EnviroSim CONSULTING

Prospective Human Health Risk and Impact Assessment for the Proposed West Wits Mining Project

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Report Details

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Statement of Experience

Nardus Potgieter is registered as a Professional Natural Scientist with the South African Council for Natural Scientific Professionals in Environmental Science field of practice. He has more than 14 years' experience in the assessment of impacts on human health and the environment from hazardous substances in air, water and the terrestrial food chain. His experience includes human health risk assessment, radiological public safety assessment and contaminated land remediation.

Declaration

EnviroSim Consulting is an independent consulting firm with no interest in the project other than to fulfil the contract between the environmental impact practitioner and the consultant for delivery of specialised services as stipulated in the terms of reference.

Disclaimer

CROSS REFERENCE TABLE

Table prepared in accordance with National Environmental Management Act (Act 107 of 1998) (NEMA) Regulation (2014), Appendix 6

Requirement	Relevant section in report
Details of the specialist who prepared the report.	Report details (page ii)
The expertise of that person to compile a specialist report including curriculum vitae.	Report details (page ii) and Annexure A
A declaration that the person is independent in a form as may be specified by the competent authority.	Declaration (page v)
An indication of the scope of, and the purpose for which, the report was prepared.	Introduction Section 1.1 and 1.3
The date and season of the site investigation and the relevance of the season to the outcome of the assessment.	Not applicable
A description of the methodology adopted in preparing the report or carrying out the specialised process.	Section 1.2
The specific identified sensitivity of the site related to the activity and its associated structures and infrastructure.	Section 1.3
An identification of any areas to be avoided, including buffers.	Not applicable
A map superimposing the activity including the associated structures and infrastructure on the environmental sensitivities of the site including areas to be avoided, including buffers.	Section 4.2.2
A description of any assumptions made and any uncertainties or gaps in knowledge.	Section 6
A description of the findings and potential implications of such findings on the impact of the proposed activity, including identified alternatives, on the environment.	Section 5.5
Any mitigation measures for inclusion in the environmental management programme report	Section 7
Any conditions for inclusion in the environmental authorisation	Section 7
Any monitoring requirements for inclusion in the environmental management programme report or environmental authorisation.	Section 7
A reasoned opinion as to whether the proposed activity or portions thereof should be authorised.	Section 7
If the opinion is that the proposed activity or portions thereof should be authorised, any avoidance, management and mitigation measures that should be included in the environmental management programme report, and where applicable, the closure plan.	Section 5.5.4
A description of any consultation process that was undertaken during the course of carrying out the study.	Not applicable.
A summary and copies if any comments that were received during any consultation process.	Comments have been recorded and considered as part of the EIA process.
Any other information requested by the competent authority.	Not applicable.

EXECUTIVE SUMMARY

West Wits Mining MLI (Pty) Ltd (West Wits) intends to develop gold mining operations over various portions of land located in an area south of Roodepoort, to the north of Soweto, Gauteng.

The proposed West Wits Mining Project will involve the development of five open pit mining areas, as well as refurbishment of two existing mining complexes to access existing underground mine workings. The project also includes the establishment of mining and supporting infrastructure, notably run of mine (ROM) ore stockpiles, topsoil stockpiles and waste rock dumps

SLR Consulting (South Africa) Pty (Ltd) (SLR) was appointed to conduct an Environmental Impact Assessment for the proposed West Wits Mining Project (the proposed Project). SLR approached EnviroSim Consulting with a request to perform an assessment of the potential impact on the health of communities, living in the vicinity of the proposed Project, with regard to exposure to airborne pollutants as well as contaminants identified as potentially relevant to groundwater and surface water resources in the area. The human health risk and impact assessment (HHRIA) is aimed at specifically addressing these concerns. The HHRIA only considers non-radiogenic health effects associated with the potential contaminants. Health concerns relating to radiation are addressed separately in a specialist study by SciRad (2019).

The health risks posed to members of the public by the activities planned at the proposed Project was evaluated using a source-pathway-receptor analysis approach. Information from specialist study reports prepared for the project site, was incorporated with toxicological data and population statistics to quantify the human health risks associated with the proposed Project.

Information presented indicates that a complete source-pathway-receptor linkage exists for the atmospheric exposure pathway. Information on the aquatic environment indicated that complete source-pathway-receptor linkage for this pathway is not possible. The aquatic pathway was therefore excluded from further assessment for the project, but health risks associated with specific contaminants detected in baseline surface and groundwater at the site was evaluated as indication of the sensitivity of water resources in the area. The potential for exposure through the atmospheric exposure pathway was evaluated for the operational life of the proposed Project.

Using approaches developed by the United States Environmental Protection Agency (USEPA) and the World Health Organisation (WHO), the predicted airborne concentrations of air pollutants were assessed and the potential environmental human health risks associated with the proposed project was quantified. The following conclusions were reached:

- Based on the modelled air pollutant concentrations the proposed Project is shown to make a quantifiable but insignificant contribution to daily personal risks of health effects in members of the public.
- Annual risks of health effects from long term exposure to air pollutants were also evaluated, although the project lifetime is shorter than the assumed exposure period of one year. The

evaluation similarly indicated a quantifiable but insignificant contribution to daily personal risks of health effects in members of the public.

- It is recommended that, in accordance with the findings presented in the Air Quality Specialist report (Airshed, 2019), that dust mitigation measures be implemented and airborne concentrations of PM_{10} and $PM_{2.5}$ be monitored in the residential areas closest to the operational areas associated with the proposed Project.
- The probability of non-cancer and cancer health effects occurring at any of the receptor locations as a result of exposure to airborne particulates or vehicle emissions is low and no mitigation or monitoring of these substances is considered necessary.
- Evaluation of measured baseline concentrations of nitrate in groundwater and surface water samples from the project area indicate that ingestion exposure to the existing groundwater and is unlikely to result in adverse health effects to chronic water users. However, members of the public utilising water in surface water should be discouraged to do so. It is recommended that seepage and runoff from the waste rock stockpile areas at each of the proposed open pit mining areas must be contained and, in accordance with recommendations of the Hydrogeological Specialist report (NOA, 2019), be prevented from entering the environment as far as possible. It is recommended that regular groundwater and surface water quality monitoring be established and maintained in the areas potentially affected by seepage and runoff from the waste rock stockpiles.

In accordance with the requirements of the impact assessment process the potential impacts to human health, identified as part of the HHRIA, has to be evaluated to determine the significance of each impact and anticipated severity of the impact. The potential health impacts identified were evaluated using a set of qualitative evaluation variables. This qualitative evaluation concluded that the significance of the impact associated with either long-term or short-term exposure to criteria pollutants is medium under mitigated conditions of exposure, while the potential impacts from exposure to diesel particulate matter and the hazardous constituents of the airborne particulates is Low.

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DECLARATION OF INDEPENDENCE AND EXPERIENCE

I, Nardus Potgieter in my capacity as Director of EnviroSim Consulting declare that:

- All work undertaken relating to the proposed Project was performed as an independent consultant;
- I have the necessary required expertise to conduct human health risk impact assessments, including the required knowledge and understanding of internationally accepted best practice, guidelines and policies that are relevant to the activity;
- I have undertaken all the work and associated studies in an objective manner, even if the findings of these studies were not favourable to the project proponent;
- I have no vested financial interest in the proposed project or the outcome thereof, apart from remuneration for the work undertaken under the auspices of the project manager, SLR Consulting (Pty) Ltd.;
- I have no vested interest, including any conflicts of interest, in either the proposed project or the studies conducted in respect of the proposed project, other than providing an objective evaluation of the identified impacts and complying with the requirements of the impact assessment process;
- I have disclosed any material factors that may have the potential to influence the competent authority's decision and/or objectivity in terms of any reports, plans or documents related to the proposed project as required by the relevant regulations.

Record of Experience

This report was compiled by Mr Nardus Potgieter.

Nardus Potgieter is registered as a Professional Natural Scientist with the South African Council for Natural Scientific Professionals in Environmental Science field of practice. He has more than 14 years' experience in the assessment of impacts on human health and the environment from hazardous substances in air, water and the terrestrial food chain. His experience includes human health risk assessment, radiological public safety assessment and contaminated land remediation.

For further information, please refer to a CV attached as Annexure A.

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TERMS AND ABBREVIATIONS

ATSDR	Agency for Toxic Substances and Disease Registry
Cardiopulmonary	Relating to or involving the heart and the lungs.
Cardiovascular system	An organ system that circulates blood throughout the human body. The cardiovascular system consists of the heart, arteries and veins.
COMEAP	UK Committee on the Medical Effects of Air Pollutants
COPD	Chronic Obstructive Pulmonary Disease: disease of the lungs in which the airways become narrowed. This leads to a limitation of the flow of air to and from the lungs causing shortness of breath.
Criteria pollutants	A term used internationally to describe air pollutants that have been regulated and are used as indicators of air quality
DPM	Diesel Particulate Matter
EIA	Environmental Impact Assessment
Epidemiological	Scientific studies of factors affecting the health and illness of populations.
HHRIA	Human Health Risk and Impact Assessment
IARC	International Agency for Research on Cancer
LOAEL	Lowest Observed Effect Level
Lung function	Lung function tests determine the lung capacity (volume of air the lungs can hold), the efficiency with which air is moved in and out of the lungs, and the efficiency of carbon monoxide and oxygen exchange. The tests aid in the diagnosis of lung diseases, and measure the severity of lung problems.
Morbidity	The state of being diseased (from Latin morbidus: sick, unhealthy), or disability irrespective of cause (e.g., disability caused by accidents).
Mortality	Number of people dying during a given time interval.
MRL	Minimal Risk Levels
NGL	Natural ground level
OEHHA	California State Environmental Protection Agency, Office of Environmental Health Hazard Assessment
PM	Particulate matter air pollution.
Prevalence	Epidemiological term indicating the total number of cases of a given disease in a specified population at a specified time.
REL	Reference Exposure Level
Respiratory system	In humans and other mammals, the respiratory system consists of the airways, the lungs, and the respiratory muscles that mediate the

	movement of air into and out of the body.
RfC	Reference Concentration
RfD	Reference Dose
RR	Relative risk or risk ratio. A ratio of the probability of an outcome (e.g. the disease under study) occurring in the exposed group versus a non-exposed group.
US EPA	United States Environmental Protection Agency
WHO	World Health Organisation

Note: Although it is generally accepted to use scientific notation when values that are either very small numbers or very big numbers are reported, the West Wits project management requested that numbers in this report be reported in decimal form.

1 BACKGROUND AND SCOPE OF THE STUDY

1.1 INTRODUCTION

EnviroSim Consulting, was contracted by SLR Consulting (South Africa) Pty (Ltd) to perform a prospective human health risk assessment for a proposed mining operation located near Roodepoort and Soweto in the City of Johannesburg Metropolitan Municipality, Gauteng. The proponent for the project is West Wits Mining MLI (Pty) Ltd (West Wits), who is planning to develop gold mining operations over various portions of land located in an the area south of Roodepoort, to the north of Soweto.

The proposed West Wits Mining Project (hereafter referred to as the Project) will involve the development of five open pit mining areas, as well as refurbishment of two existing mining complexes to access existing underground mine workings. The project also includes the establishment of run of mine (ROM) ore stockpiles, topsoil stockpiles and waste rock dumps. The proposed Project will further include supporting infrastructure, including material storage and handling facilities, general and hazardous waste management facilities, sewage management facilities, water management infrastructure, communication and lighting services, centralised and satellite offices, workshops, washbays, stores, change houses, lamprooms, vent fans and security facilities.

The expected life of mine for the open pit operations (inclusive of rehabilitation) is three to five years, during which the pits will be mined in a phased approach with each pit taking between 5 and 9 months to be mined and rehabilitated. The underground workings are expected to operate for a period of between ten and twenty years.

Figure 1.1 show the locations of the various operational areas with the five open pit operations (referred to as the Mona Lisa Bird Reef Pit, Roodepoort Main Reef Pit, Rugby Club Main Reef Pit, 11 Shaft Main Reef Pit and Kimberley Reef East Pit on Figure 2) located to the west, north and east of the two existing underground mining complexes (referred to as the Bird Reef Central Infrastructure Complex and Kimberley Reef East Infrastructure Complex).

In general, mining and mineral processing activities are known to be responsible for various environmental disturbances, which have the potential to release various pollutants to the environment. It is therefore necessary to address the concerns of communities living in the vicinity of such operations with regard to potential health risks, by performing a human health risk assessment. The assessment results are intended to serve as a scientific basis for the understanding of potential health risks.

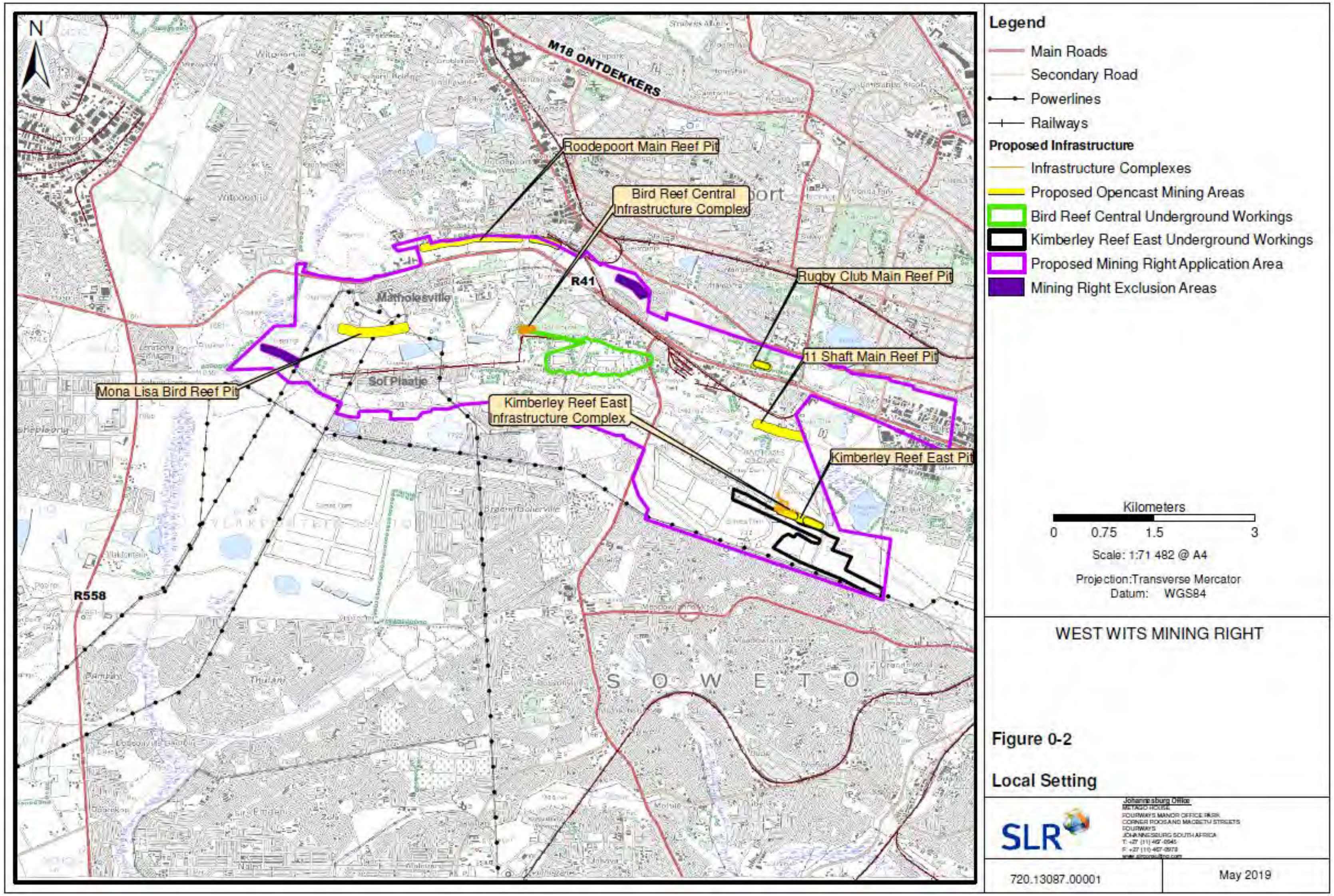

Figure 1.1 **West Wits Project proposed Mining Right application area and proposed operational areas (SLR, 2018).**

SLR Consulting, approached EnviroSim Consulting with a request to perform an assessment of the potential impact on the health of communities, living in the vicinity of the proposed Project, with regard to exposure to airborne pollutants as well as contaminants identified as potentially relevant to groundwater and surface water resources in the area. The human health risk and impact assessment (HHRIA), is aimed at specifically addressing these concerns, and thus is limited to the quantitative evaluation of potential health risks relating to the inhalation of airborne pollutants and ingestion of waterborne contaminants.

This HHRIA forms part of the broader environmental authorisation process and includes all aspects relevant to the quantification and assessment of human health risks, as it pertains to the requirements of the Environmental Impact Assessment.

1.2 Study Framework

1.2.1 Risk Based Approach

Overall, a risk-based approach is followed in development of the HHRIA. This approach is aimed at defining the relationship between cause and effect for the impact under investigation, which is, understanding how a potential hazard occurs, the probability of its occurrence and the consequence if it occurs. The methodology for performing the risk-based assessment is based on defining and understanding the three components of the risk, namely the source of the potential hazard, the pathway along which the hazard propagates and the receptor that experiences the risk.

This Source-Pathway-Receptor analysis methodology is inherently systematic, traceable and transparent and provides the opportunity for iterative evaluation of the system under investigation. Since all three components (source, pathway and receptor) are necessary to demonstrate risk, the Source-Pathway-Receptor methodology allows screening of issues that are not relevant to the investigation.

The Source-Pathway-Receptor methodology is central to the identification and evaluation of potential impacts associated with the proposed Project. Assessment and quantification of the identified impacts is performed in accordance with the principles of health risk assessment as defined by the health risk assessment paradigm.

1.2.2 Health Risk Assessment Paradigm

Human health risk assessment is the qualitative or quantitative characterisation of the probability of potentially adverse health effects in humans from exposure to environmental hazards (Hall *et al.*, 1997). The outputs of a human health risk assessment, performed for mining activities such as the proposed Project, are necessary for informed regulatory decisions regarding emissions and effluents from the operation and contamination of ambient air, water or the terrestrial food chain to which humans may be exposed.

The original paradigm for regulatory human health risk assessment was developed in the USA by the US National Research Council (NRC, 1983). This model has been adopted and refined by, among other, the US Environmental Protection Agency (US EPA) and is widely used for quantitative health risk assessments (IPCS, 1999).

The risk assessment paradigm essentially divides a human health risk assessment into a number of logical steps, as follows:

- **Hazard identification** involves the identification of substances relevant to the situation under investigation, which have the potential to be released to the environment and are suspected to pose hazards to human health and the environment.
- **Dose-response assessment** addresses the relationship between levels of biological exposure and the manifestation of adverse health effects in humans.
- **Exposure assessment** is a description of the environmental pathways involved in the distribution of hazardous substances and the identification of potentially exposed receptors.
- **Risk characterisation**, which involves the integration of the components described above, with the purpose of determining whether specific exposures to an individual or a community might lead to adverse health effects.
- **Uncertainty analysis** is identifying the nature and magnitude of the uncertainty and variability inherent in the characterisation of risk.

1.3 Scope of the Assessment

1.3.1 Pathways, and Receptors of Concern

In the preparation of the HHRIA, the following documents and specialist study reports were consulted:

- Scoping Report for the Proposed West Wits Mining Project (SLR, 2018).
- Air Quality Impact Assessment report for the West Wits Mining Project (Airshed, 2019).
- Geochemical Specialist Assessment report for the West Wits 11 Shaft Gold Mine (GeoDyn, 2018a).
- Geochemical Specialist Assessment report for the West Wits Kimberley East Gold Mine (GeoDyn, 2018b).
- Geochemical Specialist Assessment report for the West Wits Mona Liza Gold Mine (GeoDyn, 2018c).
- Geochemical Specialist Assessment report for the West Wits Roodepoort Mine (GeoDyn, 2018d).
- Geochemical Specialist Assessment report for the West Wits Rugby Club Mine (GeoDyn, 2018e).
- Hydrogeological Specialist Investigation West Wits MLI (Pty) Ltd (NOA, 2019)

- Social Impact Assessment Report (Mercury, 2019).

Based on the understanding of the proposed activities and the environmental conditions, gleaned from the documents and reports listed above, the atmospheric and aquatic pathways are identified as the most prominent means by which humans may come into contact with potentially hazardous contaminants from the proposed Project.

These specialist study reports are the primary sources of quantitative information on environmental concentrations of airborne and water borne contaminants originating from the proposed Project. The scope of the HHRIA is limited by the reported data and findings of specialist studies that describe the atmospheric and aquatic pathways, and the transport and dispersion of potentially hazardous contaminants within these pathways. The information and data obtained from the specialist studies is accepted to be accurate and no verification of the data has been undertaken by EnviroSim.

The HHRIA will only consider non-radiogenic health effects associated with the potential contaminants. Health concerns relating to radioactive contaminants that may be generated from the proposed operations will not be considered. Radiological impacts to humans and the environment are addressed in a specialist report by SciRad (2019).

The assessment endpoint of the HHRIA is limited to the evaluation of the risks posed to the health of members of the public residing in the vicinity of the proposed Project. Potential receptors will be identified from the communities closest to the proposed Project location, based on information available for these communities. For the purpose of the HHRIA, a sensitive receptor is defined as:

Any individual or population group whose habits, location or other characteristics could cause them to be exposed to higher concentrations of contaminants than the rest of the exposed population.

2 HAZARD ASSESSMENT

2.1 INTRODUCTION

Hazard assessment is the identification of contaminants suspected to pose a hazard to human health and a description of the type of health hazard they may produce. The hazard assessment step is designed as logical processes for screening the myriad of possible contaminants, as well as the possible circumstances that may lead to human exposure, and so simplify the identification of contaminants of potential concern.

Screening and identifying contaminants of potential concern requires information about the potential sources of health hazards as well as a description of the most likely exposure pathways and receptor populations. The conceptual understanding of the hazard sources, exposure pathways and receptors associated with proposed Project, was based on the information presented in the documents and specialist reports listed in Section 1.3.1.

The hazard assessment starts with a summary overview of the proposed Project and associated facilities as well as the environmental disturbances that are expected as part of the proposed Project. The level of detail presented in the overview is proportionate to the information available and that needed for the identification of potential hazards. That is, the project description is intended to provide a clear representation of the features of the project relevant to the potential impacts under evaluation, and therefore does not necessarily represent a comprehensive, detailed description of all aspects.

The summary project description is followed by an identification of contaminants of potential concern and a description of the environmental health significance of each identified contaminant.

2.2 PROJECT DESCRIPTION

The Project comprises two historic mining centres known as the Durban Roodepoort Deep and the Rand Leases, both located on the northern edge of the Witwatersrand Basin, southwest of the city of Johannesburg on various portions of the farms Roodepoort 236 IQ, Roodepoort 237 IQ, Witpootjie 245 IQ, Vlakfontein 238 IQ, Vogelstruisfontein 231 IQ, Volgelstruisfontein 233 IQ, Doornkop 239 IQ and Glenlea 228IQ.

As indicated earlier, West Wits intends to establish open pit and underground gold mining operations. Initial operational activities will be focussed on open pit mining activities in five areas namely the Mona Lisa Bird Reef Pit, Roodepoort Main Reef Pit, Rugby Club Main Reef Pit, 11 Shaft Main Reef Pit and Kimberley Reef East Pit (see Figure 1.1).

According to the Scoping Report for the proposed Project (SLR, 2018), establishment of the facilities required for the opencast mining activities will take place during the construction phase. Construction activities such as clearing of vegetation and removal of overburden will be ongoing, also forming part of the mining (operational) phase of the project.

Once the vegetation, topsoil and overburden have been removed and stockpiled for later use in rehabilitation, ore would be excavated and hauled to an ore stockpile for crushing before transportation off-site. Figure 2.1~~Figure 2.1~~ shows, as an example, the proposed layout of the Mona Lisa pit and associated infrastructure.

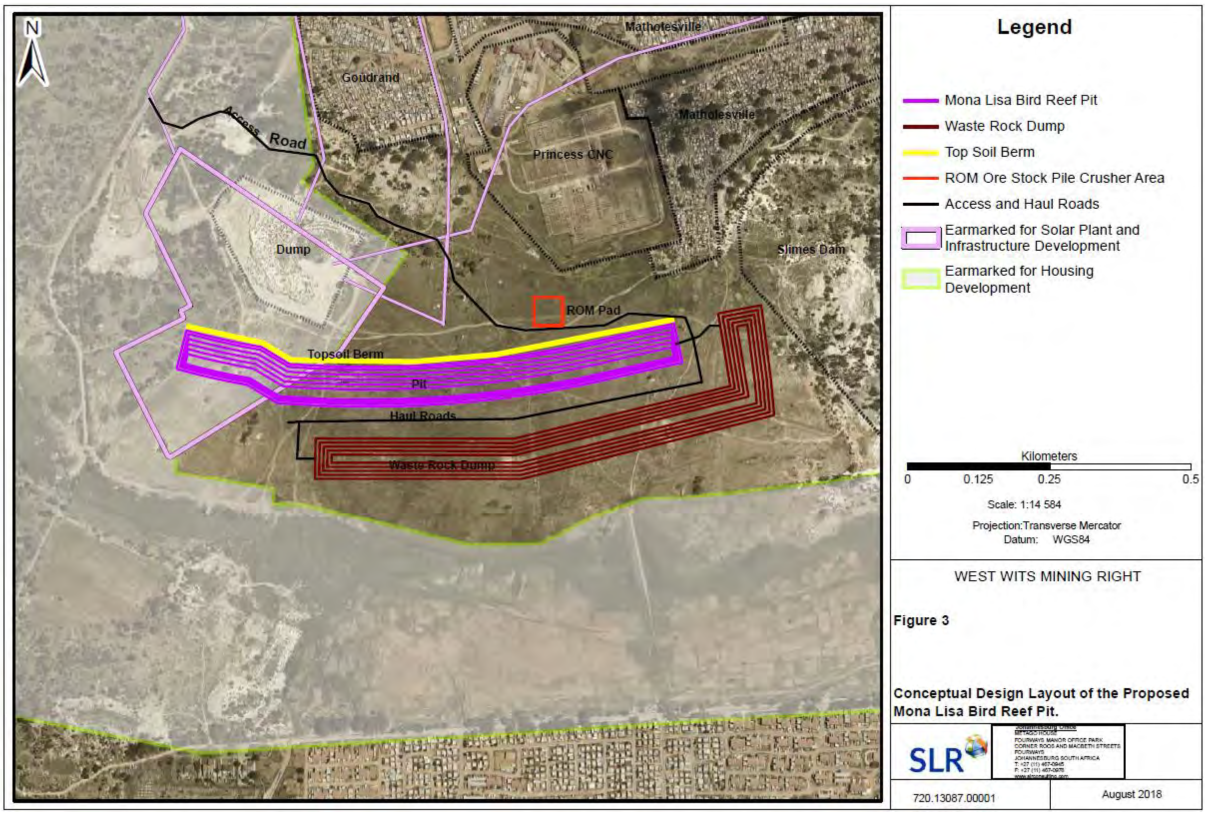

Figure 2.1 Planned layout of the proposed Mona Lisa Bird Reef open pit operations (SLR, 2018).

In Figure 2.1~~Figure 2.1~~ the location of the topsoil stockpile (marked in yellow) to the north and of the open pit (marked in pink) is indicated. Access to the site will be from the existing road network and internal haul roads will be linked up with access roads. Access roads are indicated in black in Figure 2.1~~Figure 2.1~~. Waste rock and overburden removed from the pit will be placed in a waste rock dump planned for location adjacent to the pit (indicated as dark brown area to the south and east of the pit). Figure 2.1~~Figure 2.1~~ further shows the ROM stockpile and crushing area as a square outlined in red. All five the proposed opencast operations have similar layouts. Refer to the Scoping Report for the proposed Project (SLR, 2018) for more detail of each operational area.

Rehabilitation and mining of the open pits will run concurrently. The five proposed opencast mining areas will be developed in phases where as soon as one opencast area has been mined, backfilled and rehabilitated, the next opencast area will be targeted. The opencast mining and subsequent rehabilitation is expected to be completed within the first 5 years of the project.

Following final rehabilitation and adequate stabilisation, each of the areas would be made available in line with post-closure land use objectives. No waste rock dumps would remain.

Upon near depletion of resources at the open pit mining areas, underground resources will be targeted. The activities required to enable extraction of the underground resources include re-establishment of existing incline, circular and vertical shafts and related infrastructure as well as rehabilitation of the existing workings in two areas known as the Bird Reef Central Infrastructure Complex and Kimberley Reef East Infrastructure Complex (see Figure 1.1).

The underground mining operations are planned as conventional drill and blast breast mining. The shafts, equipped with a winder house, will provide means for movement of personnel, material and rock to and from the underground workings. Ore will be transported to the shafts by means of conventional track bound equipment, taken to surface where it will be stored for initial crushing before transportation off-site. Any waste rock produced by the underground mining operations will remain underground. It is anticipated that up to 360 000 tonnes of ore will be mined per annum from the underground resources, giving the underground operations an estimated life of 10 years (Bird Reef Central Complex) and 20 years (Kimberley Reef East Complex).

2.3 Sources of Contamination

2.3.1 General

Based on the description of the proposed Project the major unit operations and activities of importance to the HHRIA, are:

- Open pit mining operations and associated activities;
- Waste rock dumps at each pit;
- Ore stockpiles at each pit;
- Access roads used for transport of materials; and,
- Underground mining operations.

In the sections that follow the characteristics of each of these five unit operations are discussed in order to highlight the potential each has to serve as source of contamination. For ease of reference, the discussions distinguish between sources of atmospheric pollutants and sources of aquatic pollutants and relies on the findings of the Air Quality Impact Assessment (Airshed, 2019) and Hydrogeological Specialist Investigation (NOA, 2019) reports for information on the source characteristics.

2.3.2 Atmospheric Pollution Sources

Air Quality Impact Assessment report (Airshed, 2019) presents an emissions inventory that is compiled by quantifying the contribution to concentrations of ambient air pollution from all potential atmospheric emission sources associated with the proposed Project.

The results presented by Airshed (2019) addresses emissions from sources and activities associated with all developmental phases of the project. Since development, mining and rehabilitation will occur concurrently, there is no sense in making a distinction between construction and operational period emissions. According to the Airshed (2019) report, dust impacts during the construction phase are expected to be short term and restricted to the immediate vicinity of the construction activities.

The Airshed (2019) emissions inventory include several sources identified as contributing to the concentrations of airborne pollutants. These sources, as they relate to the five unit processes listed above, are as follows:

- **Open pit mining operations and activities** – the airborne particulate sources associated with this unit of operation include fugitive dust emissions from rock breaking and loading of run-of-mine (ROM) and waste rock in the open pits, as well as from the crushing of the ROM. Fugitive dust generated by dozers and graders used in the clearing of the top soil from the surface of the pits, as well as the backfilling of the pits is also considered. Wind erosion of open areas in and around the open mining pits is also included.
- **Waste rock dump** – fugitive dust emissions from unloading of waste rock at the waste rock dumps located at each of the five pits, as well as wind erosion of the surface of these dumps is included.
- **Ore stockpile** – emissions from materials handling of the ROM deposited onto stockpiles, as well as airborne dust generated from the wind erosion of the surface of the ROM stockpiles at each pit are accounted for.
- **Access road** – For the access road unit, all particulate emissions associated with the movement of vehicles used in the transport of waste rock to the waste rock dumps, as well as transport of ROM are accounted for. The emission inventory includes estimates for the entrainment of dust from roads by the wheels of the vehicles, as well as the exhaust emissions from the vehicles. The pollutants evaluated for the exhaust emission not only include particulates but also gaseous pollutants like carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_2/NO_3) and sulphur dioxide (SO_2).
- **Underground operations** – since no waste rock is expected to leave the underground workings, the only emission from the underground works evaluated as part of the Air Quality Impact Assessment, are emissions of particulates from the underground ventilation shafts. Airshed (2019) used the limits prescribed in the South African Mine Health and Safety Act for particulate concentrations in workplace air as estimate for the concentrations of particulate in the vented air.

In the Air Quality Impact Assessment report (Airshed, 2019), other sources of particulate and gaseous pollutant emissions in the area, which may impact on the background ambient air quality at communities surrounding the proposed Project, are noted and discussed. These sources can be expected to contribute to the cumulative concentrations of air pollutants once the proposed Project is underway. However, it is noted that the quantification and subsequent modelling of these sources did not form part of the scope of the Air Quality Specialist report.

2.3.3 Aquatic Pollution Sources

The Hydrogeological Specialist Investigation report (NOA, 2019), includes a detailed discussion of the potential impacts on groundwater levels as a result of the proposed open pit mining activities, as well as impacts relating to water quality from the management of waste rock material that will be generated at each of the mining pits from the proposed Project. The report indicates that a possible impact to water quality due to seepage from the waste rock is expected only during the post operational phase, after the waste rock is backfilled into the open pit. During the operational phase, when it will be managed as an above ground dump, it is reasoned that dewatering of the mining pit will capture all possible seepage from the waste rock and prevent off-site migration of potential contaminated water. However, according to the report (NOA, 2019), numerical mass transport simulations indicated that during both operational and post-operational phases there is a potential for contaminants that may leach from the waste rock at all of the open mining pits, to enter groundwater and be transported off site.

Although mention is made in the Hydrogeological Specialist Investigation report (NOA, 2019) of predictive scenarios simulating dewatering impacts from the underground mining operations, as well as post operational contaminant transport, no quantitative information in this regard is presented. For the purpose of the HHRIA, potential impacts originating from the underground works is therefore not considered further.

2.4 Contaminants of Potential Concern

2.4.1 Atmospheric Pathway

Particulate matter (dust) was identified in the Air Quality Impact Assessment (Airshed, 2019) as one of the potential impacts to the atmospheric pathway from the proposed Project.

Particulate matter (PM) is normally assessed as different categories, classified by aerodynamic size. The inhalable particulate fraction, PM_{10}, refers to PM with an aerodynamic diameter of up to 10 µm, i.e., the fine and coarse particle fractions combined. Fine or respirable particles are up to 2.5 µm in diameter ($PM_{2.5}$) and include the fine and ultrafine fraction, the latter which refers to particles less than 0.1 µm in diameter ($PM_{0.1}$). The full particle size spectrum is normally referred to as Total Suspended Particulates (TSP), which includes all size fractions of PM that are suspended in air. The Air Quality Impact Assessment includes emission estimates for PM_{10}, $PM_{2.5}$ and TSP.

Concerns have also been raised regarding the composition of the particulate matter, and specifically the effects of potentially hazardous constituents of the particulates on the health of potentially affected communities. In order to identify the constituents of the particulate matter which could have an effect on the health of potentially affected communities, a screening assessment is performed using health-risk based guidance values from literature.

As estimate of the composition of the particulate matter that will be generated from the five proposed opencast operations and two underground operations, information available for the most likely source material, the waste rock, is used. The results of a compositional analysis performed on the samples of waste rock from the five open pit mining sites, as obtained from the Geochemical Specialist report for each site GeoDyn (2018a; 2018b; 2018c; 2018d; 2018e), are presented in Table 2.1~~Table 2.1~~.

The mineralogical composition of the waste rock, reported by GeoDyn (2018a; 2018b; 2018c; 2018d; 2018e), indicate that the waste rock consists primarily of aluminium silicate minerals, with silicon, iron and aluminium the primary elements present, while calcium, potassium and sodium are included as major constituents.. Several potentially hazardous elements, such as arsenic, cobalt and thorium are also present in trace amounts.

Table 2.1: Elemental analysis of waste rock samples representative of the five open pit mining areas reported in units of per cent of total mass (wt%) and parts per million (ppm).

Constituent	Unit	Roodepoort	Rugby Club	Mona Liza / 11 Shaft	Kimberley East
Iron	wt%	0.44%	2.4%	0.44%	0.43%
Aluminium	wt%	0.07%	0.5%	0.11%	0.12%
Silicon	wt%	29.0	30.3	26.8	25.6
Antimony	ppm	<2	<2	<2	<2
Arsenic	ppm	20	42	72	21
Barium	ppm	4	4	7	9
Boron	ppm	6	<4	<4	<4
Cadmium	ppm	<2	<2	<2	<2
Calcium	ppm	309	325	149	124
Chromium (total)	ppm	30	58	35	27
Cobalt	ppm	<2	<2	6	3
Copper	ppm	7	21	19	7
Lead	ppm	<2	<2	9	4
Magnesium	ppm	35	57	47	31
Manganese	ppm	19	20	37	20
Mercury	ppm	<1	<1	<1	<1
Molybdenum	ppm	<2	<2	<2	<2
Nickel	ppm	3	11	17	3
Potassium	ppm	165	104	138	213
Selenium	ppm	<2	<2	<2	<2
Sodium	ppm	69	85	82	161
Strontium	ppm	4	3	5	8
Thorium	ppm	<1	1	3	3
Uranium	ppm	<1	1	7	1
Vanadium	ppm	4	14	5	4
Zinc	ppm	8	9	14	7

In order to estimate the concentrations of these elements communities may be exposed to from the proposed Project, the modelled airborne concentrations of particulate matter reported by Airshed (2019) was used. According to the Airshed report, the highest average concentrations of PM_{10} to which the closest residential communities will be exposed ranges between 40 $\mu g.m^{-3}$ for communities near the Kimberley East mining pit and 260 µg.m^{-3},for communities near the 11 Shaft mining pit. These maximum modelled particulate concentrations represent the 99th percentile of modelled values and thus represent a frequency of approximately 4 days per year. Please see the Airshed (2019) Air Quality Impact Assessment report (Section 5) for further information.

Using the concentrations of each of the elements listed in Table 2.1~~Table 2.1~~ the reported airborne particulate concentrations relevant to each open pit mining area are scaled to estimate airborne concentrations of the different elements in air at the nearby communities. The concentrations estimated in this way are conservative, as the particulate concentration values used are actually likely to occur for only a few days a year at a specific point on the nearest residential areas to each of the mining pits. However, the results are appropriate for use in a screening assessment.

The estimated concentrations are compared to health-risk based screening values, where values were available. Table 2.2~~Table 2.2~~ present a summary of the screening assessment. The reported airborne particulate concentrations relevant to the community near each open pit mining area, are also listed.

Table 2.2 Screening of elements present in the dust dispersed from the proposed Project.

Constituent	Estimated Element Concentration in Air (µg.m^{-3})					Screening Value
	Roodepoort	Rugby Club	Mona Liza	11 Shaft	Kimberley East	µg.m^{-3}
Arsenic	0.00198	0.0048	0.0039	0.0187	0.00084	0.066 to 0.00066[1]
Cadmium	0.000198	0.00023	0.0001	0.0005	0.00008	0.005[1]
Chromium (total)	0.00297	0.00667	0.0019	0.0091	0.0011	0.1[3]
Cobalt	0.000198	0.00023	0.000324	0.0016	0.0001	0.1[3]
Copper	0.000693	0.00242	0.0010	0.0049	0.00028	100[6]
Lead	0.000198	0.00023	0.0005	0.0023	0.00016	0.5[1]
Manganese	0.00188	0.00230	0.0020	0.0096	0.0008	0.15[1]
Mercury	0.000099	0.00012	0.000054	0.0003	0.00004	1[1]
Nickel	0.000297	0.00127	0.00092	0.0044	0.0001	0.025[1]
Thorium	0.000099	0.00012	0.00016	0.0008	0.0001	9.7[5]
Uranium	0.000099	0.00012	0.00038	0.0018	0.00004	0.04[4]
Vanadium	0.000396	0.00161	0.00027	0.0013	0.00016	1[2]

1. WHO Guidelines (µg/m³) (2000) chronic guidelines (1 year+)
2. WHO Guidelines (µg/m³) (2000) acute & Sub- acute guidelines (24hr)
3. US ATSDR Maximum Risk Levels intermediate exposure (up to 1 year)
4. US ATSDR Maximum Risk Levels chronic exposure (up to 1 year)
5. US ATSDR Toxicological Profile for Thorium (ATSDR, 1990)
6. The Californian Office of Environmental Health Hazard Assessment acute Reference Exposure Levels

The comparison shows that airborne concentrations of arsenic exceed the screening criteria, if the lower value in the range is used. The guideline value considers chronic exposure (more than a year). Given that any one of the mining pits will be operational for less than a year, assessing exposure at this level is very conservative. Nevertheless, arsenic is evaluated further as a pollutant.

The other air pollutants evaluated as part of the Air Quality Impact Assessment (Airshed, 2019) are all associated with tailpipe emissions of vehicles. Emissions from vehicles travelling on access roads to the various operations, as well as vehicles used in the mining operation are considered. The airborne pollutants identified include:

- Oxides of sulphur (SO_2)
- Oxides of nitrogen (NO_X)
- Carbon monoxide (CO)
- Diesel particulate matter (DPM)

2.4.2 Aquatic Pathway

2.4.2.1 Waste Rock Leaching Potential

In order to indicate the significance of the contamination that could be released from the waste rock stockpiles at each of the open pit mining areas, the NOA (2019) report includes results of a geochemistry specialist assessments conducted by GeoDyn Dynamic Systems. The GeoDyn (2018a; 2018b; 2018c; 2018d; 2018e) assessments have as its purpose to classify waste rock from each of the five open pit mining areas in terms of South African waste management regulations. In support of this classification, GeoDyn performed a geochemical characterisation of the waste rock materials in order to determine the likelihood of the development of acid mine drainage (AMD) conditions and leaching of potential contaminants from the waste rock.

To determine the geochemical characteristics of the waste rock, samples of material representative of the waste rock form each of the open pit mining areas were collected. Five samples of waste rock material were collected from each of the Kimberley East, 11 Shaft and Mona Lisa areas. These were combined into a single composite sample representative of each of the mining areas. Due to the relative number of samples available from the different areas, double the number of samples (10) of waste rock were collected from the Rugby Club and Roodepoort mining areas. The two sets of 10 samples were each combined into two individual composite samples and, along with the composite samples from the other three areas, were sent for laboratory leach testing and analysis. The results of the laboratory tests show that, although trace quantities of several constituents of the waste rock are dissolved, only the concentration of arsenic leached from the composite samples from the 11 Shaft, Rugby Club, Mona Lisa and Roodepoort waste rock exceeded the waste management threshold values used for assessment. None of the constituents leached from the Kimberley East sample exceeded any of the regulatory threshold values.

GeoDyn used the results of the laboratory tests to develop a numeric geochemical reaction model, to predict the likely elements and compounds to dissolve from the waste rock over time. Where the laboratory leach tests provide a picture of the instantaneous release of contaminants over a single period of a few hours, the geochemical model attempts to predict the release of contaminants over the long term by taking geochemical processes such as dissolution, precipitation and adsorption into account. Table 2.3~~Table 2.3~~ present the findings of the geochemical reaction model for waste rock from each of the open pit mining areas. The results confirm the findings of the laboratory leach tests and demonstrate that the waste rock material is not likely to leach any constituents other than a few soluble ions such as potassium, sulphate and trace quantities of nitrate. Table 2.3~~Table 2.3~~ further present the water quality guideline values for each of the parameters reported by GeoDyn (2018a; 2018b; 2018c; 2018d; 2018e), for comparative purposes. The comparison shows that the predicted leachate will most likely comply with drinking water guidelines. Also important to note is that arsenic is not predicted to dissolve from any of the waste rock samples.

Table 2.3: Results from geochemical leach extract modelling for waste rock from open pit mining operations GeoDyn (2018a; 2018b; 2018c; 2018d; 2018e).

Parameters	Units	Predicted Values					SANS Guideline values
		Roodepoort	Rugby Club	Mona Liza	11 Shaft	Kimberley East	
pH	pH units	7.02	7.02	7.02	7.02	7.05	5 - 9.7
Total dissolved solids	$mg.l^{-1}$	19.8	19.8	19.8	19.8	6.5	1 200
Total Alkalinity	mg $CaCo_3.l^{-1}$	<10	<10	<10	<10	< 10	-
Sodium	$mg.l^{-1}$	<1	<1	<1	<1	< 1	Aesthetic ≤200
Calcium	$mg.l^{-1}$	<1	<1	<1	<1	< 1	Aesthetic from 32
Magnesium	$mg.l^{-1}$	<1	<1	<1	<1	< 1	Aesthetic and mild health issues from 70
Potassium	$mg.l^{-1}$	13	13	13	13	2.9	No effect below 50
Aluminium	$mg.l^{-1}$	<0.01	<0.01	<0.01	<0.01	< 0.01	0.3
Arsenic	$mg.l^{-1}$	<0.01	<0.01	<0.01	<0.01	< 0.01	0.01
Copper	$mg.l^{-1}$	<0.01	<0.01	<0.01	<0.01	-	-
Iron	$mg.l^{-1}$	<0.01	<0.01	<0.01	<0.01	< 0.01	2
Nitrate	$mg.l^{-1}$	0.4	0.4	0.4	0.4	0.4	10
Sulphate	$mg.l^{-1}$	6.4	6.4	6.4	6.4	3.2	500

2.4.2.2 Acid Generating Potential

Laboratory acid base accounting tests results reported by GeoDyn (2018a; 2018b; 2018c; 2018d; 2018e) for all the composite waste rock samples, together with the geochemical modelling results, show that the risk of AMD conditions developing in the waste rock is negligible. This is attributed to the absence of iron sulphide minerals in the waste rock.

2.4.2.3 Baseline Water Quality

A project wide hydro census was conducted as part of the Hydrogeological Specialist Assessment. The census identified all boreholes and surface water streams in the area. According to the NOA (2019) report, 123 properties were investigated over the project area but only 13 boreholes could be identified. Of the 13 boreholes identified only four could be accessed or had water of which the level could be measured. In addition to the boreholes, four surface water streams were identified the four streams are described as follows:

- Stream on Eastern side of Mona Lisa, Stream flowing West
- Stream on Most Western point of Zamma Zamma Mining from Mona Lisa
- Stream to the Eastern side of Kimberley and 11 Shaft, stream flowing East
- Stream on Western side of 11 Shaft

The Based on the findings of the census and the results of the flow and contaminant transport simulations, it was concluded that within the simulated zone of potential influence for each of the five proposed open pit mining areas, no recorded groundwater users will be affected by the proposed Project.

During the hydrocensus, samples of groundwater and surface water were collected from six boreholes and four surface water points and analysed to determine the baseline water quality. Results of the analysis was compared to SANS 241 drinking water standards. This comparison indicated that two of the groundwater and three of the surface water samples are not fit for human consumption. The results indicated historical and a high present impact on the baseline groundwater and surface water environments. Table 2.4 present a summary of the elements and ions present in the groundwater and surface water that exceed drinking water standards.

Table 2.4 Summary of elements and ions in baseline samples of surface and groundwater from the Project area exceeding health risk based SANS 241 drinking water standards.

Groundwater	Surface Water
Aluminium (Al), Lead (Pb), Manganese (Mn), Nickel (Ni), Nitrate (NO_3), Sulphate (SO_4), and Uranium (U).	Aluminium (Al), Iron (Fe), Lead (Pb), Manganese (Mn), Nickel (Ni), Nitrate (NO_3), Sulphate (SO_4), and Uranium (U).

2.4.2.4 Summary

The NOA (2019) report is concluded with a statement indicating that since the development of AMD conditions as well as the leaching of contaminants from the waste rock is unlikely, there is no impact expected on the quality of groundwater or surface water resources as a result of the proposed Project.

The Geochemistry specialist reports for each of the five open pit mining areas GeoDyn (2018a; 2018b; 2018c; 2018d; 2018e), states that all the waste rock samples evaluated are considered inert as the mineralogical makeup of the waste rock is environmentally stable and contain no readily leachable constituents. The laboratory leach tests and geochemical reaction modelling performed and reported by GeoDyn (2018a; 2018b; 2018c; 2018d; 2018e), indicated that the concentrations of constituents that may leach from the waste rock are all within accepted drinking water criteria. No contaminants of concern can therefore be identified for further assessment of potential impacts from the proposed Project on the aquatic pathway.

2.5 Health Significance of Air Contaminants

2.5.1 Criteria Pollutants

2.5.1.1 Introduction

A report by the UK Committee on the Medical Effects of Air Pollutants (COMEAP, 2006) concluded that evidence from epidemiological studies link daily cardiovascular deaths with the concentrations of particulates (measured as PM_{10} or $PM_{2.5}$), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), and carbon monoxide (CO) in air. There are also statistical significant associations between daily measurements of these pollutants and daily admissions to hospital for a variety of conditions relating to cardiovascular disease (COMEAP, 2006).

The four pollutants listed above are included in a group of air pollutants generally referred to as 'criteria pollutants'. Criteria pollutants is a term used internationally, to describe air pollutants that are regulated and used as indicators of air quality. The term criteria pollutants is used in the rest of this report in reference to the group of air pollutants including particulates ($PM_{2.5}$ & PM_{10}), SO_2, NO_x, and CO. The sections that follow describe the significance of each of the criteria pollutants in terms of its potential to affect human health.

2.5.1.2 Environmental Health Significance of Particulate Matter

Particulate matter was identified as the main atmospheric pollutant of concern for the proposed Project (Airshed, 2019). Over the past decade, evidence has accumulated indicating that airborne particulate matter (PM), including PM_{10} and $PM_{2.5}$, exert a range of adverse health effects. Statistical evidence suggests that the health effects of particulates occur independently of the presence of other pollutants, such as NO_2 and SO_2 (COMEAP, 2006; 2009; WHO, 2005). The identified health effects are diverse in scope, severity, duration, and clinical significance, but there is general agreement that the cardio-respiratory system is the major target of PM effects. A critical review by the UK Committee on the Medical Effects of Air Pollutants (COMEAP, 2006) indicated that long-term exposure to PM (for years or decades) was associated with elevated total, cardiovascular, and infant mortality, and also with respiratory symptoms and effects on lung growth and immune system function. Short-term studies showed consistent associations of exposure to daily concentrations of PM with mortality and morbidity on the same day or the subsequent days. Patients with asthma, chronic obstructive pulmonary disease (COPD), pneumonia, and other respiratory diseases; with cardio-vascular diseases and with diabetes were especially affected.

The US EPA (2004) concluded that available short-term exposure studies generally showed positive and statistically significant associations of $PM_{2.5}$ with excess total non-accidental and cardiopulmonary mortality. The US EPA also noted that a growing body of evidence showed acute cardiovascular disease morbidity effects of PM and co-pollutants and pointed out the possible roles of gaseous co-pollutants (e.g., CO) as potential confounders of the PM effect on cardiovascular disease.

Potential associations between ambient PM and lung cancer were regularly studied. A US EPA Criteria Document (USEPA, 2004) concluded that the evidence for ambient fine particle ($PM_{2.5}$) exposure relationships with increased lung cancer is much clearer and stronger than for PM_{10}. The COMEAP (2006) review presented considerable evidence indicating a lack of association, with only one study indicating that $PM_{2.5}$ concentrations were statistically significantly related to lung cancer mortality.

The US EPA (2004) concluded that mixed results were available regarding the potential relationship between PM_{10} exposures and increased risks of low birth weight or early postnatal mortality, with some studies reporting significant positive relationships, while others found little evidence. It was also pointed out that these results, overall, highlighted the need for more research to elucidate potential ambient PM effects on foetal development, foetal and postnatal mortality and also on postnatal morbidity.

2.5.1.3 Environmental Health Significance of SO_2

In terms of short-term exposure, the respiratory tract is the primary target organ system affected by exposure to sulphur dioxide. Acute responses occur within the first few minutes after commencement of inhalation. Effects include severe bronchoconstriction and symptoms such as wheezing or shortness of breath are observed (WHO, 2000). Effects are generally short-lived and lung function returns to normal after some minutes to hours, varying with the individual and the severity of the response.

In many instances, it is difficult to separate the adverse effects resulting from exposure to SO_2 from those resulting from concurrent exposure to mixtures including other known pollutants such as nitrogen dioxide and particulate matter. However, results from controlled exposure studies on SO_2 exposure support the epidemiological findings of exacerbation of asthma, increases in respiratory symptoms and decreases in lung function (WHO, 2000).

Environmental exposure to SO_2 is not only related to respiratory effects, but also to cardiovascular effects. In large European and North-American multi-city studies, variations in SO_2 concentrations have been linked to variations in non-accidental mortality (due to medical causes) (WHO, 2000).

2.5.1.4 Environmental Health Significance of NO_x

Combustion sources, such as vehicle engines, can emit a variety of nitrogen oxides to the atmosphere. These nitrogen oxides can form other secondary pollutants in the atmosphere, as a result of chemical reactions, such as hydrolysis, oxidation, or photochemical reactions. The Air Quality Impact Assessment report presented by Airshed (2019) for the proposed Project present results for oxides of nitrogen in the atmosphere in terms of NO_2. Health effects of NO_x from the proposed Project are therefore considered in terms of NO_2.

With regard to health, NO_2 is the most significant of the several oxides of nitrogen (NO_x) that may occur in the ambient atmosphere. Exposure to NO_2 has been shown to cause effects on lung metabolism, structure, function, inflammation and susceptibility to pulmonary infections, in experimental animals. It is however proving difficult to deduce, with any level of confidence, exactly what exposures would lead to these effects in humans and whether, at ambient concentrations, NO_2 is an inhalant toxicant in humans or not (WHO, 2005).

Controlled clinical studies on human exposure to NO_2 showed that, in general, concentrations of nitrogen dioxide in excess of 1 880 $\mu g.m^{-3}$ are necessary to induce changes in pulmonary function in healthy adults. Since these concentrations almost never occur in ambient air, examination of the effects of nitrogen dioxide has focused on people with pre-existing lung disease. Numerous studies on people with asthma, chronic obstructive pulmonary disease or chronic bronchitis have shown that exposure to low levels of NO_2 can cause effects on lung function. Asthmatics are the most responsive group to NO_2 studied to date, although controlled studies on the effects of short-term exposure on the symptoms and severity of asthma have not led to clear findings (WHO, 2005).

NO_2 apparently enhances the effects of exposure to other known irritants, such as SO_2 and particulates. However, this is difficult to study epidemiologically since NO_2 is a constituent of combustion-generated air pollution and is highly correlated with other primary and secondary combustion products. It is therefore often not clear to what extent the health effects observed in epidemiological studies are attributable to NO_2 itself or to other associated pollutants (WHO, 2005).

Several animal studies have indicated that Inhalation of NO_2 increases lung susceptibility to bacterial and perhaps viral infections. Studies on humans, however, provided inconclusive results in this regard (WHO, 2005)

2.5.1.5 Environmental Health Significance of CO.

Evidence from a large number of time-series studies reviewed by COMEAP (2006) show very clearly that all of the commonly measured pollutants (particles, SO_2, NO_2 and CO) are positively associated with increased mortality and hospital admissions for cardiovascular disease.

These associations are likely to be explained by air pollution making existing disease worse or by precipitating an acute event such as a heart attack in one who is already vulnerable to this possibility. It is, however, difficult to conclusively prove effects associated with individual gaseous pollutants as the various air pollutants tend to be correlated with one another as they have common sources (e.g. vehicle engine emissions).

However, statistically significant associations between ambient concentrations of CO and admissions to hospital for treatment of cardiac disease have been reported. Studies show that exposure to low concentrations of CO can exacerbate cardiac conditions in patients with impaired coronary arterial blood flow. Studies of the effect of CO exposure only on cardiopulmonary mortality do not show clear positive associations.

It was concluded that though a case could be made for acute exposure to ambient concentrations of carbon monoxide having an effect, there was little evidence to suggest that long-term exposure to ambient levels contributed to the development of cardiovascular disease (COMEAP, 2006).

2.5.2 Environmental Health Significance of Arsenic

Arsenic is widely distributed in the environment from natural sources and is naturally present at low levels in soil, water, and air. Arsenic is classified chemically as a metalloid, having both properties of a metal and a non-metal; however, it is frequently referred to as a metal. Elemental arsenic, also referred to as metallic arsenic, is rarely encountered in the environment (USEPA, 2010b). In compounds, arsenic typically exists in one of three oxidation states, -3, +3, and +5. Arsenic compounds can be categorised as inorganic, compounds without an arsenic-carbon bond, and organic, compounds with an arsenic-carbon bond.

In the environment, there are many processes (chemical and biological) that control the overall fate and impact of arsenic. Arsenic does not break down in the environment but can change from inorganic to organic forms through microbial interaction. Most arsenic compounds are soluble in water but do not evaporate. Arsenic can be released into the air when minerals containing arsenic are processed or smelted, or when materials containing arsenic are burned. Airborne particles that contain arsenic, can settle on the ground, surface water, and plants.

Arsenic in soil can exists in various oxidation states and chemical species, but is largely immobile and tends to remain in upper soil layers. However, reducing conditions can form soluble forms of arsenic that can leach from the soil (ATSDR, 2007).

Analysis of the toxic effects of arsenic is complicated by the fact that arsenic can exist in several different oxidation states and many different inorganic and organic compounds. According to the U.S. Agency for Toxic Substances and Disease Registry (ATSDR), most cases of human toxicity from arsenic have been associated with exposure to inorganic arsenic. Organic forms of arsenic are generally considered to be less toxic than inorganic forms (ATSDR, 2007).

Most cases of arsenic-induced toxicity in humans are due to exposure to common arsenic oxides and oxyacids, and there is an extensive database on the human health effects of these compounds. Although there may be some differences in the potency of different chemical forms, these differences are usually minor (ATSDR, 2007).

Non-cancer effects associated with inhalation exposure to airborne arsenic include respiratory irritation, nausea, skin effects, and neurological effects. There are limited quantitative data on non-cancer effects in humans exposed to inorganic arsenic by the inhalation route. Animal data similarly identify effects on the respiratory system as the primary non-cancer effect of inhaled inorganic arsenic compounds, although only a few studies are available.

Arsenic is a known human carcinogen by both the inhalation and oral exposure routes. By the inhalation route, the primary tumour types are respiratory system cancers, although a few reports have noted increased incidence of tumours at other sites, including the liver, skin, and digestive tract (ATSDR, 2007).

2.5.1 Environmental Health Significance of Diesel Particulate Matter

Emissions from diesel engines (referred to as diesel exhaust or DE) consist of a complex mixture of gaseous pollutants and particles. In estimating the potential health risks associated with human exposure to DE, researchers have focused mostly on the particulate matter components. Diesel particulate matter (DPM) consists mainly of:

- elemental carbon (EC) particles having relatively large surface areas,
- soluble organic carbon, including 5-ring or higher polycyclic aromatic hydrocarbons (PAHs) such as benzo(a)pyrene, and other 3- or 4-ring organic compounds distributed between gas and particle phases,
- metallic compounds , and

- small amounts of sulphate or sulphuric acid, nitrates, trace elements, and water.

DPM is made up almost entirely of fine particles (<1 to 3 µm) with a significant subset of ultrafine particles (below about 0.1 µm). The USEPA (USEPA, 2002) report that toxicological data indicate DPM to be the prime etiologic agent of non-cancer health effects when DE is sufficiently diluted to limit the concentrations of gaseous irritants (NO_2 and SO_2), CO, or other systemic toxicants. The experimental evidence concerning DPM's association with non-cancer effects along with the fact that DPM is easily and most frequently measured and reported in toxicological studies of diesel emissions, make DPM a reasonable choice as a measure of diesel emissions (USEPA, 2002).

The airborne DPM concentrations presented as part of the Air Quality Impact Assessment report (Airshed, 2019) are therefore taken to be representative of DE that will be emitted by vehicles associated with the proposed Project.

Acute effects of DE exposure include irritation of the nose and eyes, lung function changes, respiratory changes, headache, fatigue and nausea. Chronic exposures are associated with cough, sputum production and lung function decrements. Diesel exhaust has been classified as a "suspected occupational carcinogen" since 1988 (IARC, 1989) but has only recently been reclassified as carcinogenic to humans, based on evidence that exposure is associated with an increased risk for lung cancer and a positive association with an increased risk of bladder cancer (IARC, 2012).

Exposure studies in healthy humans have documented a number of profound inflammatory changes in the airways. These changes were detected before changes in pulmonary function could be detected. In many experimental systems, diesel exhaust particles were shown to increase the response to allergens. DPM has therefore been associated with a variety of adverse health outcomes involving potential immune mechanisms, including acute pulmonary inflammation, altered allergic sensitisation, and exacerbation of asthma and respiratory infections (USEPA, 2002).

3 DOSE RESPONSE ASSESSMENT

3.1 Principles of Dose-Response Assessment

The dose-response assessment (toxicological assessment) is the analysis of the relationship between the total amount of a chemical or substance absorbed by the exposed group and the changes developed in the group in reaction to the substance. Dose-response assessment is therefore the process of quantitatively evaluating the toxicity of a given chemical agent, as a function of the dose of the contaminant administered or received, and the incidence of adverse health effects in the exposed population. From this analysis, toxicity values are derived that describe the numerical relationships between the dose quantity and the severity or probability of the resultant health effect. Examples of toxicity values are reference concentrations, reference doses and slope factors.

Toxicity values can be used to quantitatively estimate the potential for adverse effects or the risk of cancer in an exposed population, based on the numerical value of the administered or received dose. The numerical value of the dose is determined as part of the *Exposure Assessment* (in this report presented in Section 4). The process of quantitative estimation of the potential for adverse effects is referred to as *Risk Quantification* (in this report presented in Section 5).

The contaminants of concern identified through the *Hazard Identification* process (see 2.4) for the atmospheric and aquatic exposure pathways are discussed in the sub-sections below and toxicity values relevant to each contaminant, which can be used to quantify the potential effects on the exposed populations, are presented.

3.2 Air Pathway Contaminants

3.2.1 Introduction

Exposure to air pollution has been associated with a variety of adverse health effects (see Section 2.5). The evidence of this association, reported in literature, focuses mainly on respiratory and cardiovascular effects attributed to short- and long-term exposure to criteria air pollutants, but it is important to acknowledge that the total impact of air pollution on the population is likely to be dominated by the less severe health effects such as sore throat, common cold, cough, wheeze and shortness of breath. The proportion of the exposed population affected by less severe health effects is much larger than that affected by more severe events such as admission to hospital and death (WHO, 2005). Nevertheless, effects including increased risk of mortality and reduced life expectancy are most often considered in risk analysis, owing usually to the better availability of routinely collected data on these health outcomes (WHO, 2005).

To quantify the impacts on the health of communities from air pollution, figures referred to as *risk factors* that relate an observed change in air concentrations of certain pollutants to hospitalisation or mortality rates, are used. Risk factors for long-term and short-term exposure to various air pollutants are obtained from studies reported in the international scientific literature. These studies use statistical methods to compare changes in reported hospitalisation or mortality rates with observed changes in air concentrations of specific pollutants, and consider large amounts of data collected in several cities all over the world. These risk factors are reported for specific modes of exposure (e.g. short-term or long-term exposure). These exposure modes, in turn, can be related to specific types of air quality information such as hourly maximum, 24 hour or annual average concentrations of pollutants for risk quantification.

As explained in the COMEAP report (2006), the risk factors derived from time-series studies generally refer to the effects of a 10 $\mu g.m^{-3}$ change in the mean pollutant concentrations. For example, a factor of 1.4% for $PM_{2.5}$ and cardiovascular mortality indicates that a 10 $\mu g.m^{-3}$ increase in the concentration of $PM_{2.5}$ is associated with a 1.4% increase in the relevant health outcome, in this case cardiovascular mortality. Thus, if 70 people die each day from all cardiovascular causes, a 10 $\mu g.m^{-3}$ increase in $PM_{2.5}$ will increase the daily deaths due to cardiovascular causes by 1.4%, or about one (1), from 70 to 71 deaths.

The discussions presented in the sections below consider both short- and long-term exposure to particulate matter. Only mortality risk factors are listed for the different exposure modes considered, as the data available for the population of the Gauteng Province, and more specifically the City of Johannesburg Metropolitan Municipality where the proposed Project will be located, only report statistics for mortality.

3.2.2 Particulate matter

3.2.2.1 General background

It is generally accepted that there is no threshold in particle concentrations below which health would not be jeopardised. Evidence discussed in a report on the long term effects of exposure to air pollution by the UK Department of Health Committee on the Medical Effects of Air Pollutants (COMEAP, 2009), indicate a linear relationship between exposure to PM and various health indictors. The data further present no evidence that the line representing the relationship between PM concentration and effect decreases in slope as it approaches low concentrations (COMEAP, 2009). It is therefore accepted that there are health effects for concentration levels from 0 $\mu g.m^{-3}$. This implies that even though concentrations of airborne PM may be within ambient air quality guidelines, the occurrence of health effects cannot be excluded.

The studies of correlations between health outcomes and PM concentrations report risk factors for both long- and short-term exposures. Across all studies the results indicate a significant difference in risk factors for short-term exposure as opposed to the risk associated with long-term exposure to the same change in PM concentration. This observed difference is reflected in the risk factors selected for the evaluation of the proposed Project. All risk factors selected are, where possible, derived from single pollutant models that focus on particulates (i.e. excluding cumulative effects of other pollutants).

The COMEAP (2009) report discusses the question of which index of the air pollution mixture should be considered as the principal metric to be used in quantifying the effects of long-term exposure to air pollution. The report (COMEAP, 2009) suggest, that based on reviews of the studies available at that time on PM exposure and mortality, it is concluded that the association of mortality with the concentrations of fine PM ($PM_{2.5}$) were clearer and more significant than the association with particle sizes greater than $PM_{2.5}$. PM_{10}, on the other hand, appears to have a weaker effect on the relative risk of death from all-causes than $PM_{2.5}$. The evidence as a whole points to $PM_{2.5}$ as the most satisfactory index of particulate air pollution for quantitative assessments of long-term exposure.

The assessment of the health effects, specifically from long-term exposure to PM associated with the proposed Project, will therefore focus on the concentrations of $PM_{2.5}$ reported in the Air Quality Impact Assessment report (Airshed, 2019). Effects relating to short term exposure are evaluated with risk factors for concentrations of PM_{10} as the existing body of epidemiological evidence is insufficient to reach a conclusion on the short term exposure–response relationship to fine particles ($PM_{2.5}$).

3.2.2.2 Short-term exposure to particulates

In the global update of the WHO Air Quality Guidelines (WHO, 2005), results of short term mortality effects of PM_{10} for studies of 29 cities in Europe and 20 cities in the US are presented. These studies reported risk factors of 0.62% and 0.46%, respectively, per 10 $\mu g.m^{-3}$ increase in 24 hour average PM_{10} concentrations. An analysis of 29 cities from outside Europe and the US reported an effect of 0.5%, which correlates well with the 0.49% reported for Asian cities. Based on these results the WHO concluded that the risks of mortality associated with PM_{10} were likely to be similar in cities in developed and underdeveloped countries at around 0.5% per 10 $\mu g.m^{-3}$ (WHO, 2005).

The risk factor for cardiovascular mortality (0.9% per 10 $\mu g.m^{-3}$) was derived by COMEAP, based on statistical analysis of 40 epidemiological studies (COMEAP, 2006).

Table 3.1 Short-term PM_{10} risk factors for mortality.

Health Effect	Percentage increase in risk per 10 $\mu g.m^{-3}$ PM10 increase	Reference
Total (non-accidental) mortality	0.5	WHO 2005
Cardiovascular mortality	0.9	COMEAP 2006

3.2.2.3 Long-term exposure to particulates

COMEAP (2009) conducted a review of the long-term significance of air pollutants and concluded that in terms of particulate matter, the best studied health effects and those recommended for quantification are; all-cause, cardio-pulmonary and lung cancer mortality.

The associations between long-term $PM_{2.5}$ exposure and associated health effects reported in long-term exposure studies (Dockery *et al.*, 1993; Jerrett *et al.*, 2005; Pope *et al.*, 1995), were reviewed to identify appropriate risk factors linking long-term exposure to air pollution and mortality. COMEAP concluded from the review that the preferred risk factors are derived from the cohort study by the American Cancer Society (ACS) (Pope *et al.*, 2002), as it is the most extensive and its data and methods have been the most intensively reviewed by other research groups. Several factors for different health endpoints were reported in the ACS study and COMEAP (2009) indicates that risk factors based on PM, represented as $PM_{2.5}$, for all-cause mortality, supplemented by factors for cardiopulmonary and for lung cancer, are the most appropriate to choose for quantification of health effects from exposure to PM.

A summary of the risk factors for mortality associated with long-term $PM_{2.5}$ exposure, which will be used for assessment of annual average particulate concentrations associated with the proposed Project, are presented in Table 3.2Table 3.2.

Table 3.2 Long-term $PM_{2.5}$ risk factors for mortality (COMEAP, 2009; Pope *et al.*, 2002).

Health Effect	Percentage increase in risk per 10 $\mu g.m^{-3}$ $PM_{2.5}$ increase
Total (non-accidental) mortality	6
Cardiopulmonary mortality	9
Lung cancer mortality	14

3.2.3 Sulphur dioxide (SO_2)

3.2.3.1 Short-term exposure to SO_2

Even at low daily levels, effects of SO_2 concentrations on mortality (total, cardiovascular and respiratory) and on hospital emergency admissions for various respiratory endpoints have been demonstrated in studies on large populations (WHO, 2005).

The WHO (2005) present results of several multi city and single city studies that analysed associations between SO_2 concentrations and total mortality. A series of cause-specific mortality analyses of results for 12 European cities reported that estimated risks were larger for cardiovascular and respiratory categories than those for total non-accidental mortality. It reported a risk estimate of 2.6% for western European cities and 0.8% for central and eastern European cities, for a 50 $\mu g.m^{-3}$ increase in SO_2 concentration. The median levels of SO_2 in these 12 cities ranged from 13 $\mu g.m^{-3}$ to 74 $\mu g.m^{-3}$.

Spanish and American multi-city studies presented similar results. The Spanish study evaluated 24-hour average and daily 1-hour maximum SO_2 levels in 13 cities, at median concentrations ranging from 8 $\mu g.m^{-3}$ to 45 $\mu g.m^{-3}$. The Spanish study concluded that 1 hour maximum concentrations better relate to mortality and a risk factor of 2.5% per 50 $\mu g.m^{-3}$ increase in SO_2 concentration. The American (90 city) study and a smaller (8 city) Canadian study evaluated effects of SO_2 and PM on mortality. The studies both showed that in single pollutant models using a lag of one day (where health effects reported the next day are correlated with pollutant measurements of the previous day) SO_2 was significantly associated with total mortality. The results further showed that by adding PM risk factors for mortality are reduced. The American study reported a mortality risk factor of 1.1% for a 50 $\mu g.m^{-3}$ increase in SO_2 concentration, at a lag of one day.

Results of the European and Spanish studies correlate well and both are based on single pollutant models. Based on the wide range in the concentrations of SO_2 in the cities and the positive associations found in both studies with short term peak concentrations of SO_2 a risk factor of 2.6%

reported for the Spanish study (with 95% confidence interval of 0.3 to 4.9) is used for evaluation of short-term SO_2 exposure associated with the proposed Project.

The quantitative meta-analysis reported by COMEAP (2006) yielded significant associations between 24-hour mean SO_2 levels and various outcome measures related to cardiovascular effects. The risk factor for cardiovascular mortality and total mortality associated with short term exposure to SO_2 are presented in Table 3.3~~Table 3.3~~.

Table 3.3 Short-term risk factors for SO_2 (based on a 24-hour mean concentration).

Health Effect	Percentage increase in risk per 10 µg.m^{-3} SO2 increase	Reference
Total (non-accidental) mortality	2.6	WHO 2005
Cardiovascular mortality	0.8	COMEAP 2006

3.2.3.2 Long-term exposure to SO_2

The American Cancer Society study by Pope *et al.* (2002) showed highly positive significant relationships reported between an incremental change in SO_2 of 6.7 ppb and total non-accidental and cardiopulmonary mortality over the long-term. The estimates per 10 µg.m^{-3} increment in annual mean SO_2 are presented in Table 3.4~~Table 3.4~~.

Table 3.4 Long-term risk factors for SO_2 (based on annual mean concentration) (Pope *et al.*, 2002).

Health Effect	Percentage increase in risk per 10 µg.m^{-3} SO_2 increase
Total (non-accidental) mortality	2.9
Cardiopulmonary mortality	1.6

3.2.4 Nitrogen oxides (NO_2)

3.2.4.1 Short-term exposure to NO_2

A large number of time series studies have used maximum hourly concentrations or daily mean concentrations of NO_2 to evaluate a wide range of adverse health effects. From these studies it was concluded that daily concentrations of NO_2 are significantly associated with increased overall mortality, cardiovascular mortality and respiratory mortality.

A meta-analysis of time series investigations on daily mortality for NO_2 from single-pollutant models showed that over a 24-hour range of mean NO_2 exposure (20.4–103.3 µg.m^{-3}), the overall effect estimate from the single-pollutant model for all-cause mortality was 2.8% per 24 ppb NO_2 (24-hour).

The WHO (2005) Air Quality Guidelines, the WHO report results of a multi-city study of short-term health effects of air pollution in European cities that show a statistically significant effect of NO_2 on daily mortality. A 1.3% increase in daily deaths per 50 µg NO_2.m^{-3} (1-hour maximum) is reported.

A later study for nine European cities reported an increase of 2% in natural all-cause mortality per 50 µg $NO_2.m^{-3}$ increase in the daily maximum 1-hour concentration, with a near-linear dose–response function in the range between 100 and 200 $µg.m^{-3}$ (COMEAP, 2006).

A summary of the risk factors that are applied to the assessment of the proposed Project is presented in Table 3.5~~Table 3.5~~.

Table 3.5: Short-term risk factors for NO_2 (based on highest hourly and daily mean concentrations).

Health Effect	Per cent increased risk per 10 $µg.m^{-3}$ NO_2 increase	Reference
Total non-accidental mortality	0.4 (based on highest hourly concentration)	(WHO, 2005)
Cardiovascular mortality	1.0 (24-hours mean concentration)	COMEAP 2006

3.2.4.2 Long-term exposure to NO_2

The WHO (2005) report that long-term concentrations of NO_2 were associated with an increased risk of all-cause mortality. None of the studies however presented evidence that NO_2, per se, is responsible for the observed associations, but rather in association with particulate pollution from traffic sources,

Results from a statistical re-evaluation of a large database to study relative risks of mortality from all medical causes, and from cardiopulmonary diseases, associated with long-term exposure to NO_2, report percentages of increased risks (WHO, 2005). The risk factors from this re-evaluation study will be used to assess long-term exposure to NO_2 associated with the proposed Project (see Table 3.6~~Table 3.6~~).

Table 3.6: Long-term risk factors for NO_2 (based on annual mean concentration).

Health Effect	Per cent increased risk per 10 $µg.m^{-3}$ annual NO_2 increase
Total (non-accidental) mortality	8.2
Cardiopulmonary mortality	9.3

3.2.5 Carbon Monoxide (CO)

The diverse effects of CO are dependent upon concentration and duration of exposure. The USEPA (2010a) has done the most comprehensive review currently available of toxicological and epidemiological literature on the effects of CO under controlled as well as environmental conditions of exposure. Overall the evidence presented indicates there is not likely to be a causal relationship between relevant long-term exposures to CO and mortality. Short-term exposures to CO in the other hand are indicated to have a causal relationship to mortality, based on epidemiologic evidence.

The most reliable correlation between short-term CO exposure and mortality is shown for cardiovascular mortality. Results from a meta-analysis of various studies indicate the percentage increase in cardiovascular mortality, associated with 1 $mg.m^{-3}$ (1 000 $\mu g.m^{-3}$) increase in CO concentration, is 1.1% (COMEAP, 2006). This value is selected for assessment of hourly maximum modelled concentrations of CO, associated with the proposed Project.

3.3 Toxicity of Airborne Arsenic

As indicated in Section 2.5.2, most cases of human toxicity from arsenic have been associated with exposure to inorganic forms. This is reaffirmed by the ATSDR (2007), who indicated that most information on human inhalation exposure to arsenic derives from occupational settings such as smelters and chemical plants, where the predominant form of airborne arsenic is arsenic trioxide dust (As_2O_3).

A limitation of information gathered from an occupational environment is that it is complicated by the fact that significant oral and dermal exposures are also likely to occur under these conditions and co exposure to other metals and chemicals is also common. Information of this type is therefore subject to some uncertainties. It has to be noted that in the occupation environment, exposure is generally from concentrations of the contaminants in air that are much higher than the concentrations that can be expected in the environment.

Review of the occupational exposure information indicated that, in adults, **acute** (short term) inhalation exposure may result in severe irritation of the mucous membranes of the upper and lower respiratory tract with symptoms of cough, dyspnoea[1], and chest pain. These may be followed by gastrointestinal symptoms including vomiting and diarrhoea (OEHHA, 2008). It is uncertain whether the gastrointestinal symptoms are directly related to inhalation exposure or to incidental ingestion of arsenic deposited in the throat through breathing.

Signs of acute poisoning in adults include: dermatitis, nasal mucosal irritation, laryngitis, mild bronchitis, and conjunctivitis (OEHHA, 2008). Although there are many studies of humans exposed to arsenic in air, no cases of lethality from short-term exposure were located. This suggests that death is not likely to be of concern following acute exposure, even at the very high exposure levels (1–100 mg $As.m^{-3}$) found previously in the workplace (ATSDR, 2007). It was further indicated that ingestion of 2 grams of arsenic trioxide dust was fatal to an adult male (OEHHA, 2008).

In studies of the effect of arsenic exposure on laboratory animals, the most notable effect is foetal malformation and foetal mortality. Arsenic is known as a developmental toxicant, and tests showed a significant increase in foetal mortality following exposure of pregnant rats to aerosolised arsenic trioxide. Another study showed a decrease in foetal weight following acute exposure of mice. This was identified as the critical effect and was the basis for the derivation of an acute REL for inorganic arsenic of 0.2 µg $As.m^{-3}$.

1 Difficult or labored breathing; shortness of breath.

Chronic (long term) exposure to arsenic dealt with I literature mainly refer to effects associated with oral exposure through contaminated drinking water. Some information on inhalation exposure is available from the occupational environment, indicating that Smelter workers, exposed to concentrations of arsenic up to 7 mg $As.m^{-3}$, showed an increased incidence in nasal septal perforation, bronchitis, and decreased lung function (OEHHA, 2008).

The adverse effects of inorganic arsenic exposure reported in children include skin lesions, neurodevelopmental effects (IQ and related effects), lung disease expressed in later years, and reproductive effects. The adverse effects of inorganic arsenic on the developing intellectual function of exposed children have been reported in several studies and, as a group, indicate that arsenic exposure, like lead exposure, presents a risk to children. The neurodevelopmental endpoint has therefore been selected by OEHHA (2008) as the critical effect for deriving 8 hour and chronic RELs for inorganic arsenic.

The REL derived for both eight hour and chronic exposure to airborne arsenic is 0.015 µg $As.m^{-3}$, based on Decreased intellectual function in 10 year old children. To date no inhalation MRL or RfC have been derived for inorganic arsenic (ATSDR, 2007; IRIS, 2007). The REL of is 0.015 µg $As.m^{-3}$ will be used for assessment of potential inhalation exposure to arsenic associated with the proposed Project.

Inorganic arsenic is known to be a human carcinogen. The US EPA has determined that inorganic arsenic is a human carcinogen based on sufficient evidence from human data that increased lung cancer mortality was observed in multiple human populations exposed primarily through inhalation. The US EPA's quantitative estimates of carcinogenic risk from inhalation exposures include a unit risk for cancer of 0.0043 $µg.m^{-3}$ (IRIS, 2007).

3.4 Toxicity of Diesel Particulate Matter

As discussed earlier diesel engine emissions (DE) consists of a complex mixture of gaseous pollutants and particles. Because of its composition the particulate component of DE (referred to as diesel particulate matter (DPM)) is identified as a surrogate for measurement and toxicological studies of DE. Research into the health effects of diesel exhaust emissions has therefore focussed on DPM and both non-cancer and cancer effects are studied.

The Health Assessment Document for Diesel Engine Exhaust published by the USEPA (2002) report the findings of several studies on DE that investigated various non-cancer effects including effects of odour, pulmonary and respiratory effects, immunological effects, allergenic effects and injury to airway cells.

The overall conclusion of studies on short term exposure to DPM is that reversible changes in pulmonary function in humans can occur, although it is not possible to relate these changes to specific exposure levels. Exposure of cell cultures to DE showed key changes and markers of allergic inflammatory disorders of the airways such as asthma and nasal allergies. Thus, short term exposure to DPM are indicated as having the potential to elicit inflammatory and immunological responses and responses typical of asthma, and that DPM may be a likely factor in the increasing incidence of allergic hypersensitivity.

Very little epidemiologic data on effects of chronic exposure to DE on pulmonary function is available. Studies on the long-term work-related exposure to DE indicated a relationship was generally observed to respiratory symptoms (such as cough and phlegm), but there was no consistent effect on pulmonary function.

The Assessment Document concluded that chronic respiratory effects are the principal non-cancer hazard to humans from environmental exposure to DE. Other effects (e.g., neurological, liver-related) observed in animal studies were found only at higher exposures than those producing the respiratory effects. As human and animal data for the immunological effects of DE are currently considered inadequate, respiratory effects are considered the “critical effect” for dose-response evaluation.

Exposure to non-carcinogenic toxicants through inhalation is normally assessed against a reference concentration (RfC) in air, if other routes of exposure are not present. An RfC is defined as (USEPA, 2002) “an estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime”.

A RfC for DPM was derived from a No Observed Adverse Effect Level (NOAEL) obtained from animal studies on the chronic exposure of rats to DPM (0.144 $mg.m^{-3}$). An uncertainty factor of 30 was applied to derive an RfC of 5 $\mu g.m^{-3}$ (USEPA, 2002).

DPM has only recently been classified as carcinogen to humans (IARC, 2012), and no guidance on the assessment of the risk associated with environmental exposure to diesel exhaust emissions have been published yet. The IARC classification cites two recent articles that considered occupational exposure of underground miners to diesel engine emissions (Attfield *et al.*, 2012; Silverman *et al.*, 2011), which concluded that study findings provide evidence that exposure to diesel exhaust increases risk of mortality from lung cancer and have important public health implications. Based on these studies, and evaluation of other available evidence, it was concluded that there was sufficient evidence in humans for the carcinogenicity of diesel exhaust and is classified as a Group 1 carcinogen.

In their 12th edition of the report on carcinogens, the US Department of Health addresses diesel exhaust particulates indicating the mechanisms of carcinogenesis relate to known mutagens and carcinogens contained in both in the vapour phase and associated with respirable particles (NTP, 2011). Diesel exhaust particles are considered likely to account for the human lung cancer findings, because they are almost all small enough to penetrate to the alveolar region in human lungs and mutagenic and carcinogenic chemicals are present. The precise mechanism of carcinogenicity is, however, as yet uncertain and although exposure to diesel exhaust particulates were shown to cause lung cancer in rats, the relevance of this finding for predicting carcinogenicity in humans has been questioned (NTP, 2011). The report further indicates that studies in humans are largely on occupationally exposed populations with higher risk estimated being found for individuals with higher cumulative or longer duration of exposure (NTP, 2011).

The Health Assessment Document for Diesel Engine Exhaust published by the USEPA (2002) note that uncertainty in the characterization of the potential cancer hazard of DE at low levels of environmental exposure is the incomplete understanding of its mode of action. Thus, although a cancer hazard is presumed possible at environmental levels of exposure, no toxicological or epidemiological evidence is currently available to confirm the levels at which health impacts may be observed. The IARC also states that although currently there is no evidence indicating a risk from environmental levels of diesel emissions, experience with other carcinogens, notably radon, has showed that initial studies showing a risk in heavily exposed occupational groups were followed by positive findings for the general population. IARC therefore make the general recommendation that actions to reduce exposures to DE should encompass workers and the general population

The only reported estimates of carcinogenicity for DPM comes from the California Environmental Protection Agency's Office of Environmental Health Hazard Assessment (OEHHA). Together with the California Air Resources Board (CARB) the OEHHA included diesel particulate matter in its consolidated list of Approved Risk Assessment Health Values (CARB, 2016), identifying it as a Toxic Air Contaminant and assigning it an inhalation unit risk of 3.0E-04 $\mu g.m^{-3}$. However, the basis on which the unit risk was derived is not clear and it is uncertain whether the value is based on the fine particulate nature of DPM or one of the components. As there is no reliable estimates of carcinogenicity currently available that can be used to relate environmental exposure to DPM to a risk of lung cancer in humans, assessment of DPM exposure associated with the proposed Project will only consider non-cancer effects.

4 EXPOSURE ASSESSMENT

4.1 INTRODUCTION

Exposure assessment provides an estimate of the levels and duration of exposure by considering the environmental distribution of hazardous substances, the environmental pathways involved, potentially exposed receptors and the routes of direct and indirect exposure. The assessment of exposure for the proposed Project relies on information presented as part of the Air Quality (Airshed, 2019) and Hydrogeological (NOA, 2019) specialist reports, as well as the Geochemistry Specialist study GeoDyn (2018a; 2018b; 2018c; 2018d; 2018e). The sections following present selected results from these specialist study reports, for ease of reference.

4.2 ATMOSPHERIC PATHWAY

4.2.1 Contaminant Dispersion in the Environment

Several criteria pollutants and other airborne contaminants were identified as contaminants of potential concern in the *Hazard Assessment* step represented in Section 2. Based on the information presented in Section 2.4.1 the contaminants that will be evaluated for the atmospheric pathway are:

- Fine or respirable particulates ($PM_{2.5}$)
- Inhalable particulates (PM_{10})
- Arsenic as component of particulates
- Sulphur dioxide (SO_2)
- Nitrogen dioxide (NO_2)
- Carbon monoxide (CO)
- Diesel particulate matter (DPM)

The Air Quality Impact Assessment report (Airshed, 2019) includes estimated airborne concentrations of all the criteria pollutants and DPM. The airborne pollutant concentrations were estimated using a numerical dispersion model. The development of the dispersion model is described in the Air Quality Impact Assessment report (Airshed, 2019).

As examples of the results obtained from the dispersion model, a graphical representation of the modelled daily maximum $PM_{2.5}$ and PM_{10} concentrations (including contributions from all sources), is presented for the open mining pits (see Figure 4.1~~Figure 4.1~~) and the ventilation shafts from the underground mining operations (see Figure 4.2). The modelled results presented by (Airshed, 2019) for each of the pollutants are accepted to represent a reasonable maximum of ambient concentrations for the airborne contaminants associated with the activities at the proposed Project.

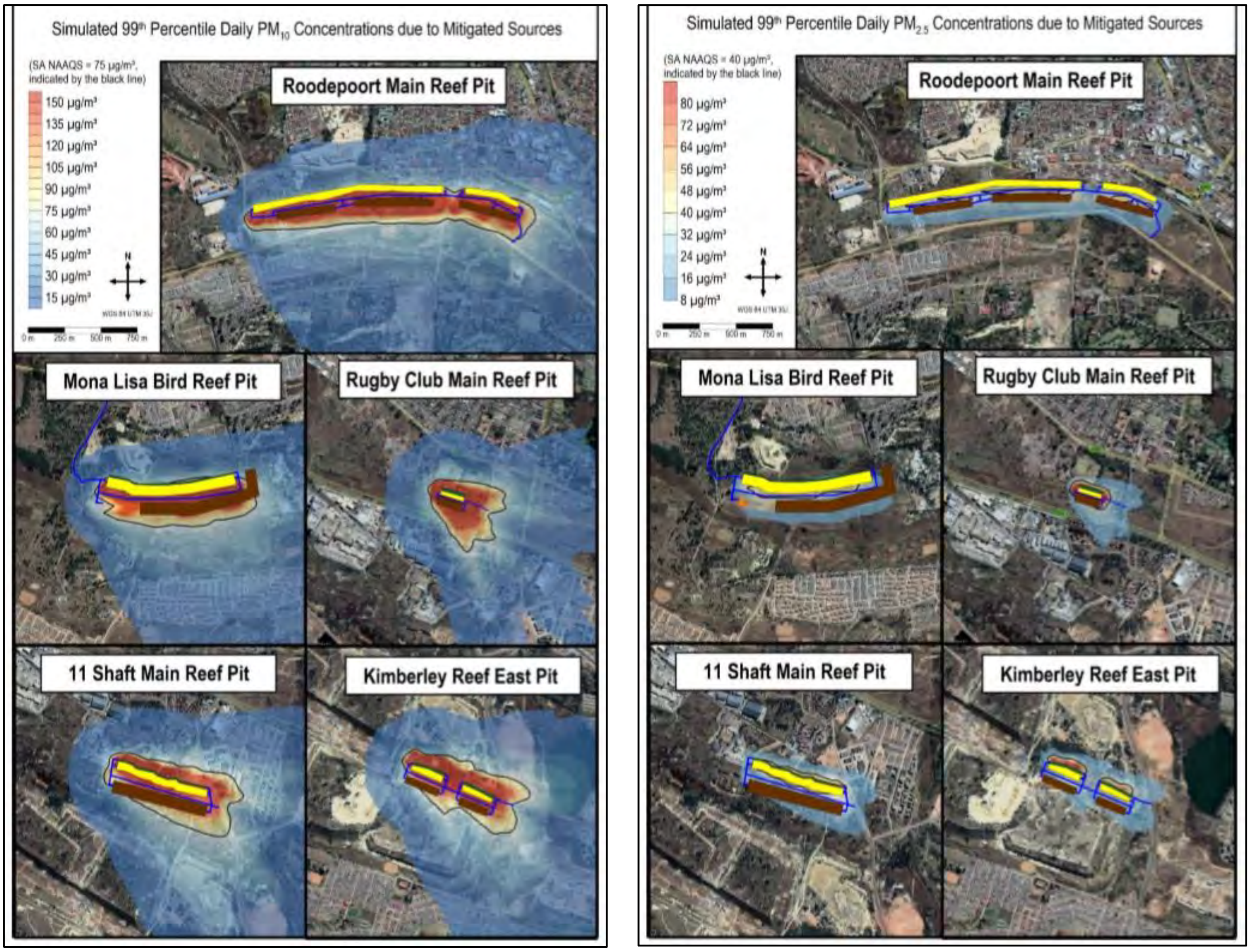

Figure 4.1 Example of particulate dispersion modelling results for the open mining pits (Airshed, 2019).

The modelled concentrations are shown as shaded zones with similar concentrations presented by a single colour (concentration isopleths) overlaid on a map of the Project area. The graphical edges of these concentration zones should not be interpreted as concentration boundaries, but rather as a continuum with some overlap between the indicated concentration values. Also, the outside boundary of the concentration isopleths is not a cut-off beyond which there are no more airborne contaminants, but is a representation of the extent of the airborne pollutants at the lowest concentration value on the scale. Airborne pollutant concentrations continue beyond this boundary, but are all lower than the lowest concentration value on the scale.

4.2.2 Receptors

There are residential communities located nearby, in some cases directly adjacent to, the proposed open pit and underground mining areas. The Airshed (2019) report included a map indicating potential receptor communities for each of the open pit mining areas.

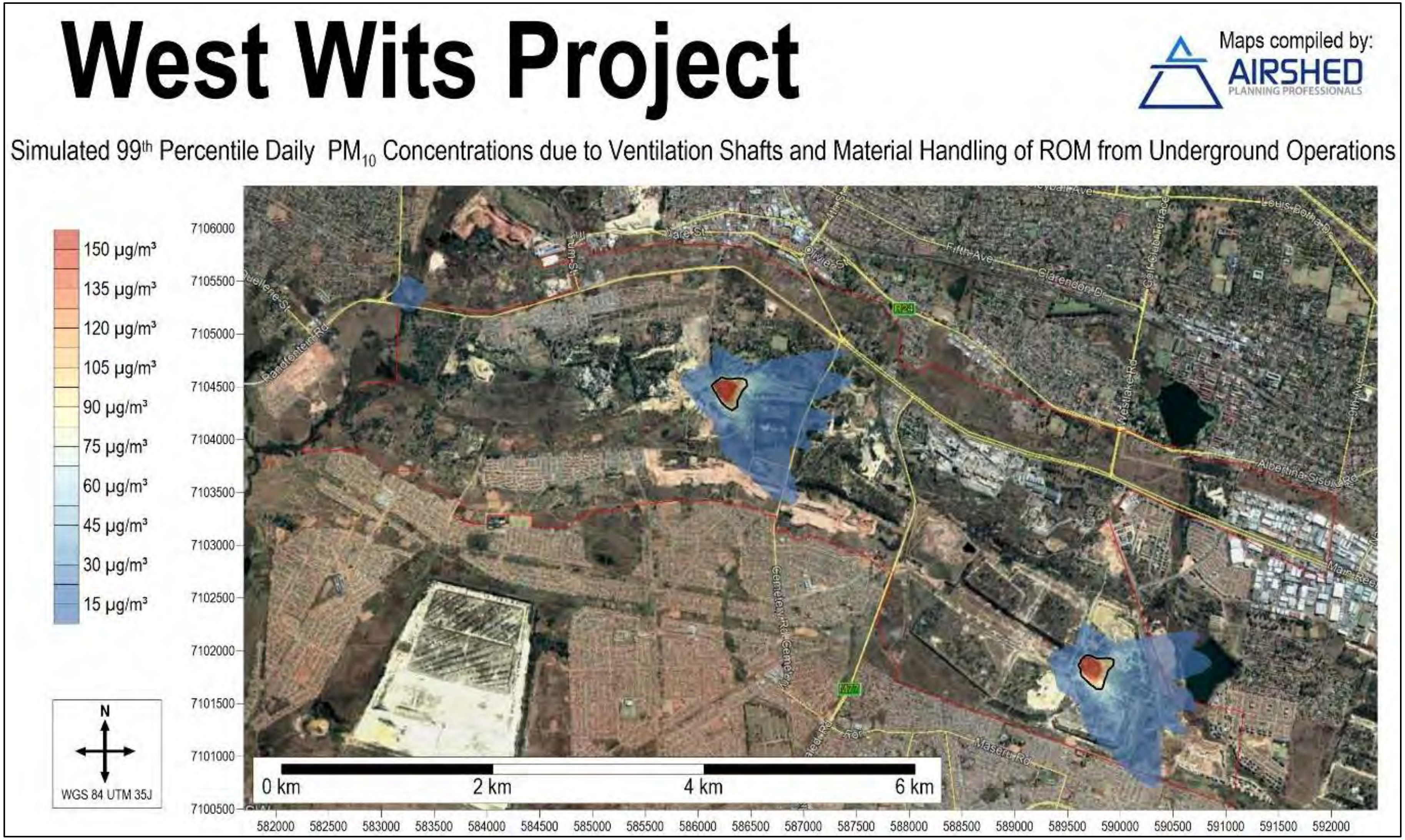

Figure 4.2 **Example of particulate dispersion modelling results for the ventilations hafts from the underground mining operations (Airshed, 2019)**

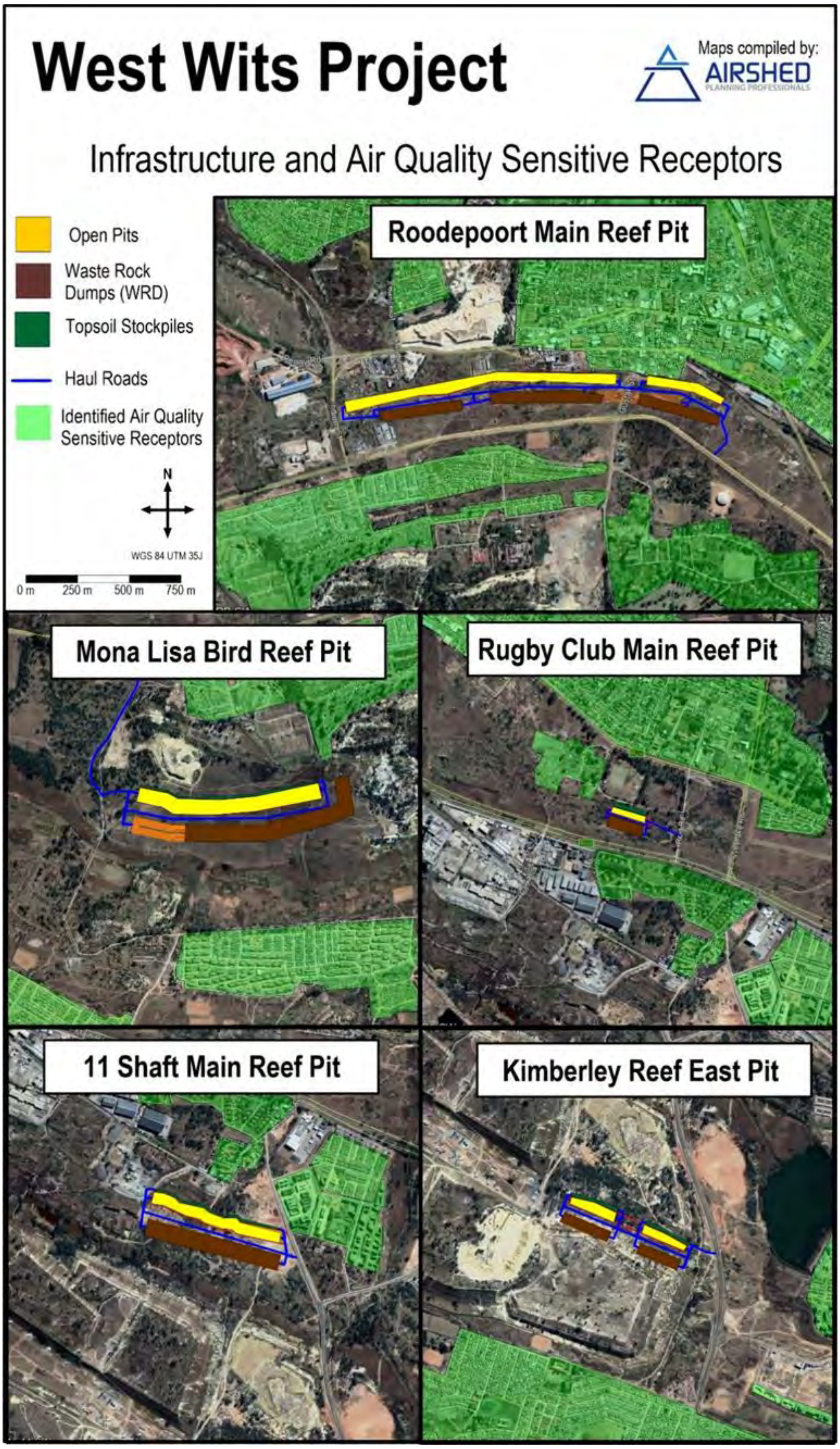

Figure 4.3 Locations of potential receptors identified by Airshed (2019).

The affected residential communities form part of the larger Roodepoort, Meadowlands and Bram Fisherville residential suburbs. There are also smaller residential areas including Witpooortjie, Goudrand, Matholesville, Florida Lake, Fleurhof and Cresswell Park that are potentially affected by the different operational areas of the Project.

The dispersion pattern of airborne contaminants, presented in Figure 4.1~~Figure 4.1~~, indicate that the dispersion is expected to occur in a southern, eastern and south-eastern direction from all of the source areas.

Airshed (2019) identified the residential areas directly adjacent to the operational areas of the proposed Project as potential receptors (see Figure 4.3~~Figure 4.2~~). It is assumed that the receptor locations selected by Airshed represent the highest exposed individuals and is a true representation of the exposure likely in each of the most exposed areas. It is thus assumed that all selected receptors conform to the definition of a potential receptor, as presented in Section 1.3.1.

4.2.3 Results

Airshed (2019) provided the modelled particulate and gaseous pollutant concentrations for different averaging times (i.e. hourly, daily or yearly average concentrations). The modelled pollutant concentrations that will be used in the HHRIA are selected in accordance with the averaging times of the dose-response data presented in Section 3.

The values, as reported by Airshed (2019) for each of the open pit mining operations, are summarised in Table 4.1~~Table 4.1~~. It is assumed that the reported concentration values listed in Table 4.1~~Table 4.1~~ include contributions, as relevant to the particular operational area, from all the sources of airborne particulates (mining pit, topsoil stockpiles, waste rock and roads) and gaseous pollutants (vehicles) discussed in Section 2.3.2. Airshed (2019) derived particulate concentrations (PM_{10}) with and without dust emission controls. Controls, mainly the wetting of roads and materials before handling, is recommended as part of the Air Quality Impact Assessment. Both mitigated and unmitigated PM concentrations are listed in Table 4.1~~Table 4.1~~.

The concentrations of arsenic (As) is estimated in the airborne particulates, based on the elemental composition of the waste rock reported in Table 2.1~~Table 2.1~~.

4.3 Aquatic Pathway

The Geohydrology Specialist Investigation report (NOA, 2019) stated as one of its objectives, the evaluation of the extent of possible contamination originating from the proposed open pit mining areas and associated infrastructure. In order to do this, information on measured water levels in the area as well as the findings from the geochemistry specialist assessment, were integrated into a numerical simulations of contaminant dispersion into groundwater from each of the five open pit mining areas. Although the underground mine workings are included in evaluation of dewatering impacts from the mining activities, the potential for contaminant dispersion into groundwater from the underground operations is not addressed in the Geohydrology Specialist Investigation report.

Table 4.1: Simulated ground level concentrations of contaminants of concern at affected potential receptors identified for the proposed Project.

Receptor Location	Daily (24-hr) Maximum			Hourly (1-hr) Maximums		Annual Average		
	PM_{10} (unmitigated)	PM_{10} (mitigated)	SO_2	NO_2	CO	$PM_{2.5}$ (mitigated)	SO_2	NO_2
	$\mu g.m^{-3}$							
Roodepoort	99	51	0.1	37	19	5	0.03	7.5
Mona Lisa	54	29	0.1	21	8	3	0.01	3.2
Rugby Club	115	91	0.2	67	36	10	0.05	14.4
11 Shaft	260	150	0.4	110	47	20	0.07	18.7
Kimberley East	40	23	0.1	17	4	1	0.01	1.6

Table 4.2: Estimated annual average ground level concentrations of DPM and particle associated arsenic at affected potential receptors identified for the proposed project (see Section 2.4.1 for discussion on derivation of arsenic concentrations).

Receptor Location	DPM Concentration	Arsenic Concentration
	$\mu g.m^{-3}$	
Roodepoort	0.6	1.50E-04
Mona Lisa	0.2	2.30E-04
Rugby Club	1.1	6.05E-04
11 Shaft	1.4	1.35E-03
Kimberley East	0.1	3.36E-05

Figure 4.4~~Figure 4.3~~ is an example of the simulated groundwater contaminant plume predicted for the Roodepoort open pit mine. According to the NOA (2019) report, numerical simulations were used to evaluate both the operational and post operational phases. The results for the operational phase demonstrated that during the mining operations there will be a hydraulic gradient from the waste rock dump towards the open pit, effectively capturing any contaminants migrating from the waste rock. Following cessation of the mining activities, the waste rock will be backfilled into the open pit during rehabilitation, thereby effectively removing it as source of contamination.

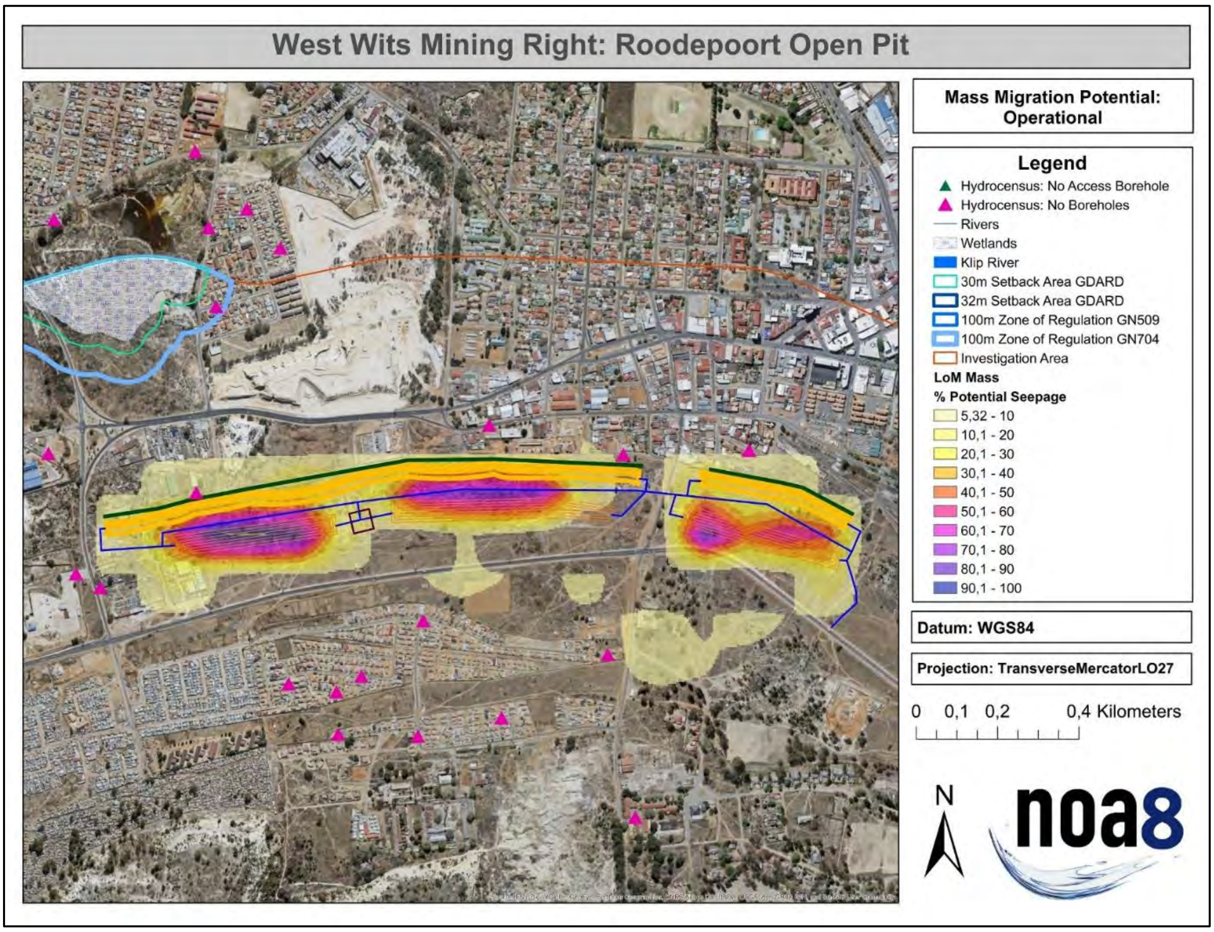

Figure 4.4 Simulated potential contaminant migration plume from waste rock at the Rodepoort open pit mining area

Although results of the post operational numerical simulation were not included, the NOA (2019) report indicates that by the end of the first year, following rehabilitation, the contaminant dispersion into groundwater from the waste rock backfilled into the pit present less than a 20% chance of increased contaminants entering groundwater beyond the limits of the rehabilitated waste rock dump footprint areas and the backfilled open pits. After 10 years post mining, the simulation reportedly indicate that the possibility for leachate from exiting the boundaries of the historical dump footprint and open pit facility is decreased to 10%, while the possible dispersion of any contaminants that may migrate from the source area is increased due to dilution and migration (NOA, 2019). The possibility of decant from the backfilled open pits entering the environment post closure, was also assessed. Since no influence was simulated during the operational phases, no decanting is expected (NOA, 2019).

The Geohydrology Specialist Investigation report (NOA, 2019) concludes that development of acid rock drainage conditions as well as the leaching of contaminants from the waste rock is unlikely and that noknown groundwater users will be affected by the possible zone of influence associated with either the open pit mining or underground mining operations.

Based on the findings of the Geochemistry GeoDyn (2018a; 2018b; 2018c; 2018d; 2018e) and Hydrogeology (NOA, 2019) specialist reports, the waste rock, and by extension the aquatic pathway, can be excluded from further assessment as both the hazard and the pathway of its propagation into the environment is absent. Risks associated with the proposed Project can therefore not be demonstrated or assessed for the aquatic pathway.

5 RISK CHARACTERISATION

5.1 INTRODUCTION

Risk characterisation involves integrating outcomes from the hazard identification, dose-response- and exposure assessments, to determine whether specific exposures to an individual or a community might lead to adverse health effects. The purpose of the risk characterisation presented here is to estimate the probabilities of occurrences of health effects on the communities potentially affected by the proposed Project.

This section describes the methodology used in the quantification of risks associated with exposure to criteria pollutants and hazardous constituents of the airborne particulates. The purpose of these descriptions is to highlight the assumptions and limitations that form part of the results that are presented. Following the descriptions of the approaches followed, the results of the risk characterisation is presented and discussed.

5.2 METHODOLOGY OF QUANTIFYING IMPACT

In general, impacts on the health of communities from exposure to criteria pollutants is quantified by calculating the potential increase in hospital admissions or in mortality due to specific causes, associated with incremental increases in air concentrations of the specific pollutants. These calculations are based on results of studies reported in the international scientific literature, in which statistical methods were used to compare changes in hospitalisation or mortality rates with changes in air concentrations of certain pollutants. Estimates of these effects for environmental exposure to the criteria pollutants were presented in Section 3.2. It is important to note that it is not unusual to observe increases in mortality or hospitalisation rates even when the available air concentrations do not exceed environmental air quality guidelines (such as the South African National Ambient Air Quality Standards).

The following equations are used to calculate the potential increase in individual risk associated with increased air concentrations of $PM_{2.5}$, PM_{10}, CO, SO_2 and NO_2. These calculations relate the potential increase in a specific health effect with an incremental increase in pollutant concentration, following the approach of the World Health Organization (Ostro, 1996).

$$E = AF \times P \times B$$

Where:

E	Refers to the potential mortalities per year (or per day) due to exposure to the pollutant
AF	The attributable fraction of mortalities due to exposure to the pollutant
P	Size of the exposed population for this assessment, is set at one (1)
B	The population incidence of mortality (deaths per number of individuals in population)

AF is given by the following equation:

$$AF = \frac{RR - 1}{RR}$$

Where:

RR:	The relative risk of death or illness due to exposure to the pollutant

The relative risk of death or illness (RR) is calculated as follows:

$$RR = e^{(\Delta_{deaths} \times \Delta_p)}$$

Where

Δ_{deaths}	Potential proportional change in mortality associated with a 1 µg.m^{-3} change in pollutant concentration
Δ_p	The modelled change in pollutant concentration in µg.m^{-3}

The change in the pollutant concentrations (Δp) is generally calculated as the difference between concentrations associated with the background (which excludes the contribution of the proposed Project) and concentrations for the background plus the contribution from the proposed Project.

According to the Airshed (2019) report, background pollutant concentrations in the study area have not been quantified and have thus not been included in the modelled values. The (Δ_p) parameter is therefore equal to the modelled pollutant concentrations at the individual receptor locations, as presented in Section 4.2, and represents the incremental contribution from the proposed Project.

In the case of the proposed Project, exposure data were modelled for individual receptor locations in the immediate area. Available information does not include information on the size of the populations residing in the various potentially affected areas. The potential increases in the numbers of mortalities in the populations potentially exposed by the proposed Project could therefore not be directly calculated. The HHRIA thus calculated the potential increases in individual (or personal) risks of mortality experienced at each of the receptor locations, in this case relating to the communities surrounding a particular open pit mining operation. For this reason, the size of the exposed population (P in the equation above), is set at one (1).

This risk assessment relies on the availability of health data and population statistics for quantifying the risk of health effects associated with changes in air concentrations of the criteria pollutants. In the case of the criteria pollutants, mortality or hospitalisation rates for respiratory or cardiovascular causes are the measure of associated illnesses that are mostly referred to in epidemiological studies.

The health data available for the Gauteng Province, and the City of Johannesburg Metro where the proposed Project is situated, only provides statistics on mortality from different causes. The assessment of the health impact will therefore consider only mortality as endpoint for risk quantification.

Data on mortality rates in the City of Johannesburg Metropolitan Municipality were sourced from a Statistics South Africa report on Mortality and the Causes of Death in South Africa for the year 2016 (StatsSA, 2018a). Data is available for the years 2006 to 2016. Cause specific mortality data extracted from the 2016 dataset is used for the effect estimate, as it represents the most recent full set of published mortality data available. Total population numbers for the Gauteng Province was taken from the Social Impact Assessment report (Mercury, 2019). The total population number for the City of Johannesburg Metropolitan Municipality was found on the StatsSA website (StatsSA, 2018b).

These data are summarised in Table 5.1~~Table 5.1~~. As indicated above, the assessment calculates increases in individual (or personal) risks of mortality. Table 5.1~~Table 5.1~~ therefore includes estimates of the baseline mortality rates calculated on a 'per-person' basis.

Table 5.1: Mortality data for the City of Johannesburg Metropolitan Municipality, for the year 2016.

Variable	Number of persons		Average incidence of death per person	
	Annual	Average Daily	Average Annual	Average Daily
Total population of South Africa (2013 estimate)	52 981 991			
Total population of Gauteng Province (2016 estimate)	13 400 000			
Total population of City of Johannesburg Metropolitan Municipality (2018 estimate)	4 434 827			
Person deaths City of Johannesburg Metro	29 366	80.5	0.00662	0.0000181
Injury deaths City of Johannesburg Metro	3 761	10.3	0.000848	0.00000232
Non-injury (non-accidental) deaths City of Johannesburg Metro	25 605	70.2	0.00577	0.0000158
Cardiovascular deaths City of Johannesburg Metro	4 451	12.2	0.001	0.00000275
Cardiopulmonary deaths City of Johannesburg Metro	6 769	18.5	0.00153	0.00000418
Lung cancer deaths (total South Africa)	6 459	17.7	0.000122	0.00000033

The reported incidence of lung cancer mortality is the national statistics reported for 2016. The cause-specific mortality dataset does not report lung cancer mortality figures for the City of Johannesburg Metropolitan Municipality specifically, or for the Gauteng Province. The reason for the omission from the published statistics is because lung cancer is not one of the ten most prominent cases of death in the Gauteng Province. The national incidence is therefore used with the total South African population to estimate a natural incidence value. Although not ideal, this is a conservative estimate of this effect as statistics from provinces where lung cancer is much more prevalent (i.e. the Western and Northern Cape) is included in this figure.

The values presented in Table 5.1~~Table 5.1~~ are interpreted as statistical probabilities of mortality for different causes. For example, based on the 2016 statistics, the probability of any person living in the City of Johannesburg Metropolitan Municipality to die from a health related (non-accidental) cause in any particular year is taken to be 0.58%. That is approximately one out of every 170 people. Similarly, statistically, any person living in the Gauteng province has a baseline chance of approximately one in 60 500 of dying from a health related cause on any particular day of the year.

The results presented in the sections following, estimate the potential increase in this baseline individual risk of daily and annual mortality that can be attributed to the modelled concentrations of criteria pollutants associated with the proposed Project.

5.3 RESULTS

5.3.1 Daily (short term) Risks Associated with exposure to Criteria Pollutants

The estimated personal daily short-term risks, attributable to criteria pollutant emissions associated with the proposed Project, are given in Table 5.2~~Table 5.2~~ and Table 5.3~~Table 5.3~~. Attributable risk is that portion of the personal risk that may be directly attributed to the contribution of specific pollutants emitted from the sources associated with the proposed Project.

Table 5.2~~Table 5.2~~ presents the incremental risk of non-accidental mortality attributable to mitigated and unmitigated daily maximum concentrations of PM_{10}, hourly maximum concentrations of NO_2 and daily maximum concentrations of SO_2, as estimated at each of the receptor locations. A graphical representation of the results is presented in Figure 5.1~~Figure 5.1~~. The incremental increase refers to the increase in the baseline statistical risk, as determined from the published statistics for the City of Johannesburg Metropolitan Municipality (see Table 5.1~~Table 5.1~~).

Table 5.2: Potential daily increase in personal risk of non-accidental mortality associated with short-term exposure to unmitigated and mitigated PM_{10} emissions, SO_2 and NO_2 emissions.

Receptor location	Baseline risk	Incremental increase in personal risk			
		PM_{10} Unmitigated	PM_{10} Mitigated	NO_2	SO_2
Roodepoort	0.0000181	0.000000876	0.000000457	0.000000267	0.00000000472
Mona Lisa		0.000000483	0.000000261	0.000000152	0.00000000472
Rugby Club		0.00000101	0.000000807	0.00000048	0.00000000943
11 Shaft		0.00000221	0.00000131	0.000000781	0.0000000189
Kimberley East		0.000000359	0.000000207	0.000000123	0.00000000472

The estimated personal daily short-term risk of cardiovascular mortality attributable to the mitigated daily maximum concentrations of PM_{10}, hourly maximum concentrations of NO_2 and CO, and daily maximum concentrations of SO_2, are presented in Table 5.3~~Table 5.3~~. The estimated increase is compared to the natural (statistical) risk of cardiovascular mortality in the City of Johannesburg Metropolitan Municipality. The results are graphically represented in Figure 5.1~~Figure 5.1~~.

Table 5.3: Potential daily increase in personal risk of cardiovascular mortality associated with short-term exposure to unmitigated and mitigated PM_{10} emissions, NO_2, SO_2 and CO emissions.

Receptor location	Baseline risk	Incremental increase in personal risk				
		PM_{10} Unmitigated	PM_{10} Mitigated	NO_2	SO_2	CO
Roodepoort	0.00000275	0.000000234	0.000000123	0.0000000999	0.000000000247	0.00000000094
Mona Lisa		0.00000013	0.0000000708	0.0000000571	0.000000000247	0.0000000004
Rugby Club		0.00000027	0.000000216	0.000000178	0.000000000495	0.00000000178
11 Shaft		0.000000574	0.000000347	0.000000286	0.000000000990	0.00000000233
Kimberley East		0.0000000972	0.0000000563	0.0000000464	0.000000000247	0.0000000002

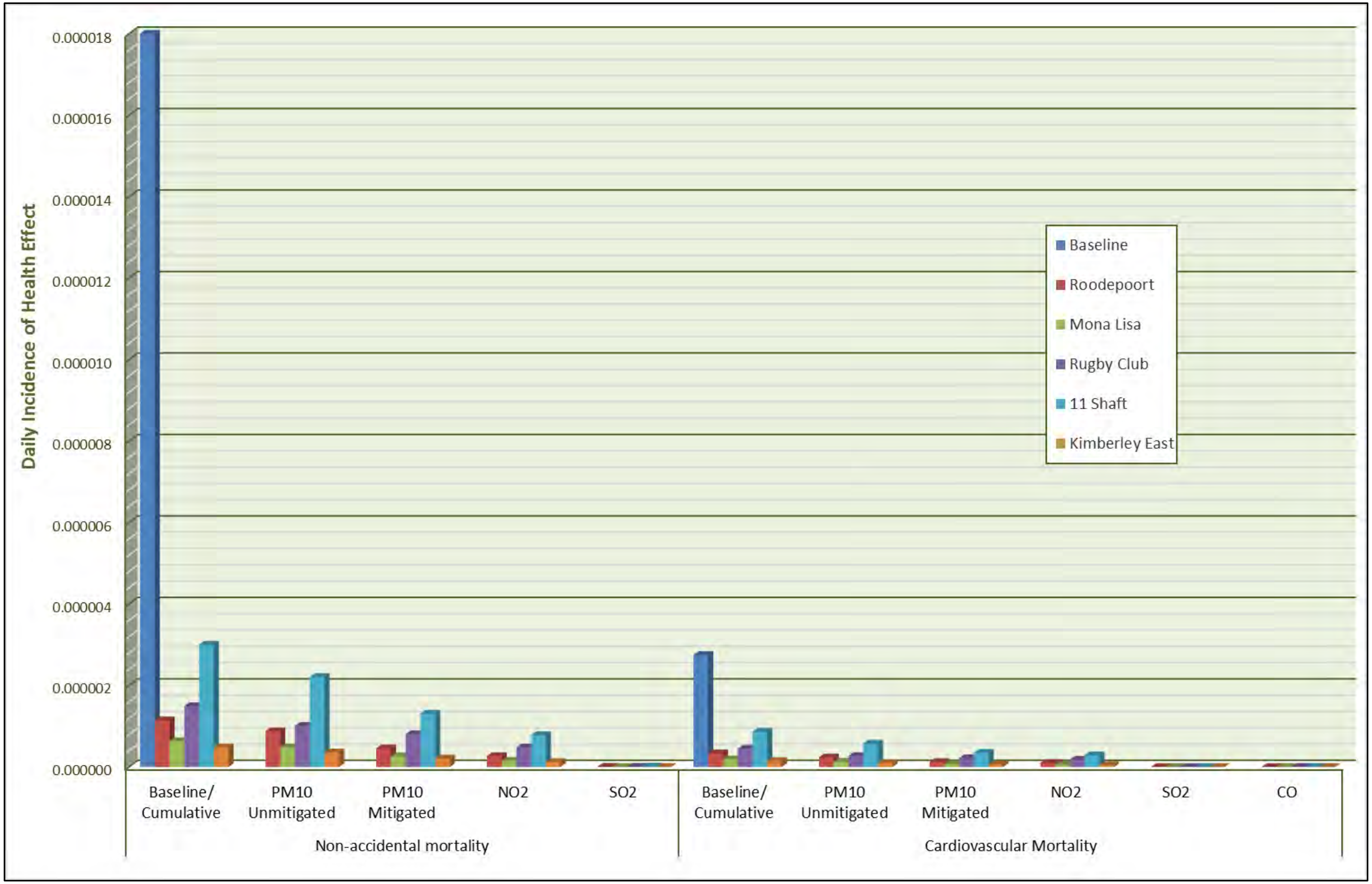

Figure 5.1: Comparison of estimated individual risks of health effects associated with short-term exposure to unmitigated and mitigated PM_{10}, SO_2, NO_2 and CO at different receptor locations.

5.3.2 Annual (long term) Risks Associated with Exposure to Particulates

The estimated increase in long-term personal risk of non-accidental mortality, attributable to the concentrations of $PM_{2.5}$, SO_2, and NO_2 predicted from the Separation Plant, are listed in Table 5.4~~Table 5.4~~. The baseline annual risk of non-accidental mortality for the City of Johannesburg Metropolitan Municipality is also listed for comparison.

Table 5.4: Potential annual increase in personal risk of non-accidental mortality associated with long-term exposure to modelled $PM_{2.5}$, SO_2 and NO_2 concentrations.

Receptor Location	Baseline Risk	Incremental Increase in Personal Risk		
		$PM_{2.5}$	NO_2	SO_2
Roodepoort		0.0000449	0.000344	0.000000502
Mona Lisa		0.0000207	0.00015	0.000000167
Rugby Club	0.00577	0.00011	0.000643	0.000000837
11 Shaft		0.000171	0.000821	0.00000117
Kimberley East		0.0000104	0.0000753	0.000000167

The estimated increases in long-term personal risk of cardiopulmonary mortality attributable to the modelled concentrations of $PM_{2.5}$, SO_2, and NO_2 are given in Table 5.5~~Table 5.5~~.

Table 5.5: Potential annual increase in personal risk of cardiopulmonary mortality associated with long-term exposure to modelled $PM_{2.5}$, SO_2 and NO_2 concentrations.

Receptor Location	Baseline Risk	Incremental Increase in Personal Risk		
		$PM_{2.5}$	NO_2	SO_2
Roodepoort		0.0000178	0.000103	0.0000000733
Mona Lisa		0.00000822	0.0000448	0.0000000244
Rugby Club	0.00153	0.0000433	0.000191	0.000000122
11 Shaft		0.0000672	0.000244	0.000000171
Kimberley East		0.00000412	0.0000225	0.0000000244

Table 5.6~~Table 5.6~~ presents the estimated increase in long-term personal risk of lung cancer mortality attributable to the modelled concentrations of $PM_{2.5}$.

Table 5.6: Potential annual increase in personal risk of lung cancer mortality associated with long-term exposure to modelled $PM_{2.5}$ concentrations.

Receptor Location	Baseline Risk	Incremental Increase in Personal Risk
		$PM_{2.5}$
Roodepoort		0.0000022
Mona Lisa		0.00000102
Rugby Club	0.000122	0.00000534
11 Shaft		0.00000824
Kimberley East		0.000000511

Graphical representations of the results showing comparisons of the incremental increase in health effects associated with long-term exposure to criteria pollutants is presented in Figure 5.2~~Figure 5.2~~.

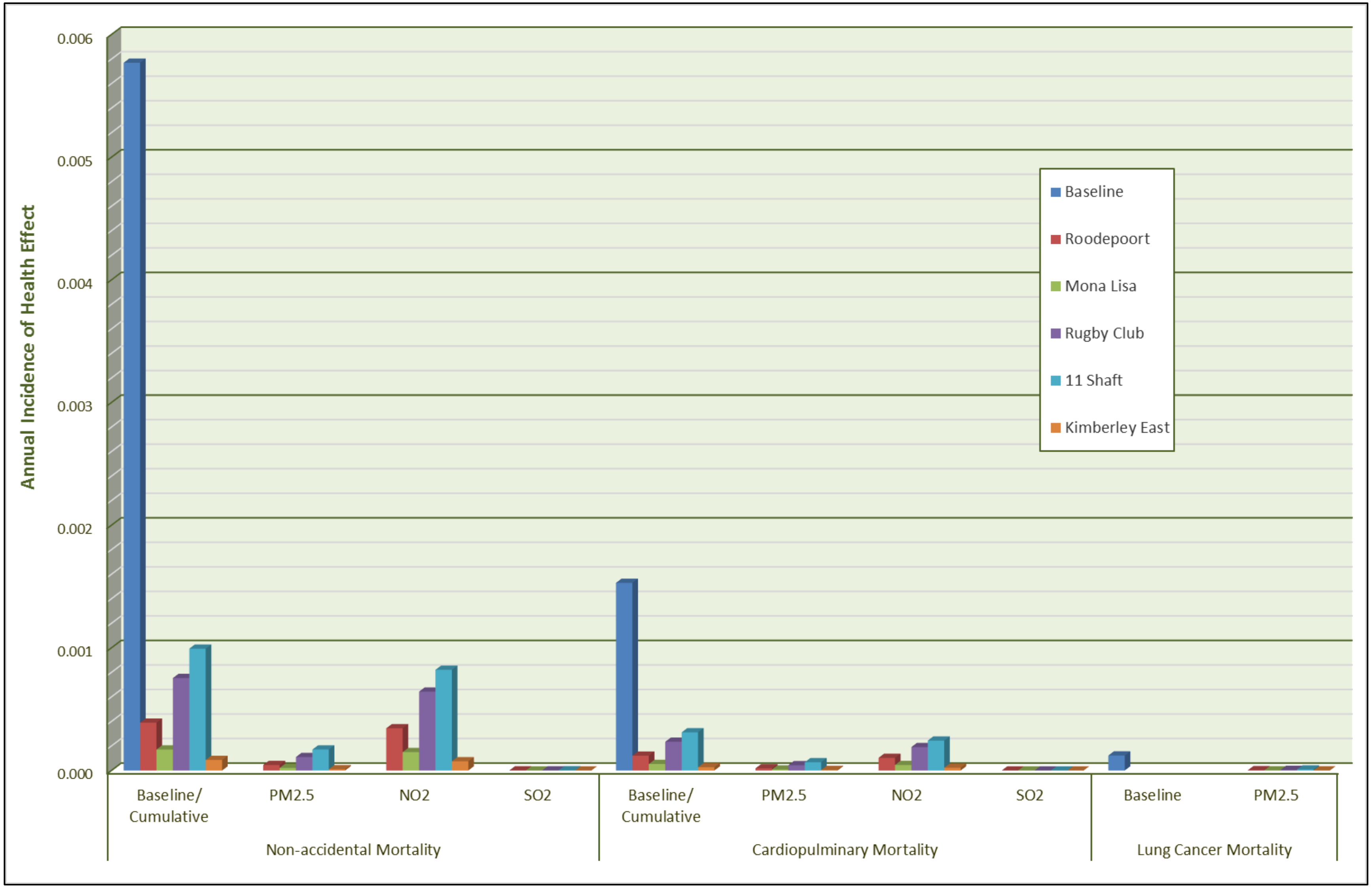

Figure 5.2: **Comparison of estimated individual risks of health effects associated with long-term exposure to $PM_{2.5}$, SO_2, and NO_2 associated with each open pit mining locations.**

5.3.3 Discussion of Results

5.3.3.1 General

The values reported in Section 5.3.1 and 5.3.2 indicate the portion of the baseline population risk of health effects attributable to the exposure to modelled concentrations of $PM_{2.5}$, PM_{10}, SO_2, NO_2 and CO, predicted for each of the five open pit mining operations.

The results presented indicate that, in general, exposure to particulates (PM_{10} and $PM_{2.5}$) has the greatest effect on personal risks experienced at receptor locations, in comparison with SO_2, NO_2 and CO. This effect of particulates on personal risks is clear specifically for health endpoints relating to short term exposures to particulates.

5.3.3.2 Short-Term Risks

In the case of daily risks, the estimated personal risk of total non-accidental mortality from exposure to a single pollutant shows an increase of over 12.2% for the 11 Shaft mining pit, while personal risks of cardiovascular mortality indicate increases of almost 21% from exposure to the daily maximum concentrations of unmitigated PM_{10}, at the same receptor.

In general, mitigation of airborne PM_{10} concentrations show a considerable decrease in estimated risks when compared to unmitigated concentrations. The estimated increase in personal risk for all effects relating to short term exposure to particulates are reduced by some 45% at all operations, when mitigation is applied.

Cumulative increases in risk from short-term exposure to PM_{10}, SO_2, NO_2 and CO shows a potential increase of 16.6% for total non-accidental mortality and 31.4% for cardiovascular mortality.

5.3.3.3 Long-Term Risks

Evaluation of long-term exposure to criteria pollutants, showed a small but measurable increase in personal risk of total non-accidental mortality and cardiopulmonary mortality. The highest estimated increase in baseline risk from a single pollutant is 15.9% for cardiopulmonary mortality from long-term exposure to annual average concentrations of NO_2, at the 11 Shaft open pit mining operations. The cumulative increase in the risk of cardiopulmonary mortality from the combined exposure to $PM_{2.5}$, SO_2, and NO_2 is 20.4%. For total non-accidental mortality the increase in the cumulative risk is slightly lower at 17.2.4%.

The estimated increase in the baseline risk of lung cancer mortality is less than 7% at all receptor locations, even without mitigation measures applied.

5.3.3.4 Evaluation

The significance of the increase in personal risk referred to above, is a qualitative statement on the increase estimated as compared to the baseline risk, and is a function of the size of the exposed population. As indicated earlier, the baseline risk of non-accidental mortality in either the City of Johannesburg Metropolitan Municipality equates to approximately one death per day in every 60 500 people. An incremental increase of for example 20% in the individual risk of non-accidental mortality due to exposure to air pollution, would result in one (1) additional death only if the population exposed to the air pollution includes a minimum of 90 000 people. As the population of the areas directly adjacent to each of the proposed open pit mining areas are smaller than 45 000 (population size of affected municipal wards reported by Mercury (2019)), the actual risk of additional deaths occurring therefore become proportionally smaller.

Nevertheless, as qualitative measure of significance a 20% increase in the individual personal risk of a particular effect (as compared with the baseline incidence of that effect), is taken as significant. This is done so that any potential problem areas may be identified. Based on this interpretation, the estimated increases in annual personal risks associated with modelled concentrations of criteria pollutants from the proposed Project, is significant for short term risks of cardiovascular mortality and cumulative risks of cardiopulmonary mortality, both estimated to increase by more than 20% in the vicinity of the 11 Shaft open pit mining operation. The largest increase is associated with exposure to unmitigated concentrations of PM_{10}. When mitigation is applied, the cumulative increase is reduced to only 12.6%. The estimated increases in annual personal risks associated with modelled concentrations of criteria pollutants from all other operational areas are insignificant.

The value attributable risk estimates presented above lies in the indication of potential problem areas, rather than in the absolute numbers of the estimated increases in personal risk. The results can therefore be interpreted as clearly pointing to a potential for health impacts from the 11 Shaft operational area, should mitigation measures fail or be insufficient to manage ambient dust concentrations.

5.4 Health Risks Associated with Exposure to Particle Associated Arsenic and DPM

5.4.1 Calculation of Non-cancer Risk Associated with Inhalation Exposure to Airborne Contaminants

Exposure to non-carcinogenic toxicants through inhalation is normally assessed against a reference concentration (RfC) (USEPA, 2002), if other routes of exposure are not present. An RfC is an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse non-cancer health effects over a lifetime of exposure.

In this case, the RfC for DPM is specified for chronic exposure (365 days and longer), and the derived reference value for evaluation of inhalation exposure to arsenic is also based on chronic exposure (0.015 µg $As.m^{-3}$). By dividing the estimated concentrations of these pollutants at each of the receptor locations by the RfC or derived reference value, as appropriate, a hazard quotient (HQ) is calculated. Where a HQ exceeds one, health effects may occur and the situation requires further attention.

The HQs associated with the concentrations of the different contaminants estimated at each receptor location, are presented in Table 5.7~~Table 5.7~~. The HQs estimated for exposure to DPM are based on the US EPA RfC of 5 µg/m^3 (USEPA, 2002).

Table 5.7: HQs associated with exposure to DPM and Arsenic.

Receptor Location	Hazard Quotients (HQ)	
	DPM	Arsenic
Roodepoort	0.12	0.01
Mona Lisa	0.04	0.0153
Rugby Club	0.22	0.0403
11 Shaft	0.28	0.09
Kimberley East	0.02	0.0022

Exposure to DPM and airborne particle associated arsenic was evaluated assuming long-term chronic exposure. The hazard quotients calculated, are all well below 1, and indicate the probability of non-cancer health effects occurring at any of the receptor locations as a result of exposure to these substances is low.

5.4.2 Cancer Risk Assessment

The unit risk values for arsenic is used to evaluate the risk of cancer incidence associate with exposure to the estimated airborne concentrations presented in Table 4.2~~Table 4.2~~. The unitless cancer risk value is calculated by multiplication of the estimated concentrations of these contaminants, at each of the receptor locations, by the relevant unit risk factor. A cancer risk in the order of one in a hundred thousand (0.00001) is usually considered to be acceptable, while one in a million (0.000001) is usually considered to be negligible. The calculated cancer risks are presented in Table 5.8~~Table 5.8~~. It has to be kept in mind that the arsenic concentrations estimated at each receptor location is based on the absolute highest (99th percentile) modelled value for particulates. The calculated values therefore represent a very conservative absolute maximum. Actual risks can be expected to be lower, especially given the fact that exposure of any particular community will last for less than a year.

Table 5.8: Cancer risks associated with exposure to particle associated Arsenic.

Receptor Location	Cancer Risk
	Arsenic
Roodepoort	0.000000645
Mona Lisa	0.000000989
Rugby Club	0.0000026
11 Shaft	0.00000581
Kimberley East	0.000000144

In spite of the very conservative approach to the calculations, the estimated cancer risk values indicate risks are negligible, with values either well below or within the 0.000001 range.

5.5 Conclusions and Recommendations

5.5.1 Criteria Pollutants

Based on the estimated increase in the personal risks associated with either short- or long-term exposure to mitigated concentrations of criteria pollutants from all but one of the proposed open pit mining operations, the increase in risk of all health endpoints assessed are insignificant. At the 11 Shaft open pit mining operations, short term exposure (highest 24 hour average) to unmitigated concentrations of PM_{10} showed a significant increase in the risk of cardiovascular mortality. However, once mitigation is applied, the risk is reduced to only 12.6%. Evaluation of the cumulative effects from short term exposure to mitigated concentrations of criteria pollutants showed that none of these estimated increases are significant.

Long-term exposure to criteria pollutants was shown to lead to insignificant increase in personal risk of total non-accidental mortality and cardiopulmonary mortality, as compared to the baseline risk. That is, except for the 11 Shaft operations where the cumulative annual risk of cardiopulmonary mortality from exposure to NO_2 (in itself an increase in risk of 15.9%) and $PM_{2.5}$ lead to a value of just over 20%. While the modelled $PM_{2.5}$ concentrations represent mitigated values, the NO_2 concentrations are unmitigated.

Although the likelihood of severe health effects occurring was shown to be low compared to baseline values, even under unmitigated conditions, less severe health effects such as sore throat, common cold, cough, wheeze and shortness of breath could still occur whenever persons are exposed to pollutants, even if the concentrations of these pollutants do not exceed guideline values, such as those prescribed by the National Ambient Air Quality Standards.

5.5.2 Hazardous Elements Associated With Airborne Particulates

Exposure to DPM and particle associated arsenic was evaluated using a set of conservative assumptions with regard to the quantities that can enter the atmosphere. The estimated airborne concentrations were evaluated assuming long-term chronic exposure. The resulting hazard quotients indicate that the probability of non-cancer health effects occurring from inhalation exposure to any of the three contaminants is low. Cancer risk assessment performed on the estimated concentrations of arsenic indicated cancer risks to be negligible. Based on these results and the conservative nature of the estimation of exposure, no mitigation or monitoring of DPM or arsenic is considered necessary.

5.5.3 Contaminants in Water Resources

The potential for health effects associated with the potential contamination of groundwater or surface water resources from activities or sources directly related to the proposed Project, could not be evaluated due to absence of a complete source-pathway-receptor linkage.

However, evaluation of baseline water quality found elevated levels of contaminants including nitrate, lead, uranium and nickel present in surface and groundwater indicating that water resources in the area is already severely impacted. Any contribution from the proposed Project will negatively impact water quality leading to a further decline in the fitness for use.

5.5.4 Recommendations

Interpretation of the results leads to the conclusion that the potential for health risks relate mainly to the area to the residential areas located in the vicinity of the proposed 11 Shaft open pit mining operations. However, although not necessarily significant, the risks estimated for all of the proposed mining operations demonstrated a potential increase over baseline risks for most health endpoints evaluated. In terms of airborne concentrations of particulates, the dust emission control measures assumed by the air quality specialist, proved critical in managing the potential risk. It is consequently recommended that dust mitigation measures, as recommended by Airshed (2019), be implemented at all open pit mining operations associated with the proposed Project to prevent possible health effects associated with particulates.

Given the demonstrated potential for health effects, it is further recommended that, in accordance with the Air Quality Impact Assessment (Airshed, 2019), airborne particulates concentrations be monitored at potential receptors for the duration of the mining and rehabilitation phases of all mining areas at the proposed Project. The monitoring values can be compared, firstly to South African National Air Quality Standards, but also to the modelled values presented by Airshed (2019). Any exceedances of the modelled values can be regarded as an indication of a potential for health effects and measures should be implemented to reduce airborne pollutant emissions.

It has to be noted that the methodology used for the assessment of potential health effects, conservatively assumed that exposure would be ongoing, at least for a period of one year or more. The limited duration of each open pit mining operation, the open pits would be mined in a phased approach with each pit taking between five and nine months to be mined and rehabilitated, implies that the concentrations of airborne pollutants will most likely not be at the operational levels it was assessed for the entire lifetime (long-term exposure). The results from this assessment are therefore considered representative of the highest potential risk of health impacts likely posed to members of the public by the different operational phases associated with the proposed Project.

The estimated potential for health risks from exposure to airborne contaminant emissions associated with the proposed Project was shown to be low for all contaminants and all potential receptor locations. All individuals or residential communities located further away from the Project site, will be subject to lower concentrations of the pollutants, and consequently also to lower risk of health effects.

Seepage and runoff from the waste rock stockpile areas at each of the proposed open pit mining areas must be contained and, in accordance with recommendations of the Hydrogeological Specialist report (NOA, 2019), be prevented from entering the environment as far as possible. Although no source-pathway-receptor linkage could be demonstrated for waterborne contaminants from any of the open mining pits, the severely deteriorated quality of the water resources in the area mean that the water is already not suitable for human consumption. Any contribution from the proposed Operation will only lead to further deterioration. It is therefore recommended that regular groundwater and surface water quality monitoring be established and maintained in the areas potentially affected by seepage and runoff from the waste rock stockpiles. Any groundwater abstraction boreholes in use by members of the neighbouring communities should be closely monitored for deterioration of water quality. Once the trend of baseline water quality variation is understood, any observed increase in the concentrations of elements and ions, especially nitrates, should be immediately investigated and the use of groundwater from the affected borehole must be suspended.

6 UNCERTAINTY ANALYSIS

6.1 Assumptions and Uncertainty in the Assessment of Health Risks

The health data on which the quantification of health effects depends, are subject to various uncertainties related to the quality and representivity of the health databases used as a basis. As indicated earlier, the health data available for the Gauteng Province, and the City of Johannesburg Metro where the proposed Project is situated, only provides statistics on mortality from different causes. For the purpose of this assessment it was assumed that the mortality rates, as available for the City of Johannesburg Metropolitan Municipality is representative of the incidence of effect specific mortalities in the communities affected by the proposed Project.

Other factors contributing to uncertainty are the quality of the air pollution databases and the reliability of the statistical models used to assess relationships between air pollutant concentrations and health effects. The uncertainties related to the databases include the completeness of data, the impact of measurement error and the limitations of using fixed air monitors to represent the entire population in environmental exposure studies. Lastly, statistical models may be biased and may over- or underestimate the potential magnitude of the predicted mortality rates.

The validity of the projected associations between air pollutant concentrations and mortality reported in the literature, is only as good as the quality of the study that produced those relationships (Ostro, 1996). As a basis for this report, care was taken to select good quality studies and the validity of the conclusions for the populations in which they were conducted, should be high. Unfortunately, these reports never included South African or even African populations. Epidemiological studies conducted in South Africa would have been the ideal basis for an evaluation of health effects associated with the proposed Project, but such studies are not available.

An important source of uncertainty is therefore the validity of applying relationships derived from non-African, mostly developed countries, to the South African, semi-developed country scenario. Since the general South African population is poorer than populations from developed countries, they can be expected to be less healthy, are likely to have poorer access to medical care (which might be of a lower standard) and therefore probably experience increased susceptibility to especially respiratory diseases, resulting in higher baseline morbidity and mortality rates.

In this regard, further uncertainty is introduced by the potential impact of high rates of infectious diseases such as HIV/AIDS and tuberculosis (TB), which may increase susceptibility to diseases, resulting in the potential underestimation of the morbidity impacts of air pollutants. On the other hand, high rates of HIV/AIDS and TB may inflate the mortality rates, and may change the value of the risk factor applicable to South African populations. In other words, risk factors calculated for South African populations may be more conservative, due to possible high incidence of HIV/AIDS and TB in the communities.

6.2 Vulnerability in the South African population

Vulnerability of a community considers the resilience of a community to recover from the impact of natural or anthropogenic hazards. Understanding of vulnerability at community or population helps to identify and protect sensitive sub-population groups from the effects of air pollution. Risks therefore should be considered within the boundaries of the susceptibility of communities to the risks.

In South Africa, the CSIR has conducted some research into community vulnerability, with the aim of developing vulnerability factors specific to the South African population. Juanette John and her colleagues (John *et al.*, 2008) has identified examples of aspects that are especially important in the South African context, resulting in people being less resilient to and therefore less able to cope with adverse effects of environmental exposures, including air pollution. These are:

- Presence of existing diseases
- Gender distribution of the household
- Presence of certain nutrients in the diet
- Source of household energy (fire or electricity).

John et al. (2008) concluded that the integration of vulnerability assessments and the traditional risk assessment process in South Africa face several challenges. Vulnerability factors specific to the South African situation are, as yet, not available for integration into the health risk assessment process.

6.3 Limitations of Health Data and Population Statistics

The South African health- and population data presented in this report are not as detailed as ideally required to perform the possible health effect estimations for which risk factors are available. In this study only mortality as effect was considered as there are no condition specific data available for rates of hospital admissions in either the City of Johannesburg Metropolitan Municipality or Gauteng Province. The assessment could have included estimates for effects on hospitalisation rates but data would have to be adapted, which means that the assessment could not have been performed with a high degree of confidence.

The provincial data used for assessment of the effect on mortality rates is approximately two years old, but is considered to be an adequate representation of cause specific mortality in the municipal area where the proposed Project will be sited. The quality of the mortality data used therefore does not detract from the level of confidence in the results obtained from the health risk assessment.

Due to limitations in the available population statistics specific to the study area, the risk factors could not be used to predict potential numbers of deaths (absolute risks). Risk was therefore presented as relative risks, which may be difficult to interpret by the community and is therefore not the method of choice. However, the results are nevertheless useful to indicate areas where modelled concentrations of pollutants may result in proportionally high effects.

6.4 Uncertainty in Assumptions

The concentrations of potentially hazardous elements (arsenic, cadmium, manganese, nickel, lead and vanadium) in the samples of waste rock evaluated as part of the Geochemistry Specialist represent is assumed to be representative of all materials that will generated airborne particulates at the proposed Project.

Analytical data from samples collected in the environment typically varies over time and space, even for samples collected from one source area. The concentrations of potentially hazardous elements used in the evaluation of health impacts from these elements can therefore be expected to vary from the different materials (e.g. topsoil, waste rock and ore) associated with the proposed Project. Although the concentrations of these elements may be higher in certain materials or areas of the mining lease, the risks calculated are low enough to allow for some increase in concentration without the risk of significant health impacts occurring.

The lack of background air monitoring data for the area, and particularly the receptor areas surrounding the proposed Project area, necessitated the assumption that the modelled concentrations represent the total pollutant concentrations in the area as a result of the proposed Project. This assumption has the potential for misinterpretation of actual risks. However, in this case the assumption is regarded as valid, because the health data used in the evaluation of effects relating to particulate exposures are relatively recent and effects associated with existing concentrations of airborne particulates are likely to be accounted for in the natural incidence derived from the available statistics.

Another source of uncertainty in the assessment is the quality and accuracy of the predicted pollutant and contaminant concentrations in environmental media that were used in the calculation of health risks. EnviroSim cannot verify input values and results obtained from groundwater and atmospheric dispersion models and therefore assume that the results, as presented by specialists are correct and a true representation of exposure.

To that effect, for the purpose of this assessment, it was assumed that the Hydrogeological and associated Geochemistry Specialist Investigations are correct in accepting that the waste rock extracted from the open pit mining areas will be the only potential source of contamination to groundwater and surface water resources in the area, whether it be through seepage or from runoff.

With regard to air quality, it is assumed that the potential receptor locations selected by Airshed represent the highest exposed individuals and is a true representation of the exposure likely in each of the most exposed areas.

7 IMPACT ASSESSMENT

7.1 IMPACT IDENTIFICATION

The HHRIA presented here is one of many specialist components to a broader Environmental Impact Assessment process undertaken by SLR on behalf of the project proponent. The EIA process requires the assessment of all potential impacts (negative or positive) associated with the proposed Project.

The health risks posed to members of the public by the activities planned as part of the proposed Project, was evaluated using a source-pathway-receptor analysis approach. Information from specialist study reports prepared for the various Project sites, were incorporated with toxicology data and population statistics to quantify the human health risks associated with the proposed Project.

Information presented indicate that a complete source-pathway-receptor linkage exists for the atmospheric exposure pathway. Information on the aquatic environment, both surface- and groundwater, indicated that complete source-pathway-receptor linkage for this pathway is not possible. The aquatic pathway was therefore excluded from further assessment. The potential for exposure through the atmospheric exposure pathway was evaluated for the operational life of the proposed Project.

The results from the atmospheric dispersion modelling conducted by Airshed Airshed (2019) indicate that the potential impact through the atmospheric pathway is limited largely to the immediate vicinity of the different Project areas, in this case defined by the extent of the surface infrastructure and operations of the five opencast mining areas and two underground mining operations. Although airborne concentrations of pollutants (e.g. particulates) may extend beyond the mining boundary, these concentrations decrease rapidly with distance from the sources and therefore become negligible. Nevertheless potential receptors were identified, by Airshed (2019), in areas that will experience an increase of airborne contaminants as a result of the proposed Project.

The impacts associated with the proposed Project that are under evaluation for this study are defined as follows:

HHRIA01 Impact to human health associated with inhalation exposure to criteria pollutants ($PM_{2.5}$, PM_{10}, SO_2, NO_2 and CO) emitted from opencast mining, crushing and screening, and materials handling activities, as well as unpaved road surfaces and, uncovered stockpiles.

HHRIA02 Non-cancer (systemic) health effects in humans as a result of inhalation exposure to DPM and arsenic present in particulate matter emanating from handling and stockpiles of waste rock material,

HHRIA03 Risk of cancer in humans as a result of inhalation exposure to DPM and arsenic present in particulate matter emanating from handling and stockpiles of waste rock material.

The potential for occurrence of the impacts are evaluated based on the risks quantified in Section 5 of this report. For the purpose of this assessment, the nature of the impacts are rated as **negative** as any detrimental health effects associated with exposure to airborne contaminants is an anomalous occurrence that is entirely due to the proposed activity.

7.2 Impact Assessment Methodology

In accordance with the requirements of the EIA process, the potential impacts to human health, identified as part of the HHRIA, has to be evaluated to determine the significance of each impact and anticipated severity of the impact. The methodology applied evaluates the significance of each impact according to the following variables (evaluation components), as described in the Scoping report for the proposed Project (SLR, 2018):

- Probability of occurrence,
- Duration (time scale),
- Spatial extent (physical and spatial size of the impact), and
- Severity

The evaluation proceeds by rating identified impacts as either Low, Medium or High, in terms of each evaluation component, as presented in Table 7.1~~Table 7.1~~. Using the assigned ratings, the significance of each identified impact is determined.

Table 7.1: Rating scheme for evaluation components (SLR, 2018).

Evaluation component	Rating scale and description (criteria)
Probability	High - Definite/Continuous Medium - Possible/Frequent Low - Unlikely/Seldom
Duration	High - Long-term: Permanent. Beyond closure. Long term. Medium - Medium-term: Reversible over time. Life of the project. Medium term Low - Short-term: Quickly reversible. Less than the project life. Short term
Spatial extent	High - Widespread – Far beyond site boundary. Regional/ national Medium - Fairly widespread – Beyond the site boundary. Local Low – Localised - Within the site boundary.
Severity (negative impacts)	High – Substantial deterioration (death, illness or injury). Recommended level will often be violated. Vigorous community action. Irreplaceable loss of resources. Medium – Moderate/ measurable deterioration (discomfort). Recommended level will occasionally be violated. Widespread complaints. Noticeable loss of resources. Low – Minor deterioration (nuisance or minor deterioration). Change not measurable/ will remain in the current range. Recommended level will never be violated. Sporadic complaints. Limited loss of resources.
Severity (positive impacts)	High+ – Minor improvement. Change not measurable/ will remain in the current range. Recommended level will never be violated. Sporadic complaints. Limited improvement of resources. Medium+ – Moderate improvement. Will be within or better than the recommended level. No observed reaction. Noticeable improvement of resources. Low+ – Substantial improvement. Will be within or better than the recommended level. Favourable publicity. Significant improvement of resources

The Consequence of each impact is a function of the Severity, Spatial extent and Duration of the impact and is determined as follows:

Siverity=L					
Duration	Long-term	H	Medium	Medium	Medium
	Medium-term	M	Low	Low	Medium
	Short-term	L	Low	Low	Medium
Siverity=M					
Duration	Long-term	H	Medium	High	High
	Medium-term	M	Medium	Medium	High
	Short-term	L	Low	Medium	Medium
Siverity=H					
Duration	Long-term	H	High	High	High
	Medium-term	M	Medium	Medium	High
	Short-term	L	Medium	Medium	High
			L	M	H
			Localised Within site boundary Site	Fairly widespread Beyond site boundary Local	Widespread Far beyond site boundary Regional/

The Significance of each impact is then determined based on the derived consequence and the probability rating of the impact, as follows:

Probability	Definite/Continuous	H	Medium	Medium	High
	Possible/Frequent	M	Medium	Medium	High
	Unlikely/Seldom	L	Low	Low	Medium
			L	M	H
			Consequence		

Significance is interpreted as follows:

- High - It would influence the decision regardless of any possible mitigation.
- Medium - It should have an influence on the decision unless it is mitigated.
- Low - It will not have an influence on the decision.

7.3 Evaluation and Rating of the Impacts

7.3.1 HHRIA01-Human health impact from inhalation exposure to criteria pollutants

The ***Probability*** of an impact refers to the likelihood of that impact actually occurring. The evaluation of the impact in terms of probability has to be considered within the context of the estimated health risks presented in Section 5. In this regard, although the likelihood of severe health effects occurring was shown to be low compared to baseline values, even under unmitigated conditions, less severe health effects such as sore throat, common cold, cough, wheeze and shortness of breath could still occur where persons are exposed to airborne pollutants.

Risks relating to human health associated with inhalation exposure to particulates, were presented as individual daily and annual risks associated with short- and long-term exposure. The risks calculated are small (given the relatively low number of people that could be exposed) but show an increase, from baseline incidence estimates for all the proposed mining pits. However, given the uncertainty in the health status of the community and the possibility that airborne concentrations may reach high concentrations on some days, the unmitigated probability is rated **Possible (M)**. However, with mitigation implemented the concentrations of particulates, in particular, is greatly reduced at all the proposed mining operations. The probability or risk of health effects is therefore reduced and the rating of the probability is expected to be similarly reduced to **Low (L)**.

Although exposure to airborne particulates would occur for the duration of the mining and rehabilitation of each pit, health effects caused by the exposure may extend beyond this period depending on the seriousness of the illness. ***Duration*** of the potential impact is therefore rated as **Medium-term (M)** for both unmitigated and mitigated conditions, as low levels of exposure may continue to occur in the residential areas that are in close proximity of to the open pit operations even with mitigation applied

Assessment of the ***Spatial Extent*** of a potential impact considers whether the impact is expected to be restricted to the local environment or whether the impact may extend further afield. The dispersion modelling results presented indicate that air pollutants, specifically particulates, are predicted to disperse beyond the boundary of the mining pits.

The application of mitigation will reduce the spatial scale of predicted impacts, however due to the proximity of residential areas to the open pit operations, exposure to airborne particulates is still expected. The scale of the potential impact is rated as **Local (M)** for both mitigated and unmitigated conditions.

The ***Severity*** of the impact is used to establish whether the potential impact will result in a measurable change in the receiving environment. The risks calculated as part of this assessment show (for exposure to the criteria pollutants) a measurable increase in the short-term and long-term health effects, especially when unmitigated concentrations of airborne particulates are considered. This is based on the maximum predicted concentration of air pollutants at receptor points.

With mitigation potential receptors would be exposed to lower concentrations however the calculated risks still show a measurable increase from baseline values. The Severity of the impact relating to exposure to criteria pollutants is therefore rated **Moderate (M)** for both mitigated and unmitigated conditions.

Table 7.2 Assessment of impact HHRIA02.

Impact Mode	Receptor	Evaluation of Impact Significance						
		Nature	Probability	Duration	Extent	Severity	Consequence	Significance
Unmitigated	Land users who live closest to operational areas	Negative	M	M	M	M	**Medium**	**Medium**
Mitigated		Negative	L	M	M	M	**Medium**	**Low**

Mitigation measures:

- It is recommended that dust mitigation measures, as recommended by Airshed (2019), be implemented at all open pit mining operations associated with the proposed Project to prevent possible health effects associated with particulates.
- Given the demonstrated potential for health effects, it is further recommended that, in accordance with the Air Quality Impact Assessment (Airshed, 2019), airborne particulates concentrations be monitored at potential receptors for the duration of the mining and rehabilitation phases of all mining areas at the proposed Project. The monitoring values can be compared, firstly to South African National Air Quality Standards, but also to the modelled values presented by Airshed (2019). Any exceedances of the modelled values can be regarded as an indication of a potential for health effects and measures should be implemented to reduce airborne pollutant emissions.

7.3.2 HHRIA02- Non-cancer (systemic) health effects from inhalation exposure to DPM and particle associated arsenic

Non-cancer risk values calculated for exposure to diesel particulate matter and arsenic associated with airborne particulate matter, show that the risk of health effects is low. ***Probability*** of impacts relating to exposure to these substances are rated **Unlikely (L)** for both unmitigated conditions and where mitigation is applied.

As is the case for the criteria pollutants the ***Duration*** of the potential impact associated with exposure to DPM and particle associated contaminants is rated as **Medium-term (M)**. ***Spatial Extent*** of the impact relates to the dispersion of the dust and as reasoned for the criteria pollutants (see Section 7.3.1) is rated **Local (M)**.

Although the levels of exposure to DPM and particle associated arsenic will be similar to that of criteria pollutants the risk of health effects developing is low as all hazard quotients calculated are below 1. No measurable change in the health of persons exposed to the DPM or particulates from the Project is therefore expected. ***Severity*** of the impact relating to exposure to diesel particulates and particle associated arsenic is therefore ranked **Low (L)** as the affected environment (human health) will not be altered.

Table 7.3 Assessment of impact HHRIA02.

Impact Mode	Receptor	Evaluation of Impact Significance						
		Nature	Probability	Duration	Scale	Severity	Consequence	Significance
Unmitigated	Land users who live closest to operational areas	Negative	L	M	M	L	**Low**	**Low**
Mitigated		Negative	L	M	M	L	**Low**	**Low**

Mitigation measures:

- It is recommended that dust mitigation measures, as recommended by Airshed (2019), be implemented at all open pit mining operations associated with the proposed Project to prevent possible health effects associated with particulates.
- Given the demonstrated potential for health effects, it is further recommended that, in accordance with the Air Quality Impact Assessment (Airshed, 2019), airborne particulates concentrations be monitored at potential receptors for the duration of the mining and rehabilitation phases of all mining areas at the proposed Project. The monitoring values can be compared, firstly to South African National Air Quality Standards, but also to the modelled values presented by Airshed (2019). Any exceedances of the modelled values can be regarded as an indication of a potential for health effects and measures should be implemented to reduce airborne pollutant emissions.

7.3.3 HHRIA03- Increased cancer incidence from inhalation exposure to particle associated arsenic

The risks calculated as part of this assessment indicate that for exposure to particulate matter associated arsenic, cancer risks are negligible even if mitigation is not applied. ***Probability*** of the potential impact is rated as **Unlikely (L).**

Duration of the potential impact is however ranked as **Long-term (H)**, as should it occur (however unlikely the occurrence may be) the effects will last beyond the duration of the project. ***Spatial Extent*** of the impact relates to the dispersion of the dust from the waste rock stockpiles specifically, and for both unmitigated and mitigated conditions is rated **Local (M)**.

As reasoned for in Section 7.3.2, the risk of cancer developing in individuals exposed to arsenic present in the airborne particulates is low as the calculated cancer risks are in the order of one in one hundred thousand to one in a million. However, given the severity of a health effect such as cancer and the possibility that sensitive individuals may be exposed the ***Severity*** of the potential impact is rated **Moderate (M)** for unmitigated conditions.

However, as the waste rock is the only source of dust that include the arsenic, dust mitigation measures directed specifically at the waste rock stockpiles should reduce the concentration of airborne particulates from this source dramatically. Cancer risks will therefore be reduced far below one in a million rendering it a change that cannot be measured. ***Severity*** of the impact relating to exposure under mitigated conditions is therefore rated **Low (L)** as the affected environment (human health) will not be measurably altered.

Table 7.4 Assessment of impact HHRIA02.

Impact Mode	Receptor	Evaluation of Impact Significance						
		Nature	Probability	Duration	Extent	Severity	Consequence	Significance
Unmitigated	Land users who live closest to operational areas	Negative	L	H	M	M	**High**	**Medium**
Mitigated		Negative	L	H	M	L	**Medium**	**Low**

Mitigation measures:

- It is recommended that dust mitigation measures, as recommended by Airshed (2019), be implemented at all open pit mining operations associated with the proposed Project to prevent possible health effects associated with particulates.
- Given the demonstrated potential for health effects, it is further recommended that, in accordance with the Air Quality Impact Assessment (Airshed, 2019), airborne particulates concentrations be monitored at potential receptors for the duration of the mining and rehabilitation phases of all mining areas at the proposed Project. The monitoring values can be compared, firstly to South African National Air Quality Standards, but also to the modelled values presented by Airshed (2019). Any exceedances of the modelled values can be regarded as an indication of a potential for health effects and measures should be implemented to reduce airborne pollutant emissions.

7.4 Conclusions and Recommendations from the Impact Assessment

The impact assessment presented above indicate that the potential impacts to human health from exposure to criteria pollutants has the potential to be of high significance, especially when particulate emissions are not mitigated.

The calculation of the risks on which the impact assessment was based was approached from a conservative standpoint and only the highest concentrations of pollutants and most severe conditions of exposure were applied throughout. However, sensitive individuals such as persons with pre-existing conditions (tuberculosis, COPD etc.) that affect the pulmonary or cardiovascular system or persons with asthma or allergies may be more severely affected by airborne pollutants. The potential severity of the impacts evaluated above was therefore always considered as a measurable change first, irrespective of how low the probability of the impact is.

The result of this is that the impact assessment indicates that even with mitigation implemented the significance of the potential impact remains medium. This finding emphasises the importance of appropriate effective mitigation measures. It is therefore essential that dust emissions be mitigated effectively to prevent any potential health effects and to protect sensitive individuals which may be present in the affected areas. It is further recommended that airborne pollutant concentrations be monitored to measure the effectivity of mitigation measures and warn of any increase in pollutant concentration which may occur.

8 REFERENCES

Airshed (2019), Air Quality Impact Assessment for the Proposed West Wits Mining Project, *17SLR20*, Airshed Planning Professional (Pty) Ltd., Midrand, Johannesburg.

ATSDR (1990), Toxicological Profile for Thorium, Agency for Toxic Substances and Disease Registry, U.S. Public Health Service In collaboration with: U.S. Environmental Protection Agency., Atlanta, GA.

ATSDR (2007), Toxicological profile for arsenic, Agency for Toxic Substances and Disease Registry, US Department of Health and Human Services, Atlanta, GA.

Attfield, M. D., P. L. Schleiff, J. H. Lubin, A. Blair, P. A. Stewart, R. Vermeulen, J. B. Cobie, and D. T. Silverman (2012), The Diesel Exhaust in Miners Study: A Cohort Mortality Study With Emphasis on Lung Cancer, Journal of the National Cancer Institute, Published on Line March 5, 2012, Oxford Journals.

CARB (2016), Consolidated Table of OEHHA / ARB Approved Risk Assessment Health Values, edited, California Air Resources Board, Sacramento, California.

COMEAP (2006), Cardiovascular Disease and Air Pollution, UK Department of Health Committee on the Medical Effects of Air Pollutants, London.

COMEAP (2009), Long term Exposure to Air Pollution: Effect on Mortality, UK Department of Health Committee on the medical Effects of Air Pollution, London.

Dockery, D. W., C. A. Pope, X. X, J. D. Spengler, J. H. Ware, M. E. Fay, B. G. Ferris, and F. E. Speizer (1993), An association between air pollution and mortality in six US cities, *N. Eng. J. Med.*(329), 1753-1759.

GeoDyn (2018a), West Wits MLI (Pty) Ltd 11 Shaft Gold Mine Mining Right Application - Geochemical Specialist Assessment, *201807001*, GeoDyn Systems, Bloemfontein.

GeoDyn (2018b), West Wits MLI (Pty) Ltd Kimberley East Gold Mine Mining Right Application - Geochemical Specialist Assessment, *201807001*, GeoDyn Systems, Bloemfontein.

GeoDyn (2018c), West Wits MLI (Pty) Ltd Mona Liza Gold Mine Mining Right Application - Geochemical Specialist Assessment, *201805001*, GeoDyn Systems, Bloemfontein.

GeoDyn (2018d), West Wits MLI (Pty) Ltd Roodepoort Gold Mine Mining Right Application - Geochemical Specialist Assessment, *201807002*, GeoDyn Systems, Bloemfontein.

GeoDyn (2018e), West Wits MLI (Pty) Ltd Rugby Club Gold Mine Mining Right Application - Geochemical Specialist Assessment, *201807002*, GeoDyn Systems, Bloemfontein.

Hall, S. K., J. Chakraborty, and R. J. Ruch (1997), *Chemical Exposure and Toxic Responces*, CRC Press, Inc., Boca Raton, Florida, USA.

IARC (1989), Diesel and Gasoline Engine Exhausts and Some Nitroarenes, Summary of Data Reported and Evaluation, IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Volume 46, International Agency for Research on Cancer, Lyon, France.

IARC (2012), Diesel engine Exhaust Carcinogenic, Press Release No213 by the World Health Organisation International Agency for research on Cancer, Lyon, France.

IPCS (1999), Principles for the Assessment of Risks to Human Health from Exposure to Chemicals, Environmental Health Criteria 210, A cooperative Agreement between UNEP, ILO, FAO, WHO, UNIDO, Unitar and OECD, International Programme on Chemical Safety.

IRIS (2007), Arsenic, edited, Integrated Risk Information System, United States Environmental Protection Agency, Washington DC.

Jerrett, M., et al. (2005), Spatial analysis of air pollution and mortality in Los, *Epidemiology*(16), 727-736.

John, J., M. Matooane, R. Oosthuizen, and C. Wright (2008), Vulnerability to air pollution: To intervene or not to intervene. Science real and relevant, 2nd CSIR Biennial Conference, CSIR International Convention Centre Pretoria, 17&18 November 2008, pp 6, Pretoria.

Mercury (2019), West-Wits MLI (Pty) Ltd Mining Right Application, Draft Social Impact Assessment Report, Mercury Financial Consultants, Rustenburg, South Africa.

NOA (2019), West Wits MLI (Pty) Ltd. - Hydrogeological Specialist Investigation for the Proposed West Wits Mining Project, Noa Agencies (Pty) Ltd, Pretoria.

NRC (1983), Narional Research Council, Risk Assessment in the Federal Government: Managing the Process, Committee on the Institutional Means for the Assessment of Risks to Public Health, National Academy Press, Washington, DC.

NTP (2011), Report on Carcinogens, Twelfth Edition., U.S. Department of Health and Human Services, Public Health Service, National Toxicology Program. 499 pp, Research Triangle Park, NC.

OEHHA (2008), Technical Support Document for the Derivation of Noncancer Reference Exposure Levels, Air Toxicology and Epidemiology Branch, Office of Environmental Health Hazard Assessment (OEHHA), California Environmental Protection Agency Oakland,CA.

Ostro, B. (1996), A Methodology for Estimating Air Pollution Health Effects., World Health Organisation, Geneva.

Pope, C. A., M. J. Thun, M. M. Namboodiri, D. W. Dockery, J. S. Evans, F. E. Speizer, and C. W. Heath (1995), Particulate air pollution as a predictor of mortality in a prospective study of US adults., *Am. J. Respir. Crit. Care Med.*(151), 669-674.

Pope, C. A., R. T. Burnett, M. J. Thun, E. E. Calle, D. Krewski, K. Ito, and G. D. Thurston (2002), Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution, *JAMA*(287), 1132-1141.

SciRad (2019), Prospective Public Radiological Safety Assessment for the Proposed West Wits Mining Project, *SR-REP-02/2019*, SciRad Consulting (Pty) Ltd, Hartbeespoort, South Aftica.

Silverman, D. T., et al. (2011), The Diesel Exhaust in Miners Study: A Nested Case–Control Study of Lung Cancer and Diesel Exhaust, Journal of the National Cancer Institute, Published on Line, March 5, 2010, Oxford Journals.

SLR (2018), Scoping Report for the Proposed West Wits Mining Project, *720-13087.00001*, Johannesburg.

StatsSA (2018a), Mortality and Causes of death in South Africa 2016: Findings from death notifications, *Statistical Release P0309.3*, Statistics South Africa, Pretoria.

StatsSA (2018b), Stats SA - Statistics South Africa Web Page, edited, Statistics South Africa, Pretoria.

USEPA (2002), Health Assessment Document for Diesel Engine Exhaust, United States Environmental Protection Agency, Washington DC.

USEPA (2004), Fourth External Review Draft of Air Quality Criteria for Particulate Matter, Volume II. EPA/600/P-99/002aD, U,S, Environmental Protection Agency, Research Triangle Park, NC.

USEPA (2010a), Integrated Science Assessment for Carbon Monoxide, Unites States Environmental Protection Agency, Washington, DC.

USEPA (2010b), Toxicological Review of Inorganic Arsenic - In support of Summary Information on the Integrated Risk Information Sustem (IRIS), *EPA/635/R-10/001*, United States Environmental protection Agency, Washington, DC.

WHO (2000), WHO Air Quality Guidelines for Europe, Second Edition, World Health Organisation, Geneva.

WHO (2005), Air Quality Guidelines Global Update. Meeting Report, World Health Organisation, Geneva.

Annexure A
Curriculum Vitae N Potgieter

Specialist Environmental Scientist

Nardus Potgieter

Practice Director – EnviroSim Consulting

Qualifications	**MSc Chemistry, University of Pretoria, 2006**
	BSc Honours, Chemical Engineering (Environmental Technology), University of Pretoria, 2003
	BSc Chemistry, University of Pretoria, 2002
Nationality	**South African**
Languages	**English, Afrikaans**

Profile

Nardus Potgieter has over 12 years of experience in the field of environmental science and has assisted both local and international clients in mining, industry and government to quantify human and environmental exposure to hazardous chemicals and radioactive elements. Among others, these include studies of air pollution, assessment of impacts associated with contaminated industrial sites, setting of risk-based goals for corrective action in soil and water, and guidance for waste management and disposal.

What sets Nardus apart is his strong academic background and experience in the scientific disciplines of environmental chemistry, human health risk assessment, numerical simulation and radiation protection.

Key Skills

- Numerical simulation of complex dynamic systems
- Human health Risk Assessment
- Radiological Public Safety Assessment
- Contaminated Land Remediation
- Environmental Sampling and Analysis

Career History

- **2010 - Present, Practice Director, EnviroSim Consulting:** Provision of specialist services in human health risk and radiological public safety assessment (see attached Business Profile).
- **2004 -2010, Environmental Scientist, Infotox Consulting Toxicologists:** Provision of specialist services in human health risk assessment.

- **2002 - 2004, Water Pollution Control Officer, South African Department of Water Affairs:** Regulatory oversight of hazardous waste management and waste disposal authorisation.

Selection of publications

- Criteria for Utilization of By-products from the Ferro-Alloy Industry co-author, paper presented at the XI International conference on Innovations in the Ferro Alloy Industry (INFACON XI) in New Deli, February 18 -21, 2007
- Diesel vehicle emissions in underground mines: The South African perspective, paper presentation, 2005 Mining Diesel Emissions Conference, Toronto, Canada

Professional Membership

- Registered as a Professional Natural Scientist with the South African Council for Natural Scientific Professionals in Environmental Science field of practice. Registration number 400215/08
- Registered as Corporate member of the South African Radiation Protection Association (SARPA), from May 2013.
- Registered as Corporate member of the *National Association for Clean Air* (*NACA*), from February 2017.