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A HUMAN HEALTH RISK ASSESSMENT OF COMMUNITIES POTENTIALLY EXPOSED TO DUST FROM THE PROPOSED RIETKOL SILICA MINE

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EXECUTIVE SUMMARY

This Human Health Risk Assessment forms part of the Environmental Impact Study by Jacana Environmentals for the proposed Rietkol silica mine near Delmas in Mpumalanga. The human health risk assessment was conducted in response to the concern of residents, in close proximity to the mine, about possible exposure to dust (particulate matter) containing silica, once the mine is in operation.

The potential for adverse health effects for the population was assessed based on the US-Environmental Protection Agency's Human Health Risk Assessment Framework, that comprises four steps. These are Hazard identification, Exposure assessment, Dose-response assessment and Risk characterization.

In the Hazard identification step, a literature search was conducted to obtain information on the possible adverse health effects that particulate matter, in this case $PM_{10,}$ $PM_{2.5}$ and silica, may have on the community. PM_{10} are particulates with a diameter of 10 µm or less, and $PM_{2.5}$ particulates with a diameter of 2.5 µm or less. The smaller the particulates, the deeper they may enter into the human lung and the higher the risk to adverse health effects.

The literature search revealed that PM_{10} and $PM_{2.5}$ in ambient air is statistically significant associated with adverse health effects such as heart disease, respiratory diseases, and lung cancer in humans. This is true for short-term (hours to days) and long-term (months to years) exposure.

Crystalline silica particulates may also cause adverse human health effects, depending on particle size and concentration as well as duration of exposure. From the studies investigated, it was evident that adverse effects were associated with particulates in the respirable size range and at relatively high concentrations where individuals were exposed for long periods of time in an occupational environment. Adverse health effects were not reported from inhalation of large particulates or at low levels or from incidental exposure in the ambient environment. The main health effect from inhalation of crystalline silica is silicosis. Silicosis is a progressive, irreversible, fibrotic lung disease resulting from inhalation and pulmonary deposition of respirable dust containing crystalline silica.

To perform a quantitative human health risk assessment on the impact a planned development may have, it is necessary to consider the short-term and long-term concentrations of pollutants that the population was exposed to before the development (the baseline concentration) as well as the concentrations they were predicted to be exposed to once the mine is in operation. Short-term concentrations are used to determine the potential for acute risks and long-term to determine the potential for chronic risks. To protect the community, ambient air standards and guidelines were used as benchmark values ("safe" values), not occupational standards.

For the baseline concentration of particulate matter (dust), the 24-h average monitored concentrations were used as short-term exposure. PM_{10} and $PM_{2.5}$ were continuously monitored for one month (4 June to 5 July 2021) at the proposed mining rights site. Unfortunately, an annual concentration could not be calculated from only one month's data. However, as monitoring happened during a winter month, it may be considered a worst-case scenario, because air pollution, including particulate matter, is generally higher in winter due to more domestic fuel being burnt for heating and because of meteorological conditions in winter that may cause inversion layers.

Modelled data (using the AERMOD dispersion model) were used to predict the potential for adverse health effects when the mine is in operation. Concentrations (24-h and annual) were modelled at the fence line of the proposed mining rights area. These concentrations were modelled as a worst-case (maximum concentration without any mitigation).

Dustfall concentrations were measured at the site and a sample was sent to an accredited laboratory to be analysed for quartz, as an indication of the current crystalline silica content of the dust. Based on the results (silica content of less than 0.033%) it can be concluded the silica content of the baseline PM was relatively low. A concentration of 26% silica was measured in dust from an existing silica mine in the area. These two percentages were used in exposure scenarios to determine the potential for residents in the area, to develop silicosis.

The average monitored and modelled concentrations for particulate matter were below the South African standards. However, the $PM_{2.5}$ concentration exceeded the 24-h standard on more occasions during the month of monitoring, than the four per year allowed by law. This indicated non-compliance of the baseline concentration to the standard.

The results of the human health risk assessment revealed the following:
When the **acute (short-term) risks from exposure to the 24-h PM_{10}** concentrations (monitored or modelled), were assessed separately, the results indicated that it would be unlikely for individuals to develop acute health effects such as respiratory effects from neither the monitored, nor the modelled PM_{10} concentrations. When the two risks were added, a potential for adverse effects was indicated. However, it must be noted that the monitored concentration as well as the modelled concentration of PM_{10} may be considered as worst-case scenarios, for the reasons mentioned. This means adding a worst-case monitored concentration to a worst-case scenario of maximum modelled concentration with no mitigation, will likely overestimate the potential for adverse effects. It is envisaged that mitigation procedures to reduce dust emissions will be implemented at the mine.

Acute short-term risks from exposure to the 24-h $PM_{2.5}$, indicated the same as for acute PM_{10} risks, namely it would be unlikely for individuals to develop acute adverse effects from exposure to the monitored or modelled concentrations, but when adding the two worst-case scenarios, then a potential for adverse effects was indicated. Again, this is considered an over estimation of the potential for adverse effects. In this case the risk was driven by the monitored $PM_{2.5}$. As mentioned above, the monitored results indicated that the baseline $PM_{2.5}$ was exceeding the South African ambient standard in a winter month (when concentrations are usually higher).

Chronic (long-term) risks from exposure to modelled annual average PM_{10} and $PM_{2.5}$. The risk assessment indicated chronic health effects as a result of exposure to the modelled annual concentrations would be unlikely. An annual average could not be calculated for the (monitored) baseline concentrations, due to the short monitoring period of one month. Current (baseline) chronic risks could thus not be assessed.

Chronic risks – crystalline silica (quartz)
Studies showed silicosis was mostly associated with exposure to crystalline silica particulates in the respirable size range over extended periods of time. Long-term respirable particulates ($PM_{2.5}$) was therefore used in this assessment.

The assessment of the risk for developing silicosis from exposure to the modelled annual $PM_{2.5}$ indicated it would be unlikely under both exposure scenarios. These were as follows: **Scenario a** - exposed to the modelled annual $PM_{2.5}$ concentration with a silica content of

0.033% and **Scenario b -** exposed to the modelled annual $PM_{2.5}$ concentration with a silica content of 26%.

Cancer risk

The International Agency for Research on Cancer (IARC), classified crystalline silica, inhaled in the form of quartz from occupational sources, as a confirmed human carcinogen. However, the incremental cancer risk for the general public could not be determined in this HHRA, as no approved cancer potency factor (inhalation unit risk) for silica could be found in the literature searched.

Non-technical Summary of Main Findings of the Human Health Risk Assessment

Once the silica mine is operational, it may release dust (particulates) into the air. This health risk assessment aimed to identify the potential that these particulates may cause health effects in the surrounding community.

Calculation of the health risks requires knowing how much of the dust and silica will be released from the mine. However, because the mine is not operational (working) yet, the concentrations could not be measured and were therefore predicted, using a mathematical model. This model calculated the highest (maximum) concentrations that could be released by the mine, which is called a “worst-case scenario”. This is done to make sure that the risk is not under-estimated, i,e., to protect people.

The results of the health risk assessment showed that even if people breathe in these high concentrations predicted by the model, it is unlikely that they will develop non-cancer health effects, such as respiratory effects. This will be true for situations where a person would be exposed for a short time or a long time to these calculated dust concentrations.

Measurement of the silica concentration in a dust sample from the area, found it was low (0.033%). A separate project found that the silica concentration in a dust sample from an operational mine in the district, was 26%. These two percentages of silica in dust were then used to determine the risk of developing silicosis if the fine dust concentrations predicted by the model, would be inhaled deep into the lungs. It was found that it would be unlikely for a person to develop silicosis at these concentrations.

The actual concentrations of dust and silica should be verified once the mine is in operation, to determine the actual risk.

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1. Background

Jacana Environmentals has been appointed to conduct an Environmental Impact Assessment (EIA) for the proposed Rietkol silica mine close to Delmas. Delmas falls within the Victor Khanye Local Municipality, which forms part of the Nkangala District Municipality, in Mpumalanga province. Residents in the area of the proposed development have raised their concerns about the new development in respect of dust, and requested that the risks associated with inhalation of dust containing silica, be determined as part of the EIA process. This report addresses the potential risks to human health from exposure to silica dust predicted to be emitted by the proposed development.

2. Terms of Reference

Perform a human health risk assessment (HHRA) of communities that may be exposed to particulate matter (dust) from the proposed silica mine through inhalation.

Assess the human health impacts of particulate matter (PM) emitted from activities at the proposed mine.

3. Scope of Work for Human Health Risk Assessment

An assessment of risks to human health from exposure to dust emissions from the proposed Rietkol silica mine near Delmas, in the Mpumalanga province, will be conducted. The HHRA will be undertaken according to the US-Environmental Protection Agency’s (US-EPA) four step approach.

4. Human Health Risk Assessment

4.1 Approach

In order to manage environmental health, it is important to link human health effects to environmental exposure. One of the linkage methods to use, is human health risk assessment (HHRA), as a HHRA identifies the potential for detrimental health effects that could be caused by exposure to a hazard. The hazard may be chemical (gases, particulates, or solutions), physical (radiation, noise and vibration) or biological (bacteria, viruses and pollen). The hazard, exposure potential, population characteristics, magnitude (concentration), frequency (how often) and duration (how long) of exposure, determine risk.

As a HHRA uses existing toxicological and exposure data to predict the potential for health effects, it may be conducted in a much shorter period of time than other methods such as epidemiology studies, which typically lasts two or more years. A HHRA is therefore also more economical.

In this study, the potential for adverse health effects for the population in the area of the proposed silica mine, was assessed based on the US-EPA Human Health Risk Assessment Framework (US-EPA, 2014). This approach, also approved by the World Health Organization (WHO) (WHO, 2010), comprises the following steps:

- Hazard identification
- Exposure assessment
- Dose-response assessment or toxicity assessment
- Risk characterisation or risk estimation

4.2 Methodology

4.2.1 Hazard identification.

Hazard identification is aimed at determining whether exposure to a particular substance may result in adverse human health effects. The focus in this first step is on aspects such as:

- Physico-chemical properties relevant to exposure
- Sources, routes and patterns of exposure
- Metabolic and pharmacokinetic properties (how the body absorbs, distributes and eliminates compounds and the effects it may have on the body)
- Short-term *in vivo* (inside the body) and *in vitro* (in a test tube) tests
- Long-term animal studies
- Human exposure studies
- Human epidemiology studies

To identify the abovementioned aspects for crystalline silica in this study, reliable databases were accessed. These included the US-EPA, the Centre for Disease Control and Prevention (CDC) in the US, the WHO, Science Direct.

4.2.2 Exposure assessment.

Exposure to pollutants takes place when the human body comes into contact with the pollutant.

Exposure assessment involves the determination of concentrations of the hazard (in this case, crystalline silica). Concentrations may be measured (using instrumentation) or may be modelled, using mathematical computer models. These models use parameters such as emissions, climate, topography, as well as fate and transport of pollutants, and deposition, as input data. The output data are then used to estimate the concentration to which populations are or may be exposed to in different media (air, water or soil), through different routes (inhalation, ingestion or dermal contact).

The duration (how long) of the exposure as well as the frequency (how often) are estimated according to geographic distribution and activity patterns of the populations. In addition to concentrations (that which the body may come into contact with), the dose received (that which ends up inside the body) may also be calculated. A dose is expressed as an oral or dermal Average Daily Dose (ADD) for non-carcinogens (a pollutant that does not cause cancer), or a Lifetime Average Daily Dose (LADD) for carcinogens (a pollutant that may cause cancer).

Exposure may further be influenced by behaviour of people, which may vary greatly among countries or regions according to culture, education and climate. When conducting an exposure assessment, time-activity patterns (the time people spend in different microenvironments, such as in the office or in a vehicle), and their activities in those environments, should ideally be evaluated. Important patterns to consider include quantities of food or water consumed and time spent outdoors vs. indoors. Specific behaviour, for example personal hygiene and smoking habits, may also add to or minimise exposure.

4.2.3 Dose-response assessment or concentration-response assessment

This is the estimation of the relationship between exposure or dose and the human body's response to that exposure or dose. As a HHRA makes use of existing data, the dose-response relationship or exposure-response relationship is ascertained from information supplied by:

- Human epidemiological studies
- Human exposure studies

- Animal exposure studies
- Short-term *in vivo* and *in vitro* tests

Although response estimates based on human data are preferable to derive a benchmark value (a “safe” concentration or dose), estimates from animal data are often used when appropriate human studies are limited or not available. In such a case, uncertainty factors are applied to get to a benchmark value. Benchmark values based on health effects are preferred to those incorporating economic or social factors.

Several agencies, such as the US-EPA, the WHO and the CDC in the US, have developed databases for benchmarks that may be used in a HHRA.

The benchmark values most commonly used are:

- **Reference dose (RfD) and reference concentration (RfC)**. These US-EPA benchmark values represent the pollutant levels where no adverse non-cancer health effects are likely to occur if ingested (RfD) or inhaled (RfC) over a specified time period. The Californian EPA’s equivalent is known as the Reference Exposure Level (REL) and that of the CDC is the Minimum Risk Level (MRL).

- **The oral slope factor and inhalation unit risk values** are used to describe the cancer potency of ingested or inhaled pollutants, respectively. Slope factors generally rely on a linear multistage model, which conservatively assumes that there is no threshold, i.e. a carcinogen may cause cancer at any level of exposure and the likelihood of developing cancer increases as the exposure increases. It must be noted that some scientists are of the opinion that some chemicals have the potential to cause cancer only when a minimum threshold level of exposure has been exceeded.

4.2.4 Risk characterization

This is the final step in the HHRA, combining all the information obtained in the previous three steps of the risk assessment to describe whether a risk to public health is predicted from exposure to the pollutant(s) of interest. This process may be qualitative or quantitative.

Whereas a qualitative risk characterisation is purely a descriptive assessment, the product of a quantitative risk characterisation is a numeric estimate of the public health consequences of exposure to the pollutant. Two types of risk estimates are calculated in a quantitative health risk assessment:

The **incremental cancer risk**, which is the probability of individuals developing cancer from exposure to a hazardous substance over and above the background cancer risk. For inhalation, the risk is a function of the Inhalation Concentration and the Inhalation Unit Risk and for ingestion a function of the Lifetime Average Daily Dose and the Slope Factor.

The Inhalation Unit Risk (risk for every one $\mu g/m^3$ of the pollutant) is the unit-less upper bound estimate of the probability of tumour formation per unit concentration of chemical (Mitchell, 2004) and the Slope Factor is an upper bound, approximating a 95% confidence limit, of the increased cancer risk from a lifetime exposure to an agent expressed in units of proportion (of a population) affected per mg/kg/day.

The hazard quotient (HQ), which is the ratio of a single substance exposure level over a specified time period to a reference concentration or dose for that substance derived from a similar exposure period, and describes the potential for developing toxic effects (other than cancer) from exposure to a hazardous substance.

Risk characterization in a quantitative health risk assessment may vary from a single exposure medium, single exposure pathway through to multi-media and multi-pathway exposure. A multi-pathway, multi-media health risk assessment refers to a health risk assessment in which risk of exposure to pollutants present in multiple environmental media (soil, water, food, air, plants) and all possible routes in which these pollutants may enter the human body (inhalation, ingestion, dermal) are evaluated. The environmental pollutants commonly assessed in a multi-media/multi-pathway health risk assessment, are metals, polycyclic aromatic hydrocarbons, chlorinated hydrocarbons and pesticides.

4.2.5 Uncertainties and limitations

The actual risk associated with a hazard can only be assessed and measured once damage from exposure to that hazard or pollutant has occurred. Human health risk assessment is therefore a *predictive* process that can assess the likelihood of adverse health effects occurring as a result of exposure to a hazardous substance. The risks can thus only be estimations of what could occur, and as such have uncertainty associated with them.

Human health risk assessments are generally quite cautiously done as they include many safety factors that are built into the process. The final risk estimate is therefore likely to overestimate the actual risk.

Uncertainty in health risk assessments may be classified into three types:

- Variable uncertainty
- Model uncertainty
- Decision-rule uncertainty

Variable uncertainty occurs when variables appearing in equations cannot be measured precisely or accurately, either due to equipment limitations or spatial or temporal variances in the quantities being measured. Steps in which variable uncertainty may occur include:

- The determination of pollutant emissions for modelling
- The determination of ambient levels (concentrations) of the pollutants from monitoring and/or modelling
- The use of population demographics or statistics
- The determination of activity patterns and health status of individuals

Model uncertainty is associated with all models (and equations) used in all phases of the risk assessment, including:

- Animal models used as surrogates for testing human toxicity and carcinogenicity
- The dose-response models used in extrapolations in the determination of health benchmark values or ambient air quality standards
- The use of computer models to quantify exposure and risk

Decision-rule uncertainty is associated with the manner in which the risk assessor conducts the study. This may include:

- The selection of the compounds of potential concern (pollutants) to be included in the risk assessment.
- The identification of the most significant exposure pathways applicable in the assessment
- The use of national and international ambient pollutant guidelines/standards as significant values with which health effects may be associated
- The decision as to which exposure pathways are most significant for the specific pollutant(s) assessed

These uncertainties were considered when the HHRA framework was applied in this study.

5. Results

5.1 Hazard identification

5.1.1 Particulate Matter (PM)

Particulate matter concentrations are often used as a proxy for air pollution, as it is considered as the air pollutant causing the most adverse human health effects (WHO, 2018). Particulate matter may be defined as "a complex mixture of solid and liquid particulates of organic and inorganic substances suspended in the air" (WHO, 2018). The smaller the particulates, the higher the potential to enter deep into the lungs and therefore considered to be a risk to human health (WHO, 2018). It is hence accepted that $PM_{2.5}$ (particulate matter equal to or smaller than 2.5 micrometer (µm) in diameter) would pose a higher risk to human health than PM_{10} (particulate matter equal to or smaller than 10 µm in diameter). To put the size of particulate matter into context, it can be mentioned that one µm is one millionth of a meter and the width of a human hair is about 80 µm, while a human red blood cell is about 7 to 8 µm in diameter and a bacterium about 2 µm in diameter.

Particulate matter is emitted from natural as well as anthropogenic (man-made) sources. Examples of natural sources include wind-blown dust and pollen, veld fires and volcanos, whereas anthropogenic sources include emissions from combustion processes (motor vehicles, industries, coal-fired power stations, domestic fuel use), construction, mining and others. Particulate matter may be emitted directly from a source (primary PM), or may form in the atmosphere through fate and transport (secondary PM). For example, sulphate particulates may form from sulphur dioxide gas. Particulate matter from combustion processes and secondary particulates are normally fine (in the $PM_{2.5}$ range) while larger particulates may form from mechanical processes and contain material from the earth's crust as well as wind-blown dust and fugitive dust from roads and industries (WHO, 2000a).

The 2019 Global Burden of Disease study (Murray, 2020) revealed that many risk factors to human health declined since 2010. Amongst these, were risks related to social and economic development, such as household air pollution and unsafe water. However, the largest increase in global risk between 1990 and 2019, was for ambient PM, drug use, high blood glucose and high body mass index. The increase in ambient PM was especially noticeable in low- and middle-income countries (Murray, 2020). South Africa falls within this category.

The adverse health effects that PM may cause, depend mostly on concentrations and time exposed, particle size and chemical composition of the PM. In this regard, a study by Thurston et al. (2016) involving more than 4 million adults in more than 100 metropolitan areas of the United States, indicated that the risk of ischaemic heart disease mortality associated with $PM_{2.5}$ differ according to compounds and source. The risk was five times higher for $PM_{2.5}$ from coal combustion, than for the same mass in general ambient air. Similarly, diesel traffic-related elemental carbon soot produced a risk, but $PM_{2.5}$ from wind-blown soil and biomass combustion was not associated with a risk of ischaemic heart disease mortality (Thurston et al., 2016).

The WHO estimated that exposure to ambient (outdoor) air pollution, globally caused 4.2 million premature deaths in 2016 (WHO, 2018). The International Agency for Research on Cancer (IARC) classified outdoor air pollution as a confirmed human carcinogen. This classification mainly resulted from the particulate matter component of ambient air's association with lung cancer (WHO, 2018, IARC, 2021). In addition, other pollutants that humans in South Africa are exposed to on a daily basis, are also classified as carcinogens.

These are for example diesel engine exhaust, classified as a confirmed human carcinogen in 2014, and indoor wood smoke (from domestic use of wood for heating and cooking) classified as a probable (class 2A) human carcinogen in 2010 (IARC, 2021).

It is well known that particulate matter in ambient air may cause adverse health effects, but less is known about the effects that relatively low concentrations may have. The WHO recently funded studies on the effects of long term and short-term exposure of PM in terms of mortality (death). The aim of these studies was to inform decisions on the revision of WHO air pollution guidelines. Meta-analyses were performed on studies that were conducted all over the world. Occupational studies were excluded from the analyses. More evidence of adverse effects from PM was demonstrated by these studies than during the 2006 WHO evaluation (Chen and Hoek, 2020).

For long-term exposure (months to years), about 3000 abstracts of articles published were screened, from which 107 studies were included in the meta-analyses. Outcomes included, were death from: ischaemic heart disease, stroke, chronic obstructive pulmonary disease (COPD), acute lower respiratory infection (ALRI), lung cancer and death from a natural cause (Chen and Hoek, 2020). It was found that the association between $PM_{2.5}$ and death from these causes, was stronger than the association with PM_{10} (Chen and Hoek, 2020).

The authors (Chen and Hoek, 2020) determined an increase in relative risk for every 10 $\mu g/m^3$ increase in long-term exposure for each of the causes of death investigated. They demonstrated a linear exposure-response graph for $PM_{2.5}$, even at concentrations below 10 $\mu g/m^3$ (Chen and Hoek, 2020), which is the current WHO annual guideline.

Exposure-response can be displayed as a graph “that shows the relationship between levels of adverse health responses in exposed populations (vertical axis) and levels of ambient concentrations of a pollutant (horizontal axis)” (Orellano et al, 2020). A linear graph indicates that there is no threshold and that even at very low concentrations a response is possible.

In developed countries that do comply with WHO guidelines for PM, an average decrease of 8.6 months in life expectancy was still found and the WHO is of the opinion that this is due to exposure to anthropogenic (man-made) PM (WHO, 2018).

The relative risk for every 10 µg/m^3 increase in long-term PM$_{2.5,}$ ranged from 1.08 for death from a natural cause, through 1.10 for respiratory death, 1.11 for death from the circulatory system, stroke and COPD, 1.12 for lung cancer, to 1.16 for ischaemic heart disease and ALRI (Chen and Hoek, 2020).

Relative risk for every 10 µg/m^3 increase in long-term PM$_{10,}$ ranged from 1.01 for stroke, 1.04 for death from a natural cause, and the circulatory system, through 1.12 (death from the respiratory system) to 1.19 for death from COPD (Chen and Hoek, 2020).

Orellano et al, (2020) conducted the meta-analyses on 196 short-term (one hour to days) exposure studies from all over the world. The study populations included young and old, and exposure was to ambient air in both urban and rural settings.

In general, the meta-analyses of the short-term exposure studies demonstrated linear concentration-response graphs for PM$_{10}$ and PM$_{2.5}$ (Orellano et al, 2020). The authors also considered the relative risk for every 10 µg/m^3 increase in short-term PM$_{2.5}$ exposure. A relative risk of 0.0065 was shown for all-cause mortality, 0.0072 and 1.0073 for cerebrovascular mortality (stroke) and respiratory mortality respectively, while the relative risk for cardiovascular mortality was 1.0092 (Orellano et al, 2020).

For PM$_{10}$ the relative risk ranged from 1.0041 for all-cause mortality and 1.0044 for cerebrovascular mortality to 1.006 for cardiovascular mortality and 1.0091 for respiratory mortality (Orellano et al, 2020).

In summary it can be said that PM (PM$_{10}$ and PM$_{2.5}$) in ambient air is statistically significant associated with adverse health effects (such as heart disease, respiratory diseases, and lung cancer) in humans and this is true for short-term and long-term exposure (Chen and Hoek, 2020; Orellano et al, 2020).

5.1.2 Silica

The Science Direct database, containing more than 3000 journals, was the main database accessed in the literature survey on silica. Publication of articles was restricted to the period 2017 to 2021. Keywords used were: silica exposure; silicosis; human health; inhalation. 1307 articles were found, of which the titles and or abstracts were scanned for relevance to the assessment.

Research on silica exposure mostly focused on occupational exposure. Those articles on occupational studies or engineered silica nanoparticulates were excluded.

The results of the literature survey on silica are discussed in Appendix I. In summary, it is evident that crystalline silica particulates may cause adverse human health effects, depending on particle size and concentration as well as duration of exposure.

5.2 Exposure Assessment

The main planned operational activities that will emit particulate matter (dust), from the proposed mine, include: blasting, open cast mining of raw material, crushing of raw material, drying and handling of the final product (EBS Advisory, 2021). It is envisaged that about 95% of the products mined, will be used within the region (EBS Advisory, 2021).

According to the Air Quality Impact Assessment (EBS Advisory, 2021), the area will be rehabilitated after closure of the mining operations. It is therefore assumed that exposure to PM and silica will return to current levels.

5.2.1 Community exposed

The communities (members of the public) potentially exposed to the particulate matter predicted to be emitted from the proposed silica mine, are those living in close proximity to the mine (See Figure 1). This includes those on the agricultural holdings surrounding the site. Eloff (4 km South of the site) and Delmas (6 km East of the site) are relatively far and not downwind from the site and therefore will not be considered in the exposure assessment (EBS Advisory, 2021).

The wind rose, compiled from the Springs meteorological station data (the closest meteorological station to the site) which is about 30 km from the proposed mining site, showed the prevailing wind was from the northeast (EBS Advisory, 2021). In addition, the windspeed was mostly below 4 m/s (EBS Advisory, 2021).

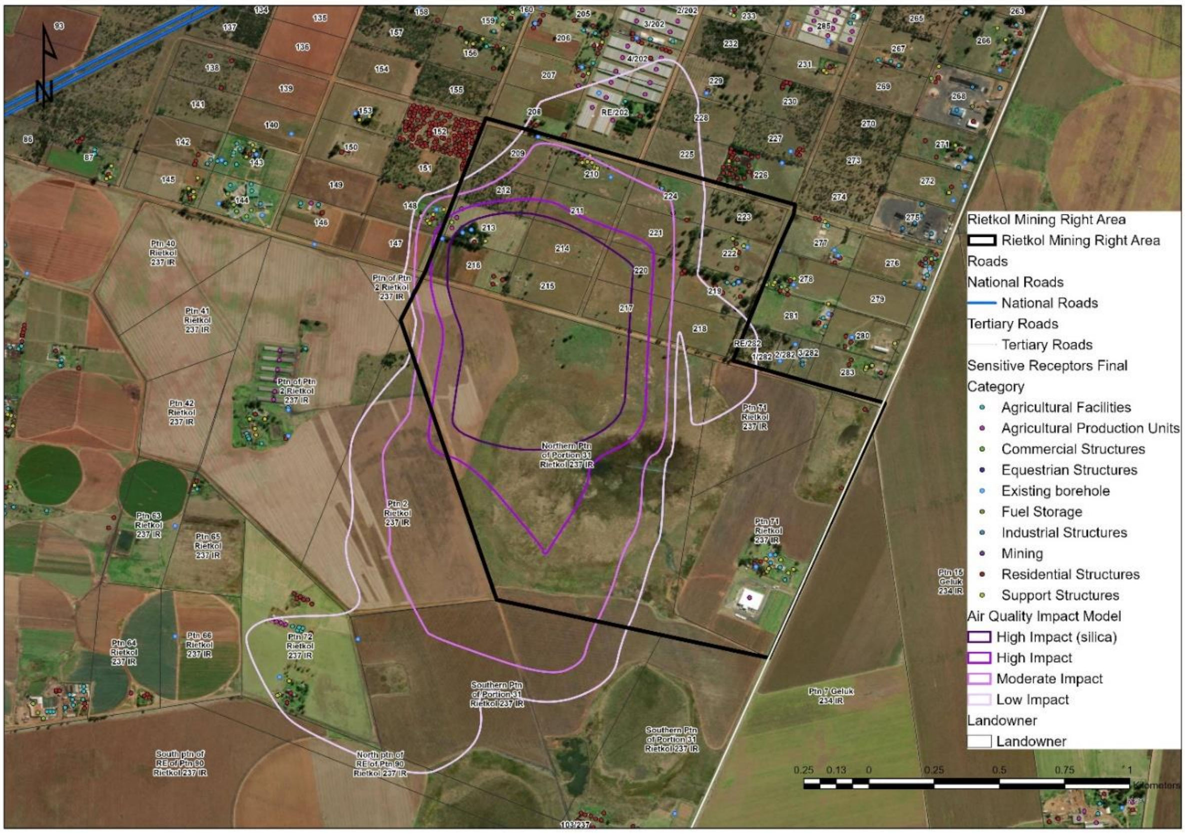

Figure 1. Air Quality Sensitivity Map showing the modelled impact zones, identifying residents most at risk of exposure to particulate matter, specifically silica and PM$_{10}$.

(Figure taken from the Draft Social Impact Assessment Report (Diphororo, 2021)).

It is clear from Figure 1 that those residents within the dark purple line will be exposed to the highest modelled silica concentrations and those residing within the slightly lighter purple area, will be exposed to the highest modelled PM_{10} concentrations. It must be noted that both these areas fall within the mining rights area (black line), and are therefore considered to be "on-site" and hence an occupational environment. This community risk assessment focused on public exposure and will therefore only consider exposure of people living outside of the mining rights area.

Sections of the moderate and low impact areas fall outside of the mining rights site (Figure 1). The average 24-h (daily) modelled PM_{10} concentrations to be emitted from operations on site, are predicted to comply with the South African ambient standard of 75µg/m^3 in the moderate impact area and are predicted to be well below the standard in the low impact areas (Diphororo Development, 2021). This daily PM_{10} standard is allowed to be exceeded four times in a year (South Africa, 2004).

5.2.2 Pollutants of concern and route of exposure

The pollutant of concern in this risk assessment is PM, specifically crystalline silica dust from the different types of sand that will be mined. Adverse health effects described from exposure to PM (both inhalable and respirable) including crystalline silica exposure, were as a result of inhalation (see Appendix I). Inhalation was therefore the route of exposure considered in this risk assessment.

As the medium of exposure in this risk assessment was ambient air, exposure frequency of the communities was considered to be every day for 24-hours per day, and the duration 365 days per year. South Africa has a warm climate, where people tend to spend more time outdoors and especially children play outside more often. The latter was found in a study by Opperman et al, (1991), when it was demonstrated that South African children spent up to 20% more time outdoors than children in the United States of America (USA). In warmer climates, houses are also not as insulated as in colder areas and most people open windows every day, also during the winter. Although the information on opening of windows and children playing outside was not available for the areas in the current study, it was assumed that individuals were exposed for 24 hours per day to the modelled ambient air concentrations.

5.2.3 Magnitude of exposure

The concentrations (the magnitude of exposure) of PM in ambient air used in this assessment, are as in Table 1. The different concentrations were monitored or modelled.

The background/baseline concentrations monitored (by ESKOM during 2017) at a chicken farm, some 30 km away from the proposed site, were not used as it was not considered to be representative of the current site. The daily PM_{10} concentrations measured at that chicken farm, exceeded the South African standard more than the four times allowed in a year (EBS Advisory, 2021).

Baseline/background concentrations used in this assessment, were those measured during the period 4 June 2021 to 5 July 2021 (Rayten, 2021). Concentrations measured during winter are more representative of a worst-case exposure scenario than concentrations measured only during summer months when it is also the rainy season of the area and PM may be removed from the air through wet deposition. Concentrations of air pollutants are normally higher in winter due to an increase in domestic fuel use for heating and also as a result of the meteorological conditions (formation of inversion layers) in winter.

To determine exposure concentrations, it is recommended that monitoring should include all seasons, thus covering at least one year. In this case it was not possible to monitor the baseline for one year. Instead, the concentrations of PM_{10} and $PM_{2.5}$ were continuously monitored from 4 June 2021 to 5 July 2021, at a site within the mining rights area (close to the western border). Concentrations during winter are in general higher for reasons mentioned above. Concentrations of PM_{10} did not exceed the South African ambient 24-h standard of 75 $\mu g/m^3$ over the monitoring period. The maximum measured was 51.79 $\mu g/m^3$ (Rayten, 2021). However, the 24-h $PM_{2.5}$ standard of 40 $\mu g/m^3$ was exceeded on several occasions (more than the four allowed per year) during the monitoring period (Rayten, 2021). The maximum 24-h average recorded for $PM_{2.5}$ was 55.94 $\mu g/m^3$. It was further reported that the concentrations of PM_{10} and $PM_{2.5}$ were very similar, indicating that the PM_{10} particulates were predominantly in the $PM_{2.5}$ range (Rayten, 2021).

Dust fall-out was measured over the month of June 2021 at the same site. The dust fall-out was at 56.27 $mg/m^2/day$, well below the South African residential standard of 600 $mg/m^2/day$

(Rayten, 2021). Dustfall rates were set for nuisance levels to humans (i.e. soiling of surfaces) and are not related to human health impacts, and human health impacts can therefore not be predicted from dustfall concentrations. However, if dustfall levels are high, it is an indication that there could be an issue with ambient PM concentrations as well. The alpha quartz content in the dust fall-out sample was determined by an accredited laboratory as an indication of the current (baseline) silica content of the dust. The alpha quartz content was below the detection limit of 0.013 mg of the laboratory. If the concentration is assumed to be at the detection limit (0.013 mg), then the percentage alpha quartz in the baseline sample sent to the laboratory (39.5 mg), was 0.033% (Rayten, 2021). AirCHECK conducted a survey at an existing silica mine in the Delmas area and found the silica content of the dust to be 26% (AirCHECK, 2017). These two percentages of crystalline silica were therefore used in the HHRA.

Predicted concentrations of PM_{10} and $PM_{2.5}$ when the mine is in operation, were modelled, using the Aermod View Dispersion Model (AERMOD). This model had been approved by the US-EPA (EBS Advisory, 2021). The concentrations of PM modelled at the fence line of the proposed site, were considered as the concentrations the public (those outside of the mining rights area) will be exposed to. These concentrations were modelled as “worst-case” scenarios, i.e., the highest concentrations predicted to be emitted while no mitigation measures were in place (EBS Advisory, 2021).

Different exposure scenarios were created for silica exposure as follows:

a) People are exposed to the modelled $PM_{2.5}$ (respirable PM) concentrations as in Table 1, with a silica content of 0.033%.

b) People are exposed to the modelled $PM_{2.5}$ (respirable PM) concentrations as in Table 1, with a silica content of 26%.

Table 1. Concentrations of particulate matter used in the community risk assessment.

Pollutant	**Average Time**	**Modelled at fence line (maximum without mitigation predicted to enter the receiving environment) µg/m^3**	**Monitored as baseline (24-h average measured over one month) µg/m^3**
PM_{10}	24-h	67.39	31.84
	Annual	13.69	
$PM_{2.5}$	24-h	10	31.44
	Annual	3	
Silica	0.033%*	$PM_{2.5}$ annual - 0.001 (silica quartz)	
Silica	26% **	$PM_{2.5}$ annual - 0.78 (silica quartz)	

***Percentage silica as analysed in fall-out dust **Percentage silica as measured at a silica mine in the region**

It is evident from Table 1, that the maximum modelled 24-h and annual PM_{10} and $PM_{2.5}$ concentrations, predicted to enter the environment beyond the mining rights fence line, were below the South African 24-h and annual standards (Table 2).

The modelled 24-h and annual $PM_{2.5}$ concentrations beyond the fence line were also below the WHO guidelines (Table 2). The modelled annual PM_{10} concentration complied to the WHO guideline, but the modelled 24-h PM_{10} concentration exceeded the WHO guideline of 50 µg/m^3.

The average 24-h concentrations measured during the short-term (one month) monitoring of PM_{10} and $PM_{2.5}$ indicated that the baseline/background concentrations complied to the South African 24-h ambient standards. However, according to the graphs in the monitoring report (Rayten, 2021), the 24-h standard of $PM_{2.5}$ was exceeded about ten times during the month of monitoring, while only four exceedances are allowed in a year under the South African air quality act (Act No. 39 of 2004). The baseline $PM_{2.5}$ therefore already exceeded the standard.

As the main concern about silica is the long-term exposure to respirable crystalline silica (quartz) that may cause silicosis, the only benchmark value ('safe concentration") found in the literature searched, was 3 µg/m^3 (Table 2) for long-term exposure to respirable crystalline silica. The modelled annual $PM_{2.5}$ was therefore used to compare to this guideline under the exposure scenarios mentioned above.

It is clear that under both **Scenario a** (exposed to the modelled annual $PM_{2.5}$ concentration with a silica content of 0.033%) and **Scenario b** (exposed to the modelled annual $PM_{2.5}$ concentration with a silica content of 26%), the calculated concentrations of respirable crystalline silica were well below the guideline of 3 µg/m^3.

It is envisaged that concentrations of the pollutants of concern (PM and silica) will be highest close to the source. In this regard, Shiraki and Holén (2002) measured PM_{10} and $PM_{2.5}$ at different distances downwind and upwind from a sand and gravel facility in the US. Unfortunately, the mass of the $PM_{2.5}$ was too small to analyse for quartz and elements, but these were analysed in the PM_{10} samples. Silica, aluminium and iron were higher at the sites 22 m, 62 m and 259 m downwind from the source, compared to the site furthest (745 m) downwind and the one upwind from the source. The composition of the latter two were similar. The mass fraction of quartz was the highest at the site closest to the facility and then decreased with increasing distance from the source.

5.3 Dose-response assessment

In the dose-response assessment step of the human health risk assessment (HHRA), benchmark values (“safe” values) from reliable databases were sought. Benchmark values derived from epidemiology and toxicology studies are available for many pollutants. However, when risk assessment is performed for criteria pollutants (those pollutants commonly found in ambient air), ambient air guidelines or standards of the specific country should be used as benchmark values. If the specific country does not have guidelines or standards, those of the WHO or the US-EPA may be used. Standards may be legally enforced, but guidelines not.

As described in the Hazard Identification section (Section 5.1), the most recent meta-analyses of short-term and long-term studies on PM indicated there is no threshold and that the concentration-response graph is a straight line. For every 10 µg/m^3 increase in concentration, there was an increase in relative risk for a number of mortalities (Chen and Hoek, 2020; Orellano et al, 2020). For long-term $PM_{2.5}$ exposure this concentration-response was demonstrated even at concentrations below 10 µg/m^3 (Chen and Hoek, 2020), which is the WHO annual guideline.

The proposed Rietkol mine will have to comply to South African laws and standards. Occupational limits/standards may only be used in an occupational environment and not in a community health risk assessment. The reason being that occupational standards are set to protect workers who are fit to work and who are not continuously exposed, but normally only for 8 hours a day and 40 hours a week. Standards that the public may be continuously exposed to (ambient standards) are set to protect children (whose physiological systems are still developing), the aged (whose physiological systems are declining) and asthmatics, over a life time. Ambient standards are therefore much lower than occupational standards. South African standards are stipulated for each of a number of pollutants (criteria pollutants), together with their averaging periods and the frequency of exceedance. The averaging period refers to the period of time over which an average has to be calculated. The frequency of exceedance refers to the number of times the limit value may be exceeded within one calendar year. If the limit value is exceeded on more occasions than specified, then there is no longer compliance with that standard.

The standards and guidelines used in this HHRA, were as in Table 2. For PM the South African standards were used and the WHO guidelines were stated for comparison. For crystalline silica, the focus in the literature was on silicosis as adverse effect from long-term occupational exposure to respirable crystalline silica, hence no ambient short-term standards or guidelines could be found in the literature searched. Even the WHO guideline was set for an occupational environment. One long-term exposure guideline was found that was set to protect sensitive individuals against silicosis; the Reference Exposure Level (REL) of the California-EPA (Cal-EPA, 2008) of 3 µg/m^3 for inhalation of respirable crystalline silica. Respirable in this case was defined as “a 50% cut-point at 4 µm particle aerodynamic diameter” (Cal-EPA, 2008).

Table 2. Guidelines and standards used in the community risk assessment.

Pollutant	**Time**	**SA Std Occupational µg/m^3**	**SA Std Ambient µg/m^3**	**WHO Guideline µg/m^3**	**Cal-EPA µg/m^3**
PM$_{10}$	24-h		75[3]	50[4]	
	Annual		40[3]	20[4]	
PM$_{2.5}$	24-h		40[3]	25[4]	
	Annual		20[3]	10[4]	
Silica*	Long-term				3[6]
Silica*	8-h/day 40-h/week	100[1,2]		40[5] (occupational)	

***Respirable fraction. (1) SA 1993 (2) SA 1996 (3) SA 2004 (4) WHO, 2018 (5) WHO 2000 (6) Cal-EPA, 2008**.

The difference in risk between the 24-h South African standards of PM$_{10}$ and PM$_{2.5}$ (which is 75 µg/m^3 and 40 µg/m^3 respectively) and the WHO guidelines for PM$_{10}$ and PM$_{2.5}$ (50 µg/m^3 and 25 µg/m^3 respectively), is that there is a 1.2% higher risk of mortality when exposed to the South African standards than when exposed to the WHO guidelines (WHO, 2017).

5.4 Risk Characterisation

In the risk characterisation step of the HHRA, the concentrations and the benchmark values were used to determine a hazard quotient (HQ), which describes the **potential** for developing detrimental health effects (other than cancer) from exposure to a pollutant. As mentioned before (Section 4.2.4), the HQ is the ratio of an air pollutant's concentration over a specified period (short-term or long-term) to a reference concentration for that pollutant for a similar exposure period. The HQ is unitless.

If the determined HQ is below 1, it is an indication that it will be unlikely for individuals, even sensitive individuals, to experience detrimental effects, but when the HQ is above 1, the potential for a detrimental effect does exist. The potential however, does not increase linearly. It does therefore not mean that everyone exposed to conditions where the HQ is above 1 will necessarily experience adverse health effects.

In this HHRA, acute non-cancer risks which are associated with short-term (24-hr) exposure were quantitatively assessed (as an HQ). Chronic non-cancer risks associated with long-term (annual) exposure were also assessed using the same formula. The HQs are presented in Table 3.

Table 3. Hazard Quotients calculated for acute and chronic exposure to PM and silica

Pollutant	**Time period**	**Hazard Quotient (HQ) baseline (monitored)**	**Hazard Quotient (HQ) fence line (modelled)**
PM_{10}	24-h (daily) – short-term	0.42	0.90
PM_{10}	Annual – long-term	NA	0.34
$PM_{2.5}$	24-h (daily) – short-term	0.79	0.25
$PM_{2.5}$	Annual – long-term	NA	0.15
0.033% Silica quartz ($PM_{2.5}$)	Annual – long-term	NA	0.0003
26% Silica quartz ($PM_{2.5}$)	Annual – long-term	NA	0.26

NA = not available.

5.4.1 Acute risks – PM_{10}

The HQs determined for acute (short-term) risks from exposure to the 24-h $PM_{10,}$ indicated that it would be unlikely for individuals to develop acute adverse effects such as respiratory effects, from exposure to the monitored or modelled concentrations (when considering the South African standards) as HQs calculated were below 1. The modelled HQ was close to 1 and when added to the HQ from the monitored data (baseline concentration), would exceed 1, indicating a potential risk. However, it must be noted that monitoring was for one winter month only, which is not representative of a 24-h average but may rather be considered a worst case. The modelled data were also representing a worst case, as it was the maximum modelled without any mitigation.

5.4.2 Chronic risks – PM_{10}

The HQ determined for chronic (long-term) risks from exposure to the modelled annual $PM_{10,}$ was well below 1, indicating that adverse effects would be unlikely. As monitoring was for one month only, an annual average could not be calculated for the baseline.

5.4.3 Acute risks – $PM_{2.5}$

The HQs determined for short-term risks from exposure to the 24-h $PM_{2.5,}$ indicated that it would be unlikely for individuals to develop acute adverse effects from exposure to the monitored or modelled concentrations, when considering the South African standards. When adding the HQs of the monitored and modelled data, it was above 1, which indicated a potential risk for acute respiratory effects, driven by the monitored $PM_{2.5}$. However, as explained in 5.4.1, this means adding a worst-case monitored concentration to a worst-case scenario of maximum modelled concentration with no mitigation, which is likely to overestimate the potential risk.

5.4.4 Chronic risks – $PM_{2.5}$

The HQ determined for chronic risks from exposure to the modelled annual $PM_{2.5,}$ was well below 1, indicating that adverse effects would be unlikely. As monitoring was for one month only, an annual average could not be calculated.

5.4.5 Chronic risks – crystalline silica (quartz)

The calculated HQs, using the California-EPA chronic guideline, were well below 1 for both **Scenario a** (exposed to the modelled annual $PM_{2.5}$ concentration with a silica content of 0.033%) and **Scenario b** (exposed to the modelled annual $PM_{2.5}$ concentration with a silica content of 26%), indicating that it would be unlikely for individuals to develop silicosis under these scenarios.

5.4.6 Cancer risk from crystalline silica

The International Agency for Research on Cancer (IARC), classified crystalline silica, inhaled in the form of quartz from occupational sources, as a confirmed human carcinogen (IARC, 1997). However, the incremental cancer risk for the general public could not be determined in this HHRA, as no approved cancer potency factor (inhalation unit risk) for silica could be found in the literature searched.

5.5 Uncertainties

5.5.1 Assumptions for the human health risk assessment

- Valid monitored and modelled concentrations of the pollutants were provided to the health risk assessor.
- The study was limited to **dust (PM and silica),** and biological and physical agents were not included.
- Occupational health and safety risks were excluded from this assessment.

5.5.2 Limitations of the study

The background/baseline concentrations were not modelled, but were based on limited (one month) monitoring, although this was done during a winter month (4 June to 5 July 2021), which may be considered a worst case for reasons mentioned in Section 5.2.

The uncertainty and variability in this assessment were addressed as follows:

5.5.3 Variable uncertainty

There is variability in each individual's activity patterns. The specific activity patterns of the individuals potentially exposed to the PM and silica concentrations in this study were not known. Based on the facts mentioned in Section 5.2 (exposure assessment) it was assumed that individuals will be exposed to the ambient concentrations for 24-hours per day, 365 days a year. A medium confidence level was attributed to this default value.

5.5.4 Model uncertainty

The Aermod View Dispersion Model (AERMOD) used to model PM from the proposed mining operations, was approved by the US-EPA. Equations used in this HHRA were also from the US-EPA. The US-EPA is considered a reputable source, therefore model uncertainty was minimised. The confidence level in the dispersion model and equations used to determine risk is therefore considered to be high.

5.5.5 Decision rule uncertainty

The compounds of concern were provided to the risk assessor as PM and crystalline silica in ambient air. The most significant exposure pathway chosen was therefore inhalation. National and international ambient guidelines/standards were used as values that could be used to predict health risks. The South African standards used were based on human health effects. Other guidelines were from well-known reliable databases such as the Cal-EPA and the WHO. A high confidence level may therefore be assigned to the standards and guidelines used.

The overall confidence level of the assessment is considered to be medium to high.

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7. APPENDIX I Literature search on silica

What is silica?

Silica is part of the crust of the earth and is therefore present everywhere in the environment, and in different forms, but mainly in the form of quartz (crystalline silica). The main component of sand for example, is quartz. Silica is emitted to the environment through the natural weathering of rocks and windblown dust, but may also be emitted by man-made activities such as burning of waste, burning of sugar cane or rice residues, forest fires, power plants, metallurgic manufacturing, mining and quarrying (CDC, 2019).

Crystalline silica is basically insoluble in water, it therefore settles in the sediment. Crystalline silica in air is present as a component of particulate matter (PM) (dust) (CDC, 2019). The highest percentage of crystalline silica in ambient air, is normally found in particulates larger than 10 µm in diameter, regardless of the source (US-EPA, 1996).

How can exposure to silica occur?

Exposure to silica cannot be avoided. As silica may be present in air, soil, food and water as well as consumer products, people may be exposed to silica through ingestion of food and water and or inhalation of air containing silica particulates. Silica may be present in food such as rice and sugar cane, as plants use silica to strengthen leaves and stems and build protective spikes. Exposure may thus also happen through ingestion of certain types of food. Even the cell walls of diatoms, present in fresh water, consist mostly of silica (CDC, 2019).

Inhalation is considered the main route for exposure of humans to crystalline silica and the route responsible for adverse health effects. This became clear from many studies related to occupational exposure, mostly from mining of metals, non-metals and coal, where exposure was to relatively high concentrations (CDC, 2019). Other non-mining occupational activities with exposure to silica, include sandblasting, glass manufacturing, porcelain and ceramic manufacturing, brick manufacturing and building of roads, as well as agricultural practices. Crystalline silica is used in asphalt, in bricks, plaster, dry walls and other building materials. Exposure may therefore also happen during construction of buildings (CDC, 2019).

In addition to occupational exposure, people may be exposed to silica present in consumer products such as art clay, sand paper, abrasives, cosmetic products, talcum powder and cleaning products (CDC, 2019).

In 2019 it was reported that in South Africa about 42 000 miners were potentially exposed to respirable crystalline silica in the formal mining industry, whereas nearly 4 000 000 workers in the non-mining industries (such as construction, manufacturing and agriculture) were exposed to respirable crystalline silica (Brouwer and Rees, 2020).

Concentrations of silica in ambient air and water

In the US it was found that most crystalline silica particulates released to the air were larger than 2.5 µm in diameter, and were stable in air (CDC, 2019). Concentrations of crystalline silica (PM_{10}) measured near industrial sand mining, processing, and transport sites, in Minesota in the US in 2015, were all below 2 µg/m^3 and for PM_4 almost all measurements were below the detectable limit of 1.2 µg/m^3 (CDC, 2019).

To determine what communities are exposed to near industries, Richards and Brozell (2015) measured crystalline silica (PM_4) at the fence lines of Frac Sand Processing Facilities in the US. Monitoring was over several years, and the geometric mean concentration found, was 0.26 µg/m^3.

Samples taken in ambient air in Rome, showed the silica particulates ranged in size from 0.3 to 10.5 µm, with 87% of the particulates below 2.5 µm. From meteorological data, the “authors hypothesized that Southern winds from the Sahara Desert carry silica particles into Mediterranean Europe” (CDC, 2019).

Concentrations of dissolved silica measured in surface water in the US, ranged from 0.12 mg/L to 6 mg/L and in ground water 17 mg/L was measured (CDC, 2019).

Reference levels for silica

According to the book “Toxicological Profile for Silica” (CDC, 2019), detrimental health effects, caused by inhalation of crystalline silica, have not been observed from exposure to the levels found in the ambient environment, or from particulates not in the respirable size range. As a result, ambient air standards are not available in most countries. There are also many uncertainties as to what the no observed adverse effect level (NOAEL) of respirable crystalline silica would be, in other words, it is uncertain at what level would no adverse health effects be expected (CDC, 2019). Not only concentration, but also time of exposure play a role in the development of silicosis (Brouwer and Rees, 2020).

The Office of Environmental Health Hazard Assessment (OEHHA) (California Environmental Protection Agency), established a chronic (long-term) inhalation reference exposure level (REL) of 3 µg/m^3 for respirable crystalline silica in 2005. Respirable particulates in this case were considered as having a 50% cut-off point at 4 µm particle aerodynamic diameter (Cal-EPA, 2008).

This REL, was extrapolated from several occupational studies and is considered to be a level of ambient respirable (PM_4) particulates that humans may be exposed to for 70 years without adverse health effects (Richards and Brozell, 2015).

South African occupational standards for crystalline silica (quartz) in the mining and non-mining environments are the same, namely 0.10 mg/m^3 or 100 µg/m^3 for inhalation of the respirable fraction (SA,1993 and SA 1996). There were however, milestones set to eliminate silicosis in both these industries. For mining, it was to: by 2024, have 95% of all individual respirable crystalline silica exposure measurements below 0.05 mg/m^3 and to have no new cases of silicosis diagnosed amongst those not exposed to mining dust before end of 2008 (Brouwer and Rees, 2020). For the non-mining industries, the milestone set was to eliminate silicosis by 2030 (Brouwer and Rees, 2020). Brouwer and Rees (2020), investigated the probability of reaching these milestones and came to the conclusion that it is unlikely, although formal mining may get close to their milestone.

The National Institute of Occupational Health (NIOH) in South Africa stated in their Pathology Report (Report number 1 of 2021), that the autopsies done during 2019 on 759 deceased individuals, of which 98.1% were miners (34.7%) or ex-miners (63.4%), revealed an increase in silicosis compared to the 2018 autopsies. The overall rate increased from 215 per 1000 to 246 per 1000.

Human health effects from exposure to crystalline silica through different routes

Oral exposure (ingestion)

Animal studies in laboratories have not shown adverse effects from oral exposure to crystalline silica and no reports on adverse effects from oral exposure in humans were found, although inadvertent ingestion is unavoidable, given the general presence of silica in the environment (CDC, 2019).

Dermal exposure

No studies, addressing health effects in humans or animals from dermal exposure to crystalline silica, could be found by the Centre for Disease Control and Prevention in the US (CDC, 2019).

Inhalation exposure

The health effects caused by inhalation of crystalline silica, depend on, amongst other factors, the particle size and the surface chemistry, which again may depend on how it was produced (CDC, 2019).

From the studies investigated, it is evident that adverse effects were associated with particulates in the respirable size range and at relatively high concentrations where workers were exposed for long periods of time. Adverse health effects were not reported from inhalation of large particles or at low levels or from incidental exposure in the ambient environment (CDC, 2019). The main health effect from inhalation, is silicosis.

What is silicosis?

Initial short-term inhalation of silica particulates may cause irritation and inflammatory reactions in the lungs (Cal-EPA, 2008). Similar to all cases where particulate matter is inhaled, the alveolar macrophages in the lung, engulf the particles and then release reactive oxygen species (ROS), which cause inflammation. The alveolar macrophages also release growth factors that stimulate fibroblasts to multiply and form collagen (Cal-EPA, 2008). As the silica particulates cannot be digested by the macrophages, these reactions continue and become chronic with chronic exposure, causing chronic inflammation and fibrosis of the lung (Cal-EPA, 2008), eventually ending in silicosis. It is normally necessary to perform chest radiographs in order to diagnose silicosis (Cal-EPA, 2008) and the silicosis is then "defined as International Labour Organisation Classification radiological profusion of 1/1 or greater" (Churchyard et al, 2004)

"Silicosis is a progressive, irreversible, fibrotic lung disease resulting from inhalation and pulmonary deposition of respirable dust containing crystalline silica" (CDC, 2019). Silicosis is also not associated with exposure to any other substance or even any other form of silica, and there is no cure for silicosis (CDC, 2019). The ancient Greeks and Romans already described silicosis and since then it had been associated with an occupational environment and not with exposure to crystalline silica in ambient air (CDC, 2019).

As mentioned above, silicosis can only develop from exposure to crystalline silica, and normally develops over a long period of time (20 years or more). It is therefore possible that the disease may still develop after exposure has stopped, because the particulates stay in the lung (CDC, 2019).

There is however, also a type of silicosis that may develop much quicker, namely ***acute silicosis***, which may develop within weeks, but typically over one to five years from the time exposure started. In any case within 10 years. Acute silicosis is associated with "heavy, intense exposure" of fine particulate matter, as one would find during sandblasting (CDC, 2019).

Silicosis in the absence of industrial exposure

A study done in the Himalayas in India, found pneumoconiosis (a group of lung diseases, including silicosis, associated with occupational exposure to dust) in communities where there were no mines or other industries that could have been the cause. Three villages were surveyed, and showed the prevalence of pneumoconiosis were 2.0%, 20.1% and 45.3% respectively. They found that the prevalence of pneumoconiosis corresponded with the severity of dust storms, where the free silica content was 60-70%. Kitchens without chimneys also played a role. Concentrations of “dust” in kitchens without chimneys were measured to be 7.5 mg/m^3 (7500 µg/m^3) during cooking periods (Saiyed et al., 1991). This study showed that pneumoconiosis may be possible outside of an occupational environment, if concentrations of components causing the illness reach high levels normally not found in a non-occupational environment.

Silicotuberculosis

When workers are exposed to respirable silica particulates, even without them having silicosis, it may make them more susceptible to the *Mycobacterium tuberculosis* bacteria, causing them to develop tuberculosis (TB), which in turn, will increase the severity of silicosis (CDC, 2019). South Africa already has a problem with TB and antibiotic resistant TB. In addition, silicotuberculosis is exacerbated by the human immunodeficiency virus (HIV) (CDC, 2019), which is also an existing issue in South Africa.

According to the World Health Organization (WHO) World Health Statistics 2021, South Africa has a high incidence (new cases) per year of TB. The incidence in 2019 was 615 for every 100 000 of the population, while it was 226 for every 100 000 of the population in the WHO African region and 130 for every 100 000 of the population as a global figure (WHO, 2021). In the early 2000s, the incidence of TB among gold miners was as high as 3000 per year for every 100 000 gold miners (Brouwer and Rees, 2020).

The National Institute of Occupational Health (NIOH) in South Africa stated in their Pathology Report (Report number 1 of 2021), that the autopsies done during 2019 on 759 deceased individuals, of which 98.1% were miners (34.7%) or ex-miners (63.4%), revealed an increase in pulmonary TB compared to autopsies done in 2018. The overall rate increased from 138 per 1000 to 192 per 1000.

The incidence of HIV in South Africa in 2019, was 3.96 per 1000 of the population, while it was 0.94 per 1000 of the population in the African Region of the WHO and 0.22 per 1000 of the global population (WHO, 2021).

As mentioned above, occupational silica exposure may make workers more susceptible to contracting pulmonary TB. A study was done in South Africa to determine if a community living close (within 2 km) to a gold mine tailings facility, has a higher risk of contracting TB than a community living more than 10 km away (Kootbodien, 2019). Pulmonary TB was radiologically diagnosed by three readers. Although there were more individuals with TB in the community closer to the tailings facility than in the community more than 10 km away, statistical analyses revealed the pulmonary TB was associated with exposure to second-hand smoke, a lower body mass index, having previously had pulmonary TB, and occupational exposure to sand, construction or mining (Kootbodien, 2019). No association was found with exposure to dust from the tailings facility (Kootbodien, 2019).

Prevalence and concentration-response of silicosis

Churchyard et al., (2004) studied the prevalence of silicosis in migrant gold miners in South Africa and found a statistical significant association between prevalence of silicosis and years of service. In this regard they reported a prevalence of less than 2% among those with 15 years or less service and a prevalence of 32% among those with more than 30 years of service. In addition, the authors suggested a linear concentration-response graph, where the prevalence of silicosis increased significantly as the exposure to quartz increased.

Health effects of silica exposure other than silicosis

Renal effects

Occupational exposure to crystalline silica is also associated with effects on the kidneys, which is collectively known as “silicon nephropathy” (CDC, 2019). The renal effects found included nephritis (inflammation of the kidneys, which prohibits proper filtering of waste from the blood) and kidney failure. It must be noted however, that associations between occupational silica exposure and renal effects were not demonstrated in all studies and the incidence was low when compared to silicosis (CDC, 2019). When data from different studies were pooled, it became evident that the risk to get renal effects from silica exposure, increased as the cumulative exposure increased and also that renal effects were demonstrated at higher cumulative exposure than silicosis (CDC, 2019).

Autoimmune effects

Occupational exposure to respirable crystalline silica particulates was also associated with autoimmune effects, such as rheumatoid arthritis and systemic lupus erythematosus (CDC, 2019). Again, it must be noted that these effects could not be demonstrated in all studies and the incidence, like in the case of renal effects, was much lower than that of silicosis (CDC, 2019). Data from the individual studies were not adequate enough to determine concentration-response functions for the different diseases, in other words were not adequate enough to demonstrate at what concentration of exposure what disease may develop (CDC, 2019).

Lung cancer

Many studies on silica exposure have been evaluated to determine if an association between silica exposure and lung cancer does exist (CDC, 2019). As the prevalence of lung cancer amongst workers exposed to silica was relatively low (much lower than for example the association with asbestos), meta-analyses of pooled data from occupational studies were necessary to get large enough study populations to demonstrate an association (CDC, 2019).

Similar to the renal and auto-immune effects, this association with lung cancer showed a dependence on cumulative exposure (CDC, 2019). The International Agency for Research on Cancer (IARC) classified crystalline silica inhaled as quartz from occupational sources, as a known human carcinogen (IARC, 2021).

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8. APPENDIX II Declaration and disclaimer

Declaration

I, Maria Aletta Oosthuizen, declare that I am a qualified medical scientist registered with the Health Professions Council of South Africa and thus suitably qualified to perform a community health risk assessment.

I declare that I am independent of the applicant and performed the work relating to the application in an objective manner, even if it should result in views and findings not favourable to the applicant.

Name Maria Aletta Oosthuizen Signature MA Oosthuizen Date 7 September 2021

Disclaimer

As a human health risk assessment is predictive, because it assesses the likelihood of adverse health effects occurring, the risks can only be estimations of what could occur, and as such have uncertainties associated with them.

The risks were assessed based on information from other studies for the proposed Rietkol silica mine as well as information received specifically related to the risk assessment. The risk assessor cannot guarantee the accuracy of the information received and is therefore not liable for any losses as a result of the implementation of interventions based on the identified risks.

9. APPENDIX III Curriculum Vitae

CURRICULUM VITAE: MARIA ALETTA (RIËTHA) OOSTHUIZEN

Profession : Medical Scientist
Specialisation : Environmental Health; Air Quality
Nationality : South African
Language Proficiency Afrikaans, English
Contact details : e-mail: rioosthui@gmail.com Tel. 084 652 9132
PO Box 905-827, Garsfontein, 0042

KEY QUALIFICATIONS

Knowledge and experience in:

- *Epidemiology studies*
- *Human health impact assessments and health risk assessment studies*
- *Ambient air quality surveys (industrial and non-industrial environment)*
- *Indoor air quality surveys (industrial and non-industrial environment)*
- *Chemotherapy research*
- *Medical technology (Haematology)*

EDUCATION AND PROFESSIONAL STATUS

Qualification	Institution	Year
MMedSc	University of KwaZulu Natal	2005
Approved inspection authority	Technikon Pretoria	1995
Registration Medical Scientist	Health Professions Council of South Africa MW 0005320	1993

Memberships:

- National Association for Clean Air
- Registered as a medical scientist with the Health Professions Council of South Africa

EMPLOYMENT AND EXPERIENCE RECORD

Period	Organisation details and responsibilities/roles
2017 -- 2021	Retired from CSIR. Part-time lecturer at TUT (Environmental Epidemiology and Research Methodology); Independent Consultant
1989 – 2016	CSIR, Senior Scientist: Competency area: Climate Studies, Modelling and Environmental Health Cross sectional epidemiology studies; Human Health Impact Assessment (HHIA) studies; Human health risk assessments; Vulnerability of SA low-income communities to environmental pollution.
1984 – 1988	Part-time financial analysis at University of Pretoria
1982 – 1984	Chemotherapy research, HF Verwoerd Hospital, Pretoria
1977 – 1981	Suburban Homemaker, mother
1972 – 1976	Researcher: Department of Internal Medicine, UOFS: Haematology, Completed Honours Degree in Pathology (Haematology)

A list of articles published and reports written are available on request.

Name Maria Aletta Oosthuizen Signature MA Oosthuizen Date September 2021