantifying and modelling wind-blown dust emissions from gold mine tailings storage facilities. Liebenberg-Enslin, H. and Annegarn, H.J. 9th International Conference on Mine Closure, Sandton Convention Centre, 1-3 October 2014.

- Gauteng Transport Air Quality Management Plan. Liebenberg-Enslin, H., Krause,N., Burger, L.W., Fitton, J. and Modisamongwe, D. National Association for Clean Air Annual Conference, Rustenburg. 31 October to 2 November 2012. Peer reviewed.

- Developing an Air Quality Management Plan: Lessons from Limpopo. Bird, T.; Liebenberg-Enslin, H., von Gruenewaldt, R., Modisamongwe, D. National Association for Clean Air Annual Conference, Rustenburg. 31 October to 2 November 2012. Peer reviewed.

- Modelling of wind eroded dust transport in the Erongo Region, Namibia, H. Liebenberg-Enslin, N Krause and H.J. Annegarn. National Association for Clean Air (NACA) Conference, October 2010. Polokwane.

- The lack of inter-discipline integration into the EIA process-defining environmental specialist synergies. H. Liebenberg-Enslin and LW Burger. IAIA SA Annual Conference, 21-25 August 2010. Workshop Presentation. Not Peer Reviewed.

- A Critical Evaluation of Air Quality Management in South Africa, H Liebenberg-Enslin. National Association for Clean Air (NACA) IUAPPA Conference, 1-3 October 2008. Nelspuit.

- Vaal Triangle Priority Area Air Quality Management Plan – Baseline Characterisation, R.G. Thomas, H Liebenberg-Enslin, N Walton and M van Nierop. National Association for Clean Air (NACA) conference, October 2007, Vanderbijl Park.

- Air Quality Management plan as a tool to inform spatial development frameworks – City of uMhlathuze, Richards Bay, H Liebenberg-Enslin and T Jordan. National Association for Clean Air (NACA) conference, 29 – 30 September 2005, Cape Town.

CERTIFICATION

I, the undersigned, certify that to the best of my knowledge and belief, these data correctly describe me, my qualifications, and my experience.

21 July 2021

Full name of staff member: Hanlie Liebenberg-Enslin