HEALTH IMPACT ASSESSMENT

FOR THE

ENVIRONMENTAL IMPACT ASSESSMENT

OF THE

DUNDEE PRECIOUS METALS TSUMEB SMELTER EXPANSION PROJECT

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DECEMBER 2016 -

revised 31 January 2019

DUNDEE PRECIOUS METALS TSUMEB: SMELTER EXPANSION COMMUNITY HEALTH STUDY AND HEALTH IMPACT ASSESSMENT FOR THE EIA

EXECUTIVE SUMMARY

This Community Health study and Health Impact Assessment has been undertaken as part of the Environmental and Social Impact Assessment (ESIA) Amendment process being undertaken for the Dundee Precious Metals Tsumeb (DPMT) proposed upgrading of the Tsumeb Smelter to increase production by 54%. As the key emissions of concern related to the smelter operations are sulphur dioxide (SO_2) and arsenic, the assessment focused mainly on these aspects as the priority hazards related to community health. No new occupational and community health hazards are expected due to the proposed project and only the existing hazards are thus discussed. Impacts were assessed cumulatively to current baseline conditions being experienced.

KEY FINDINGS

Baseline Conditions

Ambient air quality monitoring shows that since the installation of the Sulphuric Acid Plant, residential areas in Tsumeb rarely experience exceedances of the World Health Organisation (WHO) daily limits for SO_2. Short-term exceedances of the hourly limits are, however, still being experienced in the northern parts of the town which can cause temporary mild upper respiratory symptoms of cough and throat irritation. Less frequently, more severe lower respiratory symptoms may be experienced. A survey of residents showed that compared with Oshakati (which is a completely unexposed control area) there is evidence of respiratory symptoms being significantly more prevalent in Tsumeb. Long-term monitoring data shows that the SO_2 exposures to the community, however, continue to decline. This was confirmed by the results of the respiratory health questionnaire survey in the community health study conducted in 2016.

Measured urine arsenic levels indicate that there is some systemic overexposure for Tsumeb residents as a whole compared with Oshakati. The geometric mean for inorganic arsenic is actually well below the most conservative occupational hygiene standard (ACGIH BEI). A small number of high exposure outliers were found in Ondundu in Town North which is likely related to behaviours such as hand to mouth and ingestion. In other areas of Tsumeb where most of the population resides, arsenic in urine levels were found to be closer to those in Oshakati, which were similar to global reference values.

When considering the likely arsenic exposure pathways to the closest communities, airborne arsenic levels in PM_{10} samples often exceed the European Union's annual criteria limit, but levels are low and unlikely to impact urine arsenic levels, or to pose a meaningful lung cancer risk for most Tsumeb residents. Ongoing measures to control fugitive dust emissions from the smelter complex is, however, still to be prioritised.

Similarly, drinking water was also not identified as a source of significant arsenic exposure to Tsumeb residents. Mean values for arsenic in drinking water in all residential areas in and around Tsumeb are well below the WHO and Namibian arsenic exposure limits. Despite all measured values being below WHO limits there is nevertheless a significant trend with small increases of arsenic in water levels the closer the residential area was to the smelter. Drinking water is not a source of significant arsenic exposure to residents.

Preliminary results of a recent soil sampling campaign identified numerous historic mine dump sites outside of the smelter boundary and in close proximity to residential areas like Ondundu in the north of town. These samples showed elevated levels of arsenic and it is most likely to be a contributor to arsenic exposure for residents in that area via the soil exposure pathway and dust inhalation from disturbance of these areas.

The community study also found that significant determinants of inorganic urinary arsenic included recent contact with the smelter, especially having household members who work at the smelter. This means that some arsenic is being brought home on clothes, shoes, bags and vehicles and other objects, and is finding its way probably via the hand-to-mouth route and ingestion to household members.

For Ondundu only, growing vegetables and fruit, and picking wild fruit, vegetables and edible insects locally also contributes to the urine arsenic burden among residents.

In summary, for the baseline situation at the current smelter throughput capacity, ambient air quality monitoring has shown continuous improvement across all measured parameters, however, an irritant burden from SO_2 emissions is still experienced periodically. Arsenic in air levels are low and are unlikely to be cause elevated urine arsenic levels. Drinking water is also not a source of significant arsenic exposure. Soil, hand-to-mouth behaviour and eating wild plants from contaminated areas are the most likely sources of arsenic exposure.

<u>Project scenario</u>

It is expected that with the higher concentrate throughput capacity, SO_2 emissions would also increase. Modelling data have shown that with the efficient utilisation of the sulphuric acid plant, it is not expected that exceedances of the long term criteria would be experienced outside of the smelter boundary. Exceedances of the hourly criteria might, however, still be experienced during upset plant conditions, leading to temporary respiratory irritation.

Modelled data for concentrate throughput, showed that for arsenic in air levels in the community, and urine arsenic levels in smelter employees, the likely cumulative impact of a 54% increase in production throughput is expected to be very low.

Other Environmetal Health Indicators

Reference is made in the report to available data on other general environmental health indicators in order to identify project risks for DPMT. Of these, housing and respiratory issues (e.g. Tuberculosis), sexually transmitted infections such as HIV/AIDS, soil, water, sanitation and waste related diseases, food and nutrition related issues and non-communicable diseases were rated as high risk areas. These ratings are, however, not surprising or alarming when compared with baseline conditions in other parts of sub-Saharan Africa. A well designed internal health management plan aligned with existing Ministry of Health and local municipal strategies and priorities would significantly mitigate any negative effects and accentuate benefits, e.g. contributions to local health care services which DPMT is already contributing to as part of its Corporate Social Responsibility.

RECOMMENDATIONS

Recommended actions are provided for reducing SO_2 and arsenic exposures to community residents, and also to smelter employees.

On balance, with the necessary strengthening of the smelter's industrial hygiene capacity and increasing application to controlling sources of fugitive emissions in the smelter, the overall levels of arsenic and SO_2 exposures will in all likelihood continue to decline, notwithstanding a 54% increase in production. The largest positive impacts come from the closure of the arsenic plant, and the remediation of legacy waste in the smelter precinct.

Progress should be monitored in two ways - continued collection of routine data from the monitoring stations; and periodic surveillance of arsenic levels in soil, locally grown and consumed vegetables, fruit and insects, house dust, and urine of members of the community, in Ondundu in particular. The first of these periodic surveillance programmes was undertaken in the fourth quarter of 2018, with data currently being analysed. Health surveillance should additionally focus on the principal adverse health effect of lung cancer. The Namibian Government should consider setting up a cancer registry.

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1. BACKGROUND

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Dundee Precious Metals Tsumeb Ltd (DPMT) has applied for an Environmental Impact Assessment[1] to be carried out for the smelter expansion in the Oshikoto Region of Namibia. The proposed smelter expansion would be contained within the existing site footprint and would include the following components, to enable the copper concentrate processing capacity to increase by 54% from 240 000 to 370 000 tons per annum:

- Upgrading of the existing Ausmelt feed and furnace;
- Installation of a rotary holding furnace (RHF);
- Implementation of slow cooling of the RHF and converter slag;
- Upgrading of the slag mill to improve copper recovery and handle the increased tonnage from slow cooled slags;
- Installation of an additional Peirce-Smith (PS) converter and new exhaust hoods;
- Additional related infrastructure improvements (power supply).

The Tsumeb Smelter is currently owned and operated by Dundee Precious Metals Tsumeb (DPMT), a subsidiary of the Canadian based Dundee Precious Metals (Pty) Ltd. The smelter is located on the outskirts of Tsumeb in the Oshikoto Region of Namibia, approximately 2 km northeast of the Tsumeb town centre. The regional and local settings of the Tsumeb Smelter are shown in Figure 1 and Figure 2.

With additional custom concentrates available worldwide and areas for operational improvements identified, DPMT is now proposing to expand their current operations in order to increase their concentrate processing capacity from approximately 240 000 to 370 000 tons per annum (tpa). The proposed expansion would be contained within the existing facility footprint and would include the following components:

- Upgrading of the existing Ausmelt feed and furnace;
- Installation of a rotary holding furnace (RHF);
- Implementation of slow cooling of the RHF and converter slag;

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[1] SLR Environmental Consulting (Namibia) (Pty) Ltd (2016): *Scoping Report as part of an EIA Amendment Process for the Proposed Upgrading and Optimisation of the Tsumeb Smelter,* July 2016, Report No. Report No. 1

- Upgrading of the slag mill to improve copper recovery and handle the increased tonnage from slow cooled slags;
- Installation of an additional Peirce-Smith (PS) converter; and
- Additional related infrastructure improvements (power supply, etc.).

The new project components and associated service infrastructure, together with the existing (approved) infrastructure/facilities, is collectively referred to as the 'Tsumeb Smelter Upgrade and Optimisation Project'.

DPMT currently holds an Environmental Clearance Certificate (ECC) in terms of the Environmental Management Act (No. 7 or 2007; EMA) for its operations at the Tsumeb Smelter. To allow for the proposed Upgrade and Optimisation Project, an amendment of the original Environmental and Social Impact Assessment (ESIA) and Environmental Management Plan (EMP) is required. This report focuses on the above mentioned additional components not covered in the current ECC and EMP.

DPMT currently also holds various other ECCs and EMPs for different project components established after the original ECC for the Smelter operations was issued. The objective of this project and ESIA Amendment process is further to combine all of the commitments in the separate EMPs into one consolidated EMP for all DPMT's facilities and operational components. This is beneficial, as impacts and related management and mitigation measures will be considered cumulatively and it would be easier to manage the environmental aspects if consolidated into one document linked to DPMT's overarching management system. If approval is granted and an Amended ECC issued, it would then serve as a consolidated ECC for the entire DPMT Smelter complex and would supersede the previous ECCs.

PROJECT MOTIVATION

Economic

The motivation to support the project is economic in nature, with the project having the potential to directly and indirectly benefit the country and surrounding communities.

The Tsumeb smelter currently employs between 600 and 700 persons in Tsumeb, with many other services directly dependent on DPMT operations. As the proposed project would largely relate to the optimisation of existing components and processes within the facility, it would not create a high number of new employment opportunities. Some opportunities would, however, be created for contractors during the construction phase. The proposed upgrade and optimisation of the smelter and related increase in the throughput capacity of the smelter would, however, promote long term efficiency and economic sustainability of the facility. By increasing the efficiency and sustainability of the facility, long term employment security would be ensured, together with downstream economic benefits to the town of Tsumeb.

The Tsumeb Smelter is unique in that it has the ability to process high sulphur, high arsenic and low copper grade concentrates. It is one of only five commercial-scale smelters in Africa capable of processing concentrates with a high arsenic content. It thus provides highly specialised services to global clients. Upgrading the smelter capacity to 370 000 tpa would ensure that the facility can operate at a higher efficiency level with the related economic benefits.

An essential aspect of the upgrade is the installation of a RHF, which would make it possible to increase the throughput of the existing Ausmelt furnace. Much of the smelter upgrades that have been implemented since 2012 have enabled the plant to accommodate a concentrate throughput of at least 370 000 tpa, but the Ausmelt production rate cannot be increased without the addition of the holding furnace. The current low utilisation is costly in terms of fixed costs and depreciation of equipment, (such as the acid plant, oxygen plant, converters, etc.) which incurred high costs over the past three years. This, however, presents a unique opportunity for the company to leverage previously invested capital and to achieve higher throughput by alleviating bottlenecks with limited additional expenditure, thereby increasing the profitability and ensuring the sustainability of the operations. In addition, the RHF would facilitate higher production rates, improved recoveries and the reduction in metal lock-up due to reverts (e.g. circulating load in furnace), resulting in a reduction in pollution (reduction of metal in slag and reduction of reverts). By ensuring sustainability and increasing the profitability of the operations, current jobs at the smelter and additional jobs related to the expansion would be preserved and the continued prosperity of Tsumeb would be bolstered.

The current proposed Upgrading and Optimisation Project is one of the later phases of an overall optimisation and expansion which has already required substantial capital investment. Recovering the cost of this investment would be significantly more challenging should the proposed project not go ahead.

Compatibility with key policy and planning guidance

A critical aspect of economic desirability of the proposed project is the compatibility of the project with key Namibian policy and planning guidance. A comprehensive review of compatibility with socio-economic policy and planning was undertaken as part of this ESIA (see Appendix H2). The review includes a consideration of the following documents:

- Vision 2030;
- The Fourth National Development Plan (NDP4);
- Namibia's Industrial Policy; and
- The Logistics Master Plan for Namibia.

The overall conclusion from the review is that the proposed DPMT expansion would be largely compatible with key economic policies and plans, provided environmental and other impacts can be adequately mitigated.

Note also that the Ministry of Trade and Industry (MTI) produced an execution strategy for industrialisation in 2015 called Growth at Home (MTI, 2015). Growth at Home identifies six sectors that show promise in terms of their potential to deliver economic growth and job creation:

- Agro-processing;
- Fish-processing;
- Steel manufacturing and metal fabrication;
- Automotive industry;
- Chemical industry; and
- Jewelry industry.

Overall, the Strategy emphasises the importance of beneficiation as a means to stimulate economic activity. Industrial policy is thus focused on encouraging greater industrial activity and local value addition. Emphasis is also placed on encouraging such activity in areas where other opportunities are limited and socio-economic needs are greatest (MTI, 2015). The proposed expansion would increase the amount of foreign revenue generated by DPMT through value addition and provide benefits in a region with relatively high socio-economic needs. It should thus achieve in-principle compatibility with the Strategy.

STUDY SCOPE AND APPROACH

The purpose of this Health Impact Assessment (HIA) is to assess potential health-related impacts associated with the DPMT expansion project. It can be used to inform key DPM decision makers, relevant Namibian Government authorities, other relevant stakeholders and to provide DPMT with information to help identify management and mitigation measures. These mitigation measures aim to avoid, minimise and reduce potential health impacts as identified below.

As requested by DPMT, the study considered the European Bank for Reconstruction and Development (EBRD) Performance Requirements (PRs) as it relates to health and safety of the surrounding community. In this regard, PR4 is of particular relevance as it recognises the importance of avoiding or mitigating adverse health and safety impacts and issues associated with project activities on workers, surrounding communities and consumers. In line with this PR and other international standards for HIAs, a further standard set of twelve health effects categories or Environmental Health Areas (EHAs) were considered in the compilation of this report. Further details of the twelve EHAs are provided in Table 2 under the HIA methodology section.

STUDY AREA AND PROJECT AREA OF INFLUENCE

Figure 1: Regional setting of Tsumeb smelter

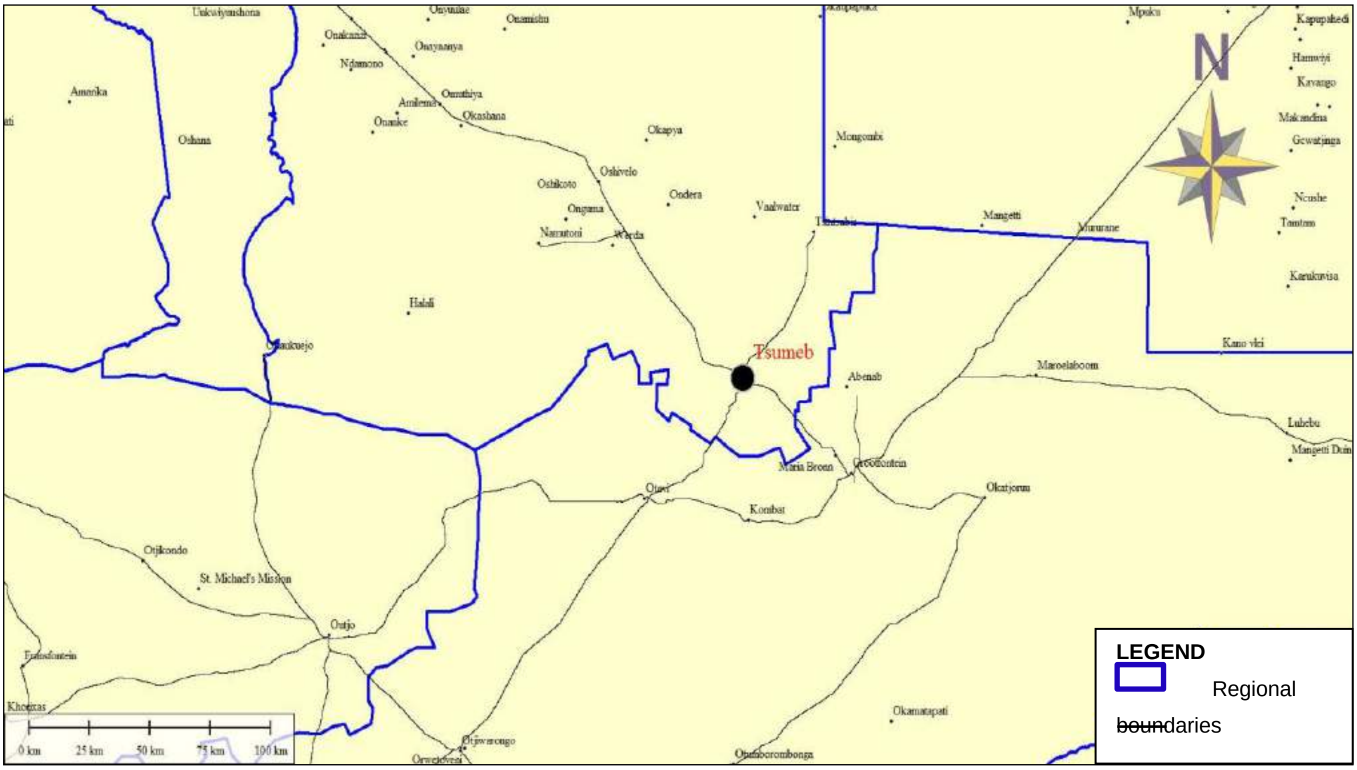
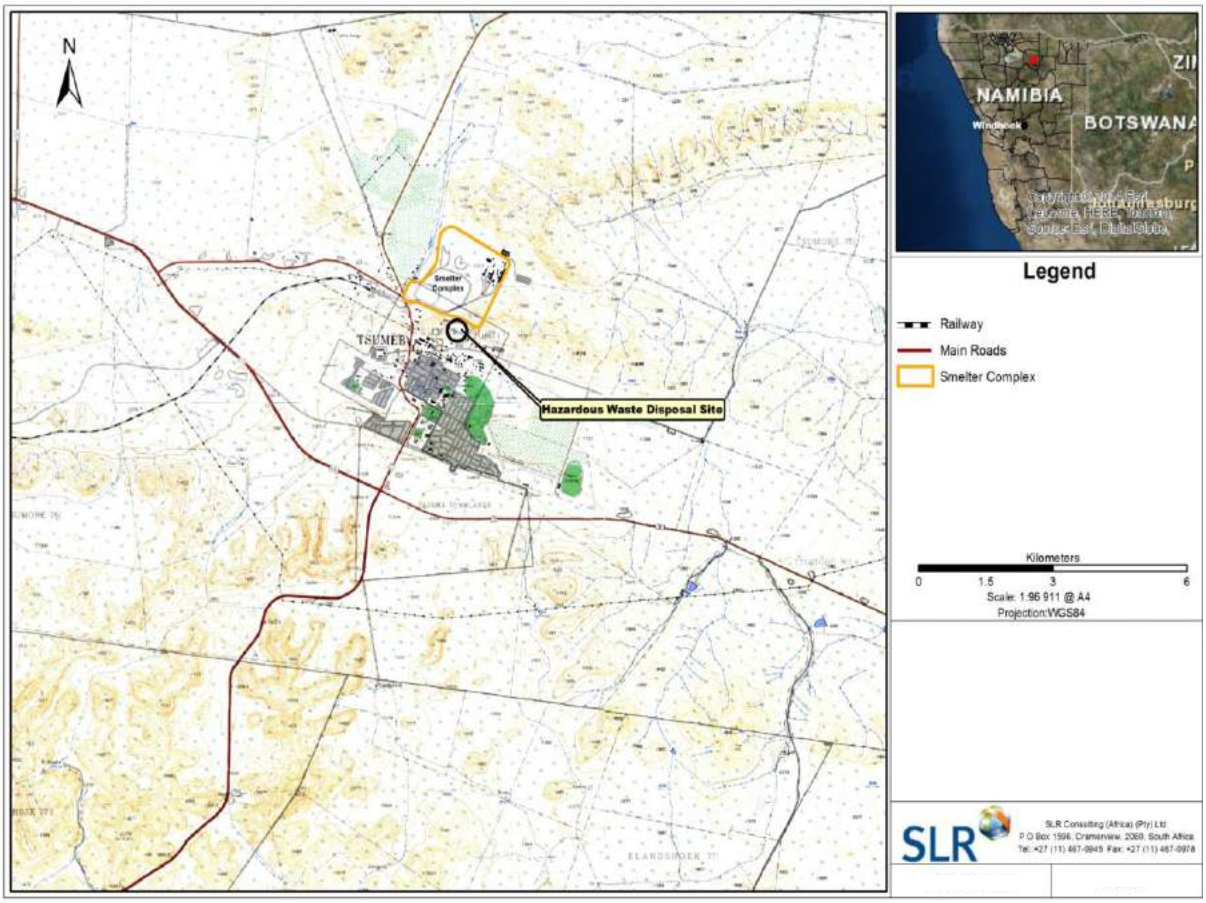


Figure 2: Local setting of the Tsumeb smelter



TEMPORAL AND GEOGRAPHICAL STUDY LOCATION

The HIA covers the period since DPM took over the smelter precinct and operations at Tsumeb in 2011. Since that time data relating to relevant exposures are available. There is a focus on the most recent data for 2016 and 2017, since important capital improvements have recently been introduced at the smelter precinct.

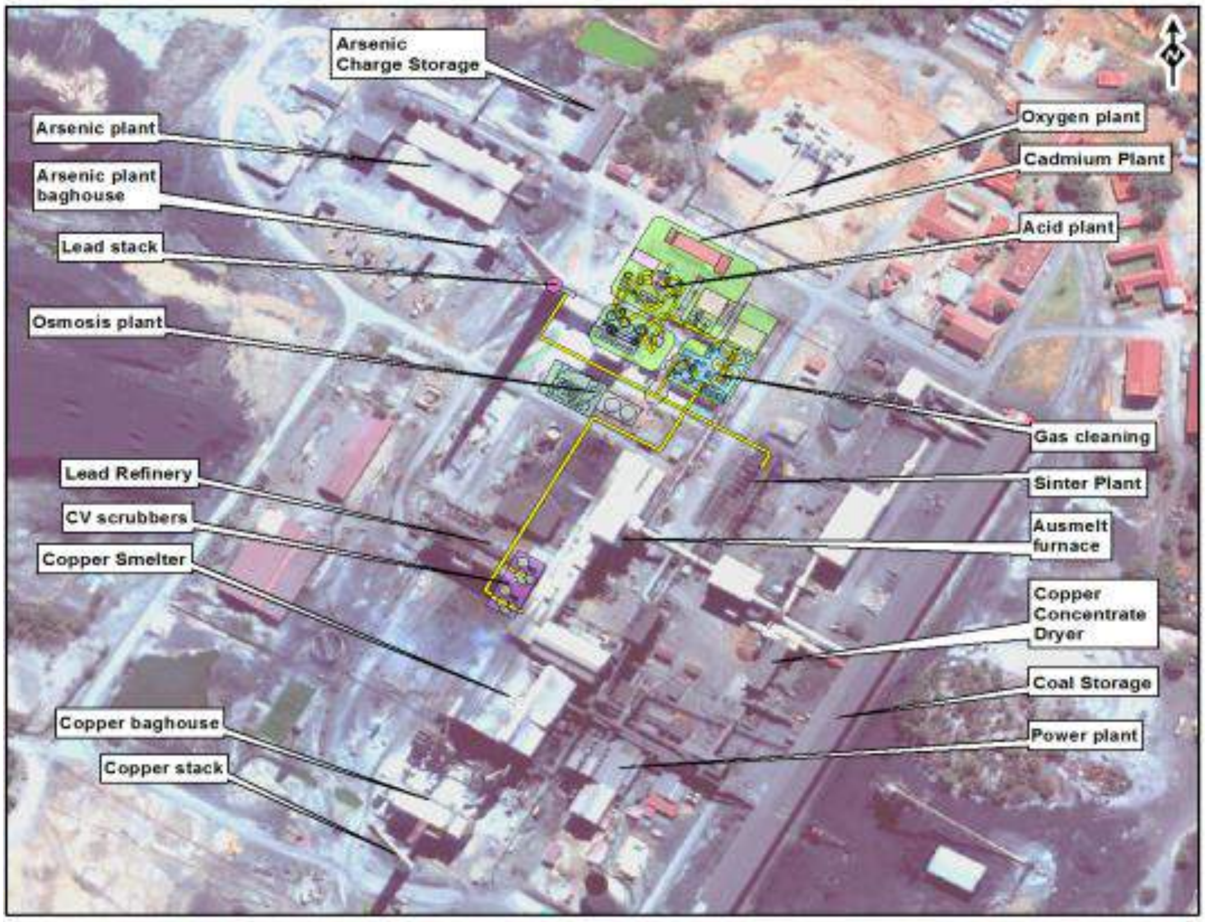
The Tsumeb Smelter is located adjacent to the town of Tsumeb in the Oshikoto Region of Namibia, approximately 2 km north-east of the town centre Figures 3 & 4). The town lies approximately 430km north of Windhoek, the capital of Namibia. The town is directly South of the smelter.

The main road link into Tsumeb is the B1 highway which connects Tsumeb to the Namibia/Angola border in the north and to Windhoek and eventually the Namibia/South Africa border in the south.

Key railway infrastructure (TransNamib) runs from Walvis Bay on the coast to Tsumeb, providing a pathway for feed materials to, and products from, the smelter, and from Windhoek to Tsumeb.

Figure 3 Site Location

Figure 4: Layout of the smelter site



CLIMATIC CONDITIONS

Temperature

The climate in Tsumeb is subtropical with a mean annual temperature of 22 °C and monthly temperatures varying between 16 °C and 26 °C. October is the warmest month when temperatures rise to a maximum of 33 °C. The coldest conditions are experienced in July when temperatures drop to a minimum of 8 °C. The monthly average temperatures are indicated in Table 1.

Rainfall

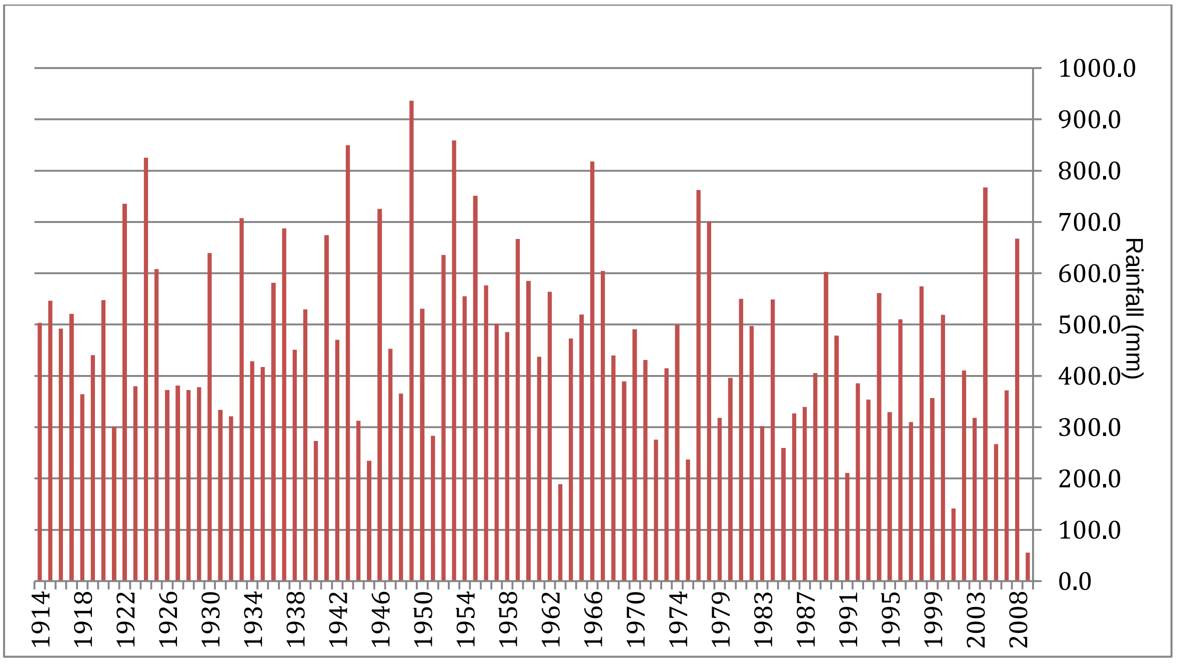
Tsumeb has an annual average rainfall of 478 mm (1914-2009). The annual rainfall in Tsumeb in this period is illustrated in Figure 5.

Table 1: Long-Term Average Monthly Temperatures in Tsumeb

	MINIMUM TEMP. (°C)	AVERAGE TEMP. (°C)	MAXIMUM TEMP. (°C)
January	19	25	31
February	18	24	30
March	17	23	29
April	15	22	29
May	11	19	27
June	9	16	24
July	8	16	25
August	11	19	27
September	16	24	32
October	19	26	33
November	19	26	32
December	19	25	32

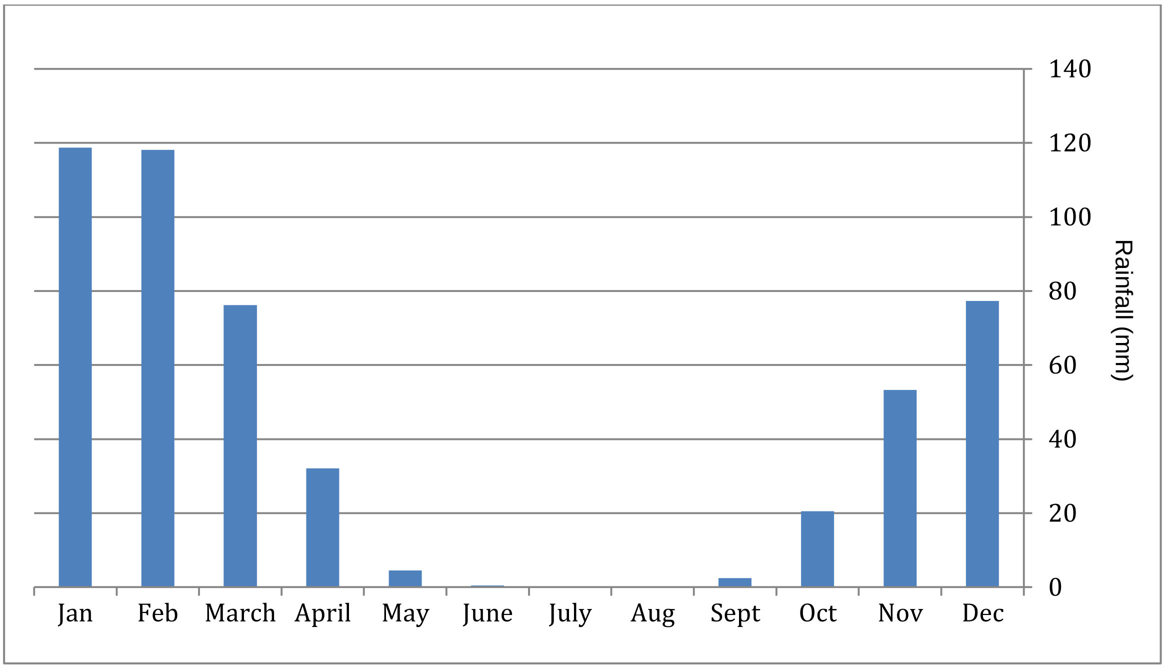
Source: Agro-ecological Zoning Project, Data from 1951-1989

Figure 5: Annual Rainfall recorded in Tsumeb (1914-2009)



Most of the rainfall occurs between October and April with January and February being the wettest months, both receiving an average of over 100 mm of rain. Average monthly rainfall (1914-2009) is shown in Figures 5 & 6.

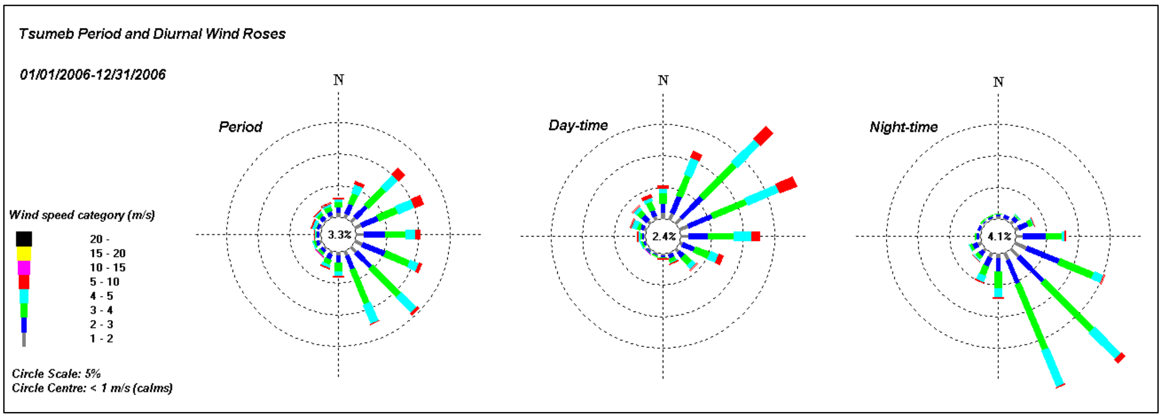
Figure 6: Average Monthly Rainfall Data recorded at Tsumeb (1914-2009)



Wind

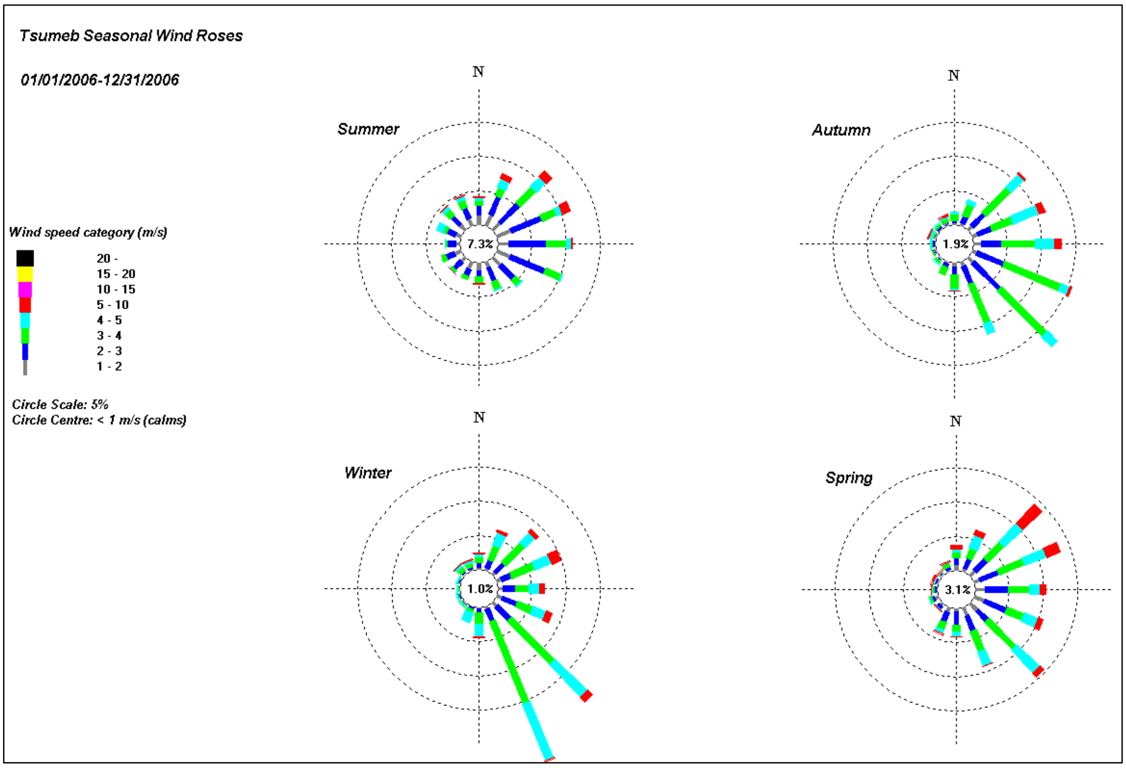
Prevailing winds in the Tsumeb area are predominantly from a south-easterly and south-south-easterly direction. During the day the wind is predominantly from the north east and during the night the wind shifts and blows from the south east. Wind direction and speed recorded at the weather station (2006) at the reservoir on the hill to the north of the Tsumeb Mine are shown in Figure 7. The windiest conditions are experienced in the drier winter months (May-August) – see Figure 8.

Figure 7: Tsumeb Period Average Wind Roses (2006)



Source: Airshed Planning Professionals (2011)

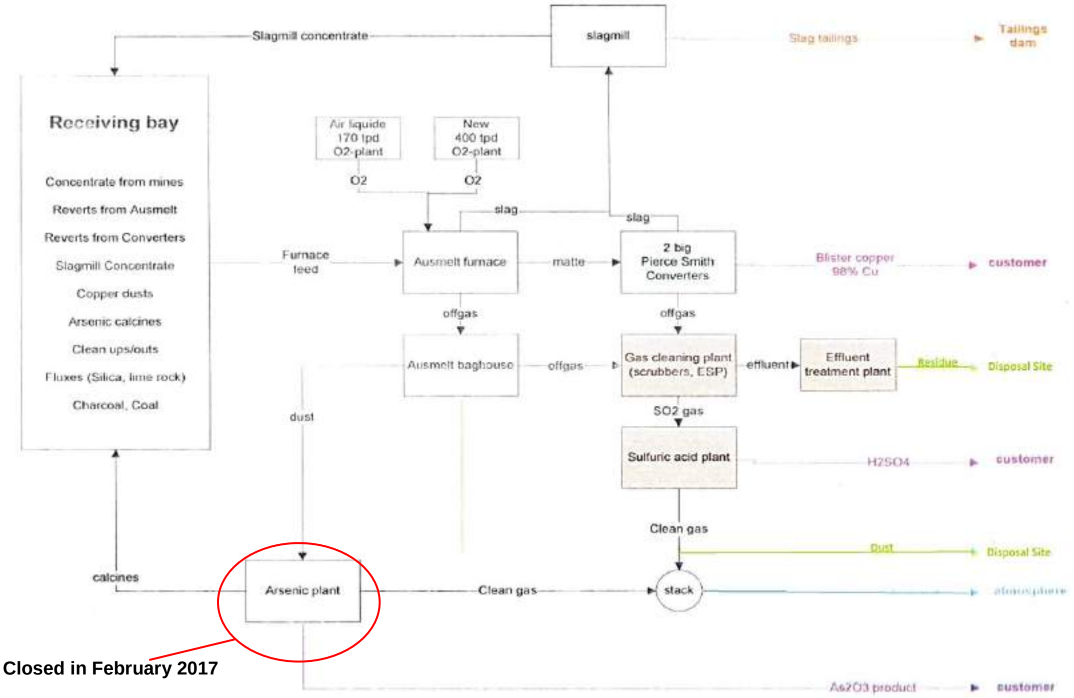
Figure 8:Tsumeb Seasonal Wind Roses (2006)



Source: Airshed Planning Professionals (2011)

2. OVERVIEW OF THE SMELTER PROCESSES AND PLANT OPERATIONS

Figure 9 : The production process



The key operational processes comprise the following:

Receiving Bay

The raw materials (which include coal, silica, concentrates and ore) are railed in mainly from Chelopech in Bulgaria and El Brocal in Peru, and offloaded at the receiving bay. These materials are stockpiled in different sections for use in the Ausmelt furnace. The necessary fuel, concentrates and additional materials are crushed and blended for introduction into the furnaces. The charge for the Ausmelt is pelletised in a small pelletising plant.

Top Submerged Lance (TSL) Furnace

The TSL furnace is charged with pelletized copper concentrates and fuelled with heavy furnace oil (the “Ausmelt”). Oxygen from the oxygen plant is injected into the Ausmelt furnace where it reacts predominantly with iron and sulphur through exothermic reactions.

The melt consists of two phases, namely matte (molten metal sulphide phase formed during the smelting of copper concentrate) and slag (silicate waste product from smelting) which are tapped separately at different elevations.

- Matte from the Ausmelt goes directly to the Peirce Smith converters (see below).
- The slag is transferred to the slow cooling process, then crushed and then transferred to the slag mill and float plant (see below).

Off-gases and fugitive gas management

- Off-gases from the Ausmelt pass through evaporative coolers and are then filtered through the baghouse where the dust which contains arsenic, is captured. The filtered gas containing sulphur dioxide (SO_2) is transferred to the sulphuric acid plant gas cleaning system.
- Fugitive gases from the tap holes and matte launder are captured and filtered through the hygiene baghouse and are released to the atmosphere via the copper stack.
- During start-up and shutdown or during emergency plant stoppages, gases from the Ausmelt are bypassed to the Ausmelt stack for short periods.
- Dust recovered at the baghouses was taken to the arsenic plant for processing until the first quarter of 2017. With the subsequent decommissioning of the arsenic plant, baghouse dust is disposed of at the Hazardous Waste Disposal Facility.

The Ausmelt furnace was refurbished to smelt copper concentrates and was re-commissioned in 2008.

Peirce Smith Convertor Furnace

Molten matte tapped off the Ausmelt furnace is transferred to a Peirce Smith converter furnace for the final production of blister copper. Here, air is added to the matte material and the oxygen reacts with sulphur, iron, lead and zinc. The sulphur from the metal sulphides provides the energy through an exothermic reaction to complete the conversion of matte to blister copper. The blister copper (98.5 % Cu) is cast into 1.62 tonne bars for shipment to refineries. The slag is transferred to the slow cooling process and is then crushed, or alternatively, if it contains large amounts of entrained matte, it is recycled to the converter for further smelting. The crushed material is transferred to the slag mill and float plant.

Off gases & fugitive gas management

- The hot primary off-gases (more than 90 % of the total gas stream) from the convertor pass through a wet scrubber gas cleaning system and the clean gas is directed to the sulphuric acid plant gas cleaning system.
- The remaining fugitive gasses that are captured during slag and matte tapping are passed through a balloon flue before being cooled in a series of U-tubes, followed by further cooling in the new gas cooling tower (installed in February 2010 in order to provide additional cooling of the gases before they pass through the convertor section of the copper baghouse, prior to being released through the copper stack at the southern section of the smelter and to allow arsenic to solidify). The ducting required to carry the off-gases was replaced in October 2010. The baghouse was also extended in February 2011 to increase its capacity.

The filtered gas containing SO_2 is transferred to the sulphuric acid plant gas cleaning system, where sulphuric acid is manufactured.

Slag mill

Slag is transferred from the Ausmelt and the convertors to the crushers, and the crushed material is transferred to the slag mill and float plant where the entrained valuable metals, consisting mainly of copper, are recovered. The concentrates produced are re incorporated into the smelting process. The tailings produced during the flotation process are deposited on the old mined section of the old tailings dam located south-west of the smelter.

Reverts

Some of the molten material that flows through launders and is transferred in ladles freezes on the walls of these transfer vessels and form coatings referred to as “skulls” or “shells”. The skulls, along with material that is inadvertently spilled, are collected as so-called reverts and are recycled to the Ausmelt.

Power Plant

Electrical power for the majority of the smelters operations was historically supplied by an on-site power plant. The power plant has been decommissioned in recent years and electrical power is drawn from the national grid as required. However, the cooling component of the power plant is still in use.

Oxygen Plant

The oxygen plant was commissioned in order to increase production at the Ausmelt. The oxygen plant extracts oxygen from air and produces oxygen (96% O2). The oxygen is injected into the Ausmelt furnace where it reacts predominantly with iron and sulphur through exothermic reactions. As a result of the additional heat in the Ausmelt it is possible to smelt greater quantities of copper concentrate and thus increase production. Burning of the sulphur in the concentrate also reduces the consumption of fuels such as coal and heavy furnace oils. The additional heat from the sulphur and oxygen provides for a higher smelting rate.

Arsenic Plant

The arsenic plant is used to produce arsenic trioxide from dusts recovered during the smelting process. Four roasters are used to convert the material into arsenic trioxide, which is sold for the manufacture of pesticides and wood treatment.

Concentrates and other secondary material processed at the smelter are traditionally high in arsenic. The majority of the arsenic passes through the smelter and is captured from the off-gases in the bag houses. Bag house dusts with high arsenic levels are used as feedstock for the arsenic plant. Bag house dusts that cannot be processed in the arsenic plant are disposed of in the hazardous waste disposal site. The arsenic plant is used to produce arsenic trioxide from dusts recovered during the smelting process. Four roasters are used to convert the material into arsenic trioxide, which is sold for the manufacture of pesticides and wood treatment.

The plant operates a two stage process, firstly converting the arsenic dusts into black arsenic and then producing 99% arsenic trioxide from the black arsenic. In the initial conversion the bag house dusts are mixed with coal fines and pyrite (or other sulphur-bearing material) and introduced to the roaster. In the second conversion the resulting black arsenic is mixed with coal and slag material and introduced to the roaster. During the roasting process arsenic sublimes and is then condensed as arsenic trioxide. Roaster calcines are formed as a by-product from the arsenic plant and are either dumped as waste or, if copper is present, returned to the smelting cycle.

Off-gases from the arsenic plant pass through a bag house before being released to the atmosphere through the same stack as the Ausmelt off-gases. Both the bag house and arsenic plant have been improved in recent years as per the currently approved EMP requirements. The original bag house was removed and replaced with a newer facility in order to improve efficiency. The arsenic plant has been improved in order to reduce dust emissions. This has primarily been achieved through the construction of a new dust transfer system, upgraded roasting and fume management facilities, bag-filling station and extraction system at the arsenic plant.
Update: The arsenic plant was decommissioned during February 2017 and arsenic trioxide is no longer produced by DPMT.

Sulphuric acid plant

The sulphuric acid plant was installed in 2014. The plant captures sulphur dioxide from the Ausmelt furnace and Peirce Smith converters and converts it to sulphuric acid for onward sale. The sulphuric acid plant has two main process steps – pre-treatment of gas (gas cleaning) and gas conversion. The gas cleaning plant processes off-gases containing a variety of impurities with different concentrations from two different sources, namely: the Ausmelt furnace and Peirce Smith converters. The gases from the smelter and the converter have different properties and impurity loads. While the gas from the smelter has already been cooled down in evaporation coolers and dedusted in a baghouse filter prior to the sulphuric acid plant, the gas from the converter

contains a high dust load depending on the blowing cycle of the copper converter.
The gases from the converter as well as the gas from the smelter are directly quenched and scrubbed in high efficiency scrubbers with an integrated quench section, each followed by a droplet separator and a fan. The gas streams from the converter and the smelter are combined and then treated in a common gas cooling tower and four wet electrostatic precipitators (WESP's).

The single-train sulphuric acid plant is based on the double absorption process, whereby the converter consists of three beds. After gas pre-treatment, the sulphur dioxide in the gas is converted to sulphur trioxide in a contact process that takes place in a catalytic converter, containing a vanadium pentoxide and caesium (final bed) catalyst. During this process the sulphur dioxide containing gas passes through a series of catalyst beds to achieve a high efficiency of conversion of sulphur dioxide to sulphur trioxide. The double contact double absorption technology allows removal of sulphur trioxide through absorption into 98.5% sulphuric acid. This occurs by means of exothermal chemical reactions.

Acid produced is stored in three bulk above ground tanks prior to transfer to railcars at the acid loading area and onward shipment by train. Site management reported that all acid is sold within Namibia. Blister copper is ultimately produced from the copper concentrate and delivered to refineries for final processing.

Waste sites (active and historical)

- Hazardous waste disposal site
- General waste disposal site
- Arsenic calcine dumps
- Blast furnace slag dump
- Old slag mill tailings dump
- Mine tailings dumps
- Tar pit
- RCC quarry operations

Ancillary operations include:

- Warehouses
- Engineering workshops
- Admin and support buildings
- New offices (container offices)
- Canteen
- Reservoirs
- Roads (gravel and tar); and
- Rail loop

At this time, approximately 550 employees are on site at any time; 480 permanent staff and 70 temporary staff.

3. THE POTENTIALLY AFFECTED COMMUNITY (PAC)

Community Health Hazards

Arsenic and SO_2 in air are the two principal hazards arising from fugitive emissions from the processing of complex copper concentrates at the Tsumeb Smelter that may affect the community. The arsenic content of airborne particulates as well as SO_2 gas present risks to the health of surrounding communities, notably respiratory health disorders including asthma, respiratory infections and cardiorespiratory insult, while Arsenic is a known cause of lung cancer.

Community Stakeholder Concerns

Since DPMT took over the smelter in 2011 there has been an active environmental monitoring programme for arsenic, dust and SO_2 in the air and groundwater at various points within, and at the boundary of, the smelter precinct. DPMT hired an occupational health consultant who reported in 2011 and noted that there was a minimal occupational health programme at that time. There was no industrial hygiene component at all, and there was a minimal occupational medical component comprising biomonitoring of arsenic in the urine of workers at the smelter. Working conditions at that time were poor with little in the way of any preventive interventions to minimise exposure or to detect any adverse occupational health effects at an early stage, whether from arsenic or SO_2. The report recommended, amongst other things, that a substantial industrial hygiene programme be established with immediate effect, together with a competent modern and ethical occupational medicine programme. These were duly instituted by DPMT.

There were also many complaints at that time by community residents, mostly with regard to respiratory problems, notably asthma, which they attributed to SO_2 pollution on a regular and frequent basis, especially when the wind blew from the smelter towards the town. The town is situated to the south of the smelter precinct and separated by a hill. The prevailing wind direction is from the North East and South East. The North East wind blows dust and gas over the Northerly and North Westerly parts of Tsumeb.

Three planning and stakeholder engagements were held in Tsumeb in August 2016 in preparation for the community study. I met with members of the community who had been publicly invited to attend one of 3 separate town hall meetings in Ondundu in the North East, The Makalani Hotel in the commercial district at the Northern end of town, and in the Nomtsoub community hall in the South West part of Central Tsumeb. Residents from all Tsumeb suburbs were alerted to the survey by Mr Isai Nekundi of DPMT's stakeholder department well before these meetings took place, and attendance was excellent, resulting in over 120 household representatives with over 440 potential survey respondents registering as being available for participation in the study. Two of these meetings were relatively straightforward with audiences appearing to be very interested and willing to cooperate in getting the survey done, including volunteering their own participation. Many questions were raised at these meetings and explanations were given in 4 languages.

The Makalani Hotel meeting, however, was rather different in that a number of community members present raised objections in an initially hostile and critical manner about the process that was being envisaged and was being presented at the meeting for the HIA. In particular, they did not want DPMT personnel to be involved in the survey in any way, as they did not trust DPMT personnel with the results. The DMPT representatives then recused themselves. I took over the chair of the meeting and was able to ask the objectors for their suggestions as to the way forward. I offered to recuse myself if the meeting felt that I was likely to be biased in favour of DPMT. I pointed out that at the end of the day it was going to be DPMT who would be paying my costs for the study I was conducting as part of a Government mandated EIA. The meeting then asked me not to recuse myself and to remain in charge of the study.

Opinions on other matters were divided. Some felt that since DPMT had taken over the smelter, there had been improvements with regard to SO_2 exposures, and further improvements over the past few months when it was widely agreed that emissions had declined substantially. DPMT was also praised for their various community contributions, including creating employment. Others at the meeting continued to view DPMT in a negative light.

Ultimately a pharmacist in the town offered to take charge of urine and tap water samples in his fridge during the survey and suggested that a system of community monitors be present throughout the survey to ensure that there was no tampering with the samples and that the questionnaires were fairly administered. Residents present offered to nominate potential monitors to assist with the taking of samples and securing their chain of custody until they reached the care of Pathcare, the laboratory service performing the analysis.

The meeting was happy for me to lead the survey process. There was also enthusiastic approval for a plan to get a number of Public Health students from the University of Namibia in Oshakati to conduct the interviews, and for community monitors to ensure the probity of the sample collection, thus ensuring independence from DPMT.

Attendees at the other two town hall meetings were quite happy with this proposed approach to the survey. Residents from different residential areas in Tsumeb volunteered to be community monitors and 6 of these were co-ordinated by Mr Moses Awiseb, a well-known community organiser in Tsumeb. They were present throughout the survey and acted as custodians of the questionnaire administration and sample collection processes and observed prompt delivery of samples to the custody of Pathcare during the period of data collection in September 2016.

Before and during the data collection phase, strangely enough, even though I had gone to considerable lengths to accommodate the Makalani objectors and there had been agreement by the end of the stakeholder meeting at the Makalani Hotel on how their objections would be handled, none of the objectors at that meeting participated in any way. They did not respond to attempts to contact them and failed to nominate community monitors as they had promised, withdrew offers to store the accumulated specimens in the pharmacy fridge, and were all unavailable as survey subjects during this phase, despite being encouraged to participate, in some cases by personal invitation.

The team of 6 community monitors headed by Mr Moses Awiseb, functioned seamlessly together with 6 UNAM public health students and myself to ensure that subjects on the register from the community engagement meetings were contacted and were available for participation in the survey; that questionnaires were administered impartially (the community monitors were there as interpreters and observers); and specifically they observed that urine and tap water samples were indeed taken on the spot from survey subjects and from their drinking water taps, and that specimen jars were immediately sealed and signed by both survey subjects and community monitors. These were then handed immediately to myself and taken directly to Pathcare at the Tsumeb Private Hospital where they were kept under lock and key (there were only 2 keys available - one for myself and one for the Pathcare Sister) in a locked fridge until despatch to the analytic laboratory in George, South Africa. Access to some of the more remote farms to the North of the smelter beyond NAMFO farms which was also volunteered and promised at the Makalani meeting did not materialise during the data collection period. This led to a waste of valuable survey time and slightly decreased the number of study subjects. I was present and exercised quality control and oversight throughout all stages of the survey in Tsumeb.

The principal concerns voiced by community residents in these various encounters were vague but were mainly about cancer, SO_2 irritation, and one report of a negative effect of SO_2 on a home garden.

Sensitive Community Receptors And Exposure Pathways

The entire community living in Tsumeb is affected by the operations of the smelter including people living on farms to the North and North West of Tsumeb town. Within Tsumeb, populations particularly likely to be affected are those at closest proximity to the smelter precinct which is immediately adjacent to the northern edge of town separated by a hill. The prevailing wind direction is Easterly with South Easterly and North Easterly winds predominating. Smelter emissions are driven westwards and alternatively northwards and southwards affecting the western industrial area and the northern part of town including Ondundu and the farms to the North West.

Oshakati residents several hundred kilometres to the north were also included as unexposed controls.

Children older than 10 and all adults of all ages were surveyed. There are two hospitals in Tsumeb, a private hospital in the Northern part of town, and a public hospital in Nomtsoub near the stadium. There are several schools, including a public and a private school in Ondundu, the most northerly residential area just below the hill behind which is the smelter and its waste disposal site.

Rather than estimating exposures from other routine sources, this study was able to directly measure accumulated arsenic doses from all exposure sources and pathways by using a biological measurement of arsenic absorption which therefore reflects individuals' integrated exposure irrespective of their age, gender, and occupational status. Similar considerations apply to respiratory health outcomes which were measured directly in this study. At the time of this survey, apart from the 5 air monitoring stations which are located at the boundaries of the smelter and within the town, there were no other independent air quality data, nor was there any modelling information available for use in this report, which could provide estimated airborne exposures beyond the monitoring stations. The Air Quality Impact Study[2] component of this EIA then became available in February 2017 after the writing of this report. By way of water samples, only 3 samples had been taken in 2016 from taps in Ondundu at the school and at a house.

In addition, the preliminary results of an ongoing Contaminated Land Assessment and recommendations for the Environmental Management Plan[3] became available in December 2016. Exposures of interest and their concentrations in different parts of Tsumeb have been estimated from soil

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[2] Appendix F: Air Quality Impact Study for the Proposed Expansion Project at Dundee Precious Metals Tsumeb Smelter. Report No: 16SLE01v2. N von Reiche. February 2017

[3] Preliminary results of the ongoing Contaminated Land Assessment and Recommendations for the DPMT Environmental Management Plan (EMP) IM Weiersbye. December 2016

samples done by DPMT and their boundary air quality results. These are marked as high, medium and low exposure zones and are superimposed onto a map of Tsumeb and surrounding areas as shown in Figure 10. It should be noted that this modelled map was not based on any substantial number of measurements outside of the smelter precinct proper, while the air quality study was based on data from the 5 permanent air monitoring stations at the boundary of the smelter precinct and within Tsumeb. Additionally the Atmospheric Dispersion Simulations for arsenic in PM_{10} show a plume that is mainly in the North Western direction from the smelter but which also has a distinct but much smaller southerly tail[4] which lies directly over Ondundu. These are due to the two prevailing wind directions. The modelled plume based on soil measurements from the CLA also shows Ondundu to lie mainly in a higher exposed zone than more southerly parts of Tsumeb.

The results of these two studies were therefore consonant showing that the western industrial area and the Northern Town industrial area (Topshop) are the most highly exposed areas in Tsumeb. Both are not residential. Together they form part of the high exposure zone (red) which overlaps with the smelter precinct itself. Next is a medium exposure zone which comprises the Endombo residential area to the West which is separated by a small hill form the Western Industrial Area and located at the Northern edge of Nomtsoub; and the Ondundu residential area to the East which abuts the hill on the other side of which is the smelter's waste disposal site. Together they form a medium exposure zone (orange) and are referred to in this report as Town North. Ondundu has two schools. The residential areas to the South of this zone comprising Nomtsoub to the West and the Eastern suburbs of Tsumeb fall into the low exposure zone (green) and are referred to collectively as Town Central. The area known as Kuvukiland to the South West of the town and furthest from the smelter was considered to be an even lower exposed area (but still green in the map) and is referred to as Town South.

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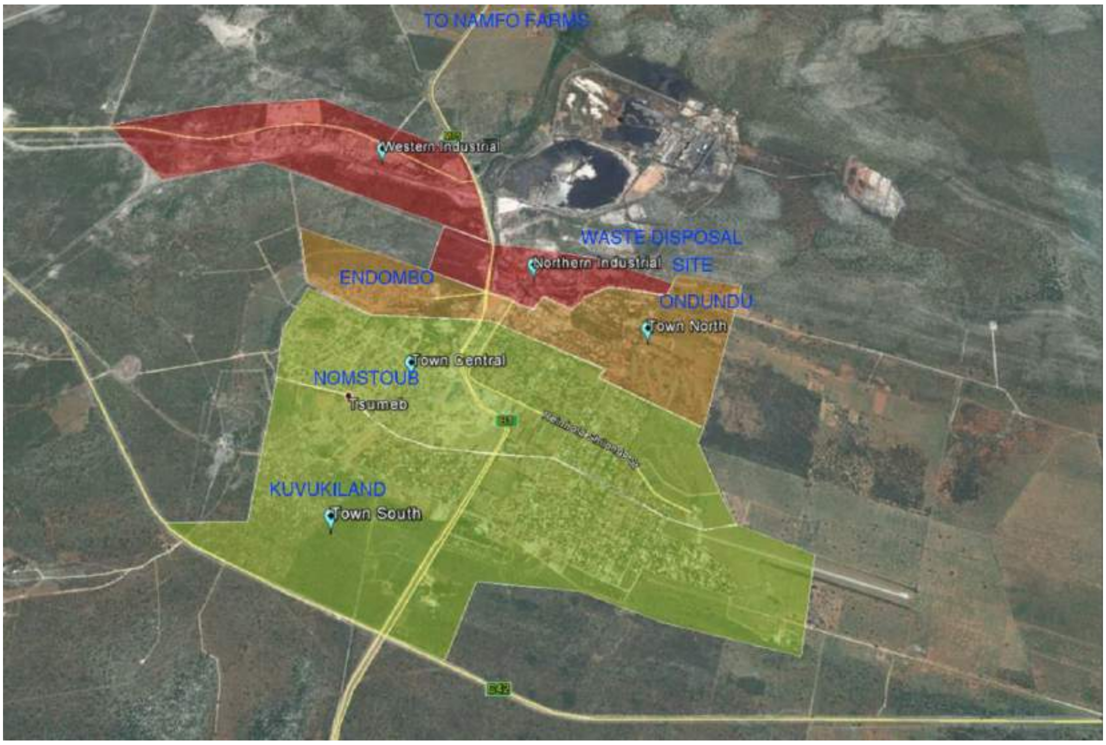
[4] Appendix F: Figures 32: Base scenario simulated 1 year average arsenic concentrations and and 35: Base scenario simulated long term arsenic deposition rates

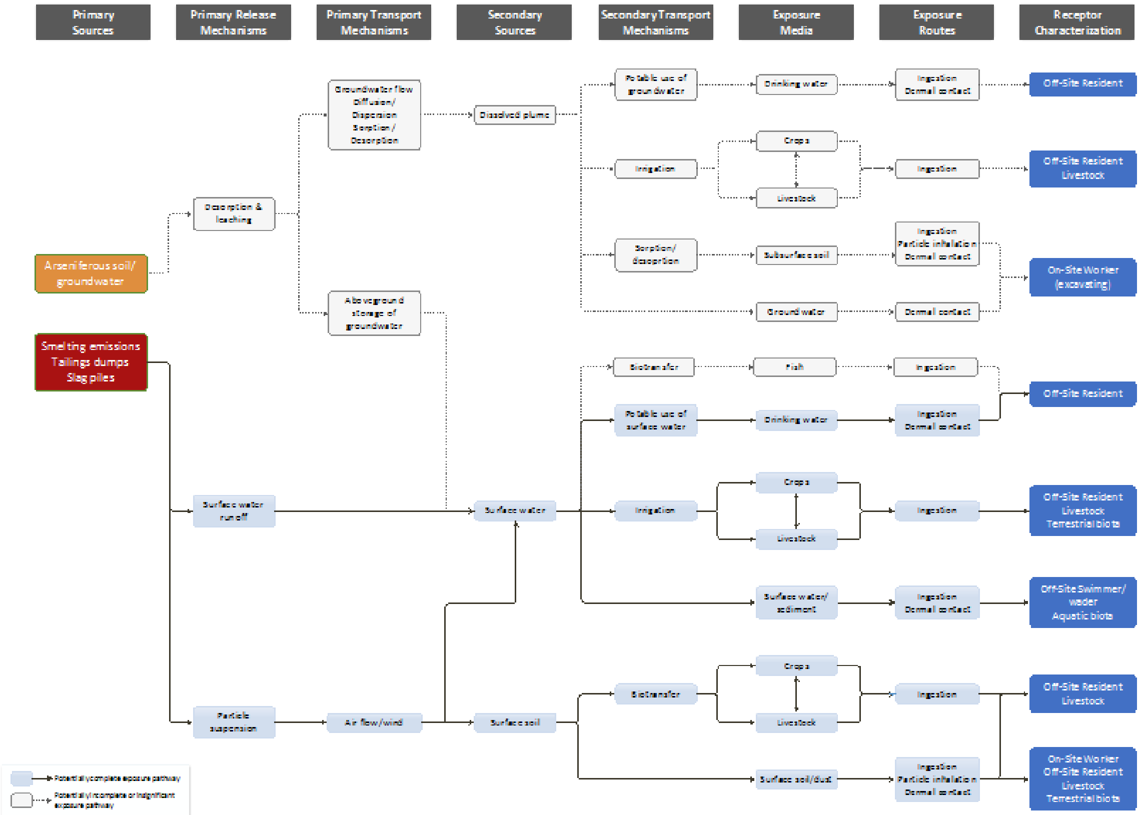
The last area is that of the NAMFO farms to the North West of the smelter and also in the path of wind dispersion of pollutants but further away from the smelter. Many farmworkers live and work there together with their families. A very few individuals were accessed in further outlying farms beyond NAMFO.

Figure 10: Exposure zones and residential suburbs in Tsumeb



The conceptual site model in Figure 11 shows the possible exposure pathways via air, water, soil, and crops. Arsenic that is deposited in the soil may be re-entrained as bioavailable inhalable or ingestible dust. These four pathways are impacted by behavioural determinants of arsenic absorption.

Figure 11: Conceptual site model showing sources and pathways of exposures to receptors.



4. LIMITATIONS

This report does not address classic occupational health concerns encountered by workers, which are referred to as 'inside the fence'. However, occupational health is addressed in Appendix 5 below.

In this study no household level data were obtained for the EHAs apart from EHA # 7 which constituted the specific objective for this study, and regarding which extensive individual data were obtained. Available data and information were sought from published sources to cover the other 11 EHAs. Consequently these data are indirect and rely to some extent on extrapolation from information in the Southern African region more generally, when they are not available for Namibia in particular. The same applies to health information from Windhoek the largest city in Namibia which is to some extent extrapolated to Tsumeb, when local information is not available.

5. METHODS

HIA METHODOLOGY

HIA is a structured planning and decision-making process for analysing the potential positive and negative impacts of programmes, projects and policies on public health. The HIA process is designed to:

- Provide a systematic methodology and process of how a project, policy or programme is potentially generating human health impacts;
- Predict the consequences (positive, negative or both) and distribution of these impacts across potentially affected communities, including vulnerable individuals or groups;
- Identify positive health effects while prioritizing the prevention of potential negative health effects;
- Be multidisciplinary in approach and use information from many different health providers, disciplines and allied technical fields, e.g. environmental, socioeconomics and human rights;
- Facilitate discussions across decision makers and key stakeholders; and
- Generate detailed baseline information that can be used to develop key performance indicators for future monitoring and evaluation.

An HIA can be a short desktop exercise that takes an expert practitioner less than 2 weeks to prepare, a rapid assessment that takes several months, or a comprehensive report that requires extensive fieldwork and data collection. Each type involves different approaches to baseline data collection and stakeholder engagement. The type of HIA chosen by the practitioner depends on a variety of factors including the type of project, the timeframe available for HIA completion, and the resources available for performing the HIA. The current study is a comprehensive HIA that involved collection of new data, and a participative and interactive process with a broad range of stakeholders across multiple levels of potentially affected communities.

The HIA can also assist in the planning process for health and social outreach programmes that extend beyond the fence line and into surrounding communities, e.g. capacity and institution building, health infrastructure support, information education and communication, vocational training, safe water projects and small-scale business (trade markets) infrastructure support. All of these programmes can provide positive and important health benefits, both in terms of strengthening public health services and enhancing household-level health outcomes, the latter being strongly associated with improved income generation.

HIA seeks to identify and estimate lasting or significant changes resulting from different actions on the health of a defined population. These changes can be positive or negative, intended or not, single or cumulative. Furthermore, the range of changes may or may not be evenly distributed across the population. The potential for uneven differences is a major concern for many impact assessment practitioners (including health) and is generally referred to as the 'assessment of equity'. The management and mitigation of potential health impacts is discussed in later sections of this report.

Environmental Health Areas (EHAs)

Given the broad definition of 'health', HIAs can potentially have extremely wide scope and latitude. The underlying philosophical model of the HIA often drives the scope of the HIA. The two traditional models of health are biomedical and social or socio-environmental. The biomedical model of health focuses on disease and illness, and related causal mechanisms. In contrast, the socio-environmental model tends to focus on the broader factors or determinants that shape and influence health and well-being. Health determinants are personal, social, cultural, economic and environmental factors that influence the health status of individuals or defined populations. Examples include age, sex, genetic factors, air, water, housing conditions, income, employment and education.

A third model/perspective known as 'ecosystems services' is also gaining traction particularly with environmental practitioners. The ecosystems services perspective received a substantial boost as the 2012 International finance corporation (IFC_ Performance Standards update included specific language regarding ecosystem services in Performance Standard 6, *Biodiversity Conservation and Sustainable Management of Living Resources.* There is a continuous effort to link biomedical and socio-environmental models and ecosystem services. According to the IFC, ecosystem services include:

- Provisioning services: e.g. food, fresh water, timber, fibres, medicinal plants;
- Regulating services: e.g. surface water purification, carbon storage, climate regulation, protection from natural hazards;
- Cultural services: e.g. natural areas that are sacred sites, or important for recreation, aesthetic enjoyment; and
- Supporting services: e.g. soil formation, nutrient cycling, and primary production.

The ‘typical scope’ for an HIA, particularly in sub-Saharan Africa, is driven by the World Bank’s in depth analysis (Listorti and Doumani, 1991) of the relationship and potential linkages between infrastructure-related activities and overall environmental health, i.e. a significant improvement (up to 50% improvement in key health performance indicators) can be achieved by improvement in community and regional area improvement across four key sectors. Sectors defined by the World Bank are: housing; water and food; transportation; and communication and information management. This integration of health and infrastructure is compatible with the design and execution of large, capital-intensive extractive industry projects in low and middle human development index (HDI) settings.

The environmental health perspective represents a shift from a disease-specific focus (e.g. malaria) toward an examination of the relationships between overall disease burden and infrastructure impacts. There are twelve defined EHAs (Table 2) that are traditionally utilized within an HIA. EHAs are a standard set of health effects categories that have been developed by both the extractive industries sector and international multilateral lending institutions (IPIECA, 2016; IFC, 2008, 2012).

Table 2: Environmental Health Areas (EHAs)

	Environmental Health Areas
1	Housing and Respiratory issues – acute respiratory infections (bacterial and viral), pneumonias, tuberculosis; respiratory effects from housing, overcrowding, housing inflation.
2	Vector-related disease – malaria, dengue, Chikungunya, schistosomiasis and ectoparasites, etc.
3	Sexually transmitted infections – HIV/AIDS, syphilis, gonorrhoea, Chlamydia, hepatitis B.
4	Soil, Water, Sanitation and Waste related diseases – e.g., giardia, hook and pin worms, etc.
5	Food and nutrition related issues – Changes in subsistence practices; stunting, wasting, anaemia, micronutrient diseases (including folate, Vitamin A, iron, and iodine), gastroenteritis (bacterial and viral); food inflation, etc.
6	Accidents/injuries – road and marine traffic related spills and releases, construction
7	Exposure to potentially hazardous materials – road dusts, air pollution (indoor and outdoor related to industrial activity, vehicles, cooking, heating or other forms of combustion/incineration), landfill refuse or incineration ash, any other project related solvents, paints, oils or cleaning agents, by-products.
8	Social Determinants of Health (SDH) – psychosocial, resettlement/relocation, violence, and security concerns, substance misuse (drug, alcohol, smoking), depression and changes to social cohesion.
9	Cultural health practices – role of traditional medical providers, indigenous medicines and unique cultural health practices.

	Environmental Health Areas
10	Health services infrastructure and capacity – physical infrastructure, staffing levels and competencies, technical capabilities of health care facilities and Program management delivery systems – coordination and alignment of the project to existing national and regional level health programmes, (e.g., TB, HIV/AIDS, Non-communicable Diseases such as diabetes and hypertension), and future development plans.
11	Non-Communicable Diseases – hypertension, diabetes, stroke, and cardiovascular disorders.
12	Zoonotic Diseases – animal to human disease transmission; potential disease distributions secondary to changes in animal migration patterns due to project-related activities or infrastructure.

EHAs have been developed to capture a variety of determinants of health. The EHA approach includes all of the biomedical and social concerns originally developed by key international health and development agencies, i.e., the World Health Organisation (WHO) and the World Bank Group. In general, while each EHA may not be relevant for a given project, it is still important to systematically analyse the potential for project related impacts (positive, negative or neutral) across the various EHAs.

Regardless of whether EHAs, the ecosystem services framework, or determinants of health are utilized, the critical objective is that the HIA utilizes a systematic methodology that is compatible with environmental, social and human rights impact assessment strategies. This focus on compatibility is important to ensure that the HIA is viewed as an integral and essential part of the overall impact assessment process, regardless of whether the HIA is a stand-alone report or part of an EIA. Overall, the DPMT expansion study utilizes the EHA methodology for evaluating potential project related impacts.

The study approach will also include:

A Baseline Health Study With Emphasis On EHA #7

The other EHAs were assessed indirectly from published sources, as this was not the main thrust of the study and no household survey data were obtained other than those required for the community survey for EHA # 7, nor were they available from other sources at the time of community study.

General Objectives

The purpose of this Health Impact Assessment (HIA) is to assess potential health-related impacts associated with the DPMT expansion project. It can be used to inform key DPM decision makers, relevant Namibian Government authorities, other relevant stakeholders and to provide DPMT with information to help identify management and mitigation measures. These mitigation measures aim to avoid, minimise and reduce potential health impacts as identified below.

Impact Assessment

The data from the literature review and survey provided an objective basis for assessing potential DPMT expansion project impacts.

In general, impacts exist in two broad categories:

Within a project span of direct control, i.e., it will be controlled both in a technical and managerial way by a project.

External to immediate project control and often require either:

- Contractor and sub-contractor co-operation;
- Government involvement and participation.

While this distinction is crucial in developing roles and responsibilities for mitigatory actions, it is less critical in the overall assessment of potential project impacts.

Each potential health risk has several different dimensions. These include:

Nature – direct, indirect, or cumulative; defined as:

- Direct – caused by an action and occurring at the same time and place;
- Indirect – caused by an action and occurring later in time or farther removed in distance, but still reasonably foreseeable;
- Cumulative – caused by an action and when added to other past, present and potential actions, may become collectively significant over a period of time.

Timing and duration – when (project phase) (i.e., construction, operations, decommissioning) and how long (i.e., days, weeks, months, years).

Frequency – the overall rate of occurrence within the defined time duration.

Extent – localities most likely to experience the projected impact (i.e., local, regional, national).

Magnitude – intensity, particularly with regard to existing baseline conditions.

Significance – perception of risks by a potentially affected community.

Manageability or ability to influence risk responses ('proactive' or 'reactive')

- High manageability – within the control of the Project Management team. Can control probability or impact (or both);
- Medium manageability – Within the influence of the Project Management team. Can influence probability or impact (or both);
- Low manageability – Outside the influence of the Project Management team. Can only influence impact.

The analysis assumes a "base case scenario", i.e., mitigation measures are not in place. This is standard HIA practice,

The results of the HIA are used in order to develop a Health Management Plan (HMP). The HMP is often a standalone report that develops specific plans to efficiently and effectively manage the potential impacts identified in the HIA. Within the structure of formal mitigation actions, the rating and ranking process is repeated using the risk matrix presented in the HIA. The goal of the mitigation strategies is to reduce potential consequence and likelihood to a level that is reasonable and practical.

Risk Rating and Ranking Process

The initial step is identification of potential high-level impacts. This is accomplished by reviewing the "Project-Place-Potentially Affected Communities" within the context of the available baseline health data and the set of defined environmental health areas (EHAs) listed in Table 2. The EHA methodology has been developed over the last two decades and is a well established strategy for analyzing potential project impacts on communities.

Risk Assessment Methods

The risk assessment process is driven by a conjoint analysis of consequence (severity) and likelihood (probability). Consequence and likelihood are defined and then combined into a matrix so that a specific impact risk can be assigned a consistent numerical value. The matrix and its consequence and likelihood inputs are based on established and practical methods that have been utilized by the HIA team across other international extractive industry projects. All risk matrices have limitations and because of the consequence terminology (e.g., high, moderate, low, etc.) tend to "overstate" actual risks as experienced by communities. Hence, the risk matrix analysis is best utilized to help focus and prioritize mitigation and management efforts.

For the DPMT expansion project HIA risk analysis, consequence has been divided into five levels of increasing severity based on general health outcomes:

1. *Insignificant or nuisance effects* - fully reversible and not requiring medical treatment; Example - headaches, sneezing, cough, eye irritation not requiring formal medical evaluation and reversing rapidly;
2. *Minor* - reversible health effects requiring treatment or medical visit/consultation; Example - Isolated short term complaints from households, e.g., noise, odours, headaches, cough, etc.
3. *Low* - reversible effects but associated with temporary impairment requiring treatment and care; Example- Health claims at local clinic, e.g., headaches, sneezing, cough, eye irritation, etc.
4. *Moderate* - irreversible health effects resulting in long-term impairment to an individual and/or multiple members of a household or community; at a community (population) level change in morbidity outcome by 10-30% over baseline;
5. *High* - severe irreversible (immediate or chronic) health effects resulting in permanent impairment and/or death to multiple members in a household and/or community; Example- major road traffic accident; major explosion or chemical release; dam failure; change in morbidity outcome by 30% over baseline with permanent impairment and/or death;

Likelihood has been divided into five numerical levels of decreasing likelihood 5 to 1.

Level – Description - Criteria:

5. *Certain* - will occur within; daily or monthly; will occur during construction phase and during operations; >90% occurrence.
4. *Likely - expected to occur; monthly to annual; has frequently been documented in similar projects; occurrence noted during construction phase in similar projects; 60-90% occurrence*
3. *Possible - event will occur under certain circumstances; could occur within a 5 year period; has occurred in similar projects in the same settings; 30-60% occurrence;*
2. *Unlikely - event has occurred within the industry; could occur in a 5-10 year period; 10-30% occurrence;*
1. *Rare - event has rarely occurred in the industry or may occur under exceptional circumstances; could occur within a 10-30 year time frame; <10% occurrence;*

The consequence-probability scales are combined into a 5 x 5 matrix. In the "5 x 5" matrix, numbers are assigned to each box to create a quantitative scale of the likelihood weighted impact. This allows for an overall ranking of potential risks. The numbers (1 - 25) reflect the relative levels of risk (risk rating):

- Minor 1 - 5
- Low 6 - 10
- Moderate 11 - 17
- High 18 - 25

The 5 x 5 risk matrix is shown below:

Figure 12: HIA 5 x 5 Risk Matrix

HIA 5x5 Risk Matrix					
Likelihood	Consequence				
	1 Insignificant	2 Minor	3 Low	4 Moderate	5 High
5 Certain	*Moderate (11)*	*Moderate (16)*	*High (20)*	*High (23)*	*High (25)*
4 Likely	*Low (7)*	*Moderate (12)*	*Moderate (17)*	*High (21)*	*High (24)*
3 Possible	*Minor (4)*	*Low (8)*	*Moderate (13)*	*High (18)*	*High (22)*
2 Unlikely	*Minor (2)*	*Minor (5)*	*Low (9)*	*Moderate (14)*	*High (19)*
1 Rare	*Minor (1)*	*Minor (3)*	*Low (6)*	*Low (10)*	*Moderate (15)*

The risk dimensions are also utilized in the overall rating and ranking process as inputs into determining the consequence level. Likelihood rating draws upon both professional experiences with other similar projects for which similar information is available.

COMMUNITY RESIDENTS STUDY METHODS

The study approach will include:

Hazards Assessment

This will be undertaken on the basis of existing routine data from DPMT occupational and environmental monitoring programmes, specialist reports, information from the international literature, and direct measurements from a community health study conducted in September 2016 in Tsumeb.

Exposure Analysis

Potential sources of exposures and pathways to community receptors that could give rise to health risks as a result of activities at, or associated with, the smelter will be identified.

Risk Characterisation

Health risks are characterised using internationally recognised exposure guidelines, by analysing the results of a questionnaire measuring respiratory health status as well as other health-related variables, and by laboratory analysis of arsenic in residents' drinking water and urine.

Risk Management

Recommendations for appropriate mitigation measures to reduce potential health impacts as well as future occupational and environmental monitoring needs will be made.

Different management scenarios and their health implications going forward will be discussed. These cover the current baseline scenario and projected future scenarios in which production throughput increases by 54%.

The Community Health Study providing both exposure and health data directly from Tsumeb residents forms a major aspect of this HIA. The study measures total as well as inorganic arsenic absorption levels among Tsumeb residents and unexposed controls from Oshakati by determining the levels of total and inorganic arsenic in their urine. It also measures total environmental arsenic in drinking water available to them and also respiratory health symptoms.

The availability of biological data makes this a high order HIA, and allows examination of the relationships between environmental exposures to PM_{10}, SO_2, airborne arsenic in PM_{10}, arsenic in drinking water, the absorbed dose of biologically available arsenic of inorganic (anthropogenic) origin, respiratory health indicators, and various relevant variables potentially confounding or modifying these relationships between exposures and adverse biological and health effects (e.g. diet, proximity to the smelter).

Only the operational phase is addressed in this impact study.

The HIA was originally finalised in 2016. Based on comments received on the Draft Environmental Impact Report distributed in 2017 and recommendations for further investigations made in the 2016 HIA, this report was updated during the first quarter of 2018 in order to include additional information on potential arsenic exposure pathways. Analyses of ambient air quality and occupational health data were also updated with 2017 data. Following a further review by the EBRD, the report was again updated in 2019 in order to comply with European standards and the EBRD Performance Requirements.

Various sources of routine data and survey methods along with findings are described below.

A cross-sectional exposure control study was conducted of residents in Tsumeb and surrounds constituting the exposed area, and Oshakati as the control area.

Sampling methods evolved from a register kept at the three town hall meetings to discuss the study. All those interested in participation were encouraged to sign a register and provide their addresses and mobile telephone numbers and the number of people over 10 years of age in their households.

The community monitoring team then contacted all of them and set a date and time for a house visit in order to survey them.

An attempt was made to balance the number of individuals and households across three presumptive exposure zones, medium, low and very low, orresponding to Town North, Town Central and Town South with additional representation at the NAMFO farms and some further outlying farms, and of unexposed controls in Oshakati at considerable distance from Tsumeb and the smelter. The intention was to interview some 270 people in their corresponding households and to obtain a urine sample from each individual and one tap water sample per household surveyed. Where those registering were not home on the day of the survey, nearby neighbouring households were accessed instead.

The questionnaires (See Appendix 2) were administered by Public Health students from the University of Namibia School of Public Health at Oshakati.

A glossary (See Appendix 3) lists the names of the variables analysed.

ICP-MS was performed in a laboratory that is SANAS accredited and certified to conduct urinary arsenic testing to ascertain the total arsenic in urine and drinking water samples. Column chromatography was used to determine the proportion of arsenobetaine, an organic form of arsenic arising from dietary sources in the urine. The inorganic arsenic fraction was then derived by subtracting the arsenic in arsenobetaine from the total arsenic measured by ICP-MS. All urinary arsenic values were corrected for urinary creatinine levels. Samples with urinary creatinine levels outside the reference range of 0.34-3.4 g/L were not included in the ensuing analysis. Detailed methods are provided in Appendix 4.

STATA 12 was used for statistical analysis. Univariate distributions of key variables such as the various arsenic in urine parameters were examined for Tsumeb as a whole, within the various exposed areas within Tsumeb, including the farms, and for Oshakati as a whole. Distributions of variables were examined graphically using box plots. Arithmetic and geometric means and their percentiles were estimated in order to better understand exposure outliers. Bivariate comparisons were undertaken to compare different suburbs within Tsumeb, and between Tsumeb as a whole with Oshakati, and to examine the relationship of arsenic in urine levels with age, gender, dietary and other relevant variables. Where appropriate, known or suspected variables that may have confounded or modified associations between geographical location and urine arsenic levels were adjusted for using multiple linear regression analysis. Significance testing was used for comparisons and trends, and in all cases the convention of a p-value of < 0.05 was used to assess the relevance of statistical testing.

Ethical approval and governmental permission were obtained prior to the study from the University of Cape Town Health Sciences Faculty Human Research Ethics Committee (Approval number: HREC REF 277/2016); and from the Office of the Permanent Secretary for Health of the Namibian Ministry of Health, Windhoek, Namibia.

After explaining the survey in detail and providing written information, signed informed consent was obtained for all participants, and by the parents of those under the age of 18 but older than 10 years.

Each household was provided with a N$100 food voucher in recognition of some inconvenience to them resulting from their participation in the study.

RESULTS

NAMIBIAN HEALTH PROFILE FOR EHA 1 - 12

In line with the EBRD requirements, Table 3 below sets out an analysis of the twelve EHAs in a Namibian and Tsumeb context.

Table 3: Results for the 12 EHAs

	Environmental Health Areas
1	Housing and Respiratory issues – acute respiratory infections[5] (bacterial and viral), pneumonias, tuberculosis; respiratory effects from housing, overcrowding, housing inflation. ▪ There will be a considerable local workforce recruited from Tsumeb and surrounds. ○ Communicable respiratory diseases are a significant concern, as there is a significant burden of disease component of respiratory diseases, including TB, influenza, acute upper and lower respiratory infections. These are aggravated by respiratory irritation by SO_2 exposures throughout the affected area. ○ TB is the manifestation of HIV/AIDS, and HIV prevalence[6] is around 17% ○ Indoor cooking is a source of fine fraction particulate exposure ▪ Project induced in-migration (employment seeking) is a significant issue in Tsumeb. ▪ Resettlement might be an issue for people living in historically polluted areas viz Ondundu. Municipal resettlement plans for the Soweto population to Ondundu should be scrapped. This includes decommissioning of the

[5] IHME Namibia profile for Burden of Disease, http://www.healthdata.org/namibia, accessed January 2019

[6] Ministry of Health and Social Services, Namibia. Surveillance report of the 2016 national HIV sentinel survey

	Environmental Health Areas
	community gardens and light industrial scheme south of Ondundu. Resettlement plans can be impacted, positively or negatively depending upon the post-resettlement housing situation and access to health care ▪ There is serious pressure on housing inflation in Tsumeb. The hitherto formal area of Ondundu is already impacted by Kombushus (Shacks) that have been erected, many in back yards, and some self standing at the margins of the formal housing area. There has been considerable expansion of shacks in the Kuvukiland informal settlement which now encroaches on the old Tsumeb West mine property. There is also pressure on housing and most likely overcrowding in the Endombo Hostel environment . A further complication with the latter is that there is uncertainty regarding ownership and tenure in Endombo and a lawsuit is underway launched by a single owner who is attempting to take control over an area that houses many hundreds of residents. Soweto to the south of Nomtsoub is a densely populated shack area reeking of sewage. Nomtsoub comprises formal housing and does not appear to be as densely populated as the other areas.
2	Vector-related disease – malaria, dengue, Chikungunya, schistosomiasis, and ectoparasites, etc. ▪ These do not appear to be a problem in Tsumeb
3	Sexually transmitted infections[7] – HIV/AIDS[8], syphilis, gonorrhoea, Chlamydia, hepatitis B. ▪ 2017 Burden of Disease data in Namibia shows that major infectious disease viz. HIV/AIDS[9] & TB, neonatal disorders, diarrhoeal and lower respiratory tract infections, are responsible for the greatest proportion (68%) of the BoD. HIV and TB alone are responsible for just under half (46%). This is followed by injury which is responsible for 15% of the BoD and is due to interpersonal violence and road traffic crash in equal proportions. The third large component (17%) is due to non-communicable diseases viz heart attack, stroke and diabetes. ▪ There is a high prevalence of HIV in Tsumeb reaching 14.5% based on 100% sampling in Tsumeb of pregnant women. The overall proportion in Namibia was 17% ▪ Hepatitis B and C are common in Namibia ▪ in-migration might then result in a slightly higher prevalence of HIV/AIDS and may add to the STI burden ▪ Behavioural changes secondary to increases in disposable income in a context of high unemployment, inequality and poverty would aggravate this situation.

[7] IHME Namibia profile for Burden of Disease, http://www.healthdata.org/namibia, accessed January 2019

	Environmental Health Areas
4	Soil, Water, Sanitation and Waste related diseases – e.g., giardia, hook and pin worms, etc. ▪ Water and sanitation-related[10] diseases are high as sewage and waste disposal infrastructure utilities are lacking especially in the informal areas like Kuvukiland ▪ Concerns related to secure safe drinking water and bathing water in informal areas and limited access to water even in formal areas like Ondundu ▪ Open defecation by residents in informal areas is the norm leading to increases in fecal oral diseases in particular Hepatitis A and E. In Kuvukiland children play in the rubbish dump and open defecation is done nearby in areas which are used for wood collection and are on West Tsumeb mine property.
5	Food and nutrition[11] related issues (Food Security[12]) • Despite being an upper middle income level country it has a high (23.8%) prevalence of chronic malnutrition[13] in children under 5 years in 2015. ▪ Changes in subsistence practices have likely resulted in stunting, wasting, anaemia, micronutrient diseases (including folate, Vitamin A, iron, and iodine), gastroenteritis (bacterial and viral) and food inflation. ▪ There was an epidemic of Hepatitis E in 2018 • Few changes in nutrition status are anticipated as a result of the expansion project

[8] CDC Global Health – Namibia. https://www.cdc.gov/globalhealth/countries/namibia/default.htm. Accessed January 2019.
[9] WHO. Global Health Observatory data. Country profile for Namibia. https://www.who.int/gho/countries/nam/country_profiles/en/, accessed January 2019
[10] IHME Namibia profile for Burden of Disease, http://www.healthdata.org/namibia, accessed January 2019
[11] World Food Programme. Namibia profile. https://www1.org/countries/namibia. Accessed January 2019.
[12] The state of food insecurity in Windhoek, Namibia. Pendleton et al., African Food security urban network (AFSUN), 2012. Urban food security series no. 14. ISBN 978-1-920597-01-6
[13] IHME Namibia profile for Burden of Disease, http://www.healthdata.org/namibia, accessed January 2019

	Environmental Health Areas
6	Injuries[14] – road traffic related injuries[15] with or without spills and releases (e.g., fuel oil) ▪ The incidence of road traffic fatalities is high in Namibia and Southern Africa as a whole at about 27 per 100 000 with substantial and severe ensuing morbidity. Collisions with wild animals crossing the road (warthogs,antelope) are relatively frequent. ▪ The expansion would lead to some increased risk due to increased traffic into and out of Tsumeb and within Tsumeb itself.
7	Exposure to potentially hazardous materials – road dusts, air pollution (indoor and outdoor related to industrial activity, vehicles, cooking, heating or other forms of combustion/incineration), landfill refuse or incineration ash, any other project related solvents, paints, oils or cleaning agents, by-products. ▪ The principal exposures are arsenic from the smelting process and processing of arsenic itself, SO_2 exposures and waste disposal of arsenic ▪ Air quality will be worse in the dry season; ▪ Project activities could result in leaks, spills or other releases of potentially hazardous materials. This is mainly SO_2 and disturbance of toxic waste dumps from prior historical activity by human activities including traffic, gardening etc.
8	Social Determinants of Health[16] (SDH) – psychosocial, resettlement/relocation, violence, and security concerns, substance misuse[17] (drug, alcohol, smoking), depression[18] and changes to social cohesion. ▪ Indirect effects, positive and/or negative associated with employment and incomes[19] are anticipated. ○ Behavioural changes (alcohol[20], drugs, tobacco) related to increases in disposable income ○ Sexual behavior changes associated with increases in income ○ Increase in the population loosens social bonds and could result in an increase in interpersonal violence and injury and traffic crash injury

[14] IHME Namibia profile for Burden of Disease, http://www.healthdata.org/namibia, accessed January 2019
[15] Namibia National Road Safety Council (data from 2012)

	Environmental Health Areas
9	Cultural health practices – role of traditional medical providers, indigenous medicines and unique cultural health practices. ▪ Extensive use made of local plants and materials for cultural purposes ▪ Extensive use of traditional healers ▪ Land contamination with arsenic could play a role in arsenic exposures.
10	Health services infrastructure and capacity[21] – physical infrastructure, staffing levels and competencies, technical capabilities of health care facilities and Program management delivery systems – coordination and alignment of the project to existing national and regional level health programmes, (e.g., TB, HIV/AIDS, Non-communicable Diseases such as diabetes and hypertension), and future development plans. ▪ The Healthcare Access and Quality (HAQ) index from Institute of Heath Metrics and Evaluation (IHME) shows that in 2016 it stood at 45%of expectation. This compares with Sweden at 95.5% in 2016. ▪ Health expenditure in 2015 was estimated to be $1 033 per person with an expectation of $ 1 260 in 2040. 63% govt, 20% private, 8.5% out of pocket, 8% development assistance for health. Sweden total is 5 550 84%, 1%, 15% and 0% respectively. ▪ Private health care and public health services are available in Tsumeb at both primary and hospital levels. ▪ DPMT provides medical aid cover for high level employees but not for all workers. ▪ There is no DPMT HIV/AIDS programme. ▪ The proportion of HIV+ pregnant women in Tsumeb is 42% compared with 62.5% for Namibia as a whole. This despite a higher prevalence of 14% in Tsumeb compared with 6% in cities like Windhoek. ▪ The high HIV prevalence together with low healthcare coverage are of concern.

[16] Social Determinants of Health from the African Regional Office of the WHO Namibia profile. http://www.aho.afro.who.int/profiles_information/index.php/Namibia: Social_determinants. Accessed January 2019.
[17] Atlas of substance use disorders. Country Profile: Namibia. WHO 2010.
[18] Mental health Atlas 2011 - Department of Mental health and Substance Abuse, WhO.
[19] Namibia Household Income and Expenditure Survey (NHIES) 2015/2016 Report. Namibia Statistics Agency.
[20] WHO Alcohol fact sheet. WHO 2014.
[21] IHME Namibia profile for Burden of Disease, http://www.healthdata.org/namibia, accessed January 2019

	Environmental Health Areas
11	Non-Communicable Diseases[22] – hypertension, diabetes, stroke, and cardiovascular disorders. • The impact of the expansion is unlikely to affect these NCDs in any major or direct way. • Indirect effects, i.e., individual changes in lifestyle and behaviours (diet, smoking, exercise, etc.) are likely with increased income, but high unemployment would lessen the impact at the community level • Shift to NCDs may already be underway and will likely increase with higher wages and rising standards of living. • Local community clinics are not trained or generally not experienced to diagnose and manage NCDs • NCD cases must seek diagnosis and treatment at the hospital facility level which places a long-term burden on these facilities.
12	Zoonotic Diseases – animal to human disease transmission; potential disease distributions secondary to changes in animal migration patterns due to project-related activities or infrastructure. • Zoonotic disease transmission is not well documented; however, there is close proximity and interaction between households and animals – especially goats and chickens which feed on ground contaminated by arsenic and other heavy metals in specific locations related to historical mining and smelting sites

[22] IHME Namibia profile for Burden of Disease, http://www.healthdata.org/namibia, accessed January 2019

RISK RATING RESULTS FOR EHA 1 -12

Rating and Ranking Specific Project Risks

Each of the EHAs is analysed using the multi-step process previously described. Effective mitigation strategies that are successfully implemented can substantially reduce overall impact ratings. The impact analysis exercise is to identify and highlight potential risks in a base case scenario setting, i.e., mitigation has not been added. In the HMP, the risk rating and ranking is repeated after a series of mitigation strategies are applied in order to demonstrate the potential effectiveness of the interventions.

EHA#1 Housing and Respiratory Issues

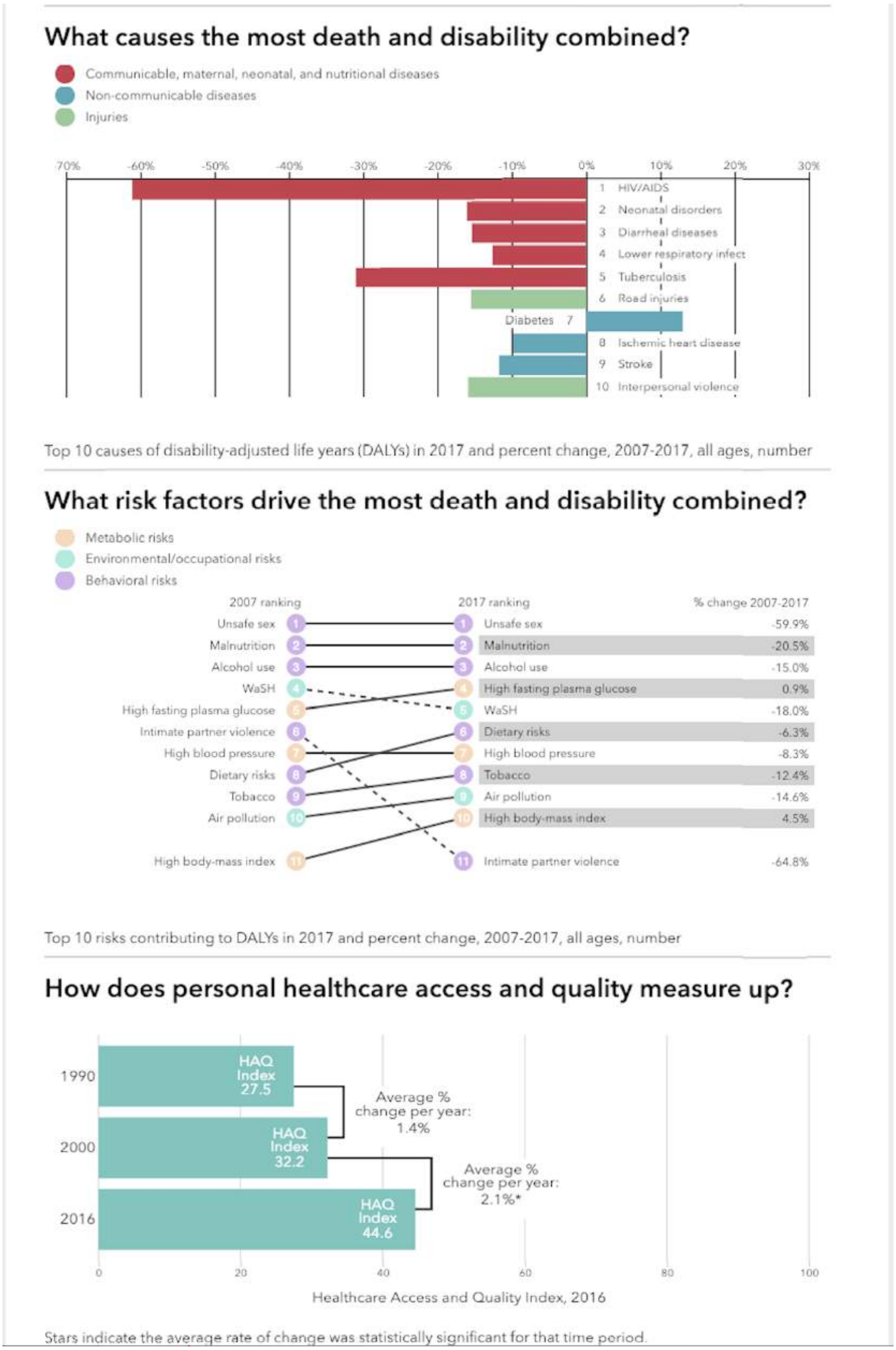
EHA 1 considers the burden of communicable respiratory diseases. The transmission of communicable respiratory diseases is strongly associated with (i) overcrowding (high household occupancy), (ii) cooking/heating with wood as a primary fuel source, (iv) low immunization levels in children and adults; and (v) poor hygiene, particularly hand washing practices. Firewood and charcoal are the dominant cooking fuel source as evidenced by most people reporting firewood collecting activity for these purposes in the toxicological survey. Both of these fuel sources are associated with production of high levels of fine particulate matter ($PM_{2.5}$). Hand washing data are covered in detail in EHA #4 WASH-Related Diseases.

Namibia does not have a functioning District Health Information Sysrwm (DHIS) with readily available morbidity data. However, Figure 13 from the IHME produces up to date estimates of burden of disease including healthcare access for Namibia. These show that the top 10 contributors to the BoD are respiratory, diarrhoeal diseases, TB and interpersonal injury which are all associated with poor housing and over crowding. In an African context, TB is a critical co-factor with HIV/AIDS as is typically the leading cause of death for AIDS patients.

Exposure to pollutants from indoor combustion of solid fuels in open fires or in traditional stoves increases the risk of ALRI and associated mortality amongst young children. Indoor combustion sources produce fine particulate matter ($PM_{2.5}$), which is substantially more toxic than coarse particulate matter (PM_{10}). Indoor air pollution from solid fuel use is estimated by the WHO to cause 36% of all lower respiratory infections and 22% of chronic obstructive pulmonary disease.

The underlying baseline level of particulate matter appears to be elevated based on environmental monitoring; and this would generally be considered a negative effect to community members in close proximity to roads. Road dust is typically an issue for community members who work or live within 200 meters of a dirt/gravel road centerline and is dominated by the coarse fraction (>10 micron size). Most of the roads in and around the residential areas of Tsumeb where the poorer and black residents live including the informal residential areas are dirt roads. Movements of earth and heavy transport in close proximity to Tsumeb and surrounds has an impact on air quality increasing the level of respirable particulates.

Figure 13: Information on Burden of Disease and Healthcare access[23]



[23] IHME Namibia profile for Burden of Disease, http://www.healthdata.org/namibia, accessed January 2019

Risk Dimension Analysis

Nature –Respiratory effects are both direct and indirect effects due to the variable incubation period that can occur between exposure and disease onset. An individual could be exposed to influenza in overcrowded dwellings and transport vehicles and other public places or gatherings and propagate such infections. Tuberculosis transmission is a particular risk given the high prevalence of HIV positivity in the residential population.

Timing and duration –All Project phases could be affected, but would be significantly less likely to occur during operations due to the smaller number of people that will be managed/employed by the Project. Road/construction fugitive dust generation is a potential concern both within and outside of the smelter boundary.

Frequency –At large worksites with rapid flux of personnel, an on-going burden of respiratory diseases should be expected.

Extent –Communicable diseases can rapidly spread beyond an immediate focus area due to variable incubation periods. Respiratory diseases originating in the household could be transmitted to the worksite.

Magnitude (intensity) – degree, extensiveness, and scale, particularly with regard to existing baseline conditions where there is a high underlying burden of disease as shown by the IHME statistics for Namibia.

Significance –There is a significant baseline burden of respiratory diseases in Tsumeb.

Manageability –The manageability is considered to be “medium” as all disease variables cannot be controlled by DPMT or the government for that matter. Coverage by government health services is not high and DPMT does not seem to facilitate access to private health services for workers and their family members. Fugitive road dust generation is an issue that is potentially within Project management sphere of control whether within or beyond the smelter boundary.

Rating

Consequence health rating would be 5 (High) if there were significant spread of TB or other communicable respiratory diseases. TB is generally a treatable infectious disease (of variable severity but with clear mortality implications) if diagnosed in a timely fashion.

Likelihood rating would be 3 (possible). There is significant risk of enhanced TB transmission associated with increases in population density (housing and transport). TB is a critical HIV/AIDS co-factor and HIV/AIDS is the largest with TB being the fifth largest contributor to the BoD in Namibia. This is likely to be slightly worse in Tsumeb than the national average.

In terms of air pollution associated respiratory diseases, there will likely be some level of increase in overall fine and coarse fraction particulate matter associated with project activities, particularly during construction, particularly involving earthworks for tailings dams and waste disposal purposes. However, overall particulate levels in the project area are impacted by seasonal weather considerations. Communicable respiratory diseases are extremely common and constitute the fourth largest contributor to the burden of disease in Tsumeb.

Overall Risk Matrix Rating

High – 22 This rating is driven by the known morbidity and mortality of TB, particularly in a setting where HIV/AIDS is a significant concern in the adult population and given their substantial contribution to the Namibian BoD accounting for 46% of this burden. .

EHA#2 Vector-Related Diseases (VRDs)

There are no significant vector related diseases in Tsumeb. Individuals migrating in from malaria areas to the North might manifest malaria infestation while in Tsumeb but this would be unlikely to be sustainable or to propagate within the Tsumeb community. The risk consequence would thus be deemed insignificant with an overall risk matrix rating of MINOR - 1.

EHA #3 Sexually Transmitted Infections (STIs)

STIs are notoriously under reported due to significant cultural stigma associated with these diseases. As noted previously, STIs are of concern given the high prevalence of HIV/AIDS (14.5% in 2016) and HIV/AIDS being the major contributor (32% or a third of the BoD) with unsafe sex being the top risk factor driving the burden of disease.

STIs are associated with significant adverse reproductive health outcomes, particularly among women who are at a higher risk of infection.

Risk Dimension Analysis

Nature – STIs would be direct (immediate symptoms), indirect (symptom development after a latency period) and cumulative, i.e. changes in HIV/AIDS burden effects.

Timing and duration –All Project phases could potentially be affected, but would be more likely during construction when employment is at peak.

Frequency – An ongoing burden of STIs would be expected.

Extent –STIs, particularly HIV/AIDS, are already widespread and a significant issue at local and national levels.

Magnitude (intensity) –The most likely scenario is increased promiscuous sexual activity associated with a large influx in money (due to construction related employment/ small scale trading, etc.) and a potential for a temporary increased influx of transactional sex activity/workers triggered by the construction phase.

Significance –This could be a high profile issue in local communities .

Manageability –The manageability is considered to be *"low"* as the significant behaviour variables cannot be easily modified. There is a significant underlying burden of STIs including HIV/AIDS in Tsumeb. There are some factors that are within the influence of the Project Management team, i.e. enhanced educational awareness, etc. that can potentially mitigate, to some degree potential impacts.

Rating

Consequence health rating would be 4 (moderate). STIs, including HIV/AIDS have broad morbidity and mortality potential.

Likelihood rating would be 4 (likely) . There is significant risk of STI, including HIV/AIDS transmission associated with industrial/infrastructure projects and hence with the DPMT expansion.

Overall Risk Matrix Rating

High - 21. This is a significant issue for DPMT, particularly given the high underlying prevalence

EHA #4 Soil, Water, Sanitation and Waste Related Diseases (WATSAN)

This EHA considers diseases and conditions that are related to quantity, quality and access to water used by households. Personal hygiene, such as hand washing behaviours and access and use of soap, are also considered. General community sanitation is evaluated, particularly related to contact with non-hazardous wastes and soils. The availability/presence of functioning latrines is also a critical consideration.

Water diseases are often strongly related to the absolute per capita volume of water available for personal hygiene, e.g., bathing, hand washing, etc. Particularly in informal areas, dwellings do not have piped water supplies and must rely on standpipes or sources of water distant from their dwellings. Additionally the informal housing frequently have no toilet facilities and people urinate on the ground inside these structures while defecating openly in the nearby bush.

Furthermore, baseline prevalence of diarrhoeal diseases are the third largest contributor to the national BoD with malnutrition being the second largest risk factor for BoD (accounting for 20.5% of the BoD).
Other potentially water washed conditions, e.g., eye infections and skin disorders are also common.

Risk Dimension Analysis
Nature –WATSAN issues are usually direct effects (immediate symptoms like diarrhoea); however, indirect (symptom development after a latency period) are possible especially with waterborne disease epidemics e.g. Hepatitis A or E.

Timing and duration –There is a high likelihood of community water related complaints throughout all phases of the expansion project.

Frequency –may occur at any time given the high underlying burden of disease in the country and inadequate access to safe water and sewage utilities in some of the residential areas.

Extent – localities most likely to experience the projected impact are local informal housing areas which are explanding. Events are unlikely to be regional.

Magnitude (intensity) – degree, extensiveness, and scale are substantial, particularly with regard to existing baseline conditions in informal residential areas.

Significance –Water quantity/quality/access impacts in communities would be viewed in a very negative manner. Perceptions, valid or not, regarding

Project-related water quality impacts have the potential to trigger negative reactions in local communities.

Manageability – ability to influence risk responses. This will depend upon municipal and other levels of government and available resources, with a very limited role for DPMT.

Rating

Consequence health rating would be 4 (moderate). Diarrhoeal diseases are associated with potentially significant morbidity and even mortality; however, the health care system is well experienced with these problems and generally adequate treatment is available if medical attention is sought in a timely manner.

Likelihood rating would be 4 (likely). There is significant underlying burden of diarrhoeal diseases present; however, it is unlikely that the project objectively affects this problem.

There is, however, a history of community concerns expressed in stakeholder meetings regarding water quality impacts, especially related to potential arsenic contamination. A substantial percentage of the overall disease burden is likely related to personal hygiene rather than absolute water quality. Concerns regarding latrines and waste sites/dumps have also been raised during community meetings and typically informal urban communities are substantially under served by functioning latrines.

Overall Risk Matrix Rating

High 21 The level of objective supporting evidence is substantial, with outbreaks of Hepatitis E, and clearly indicates that a substantial effort should be made to monitor water quantity, quality and access issues.

EHA #5 Food and Nutrition Related Issues

This EHA considers the situation regarding community and household levels of nutrition and food security. Nutrition is strongly tied to a wide variety of health outcomes, including anaemia, micronutrient deficiencies, and anthropometric outcomes such as height and weight for age in children and adults. Nutrition is at the heart of the public health challenges faced by most developing countries today. Many people and communities, particularly in rural settings, still face the threat of under-nutrition. Standard methods of non-invasively evaluating nutritional status involve (i) food security household survey modules and (ii) the use of anthropometry.

Changes in incomes (i.e., wage-based employment) can also trigger a movement from subsistance agriculture towards processed commerical food products with a marked upsurge in non-communicable diseases, e.g., diabetes, hypertension, cardiovascular disorders. In addition there can be changes in food security associated with a movement from agricultural activities towards small-scale petty trading. Trading activities can have a rapid (and profitable upsurge) during project construction phases followed by a marked downturn as the project moves from construction to operations.

Rapid urbanization and persistently high unemployment rates (34% of the total labour force) affecting most youth and women in Namibia have resulted in a growing number of poor people lacking access to food and basic social services. The poverty rate was 17.4% in 2017.

Namibia produces around 40% of food consumed and is dependent upon imports. While food is available, price fluctuations impact food access negatively for 28% of families. This impacts 80% of the population who are dependent on markets and shops. Small farmers also have limited food access due to recurrent droughts and floods and lack of access to land and the means of production.

About a quarter of children aged 6 months to 5 years are chronically malnourished. The rural population is worse off than the urban population.

Food security has been evaluated in Windhoek by the African Food Security Urban Network (2012) which found that the poor population living in informal areas was worse off than 10 other African cities. The African regional average for the Household Food Insecurity Access Scale (HFIAS) was 10.3 compared with 12.4 in informal housing in Windhoek. The Household Food Insecurity Prevalence Indicator (HFIAP) average was 77% food insecure for the African Region and 89% for Windhoek. The latter was the third highest in the SADC region. Food security policy is oriented mainly to rural areas and the urban informal poor fall through the cracks. The Lived Poverty Index (LPI) is higher for those in informal areas. This applies to the large and growing informally housed population in Tsumeb which is likely to be worse off than Windhoek. While there is a school feeding scheme with good coverage, the poor living in informal housing are at high risk for food insecurity.

Risk Dimension Analysis

Nature –Food security issues are significant directly, indirectly and cumulatively.

Timing and duration –All Project phases could be potentially affected; informal housing area populations are potentially the most “at risk” groups.

Frequency – This is a continuing baseline problem

Extent – localities most likely to experience the projected impact are likely to be focused and local.

Magnitude (intensity) – degree, extensiveness, and scale are substantial with regard to existing baseline conditions

Significance – Food insecurity would not be perceived to be linked to the project.

Manageability –The manageability is considered to be “low” as food security is extremely complex and multifactorial.

Rating

Consequence health rating would be 4 (moderate) with potentially vulnerable households suffering more major effects (HIGH (5), particularly young children, the elderly or individuals with significant underlying pre-existing morbidity (e.g., individuals living with HIV/AIDS. There are already significant levels of food insecurity.

Likelihood rating would be 4 (possible). Vulnerable households are present.

Changes in non-communicable diseases (EHA#11) and social determinants of health (EHA #8) can also occur and are discussed in these specific sections.

Overall Risk Matrix Rating

High (21) especially in the vulnerable informal residential areas.

EHA #6 Injury burden (intentional and unintentional)

Injuries are a neglected epidemic in developing countries, causing more than 5 million deaths each year, roughly equal to the number of deaths from HIV/AIDS, malaria, and TB combined (Gosselin *et al.* 2009). The Global Burden of Disease and Risk Factors study forecasts that by 2020, 20% of ill-health in the world will be injury related (Gosselin *et al*. 2009). For Namibia specifically both injury from traffic-related incidents and interpersonal violence rank in the top 10 contributors to BoD. As is the case in the Southern African region, alcohol consumption is the major risk for injury along with speeding. For Namibia alcohol consumption is the third biggest risk factor for BoD.

More than 90% of injury deaths occur in low- and middle-income countries, where preventive efforts are often nonexistent and health care systems are least prepared to meet the challenge. As such, injuries clearly contribute to the cycle of poverty and have an impact on individuals, communities, and societies. There are many dimensions to injuries: human (victim, caregiver) environment (infrastructure, legislation), and vector (motor and marine and river vehicles for injuries, weapons for violence, open fires for burns). The Project involves a minor increase in road transport which may impact morbidity and mortality for Tsumeb residents.

Risk Dimension Analysis

Nature –Accidents are direct effects (immediate medical consequences); however, indirect (release scenarios, post trauma rehabilitation, etc.) are possible especially with a multi-vehicle accident.

Timing and duration –Accidents and injuries from other physical hazards are most likely to occur during construction when employment, traffic, and Project activity are at peak. After the operational phase of the project, there is likely to be a longer term gradual increase in both traffic and injury burden due to natural increase in the population particularly in informal areas.

Frequency – the overall rate of occurrence is likely to increase with time due to population increase and congestion, especially in informal areas.

Extent –Traffic crash events can occur on any travelled roadways including on the project sites. Physical hazard driven injury can occur anywhere in community residential areas.

Magnitude –The most likely scenarios range from solo vehicle accidents without personnel injury or release of materials/product, to multi-vehicular accidents or crash events with morbidity/mortality and release of potentially hazardous materials.

Significance –Any accident or other injury mishap involving the community would be a potentially serious event.

Manageability –The manageability is considered to be “medium” as the Project has control over journey management for Project vehicles; however, the Project has no control over other vehicles or sudden changes in weather conditions, e.g., precipitation affecting visibility, driving conditions. Increased alcohol consumption or interpersonal violence is not manageable, especially in informal housing areas.

Rating

Consequence health rating would be Moderate (4)

Likelihood rating would be 4 (likely) based on the significant level of traffic crash incidence on major Namibian highways. The Project is vulnerable to traffic crash incidents due to the driving practices, volume of mixed traffic (pedestrians, bicycles, motorbikes, cars and large trucks) all operating on the same roads. In addition, roads are associated with significant trading activity which all increases the likelihood of an unplanned interaction between a motor vehicle and a pedestrian.

Overall Risk Matrix Rating

Moderate (16) due to the underlying high rates of RTA in Namibia and the likelihood of increased truck/transport traffic during the operational stage. Given that additional product is mainly transported by rail the expansion project is unlikely to have a large ongoing effect.

EHA #7 Exposure to Potentially Hazardous Materials (See separate chapter on Baseline Health Study related to Arsenic and SO_2)

This section addresses exposure to potentially hazardous materials – road dusts, air pollution (indoor and outdoor related to industrial activity, historical waste sites related to historical and current mining and smelting activities, cooking, heating or other forms of combustion/incineration), landfill refuse or incineration ash, any other Project related solvents, paints, oils or cleaning agents, by-products. The principal focus will however be on arsenic and SO_2

emissions and the impact of the expansion project on these. These hazards are the focus of a **community baseline health study** of the community living in Tsumeb and surrounds completed in September 2016. There have been many complaints over many years from community members principally of SO_2. There is also a tendency to conflate arsenic with SO_2 among community members as the latter is easily detectable while the former is not. There is a presumptive assumption that the two are related in the minds of the community which is not unreasonable.

Additional volumes of hazardous wastes will be generated by the expansion project, while higher volumes of sulphuric acid will be produced through the sulphuric acid plant The fate of the decommissioned arsenic plant and developments in respect of the waste disposal facility are also considered as potential hazard sources. The project will also generate construction and traffic emissions including associated roadway dust during earthworks. The two principal hazards of concern remain arsenic and SO_2.

Risk Dimension Analysis

Nature –Hazardous materials events are usually direct effects (immediate symptoms or exposures); however, indirect (symptom development after a latency period) effects are possible. Multiple exposures can have cumulative and/or synergistic effects.

Timing and duration –The risk will remain present as it has been to date, and will arguably increase with the expansion project. SO_2 releases from time to time and/or changes in wind direction currently generate community complaints and these might be expected to increase in frequency should the acid plant not function at optimal levels.

Frequency –Hazardous materials events can occur at any time and are both continuous and episodic. Road dust and construction dust can be a daily occurrence and is typically negatively perceived by communities and small traders with roadside stalls.

Extent – localities most likely to experience the projected impact are local. Hazardous materials events are more likely to be experienced at the worksite, or along roadways. Those areas of Tsumeb nearest the smelter will be most affected as they are currently viz. Ondundu, the Western Industrial Area and Town North.

Magnitude –The most likely scenarios are unplanned environmental releases, particularly SO_2 emissions. Low level arsenic in air emissions are likely to persist and possibly increase.

Significance –Air quality issues may remain a concern in respect of SO_2.

Manageability –The manageability is considered to be “high” as the Project has control over the key operational issues.

Rating

Consequence health rating would be moderate (4) for arsenic and minor (2) for SO_2.

Likelihood rating would be *possible (3)* for arsenic and (*5) certain* for SO_2. Road dust events are certain to occur depending upon the weather conditions/seasonality and could impact arsenic exposure.

Overall Risk Matrix Rating

Moderate for arsenic (12); low (10) for SO_2 events;

EHA #8 Social Determinants of Health (SDH)

SDH are the conditions in which people are born, grow, live, work, and age, and include the state of the health system with which they interact (described in EHA #10 Health Systems). These circumstances are shaped by the distribution of money, power, and resources at global, national, and local levels, which are themselves influenced by policy choices. The SDH are often responsible for health inequities — unfair and avoidable differences in health status seen within a country, such as rural versus urban Namibia.

It is well established that health follows a social gradient: better health with increasing socio-economic status, literacy, and educational attainment, particularly for women. All of these elements are associated with a higher housing standard, healthier working conditions, and better access to health care and health education.

Substance abuse including alcohol, tobacco, or other drugs is not only an important health determinant but also closely linked to mental health. Misuse is associated with crime, transactional sex, and domestic violence. Dramatic, even if short-term, changes in employment can be both positive and negative depending upon an individual’s behavioral practices.

SDH changes and impacts are typically associated with employment and income. Changes in employment and income can trigger behavioural changes at the household level and may include increases in drug and alcohol use. Employment/economic opportunities appear to be a key sensitivity among residents. Social discord may occur among the “haves” and “have nots”, or those that do and do not believe they benefit from the Project in terms of compensation and employment.

Risk Dimension Analysis

Nature – SDH effects are typically indirect and cumulative but generally mediated by personal behavioural choices.

Timing and duration –All Project phases could be affected but typically SDH are seen during construction and operations.

Frequency –. A significant influx in money could change habits/behaviours. Migrants and residents of informal areas are potentially vulnerable to behavioural changes including alcohol/tobacco and drug usage.

Extent –SDH changes could occur in the informal residential areas locally; however, any impacts positive or negative are more likely to be at a household/family level.

Magnitude (intensity) –Magnitude of impacts will depend on the number of residents employed DPMT.

Significance –These would likely be imperceptible

Manageability –The manageability is considered to be *"low;"* although, clear communication regarding socio-economic opportunities/benefits is critical and within the project's ability to manage.

Rating

Consequence health rating would be low (3). There is a potential for detrimental interactions with changes in social cohesion, i.e., "haves and have nots" ; however, there is the potential for positive benefits.

Likelihood rating would be *likely (4).* Behaviours can and do change and there is a potential for significant positive outcomes.

Overall Risk Matrix Rating

Moderate (12) SDH are complex and encompass issues such as community social cohesion and psycho-social effects (drugs, alcohol, gender based violence).

EHA #9 Cultural Health Practices

The analysis of cultural health practices applies a medical anthropology lens to a community's knowledge, attitude, and practices regarding health and illness. All cultures have systems of health beliefs to explain what causes illness, how it can be cured or treated, and who should be involved in the process. The extent to which patients perceive health education as having cultural relevance for them can have a profound effect on their reception to information provided and their willingness to use it.

Cultural differences affect patients' attitudes about medical care and their ability to understand, manage, and cope with the course of an illness, the meaning of a diagnosis, and the consequences of medical treatment. In addition, culture specific values influence patient roles and expectations.

Cultural health changes and impacts can be associated with environmental destruction of cultural resources utilized by traditional healers. A gap exists for the HIA in terms of understanding what these cultural health resources actually may be. The influx of migrants into the area may also lead to increased utilization of traditional healers.

Risk Dimension Analysis

Nature –Cultural health effects are typically indirect and cumulative but generally mediated by personal behavioural choices, unless cultural health environmental resources are directly damaged / destroyed.

Timing and duration – All Project phases could be affected.

Frequency –Negative behavioural changes associated with the project are less likely than positive changes associated with a safety and wellness culture, and increased health education regarding health promotion and disease prevention targeting residents employed by DPMT.

Extent –Cultural Health changes could occur in communities; however, any impacts positive or negative are more likely to be at a household/family level.

Magnitude (intensity) –Magnitude of impacts will depend on the baseline status of cultural health resources.

Significance –The project is unlikely to materially change current practices.

Manageability –The manageability is considered to be *"low."* While the Project can minimise damage to cultural health resources, health-seeking behaviours cannot be controlled by the Project.

Rating

Consequence health rating would be insignificant (1)

Likelihood rating would be *unlikely (2).*

Overall Risk Matrix Rating

Minor (2)

EHA #10 Health Services Infrastructure/Capacity - Programme Management Delivery Systems

This health systems EHA is broad-based and designed to capture baseline information regarding the status and performance of the health care system in Tsumeb. This assessment includes the suite of health care facilities and programs. The following considerations within this EHA are important:

- Mix of health care facilities
- Physical state of the available infrastructure.
- Facility staffing.
- Equipment and supplies, particularly drugs and laboratory equipment.
- Kinds of programs that are being implemented (e.g., maternal and child care, vaccinations, and antenatal clinics); disease-specific programs such as HIV/AIDS, TB, and VBDs are considered in other named EHAs.
- Non communicable disease (NCD) health services are typically not available at the local clinic level and patients need to seek diagnosis and treatment at the hospital facility level.
- Access to care.

The IHME report for Namibia estimates personal healthcare access and quality in a single measure (HAQ) at 45% in 2016 with 100% representing adequate access. A town like Tsumeb is likely to have less access than this national average which is elevated by the better services located in Namibia's cities. By comparison, Sweden for 2016 is 96%. As mentioned elsewhere in this report there are both private and state health services available in Tsumeb ranging from the preventative and promotive facilities offering primary care as well as two hospitals and private general practitioners. DPMT however does not provide full medical aid coverage for the bulk of its unskilled workforce. There is only a public sector HIV/AIDS programme. Permanent resident specialist services are not available.

Risk Dimension Analysis

Nature –Access to health care facilities is a substantial issue due to inadequate capacity in the public sector.

Timing and duration –Risk will be present for the entire duration of the Project.

Frequency –Increasing population can put pressure on health care facilities that may not be adequately staffed for a population influx.

Extent – localities most likely to experience the projected impact are local

Magnitude – A perceptible increase over time in demand for services might be expected

Significance – The project is unlikely to result in any change in access to health services.

Manageability –The manageability is considered to be *"low"* as DPMT has the ability to potentially enhance the health infrastructure in Tsumeb for some services.

Rating

Consequence health rating could be low (3) depending upon influx.

Likelihood rating would be possible (3) .

Overall Risk Matrix Rating

Low (9).

EHA #11 Non-Communicable Diseases (NCDs)

As can be seen from the top ten risk factors for BoD, almost all of them (7) are risks for NCD. Moreover, 3 of the major NCD categories viz. diabetes, ischaemic heart disease and stroke are to be found in the top 10 contributors to the BoD. Some are due to changes in employment and income can trigger behavioural changes involving diet, alcohol and tobacco consumption which substantially impact NCD patterns. The rural to urban transition is also associated with increased prevalence and severity of high blood pressure and exposure to air pollution.

Risk Dimension Analysis

Nature – NCD impacts are likely to be negative, indirect and cumulative.

Timing and duration – All Project phases are likely to be affected.

Frequency – Local health care facilities may see a gradual increase in NCD-related problems with greater utilization of acute care services (cardiovascular or diabetes related).

Extent – localities most likely to experience the projected impact are local.

Magnitude (intensity) –Major negative impacts could be seen over long time periods.

Significance –The Project is unlikely to be perceived as a major negative change agent at the public health level.

Manageability –The manageability is considered to be *“low”*.

Rating

Consequence health rating would be moderate (4) for increases in cardiovascular disease, and diabetes. A clear rise in relevant risk factors for NCDs is evident since 2007 for Namibia as a whole.

Likelihood rating would be *certain (5);* As economic conditions change and improve due to greater employment and wages, large projects tend to drive an acceleration in the epidemiological transition, i.e., the movement from infectious diseases to non-communicable disease burden. The NCDs are often more difficult and expensive to treat medically versus simple communicable infectious diseases and diagnosis and treatment is only provided at the hospital level not at local clinics, where access is more limited.

Overall Risk Matrix Rating

High 23. This illustrates the onerous triple burden of disease born by the majority black population in Namibia which includes infectious disease/malnutrition, injury from traffic crash and violence, and also NCDs.

EHA #12 Zoonotic Diseases

This EHA considers the underlying burden of diseases transmitted from animals to humans. Diseases that originate from animals but can be transmitted to humans are known as zoonotic illnesses. There are multiple causal factors for zoonotic illness emergence and spread, including intensification of livestock production, increased human travel and food-associated trade, and reduction of and encroachment on wildlife habitat (Bordier and Roger 2013). Local animal husbandry practices currently involve chickens and goats and are unlikely to change.

Risk Dimension Analysis

Nature –Transmission of zoonotic diseases would have direct effects.

Timing and duration –All Project phases could be potentially affected.

Frequency –This is a low likelihood event.

Extent –The extent would typically be local.

Magnitude (intensity) –As these diseases are not transferred from person to person, a major outbreak would not be expected, however consequences for individuals affected would be significant.

Significance –This is unlikely to be a high profile issue in local communities.

Manageability –The manageability is considered to be *"low"* as significant disease variables cannot be controlled by the Project. Changes in animal husbandry practices by resettlement communities/populations could be a significant issue/concern.

Rating

Consequence health rating would be low (3). This is not expected to be a significant problem. Animal husbandry practices are stable and do not involve large animals (cattle or pigs) at significant levels.

Likelihood rating would be *rare (1)*

Overall Risk Matrix Rating

Minor (3). At present zoonotic diseases have not been documented to be a significant issue.

Summary Ratings

A summary of the overall ratings by EHA is shown in Table 4 below.

Ratings by EHA

Table 4: Summary risk ratings

Environmental Health Area	Initial Rating
#1 Housing and Respiratory issues	High 22
#2 Vector-related disease	Minor 1
#3 Sexually Transmitted Infections	High 18
#4 Soil, Water, Sanitation and Waste related diseases	High 21
#5 Food and nutrition related issues	High 21
#6 Accidents/injuries – roadway and marine traffic related accidents, spills and releases	Moderate 16
#7 Exposure to potentially hazardous materials	Moderate 12 for arsenic & Low 10 for SO_2 ** **But alternative method also used – see next section**
#8 Social Determinants of Health (SDH)	Moderate 12
#9 Cultural Health Practices	Minor 2
#10 Health services infrastructure and capacity, Program Management delivery systems	Low 9
#11 Non-Communicable Diseases (NCD)	High 23
#12 Zoonotic Diseases	Minor 3

** These ratings are similar to the alternative method used for EHA#7 in this HIA to be consistent with the ratings in the rest of the EIA. Similar caveats apply to the moderate rating which is more accurately a low rating forced to be moderate because of the severity of cancer

Five of the EHAs are rated "High" with numerical ratings between 18-25. These ratings are neither alarming nor surprising based on comparative experience and baseline conditions in sub-Saharan Africa. Experience indicates that with a well designed HMP, negative effects can be significantly mitigated and positive benefits accentuated. The HMP should be carefully aligned with existing Ministry of Health and local municipal strategies and priorities. A surveillance system for the hazards and risks of greatest importance will enable relevant concerted action going forward.

RISK RATING RESULTS FOR EHA # 7: COMMUNITY HEALTH BASELINE STUDY FOCUSSING ON ARSENIC AND SO_2 RISKS

The risk rating for EHA # 7 has additionally been analysed by a different method in the following section in order to maintain consistency with the other components of the EIA. This additional rating is based upon the findings from a household community survey.

COMMUNITY RESIDENTS BASELINE HEALTH STUDY FINDINGS

The findings are presented below in relation to the likely pathways for arsenic exposure from source to receptors in the community.

These deal with:

Review of air quality data generated by the routine monitoring systems operated by the smelter at the boundary of the works yielding information for PM_{10}, SO_2 and arsenic in PM_{10} levels.

Additionally the study of Tsumeb residents and Oshakati exposure controls conducted specifically for this HIA has collected new and current data on arsenic levels in drinking water from their municipal supply

The study also yielded demographic, respiratory health, and dietary information from residents and most importantly arsenic in urine levels for all participants. Moreover, it has been possible to separate organic arsenic of dietary origin from inorganic arsenic of anthropogenic origin. This latter biological data integrates all inorganic arsenic exposure from all sources by all pathways and renders more speculative extrapolation and modelling from routine lower order arsenic exposure in the environment including air, soil and water data unnecessary.

Data since 2011 from the occupational health surveillance system for workers at the smelter relating to both industrial hygiene arsenic in workplace air and urinary arsenic biological monitoring were reviewed.

The population has been estimated as being between 16 000 and 25 000 for Tsumeb and surrounds (the higher figure). This has grown considerably since 2011 and the takeover by DPMT. 197 individuals were surveyed in Tsumeb and surrounds and 45 in Oshakati. Tsumeb subjects were representative of all residential exposure zones on the map (Figure 10).

REVIEW OF THE DUNDEE SMELTER ROUTINE AIR QUALITY DATA AND ESTIMATION OF THE IMPACT OF AIRBORNE POLLUTANTS ON HEALTH

The objective was to estimate likely exposures to airborne PM_{10}, SO_2 and airborne arsenic from the results of routine monitoring data from appropriate monitoring stations near the residential areas and to draw on air dispersion models from the environmental air monitoring component of the EIA (Appendix F) to refine these.

Exposure standards for air pollutants of concern

Particulate matter (PM) comprises solid or liquid particles suspended in the air. These vary in size from particles that are only visible under an electron microscope to soot or smoke particles that are visible to the human eye. Ambient particulates limit visibility and pose health risks since small particles (PM_{10}) can penetrate deep into lungs, while even smaller particle sizes ($PM_{2.5}$) can enter the bloodstream via capillaries in the lungs. Health effects include respiratory problems, lung tissue damage, cardiovascular problems, cancer and premature death.

The current South African air quality standard for PM_{10} is 75 µg/m^3, while the WHO air quality guideline is more stringent and specifies a 24-hour limit of 50 µg/m^3 for PM_{10}.

Sulphur dioxide (SO_2) is formed during the combustion of sulphur-containing fuels. This gaseous pollutant is a major respiratory irritant, resulting in respiratory illnesses, alterations in pulmonary defences and aggravation of existing cardiovascular disease. SO_2 also forms sulphuric acid as a result of its water solubility, producing acid rain. Once emitted, SO_2 may oxidize in the atmosphere to produce sulphate aerosols, which are also harmful to human health, limit visibility and in the long term have an effect on global climate. The South African 24-hour air quality standard[24] for SO_2 is 125 µg/m^3, while the WHO 24-hour air quality guideline is more stringent at 20 µg/m^3 for SO_2. WHO's 24-hour Interim Target 1 is similar to the South African standard of 125 µg/m^3, with the Interim Target 2 set at 50 µg/m^3.

Bioavailable Arsenic

The concentration of metabolites of inorganic arsenic in urine reflects the absorbed dose of inorganic arsenic on an individual level.

Generally, non-industrially exposed background levels range from 5 to 20 µg/L of total arsenic (uncorrected for creatinine). Large population surveys in the USA (2011-12 most current data) showed a geometric mean of 6.85 µg/L urinary total arsenic.

Both pentavalent and trivalent soluble arsenic compounds are rapidly and extensively absorbed from the gastrointestinal tract. Absorption of arsenic from inhaled airborne particles is highly dependent on the solubility and the size of particles. Dermal absorption appears to be much less than absorption by the oral or inhalation routes. Arsenic and its metabolites distribute to all organs in the body; preferential distribution has not been observed. Arsenic readily crosses the placenta. Arsenic trioxide is a corrosive compound and may cause local damage to the skin, eyes and respiratory tract.

Arsenic is considered to be a non-stochastic (characterized by a threshold dose below which effects do not occur) genotoxic (affects DNA) compound. Clastogenic damage (giving rise to or inducing disruption or breakages of chromosomes), was observed in different cell types of exposed humans and in mammalian cells *in vitro*. For point mutations, the results are largely negative. With regard to the mechanism which caused the genotoxic effects, there is evidence that DNA repair enzymes are inhibited by arsenicals.

Long-term exposure to arsenic in drinking-water is causally related to increased risks of cancer in the skin, liver, lungs, bladder and kidney, as well as other skin changes such as hyperkeratosis and pigmentation changes. The

[24] As 2ppm = 5mg/m^3 for SO_2, 20µg/m^3 = 0.008ppm and 125 µg/m^3 = 0.05 ppm

effects have been most thoroughly studied in Taiwan but there is considerable evidence from studies on populations in other countries as well. Increased risks of lung and bladder cancer and of arsenic-associated skin lesions have been reported to be associated with arsenic exposure categories of > 50 µg/L. There is good evidence from studies in several countries that waterborne arsenic exposure can cause peripheral vascular disease. Studies on oral exposure to arsenic in drinking water show that arsenic cannot be excluded as a causal factor for reproduction toxicity (spontaneous abortion, neonatal and postnatal mortality, preterm delivery, reduced birth weight).

Conclusions on the causality of the relationship between oral arsenic exposure and other health effects (hypertension, cardiovascular disease, diabetes, cerebrovascular disease, long-term neurological effects) are less clear-cut.

Occupational exposure to arsenic by inhalation is causally associated with lung cancer. Exposure-response relationships and high risks have been observed. Increased risks have been observed at relatively low cumulative exposure levels in smelter cohorts in Sweden (Rönnskär; arsenic exposure category of < 250 µg/m^3_ year) and in the USA (Tacoma; arsenic exposure category of < 750 µg/m^3_ year). Studies indicated that smoking had a synergistic effect on the lung cancer effects of arsenic exposure. Several studies have examined a number of reproductive end-points in relation to arsenic exposure. Occupational exposure studies are not conclusive on a causal relationship between arsenic and reproductive toxicity effects.

Arsenic and arsenic compounds are considered to be known human carcinogens. The International Agency for Research on Cancer (IARC) has classified arsenic and arsenic compounds as *carcinogenic to humans* (Group 1), which means that there is sufficient evidence for their carcinogenicity in humans.

Lung cancer is the critical effect after inhalation exposure to arsenic and arsenic compounds. Sufficient quantitative information from human studies on the levels of arsenic exposure to ensure reliable assessment of the exposure response relationship was available for three copper smelter cohorts:

Tacoma, Washington (USA), Anaconda, Montana (USA) and Rönnskär (Sweden). Because sufficient adequate human data on arsenic and arsenic compounds are available, human data are used for derivation of the occupational limit value.

This is an established methodology for calculating an inhalation “unit risk factor” (URF). The unit risk is the quantitative estimate in terms of either risk per µg/L drinking water or risk per $\mu g/m^3$ air breathed. Both WHO and USEPA have calculated URFs. In addition, independent researchers and/or various countries and US states (Alberta Environment, 2004; Erranguntla, 2012) have also published URFs. There is not complete unanimity across all of the published URFs due to subtle, (but critical), differences in statistical approaches and uncertainty analyses to the arsenic occupational cohort studies.

The EU has adopted the WHO analysis and calculation of the URF for generating a risk-based arsenic community air standard. WHO derived a lifetime unit risk of 1.43 $E10^{-3}$ which was rounded up to 1.5 $E10^{-3}$. A linear extrapolation from the unit risk estimate recommended by the WHO of 1.5 x 10^{-3} ($\mu g/m^3$)-1 so as to satisfy the one-in-a-million excess lifetime cancer risk criterion, would result in a limit value of 0.66 ng[25] As/m^3 air. The one per million level is traditionally considered to be the “point of departure.” Regulators, particularly in the USA often consider a $E10^{-4}$ (one per 10,000) to $E10^{-6}$ (one per million) risk range. The typical EU practice is to adopt a $E10^{-5}$ (one per 100,000) cancer risk criterion. Hence the EU community arsenic air standard is 6.6 ng/m^3.

Data sources used for community study

The following data were obtained from 5 DPMT monitoring stations for PM_{10} , SO_2 and the arsenic content of PM_{10}.

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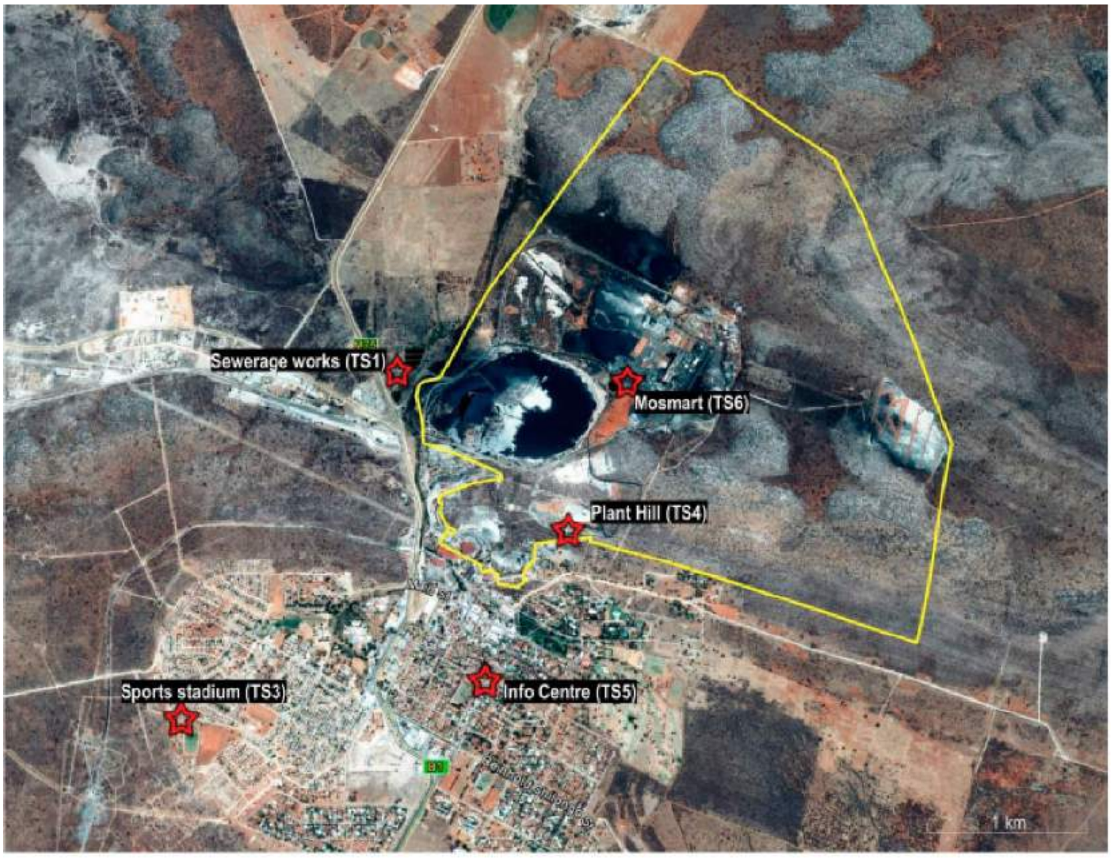
[25] ng = nanogram

Data go back to the commissioning of the monitoring stations for the various areas, the earliest of which was installed in mid-2012.

Figure 14: Map of monitoring stations



The monitoring stations with greatest relevance for Tsumeb residents are those shown in Figure 14 at the Sports Stadium in the middle of Nomtsoub a densely populated residential area with formal housing and tarred roads, but including quite a number of gravel roads and unsurfaced spaces, and the DPMT Information Centre which is in the commercial centre of Tsumeb at the Northern end of town closer to the smelter precinct. The vicinity of this station is characterised by formal building structures and tarred roadways.

Other monitoring stations are Sewerage Works which is situated at the sewerage plant across the road from the Western Industrial zone, and the Hill station which is situated in the smelter precinct above the waste disposal facility on top of the hill to the South of the smelter. Lastly there is a mobile station which has variously been stationed at NAMFO farms to the north west of the smelter, and within the smelter precinct itself at a high exposure position named MOSMART from time to time. It has also been termed the MOBILE station.

Data collection began in mid-2012 for the earliest functioning stations. The data are by no means complete and it is notable that some of the components of these monitoring facilities seem to remain out of action for many months after they have broken down. For example, the PM_{10} sampler at the Stadium monitoring station was down from February 2016 to April 2017, while the one at the Information Centre was out of action from August 2015 to January 2016. These are long periods during which valuable information is lost.

As there have been many recent changes at the smelter since DPM took it over in 2011 it is most pertinent to the purpose of this EIA to focus on 2017 results. As the acid plant has come on stream in late 2015/early 2016, and as there have been engineering improvements in 2016 and 2017, these values will be most useful for forward projection given increasing production throughputs.

Some of the past information is still useful insofar as it sheds light on trends over the past few years, and will be referenced here.

The data in the ensuing tables have been taken from monthly SGS[26] reports on measurements taken at the monitoring stations

[26] SGS. Ambient Air Quality Monitoring Monthly Reports for Tsumeb

PM_{10}

Table 5: PM_{10} and SO_2 exceedances for the residential areas of Tsumeb in 2016

MONTH				2016					
		STADIUM					INFO CENTRE		
LIMIT VALUES	SA PM_{10}[27]	WHO PM_{10}	SA SO_2	WHO SO_2		SA PM_{10}	WHO PM_{10}	SA SO_2	WHO SO_2
	75 µg/m^3	50 µg/m^3	125 µg/m^3 daily	20 µg/m^3 daily		75 µg/m^3	50 µg/m^3	125 µg/m^3 daily	20 µg/m^3 daily
December	-	-	-	-		-	-	-	-
November	0	0	0	6		0	0	1	7
October	0	0	2	0		3	8	0	1
September	-[28]	-	0	4		0	19	0	4
August	-	-	0	1		0	12	0	2
July	-	-	0	0		1	8	0	0
June	-	-	0	4		0	3	0	6
May	-	-	0	4		0	0	0	3
April	-	-	0	5		0	0	0	4
March	-	-	0	4		0	0	0	2
February	-	-	1	7		0	0	0	8
January	0	2	0	12		1	1	0	5
Total number of exceedances for 2016	**-**	**2**	**3**	**47**		**5**	**51**	**0**	**42**

The total number of PM_{10} exceedances of the 24-hour limit for the year were in line with the South African standard, but about 10 times more than the allowable annual exceedances as per the WHO PM_{10} target value[29] were recorded. The WHO also has interim targets specifically for developing countries experiencing difficulties in attaining their target values. For PM_{10} the interim target values start at 150 µg/m^3 reducing to 100 µg/m^3 and 75 µg/m^3. The EU[30] has a limit of 50µg/m^3 with up to 35 exceedances allowed annually.

[27] The SA PM_{10} limit changed in April 2016 to 75 µg/m^3

[28] missing data due to non-functioning PM_{10} monitor

[29] WHO Air quality guidelinesfor particulate matter, ozone, nitrogen dioxide and sulfur dioxide lobal update 2005

[30] http://ec.europa.eu/environment/air/quality/standards.htm

Table 6 shows data from the 2 monitoring stations for PM_{10}. It is evident that the one year average concentrations have not changed appreciably in the last few years. If anything concentrations have slightly increased.

Table 6: Trends in average PM_{10} concentrations in ug/m3

1-year average PM_{10} concentrations

	Plant Hill	Stadium
2013	29.8	62.6
2014	19.4	55.5
2015	23.9	65.0
2016	21.5	29.3
2017	29.7	71.4

99th percentile of 24-hour average PM_{10} concentrations

	Plant Hill	Stadium
2013	117.8	168.9
2014	77.3	170.0
2015	112.2	218.2
2016	75.8	58.1
2017	124.0	279.8

A WHO report[31] on the global burden of disease from air pollution in 2016 showed that more than 90% of the global population is exposed to air pollution at levels exceeding the WHO PM_{10} limit of 50 μg/m^3 daily and 20 μg/m^3 annually.

The article estimates the health impact of these PM_{10} exceedances for different countries using burden of disease units of disability adjusted life years (DALYs) which integrate a measure of premature mortality measured as years of life lost prematurely (YLL), and increased morbidity in life as years lived with disability (YLD). Given the paucity of morbidity studies in low income countries the health impact is expressed in YLL in Table 7.

This corresponds to a burden of disease due to air pollution as measured by PM_{10} exceedance measured in years of life lost (YLL) per 100 000 population

[31] World Health Organisation 2016. Ambient air pollution: a global assessment of exposure and burden of disease.

as shown for different countries in Table 7. Namibia has a lower burden of disease than Canada (DPM Head Office) and a substantially lower burden than South Africa (a more industrialised middle income country) and Bulgaria (an EU country where some of the ore for the smelter is sourced) by comparison.

Assuming a population in Tsumeb and surrounds of 25 000, the number of YLL is calculated for Tsumeb as 175 per annum. This amounts to 0.007 year per person or about 2.5 days of life lost per year on average due to air pollution.

Table 7: Burden of disease due to air pollution

Country	YLL Per 100000 population	Number of YLL for a population of 25 000
Namibia	**700**	**175**
Botswana	657	164
Angola	1794	449
South Africa	1116	279
Bulgaria	1302	326
Canada	868	217
USA	168	42
UK	277	69
Sweden	3	<1
Netherlands	279	70

The 2017 data appear to show an increase in PM_{10} concentrations over 2016 concentrations across the board at all monitoring stations. As per the analysis of the updated air quality impact assessment conducted by Airshed in 2018 as part of the EIA process, the PM_{10} levels measured in the Tsumeb town area are mostly related to localised sources, especially at the Sports Stadium. It appears that sources to the south east and south west of the Sports Stadium are the highest contributors to PM_{10} measured. Likely sources relate to vehicle traffic, domestic fuel burning and community activities, with spikes in levels recorded between 18:00 and 21:00 in the evenings. An analysis of wind direction and time variation showed that DPMT is likely the main source of elevated PM_{10} at the Sewerage Works station (Airshed, 2018).

SO_2

The total exceedances per year for SO_2 for 2016 were found to be negligible for the South African limit, the WHO interim targets and the EU limit, but above the WHO[32] SO_2 target. For SO_2 the WHO interim target values start at 125 µg/m^3 reducing to 50 µg/m^3 and the eventual guideline of 20 µg/m^3. The EU[33] has a limit of 125 µg/m^3 with up to 3 exceedances allowed annually. Within Tsumeb town, levels were slightly higher at the Stadium station than at the Info Centre. The SO_2 exceedances of the more stringent WHO daily limit at around once a week on average are confirmed by the results of the respiratory questionnaire administered in September 2016 in residential areas of Tsumeb as shown below.

The 2017 data show continued improvement upon 2016 emissions.

Previously (SGS data not shown here) Stadium experienced an average of 13.2 daily exceedances per month of the WHO PM_{10} limit and 12.1 exceedances for SO_2 in 2015. The laxer South African limits were exceeded only 4 times for SO_2 per month back then.

Table 8 shows a step change in SO2 concentrations in residential areas (Stadium) and at the perimeter of the smelter (Plant Hill) between 2015 and 2016, but little change in the annual average from 2016 to 2017.

[22] WHO Air quality guidelinesfor particulate matter, ozone, nitrogen dioxide and sulfur dioxide
lobal update 2005
[23] http://ec.europa.eu/environment/air/quality/standards.htm

Table 8: Trends in annual average SO_2 concentrations in ug/m3

1-year average SO_2 concentrations

	Plant Hill	Stadium
2013	122.6	48.5
2014	168.3	51.0
2015	200.5	34.6
2016	42.3	11.3
2017	25.2	9.2

99th percentile of 1-hour average SO_2 concentrations

	Plant Hill	Stadium
2013	2575.0	1089.0
2014	3604.0	1139.6
2015	4260.4	709.7
2016	894.0	173.1
2017	469.4	79.4

To provide some idea of possible health impacts of these SO_2 exposure levels, Linn *et al*.[34] studied normal, atopic (allergic), minimal/mild asthmatics and moderate/severe asthmatics in an exposure chamber at various concentrations of SO_2. The average exposures given were 0, 0.2, 0.4 and 0.6 ppm - all these exposures were an order of magnitude[35] above the South African, and 2 orders of magnitude above the WHO limit. Normal and atopic individuals were unaffected at these levels, while asthmatics, whether minimal/mild or moderate/severe, showed mild and reversible effects (bronchoconstriction and respiratory symptoms with no impact on their ability to exercise).

Arsenic in PM_{10}

For similar reasons only data from 2016 and 2017 are shown in Table 9 for current Arsenic in PM_{10} exposure levels for residents of Tsumeb.

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[34] Linn WS *et al*., Replicated dose-response study of sulfur dioxide effects in Normal, Atopic and Asthmatic Volunteers. Am Rev Respir Dis 1987; 138:11271134.

[35] The Namibian National Department of Environmental Affairs (DEA) has air quality standards of 125 for SO_2 while the WHO air quality guideline is more stringent and has limits of 20 µg/m^3 for SO_2. As 2ppm = 5mg/m3 for SO_2, 20mcg/m3 = 0.008ppm and 125 mcg/m3 = 0.05 ppm

As can be seen on the map in Figure 10, a combination of air and soil sampling done mainly in the smelter precinct has shown presumptive exposure zones which were also used in our survey for sampling subjects in different exposure zones at distance from the smelter.

The Stadium and Information Centre monitoring station data are a crude proxy for arsenic levels in air at most of the residential sites. More specifically, they may be considered to be upper bounds for those living in the central town and southern town areas. Those living in Ondundu and Endombo in Town North may be considered to be exposed at higher levels, likely between the Hill and Sewerage monitors and the Info Centre and Stadium monitors.

Table 9: Arsenic in PM_{10} monitoring results at 5 monitoring stations

2016 and 2017		**Sewerage**			**Stadium**		**Hill**		**Info Centre**		**NAMFO**
		µg/m³			µg/m³		µg/m³		µg/m³		µg/m³
	EU	**reference limits**	**=**	**0.006 µg/m³**							
December		0.25			0.03		0.26		0.07		0.02
November		-			-		-		-		-
October		0.23			0.08		0.42		0.17		0.30
September		0.26			0.03		0.20		0.04		0.64
August		-			-		-		-		-
July		0.51			BDL		0.08		BDL		0.34
June		0.18			0.09		0.09		0.06		2.84[36]
May		0.37			0.05		0.18		0.03		0.22
April		0.23			0.04		0.26		0.06		0.07
March		0.09			0.008		0.08		BDL		0.15
February		0.39			0.08		1.13		0.23		0.13
January		0.07			0.17		0.13		BDL		0.21
2016 average		**0.26**			**0.06**		**0.28** Nearest Ondundu		**0.07**		**0.49 (0.23) with/without outlier**
2017 average		**0.53**			**0.07**		**0.54**		**0.08**		**0.21**

36 This appears to be a very high outlier and is most probably an error of transcription. Consequently the average has been calculated both with and without this value.

From 2012 onwards the annual averages for Info Centre and Stadium monitors (not shown here) were in the vicinity of 0.1 µg/m^3.

In 2016 for both Stadium and Info Centre the arithmetic mean values shown here had decreased to roughly half of that value. The 2017 annual averages appear to have increased slightly for Stadium (by 17%) and Info Centre (by 14%). The increases for Plant Hill and Sewerage appear to have roughly doubled. Namfo appears to be similar to 2016, casting doubt upon the high outlier in 2016. These are consistent with an increase in the PM_{10} noted above in 2017. Arithmetic means presented here are most likely the best estimates given that very few measurements are taken (between 4 and 6 a month), and that they display great variability. All means here are slight underestimates as BDL (below the limit of detection) values have been assumed to be 0 instead of a very small number.

The other monitoring stations have averages which are about an order of magnitude higher than those indicative of residential exposures, and these are crude proxies for exposure in the Western Industrial area (Sewerage) and the smelter precinct itself (Plant Hill).

The NAMFO data are not clear. The mobile monitoring station there has moved around quite a bit and is sometimes stationed within the smelter precinct at Mossmart where exposure levels are very high. There was a very high value for 2016 in July, with an average of 0.53 µg/m^3 for the year, which seem unlikely to be experienced at NAMFO farms. Levels at these farms might be expected to be lower than the Sewerage levels due to the further distance away from the smelter in the same direction given the prevailing winds. It is not therefore clear whether the NAMFO column in Table 9 can be taken as representative of exposure at the farms, or whether it is possibly a mix of different locations or whether the single outlier is a transcription error.

These values of arsenic in air only have utility as rough indicators of exposure and need to be read together with the results of the urine arsenic levels from the community survey (see below).

The main point of interest arising from these measurements is that exposures at around 0.05 or 0.06 μg/m^3 or 60 ng/m^3 are one order of magnitude higher than the current EU [37]environmental exposure limit for arsenic in air of 6 ng/m^3 or 0.006 μg/m^3.

These exposure levels will be revisited in later sections below, particularly in regard to estimating lung cancer risk.

Summary of airborne pollutant findings

Tsumeb can be seen to be experiencing relatively few, but nonetheless continuing monthly, SO_2 exceedances of the WHO limits after the installation of the Acid Plant at the smelter.

However, the burden of disease due to air pollution as estimated by PM_{10} exceeding the WHO limit, and measured as years of life lost, is estimated at only 2.5 days per per annum and thus rather small at the level of the Tsumeb population.

The level of exposure to SO_2 when compared with findings of Linn *et al.* which found no irreversible adverse respiratory impact even on asthmatics and atopic individuals in controlled experimental conditions under conditions of exposure at least an order of magnitude higher are somewhat reassuring. This is confirmed by the results of the respiratory health questionnaire in the community health study.

Given a background of particles from wood smoke generated by burning wood in the production of charcoal, or from other outdoor fires, as well as the use of biomass fuel

[37] EEA Report No 5/2015 Air Quality in Europe- 2015 Report

inside the home for cooking, the contribution from the smelter is likely to be relatively small for community residents. The particulates in the $PM_{2.5}$ fraction of dust in the air are more relevant for health impacts but the monitoring stations were not able to measure this fraction until recently. The broken monitors should be repaired more promptly in future.

On the other hand the SO_2 exceedances have an irritant effect on the respiratory system causing a symptom burden for the receptor population, especially for those with asthma-linked symptoms. While the level of exposure is not likely to cause a substantial symptom burden, there is definitely a nuisance burden. This will be discussed further with the results of the respiratory questionnaire survey.

The Arsenic in PM_{10} levels are unlikely to pose a meaningful lung cancer risk as shown below when discussing the cancer risk. This is the case both for one order of magnitude above the EU limit at Info Centre or Stadium, and at higher levels (two orders of magnitude above the EU limit) experienced at the Hill site monitor. These exposures are also unlikely to elevate the arsenic in urine by more than a negligible amount. An increase of airborne exposure of 0.05 $\mu g/m^3$ (will correspond to an increase of arsenic in the urine of just 0.015 μg/L, while an average air exposure of 0.5 $\mu g/m^3$ will only elevate the urine level by 0.5 μg/L using the ACGIH[38] equation. These increases in urine level are to small to have a meaningful impact on cancer risk.

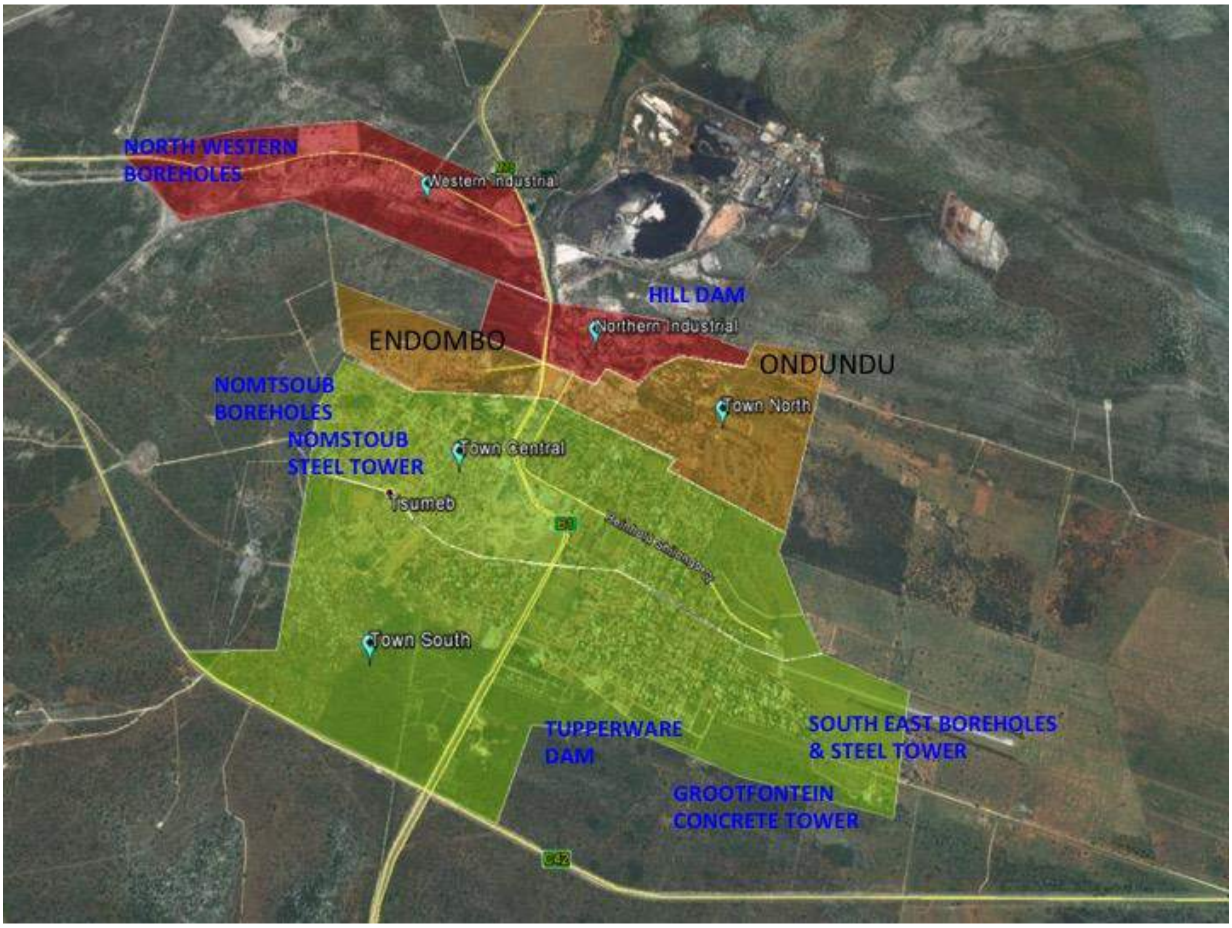
[38] ACGIH BEI 2001. Arsenic and soluble inorganic compounds. Equation 1

Sources of data

A tour of the water supply system for Tsumeb town was arranged by the Municipal Manager for Tsumeb and conducted by the Water Supervisor on 6 September 2016.

A water scheme layout for 2005 was supplied which mapped the various boreholes and water reservoirs/dams and pumping stations. Most of the water reservoirs are elevated water towers, with the Tupperware and Hill reservoirs being dams (see Figure 15).

Figure 15: Water scheme layout in Tsumeb



All dams and reservoirs are covered over because of the potential airborne arsenic hazard from the smelter.

We began in the extreme South East edge of Tsumeb which is the least exposed area in Tsumeb to arsenic from the smelter due to the direction of the prevailing easterly winds.

The South East Steel Tower is supplied by the Poskantoor Number 2 borehole.

Nearby is the Grootfontein Dam which is a raised concrete water tower. It has a booster pump and can supply the South East Steel Tower if the latter is empty. It is supplied by the Grootfontein borehole number 4. The other boreholes in this area do not work due to insufficient water.

The SE Steel Tower supplies all the residences in the South East of Tsumeb up to 19th street on the western border.

The Grootfontein Tower supplies residences in the lower central area to the West of this demarcation line but not to Nomtsoub on the western side of the B1 highway.

There is some mixing of water arriving at residents from these 2 sources as not all of it comes from the Tupperware dam. The reason is that these two towers supply the residential users when there is ample water supply. When this is low water is pumped up to them from the Tupperware dam to supplement the supply. Water also flows from the 2 towers in the other direction into the Tupperware dam.

The Tupperware dam is the largest of the dams and the main supply of the town.

The dam takes input from the 2 towers and has 3 output pipes. There is a pump station and dosing take place here with going out to Nomtsoub, the Hill Dam and the 2 towers.

The other set of boreholes is at the extreme North Western edge of town in the industrial zone. This is the most highly exposed part of Tsumeb from the point of view of arsenic due to the prevailing easterly winds. There are 4 boreholes here - Wolf 1, Wolf 2 and 2 solar powered boreholes (1N and 15.3). The other boreholes in the area do not work. These supply water via a Northern Booster to the Tupperware dam.

In the Northwest corner outside of the Nomtsoub residential area are 4 boreholes, Nomtsoub 1 and 2 and Icon3 and Icon6. Icon 1 is defunct and has no water. These pass to the Nomtsoub Steel Tower where water is pumped by the Nomtsoub booster to the Tupperware dam.

The Tupperware dam then supplies water to the Southern Part of Nomtsoub and South Central town.

The Hill Dam supplies water to the smelter for drinking purposes and also to the town where it supplies Ondundu, Northern Town, Northern half of Nomtsoub and Endombo and the Western Industrial area.

Surface water in the Western Industrial area when it rains all runs off in the direction of Tsintsabis and away from the town. Also the groundwater flow is very deep and northwards.

Ministry of Water Affairs and Forestry takes samples from the various dams and reservoirs and supplies the results to the Town Engineer. However the Town Engineer resigned some time ago and hard drive used by the municipality to store reports crashed. It was not possible to get reports as a result.

One set of 3 samples was taken by DPMT[39] in June 2016 of drinking water from taps at Ondundu. Two were taken at the School and one at a house. All three were found to have arsenic levels below 1 µg/L.

We collected 96 samples of drinking water from the households that participated in the survey which were situated in different suburbs of Tsumeb at different distances from the smelter precinct and also on NAMFO farm and some farms further away. In addition we had samples from an external control group in Oshakati sufficiently far away to the North to be unimpacted by any arsenic from the smelter.

Drinking water pollution findings

Table 10 shows these results for the different areas.

Table 10 : Arsenic in water levels

Town	Suburb	# samples	Arithmetic mean (SD) in µg/L	Minimum	Maximum
Oshakati		18	0.73(0.21)	0.4	1.1
Tsumeb		78	2.13 (0.75)	1	3.9
	Town North	18	**3.08** (0.49)	2.4	3.9
	Town Central	35	**2.02**(0.60)	1	3.1
	Town South	9	1.49(0.30)	1.2	2.1
	NAMFO	12	1.68(0.40)	1.1	2.7
	Distant farms	3	1.53(0.23)	1.4	1.8

39 Dundee Precious Metals Tsumeb (2016): *Community Campaign / Project Report Evaluation of Quality of Drinking Water Samples obtained from the Ondundu Community, Tsumeb*, June 2016, Document no. DPMT(ENV)-2016-001-CS .

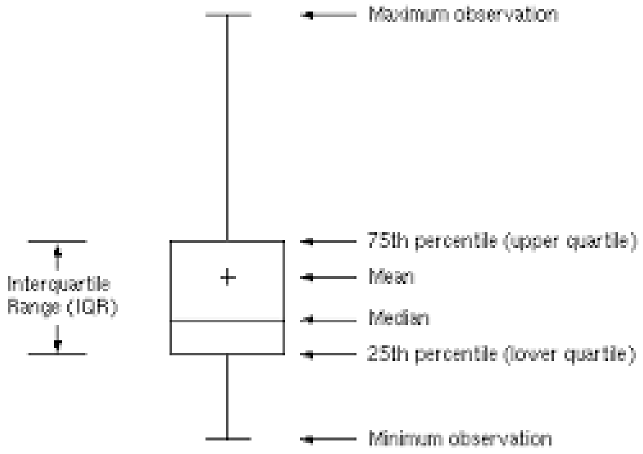
For Tsumeb as a whole and in all the exposed areas, all drinking water samples were well below the WHO[40] limit of 10µg/L.

Oshakati is an external exposure control and was lower still.

Notwithstanding the fact that they are all within the acceptable limit there is a significant trend visible (see Figure 15) where the further one goes in a southerly direction from the smelter the lower the mean value. These results are consistent with the starting assumption that distance from the smelter is correlated with exposures.

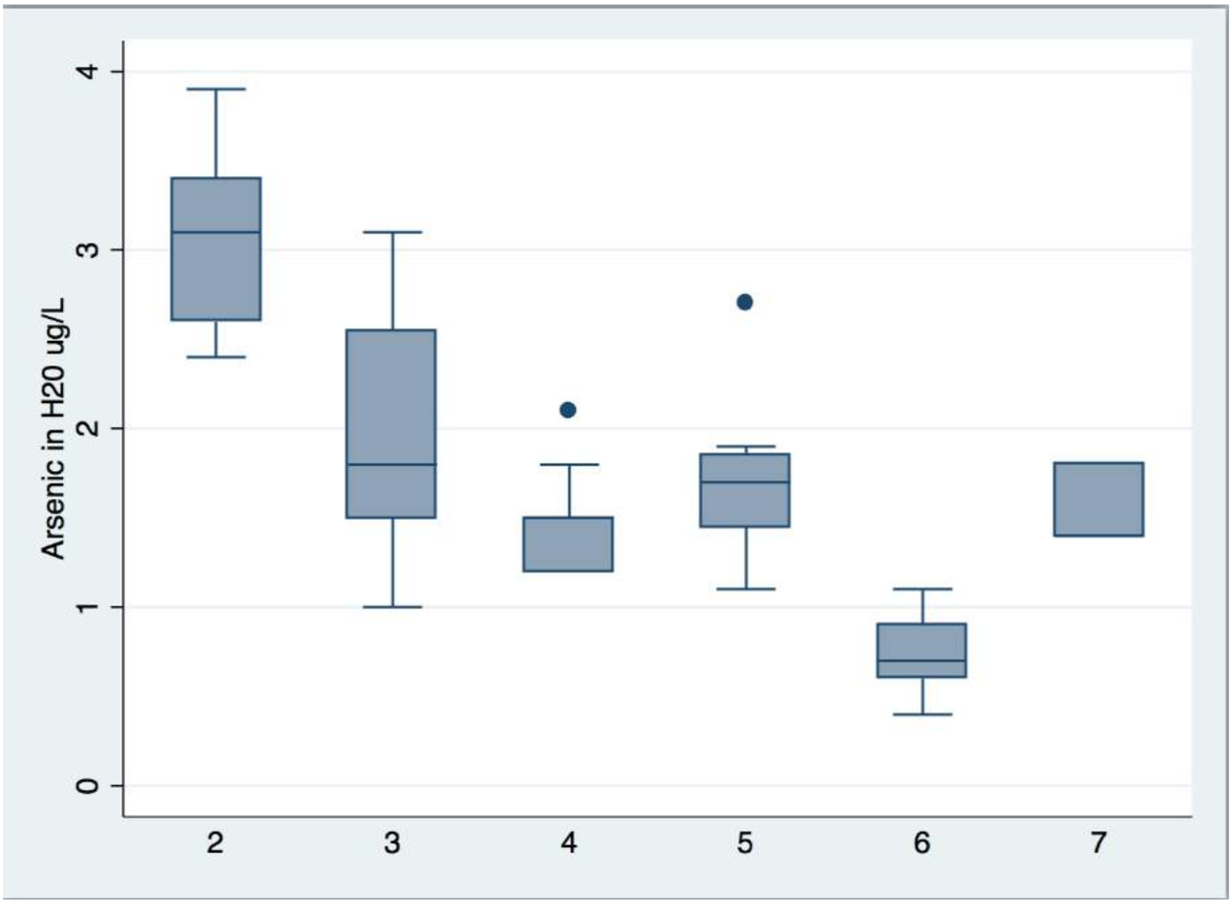
Figures 16 and 17 shows these results graphically by way of a box and whisker plot display. Outliers are plotted in the graph as dots above the 75th percentile and below the 25th percentile.

Figure 16: Generic Box and Whisker Plot



[40] WHO (2011) : *WHO Guidelines for Drinking-water Quality (fourth edition)*. World Health Organisation 2011. ISBN: 978 92 4 154815 1

Figure 17: Arsenic levels in water by residential area[41]



Area 2 = Town North, 3 = Town Central, 4 = Town South, 5 = NAMFO, 6 = Oshakati, 7 = remote farms

The highest is Endombo at a mean of 3.1 μg/L and Ondundu with a mean of 3 μg/L and the lowest is Kuvukiland at a mean of 1.5 μg/L.

Town Central has values in-between Town North and Town South

Surprisingly, NAMFO which typically has higher levels of arsenic air pollution in the SGS reports than Stadium and Info Centre within Tsumeb residential suburbs had a mean value of 1.7 μg/L implying that arsenic does not get into the groundwater at the farms which it should by all accounts if the water plume from the smelter precinct flows in that direction, and if the prevailing wind blows in the direction of the farms. The 2018 updated ground water model shows that the plume does not reach the farms and that is is unlikely for any contaminated groundwater from the smelter to reach the

[41] Area 2 = Town North, 3 = Town Central, 4 = Town South, 5 = NAMFO, 6 = Oshakati, 7 = remote farms

farms over the next 200 years[42]. As mentioned before, with regards to arsenic in air, the higher levels recorded might be due to the mobile nature of the monitoring station which has also been placed within the smelter precinct for some if its time, and consequently casts doubt upon the validity of the NAMFO air monitoring results.

A farm even further away in the same direction showed a groundwater concentration of 1.5 μg/L the same as Kuvukiland.

Oshakati as an external exposure control was only 0.7 μg/L.

It is hard to understand why there should be an exposure gradient across town in relation to the smelter as all dams and reservoirs are closed to the air, hence airborne emissions are unikley to be a significant source of groundwater contamination. Also, background levels may be high due to naturally occurring sources.

Summary of arsenic in drinking water study

All of the arithmetic mean values for the different areas were well below the WHO exposure limit of 10 μg/L and very much below the Namibian drinking water standard of 100 μg/L.

There was however a significant difference between the arsenic concentration in Tsumeb as a whole and Oshakati ($t = 7.8$, $p < 0.00001$)

There was also a significant trend towards higher exposures the closer the residential area was to the smelter, even though the differences were small and all measured values were below the WHO limit. Town North was higher than Town Central ($t= 6.6$, $p < 0.00001$) and Town Central was higher than Town South ($t= 2.54$, $p = 0.008$).

Drinking water is not a source of significant arsenic exposure to residents.

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[42] SLR Consulting. 2018. 3D Groundwater Flow and Contaminant Transport, compiled for DPMT.

RESPIRATORY HEALTH SYMPTOMS

Asthma-related symptoms

Several questions were asked for respiratory symptoms intending to measure various proxies for asthma in order to examine the impact of SO_2 exposures on residents in different areas within Tsumeb. There was also an external unexposed comparison group in Oshakati against which these measures could be evaluated.

Six main questions with the first question having 3 subcomponents were asked (see Appendix 2: survey questionnaire). These questions were derived from the European asthma study[43] and are well validated and used in many countries across the globe.

Advice was sought from one of the principal investigators in that study, Professor Peter Burney at University College London, UK regarding the scoring and weighting of these questions in order to obtain the most sensitive and specific estimate of asthma. He proposed 3 combinations of questions. In addition the asthma scoring system of Pekkanen[44] was also used.

The following question combinations were used:

Burney 1: Wheezing and breathlessness while wheezing in the past 12 months
Burney 2: Wheezing when one does not have a cold in the past 12 months
Burney 3: Being woken up at night by an attack of shortness of breath in the past 12 months

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[43] Burney P, Jarvis D. ECRHS II Screening Questionnaire (for Adults). The European Community Respiratory health survey II. Page 2.

[44] Pekkanen J et al. 2005, Operational definitions of asthma in the study of its aetiology Eur Respir J 2005; 26: 28–35

The Pekkanen score was based on the added presence of each of the following symptoms which counted for a score of 1 each:

Wheezing with breathlessness
Waking short of breath
Wheezing during or after exercise
Waking with coughing
Have had attacks of asthma
Taking asthma medications

For Burney 1 (Wheezing with breathlessness in the past 12 months)

Table 11 shows that the prevalence of this symptom cluster was raised for the whole of Tsumeb compared with Oshakati, but that this was only of borderline significance.

Within the different exposed areas, only Town North and NAMFO were significantly raised with respect to Oshakati. No trend was discernible from Town North (high) through Town South (low).

Table 11: Burney 1 asthma-related symptoms

area	Oshakati	All the exposed	Town North	Town Central	Town South	NAMFO farms	Remote farms	total
Burney1 +	6	54	14	23	5	11	1	
denominator	41	176	38	90	16	27	5	217
Prevalence	0.15	0.31	0.37	0.26	0.31	0.41	0.2	
Fisher's exact test	-	Borderline s	s	ns	ns	s	ns	
p	-	0.051	0.037	0.115	0.260	0.022	1	

s = significant, ns = non significant

For Burney 2 (Wheezing while not having a cold in the past 12 months)

Table 12: Burney 2 asthma-related symptoms

area	Oshakati	All exposed	Town North	Town Central	Town South	NAMFO farms	Remote farms	total
Burney2 +	7	53	11	23	7	12	0	
denominator	41	176	38	90	16	27	5	217
prevalence	0.17	0.30	0.29	0.26	0.44	0.45	0	
signif								
Fisher's exact test	-	ns	ns	ns	s	s	-	
p	-	0.121	0.284	0.371	0.047	0.026	1	

The prevalence of this symptom was raised for Tsumeb as a whole compared with Oshakati but this was again not significant. Within the different exposed areas only Town South and NAMFO farms were significantly raised with respect to Oshakati. No trend was visible from areas Town North (high) through Town South (low).

For Burney 3 (Woken up at night with shortness of breath in the past 12 months)

Table 13: Burney 3 asthma-related symptoms

area	Oshakati	All exposed	Town North	Town Central	Town South	NAMFO farms	Remote farms	total
Burney3 +	6	59	15	25	5	12	2	
denominator	41	176	38	90	16	27	5	217
Prevalence	0.15	0.33	0.4	0.27	0.43	0.45	0.4	
Fisher's exact test	-	s	s	ns	ns	s	ns	
p	-	0.022	0.021	0.123	0.260	0.011	0.203	

The prevalence of this symptom was significantly raised for the exposed areas as a whole compared with Oshakati. Within the different exposed areas only Town North and Town NAMFO were significantly raised with respect to Oshakati. No trend was visible within Tsumeb town from Town North (high) through Town South (low).

The mean Pekkanen score in Table 14 was significantly raised for all of exposed areas individually and as a whole compared with Oshakati. No trend was visible within Tsumeb town from Town North through Town South.

Table 14: The Pekkanen score for asthma-relatedness

area	Oshakati	All exposed	Town North	Town Central	Town South	NAMFO farms	Remote farms
n	41	176	38	90	16	27	5
Pekkanen score	1.67	2.29	2.14	2.34	2.2	2.55	0.4
SD	0.82	1.41	1.29	1.67	1.10	1.21	-
significance	-	s	s	s	s	s	-
t-Test	-	2.71	1.95	2.43	1.99	3.58	-
p	-	0.0037	0.028	0.008	0.026	0.0003	-

The risk of any of the 3 Burney symptom combinations was about double for Tsumeb residents compared with those in Oshakati. It is notable that throughout, Town Central had lower prevalence than both Town North and Town South. There was no consistent elevation in any particular suburb (apart from Town North which was significantly higher in three comparisons) over all four of these comparisons above.

Of the 83 people (48% of those in the exposed areas) who experience wheezing in any form, 54 (64% of 83) have frequent episodes at least once weekly, which provides some idea of the severity.

Forty (48% of the 83 who experience wheezing in any form) have frequent episodes and are breathless with the wheezing.

Thirty nine (47% of the 83) have frequent episodes and wheeze in the absence of a cold with the wheezing attacks.

Thirty (36% of the 83) have frequent episodes and wake up at night short of breath.

Summary of asthma-related symptoms in relation to SO_2

Compared with Oshakati there was evidence of asthma-related symptoms being significantly more prevalent. This is consistent with the 2012 Namibian Government Survey[45] which found an excess of respiratory symptoms in Tsumeb in comparison with Grootfontein – another town distant from the smelter. Half of all those in Tsumeb had some asthma-related symptomatology and a half of these again experienced some degree of severity of these symptoms constituting an appreciable burden of asthma-related morbidity spread across all the areas of Tsumeb and the farms to the North. There was no visible trend in these symptoms across areas within Tsumeb which would make sense for asthma-related symptoms which are not dose-related but can be triggered by low levels of exposure to SO_2 affecting the whole of Tsumeb.

It needs to be stressed that these findings are in a sense sub-clinical, and were not reported spontaneously as “asthma” by interviewees. These findings need to be considered together with a count of only 7 reports of a medical diagnosis of asthma for all survey subjects (2 from Oshakati and 5 from Town Central in Tsumeb). This constitutes an actually higher prevalence in Oshakati (5%) than in Tsumeb (2.9%). Of these, almost all of them (6) take medication for their asthma. So it can be inferred that there definitely is some asthma-related impact from exposure to SO_2 from the smelter, but that this is mostly mild to moderate.

Odour perception

The prevalence of perception of a strong unpleasant smell in the air was elicited in the questionnaire. Table 15 shows that there was an overwhelmingly prevalent perception of incidents of strong unpleasant odour in the air in all exposed areas without exception, and without any meaningful differences between the different exposed area including suburbs of Tsumeb, although there is a slight trend from the

[45] Namibian Government survey, 2012

North to the South. A quarter of the Oshakati respondents also replied in the affirmative but the odours they reported were invariably described as woodsmoke or, in one case, hydrogen sulphide from a nearby sewerage plant.

Table 15: Perception of strong unpleasant odour

area	Oshakati	All exposed	Town North	Town Central	Town South	NAMFO	Remote farms
# Smell +	10	151	33	77	12	25	4
# denominator	41	176	38	90	16	27	5
%Ever smell	0.24	0.85	0.87	0.84	0.75	0.89	0.8
#(%)Never Smell	31(76)	25(15)	5(13)	13(14)	4 (25)	2 (7)	1 (20)

Table 16: Frequency of malodorous incidents for those who perceived the problem

area	Oshakati #(%)	All exposed Yes smell	Town North #(%)	Town Central# (%)	Town South #(%)	NAMFO farms #(%)	Remote farms #(%)
Ever smell	10	151	33	77	12	25	4
Very infrequently	5 (12)	36 (20)	9(24)	16(18)	1(8)	6(22)	4 (80)
Less than monthly	2(5)	13 (7)	1 (3)	8(9)	0	4(15)	0
More than monthly	2(5)	28(16)	8(21)	10(11)	4(33)	6(22)	0
At least once weekly	1(2)	58(33)	9(24)	36(40)	4(33)	9(33)	0
daily	0	16(9)	6 (16)	7(8)	3(25)	0	0

It can be seen from Table 16 that the typical frequency of bad odour is around once a week. This confirms the average of 4 to 5 SO_2 exceedances reported for the monitoring stations at Stadium and Information Centre for the period since the acid plant has come on stream late in 2015. Before this it was much more frequent.

The responses to the questionnaire also confirm many statements about improvements with regard to SO_2 exposures in the residential areas made by community members at the Town Hall meetings prior to this survey. Of responses to the question of whether these incidents were more or less frequent, the overwhelming majority (82%) felt that they were less frequent in 2016 than in 2015, while only 16% felt that they were more frequent. Prevalence for improvement within the exposed areas all hovered around 80%, except for Town South where 90% experienced less frequent exposure episodes.

Symptoms of irritation due to SO_2

Of 161 who were aware of the smell, almost all i.e. 133 or (83%) were affected in some way physically by the smell.

Table 17: Symptoms of SO_2 irritation

area	Oshakati #(%)	All exposed Yes smell #(%)	Town North # (%)	Town Central # (%)	Town South #(%)	NAMFO farms #(%)	Remote farms #(%)
Affected +	10	151	33	77	12	25	4
denominator	41	176	38	90	16	27	5
prevalence	0.24	0.85	0.87	0.84	0.75	0.89	0.8
Cough +	1 (10)	64(42)	18(55)	27(35)	7(58)	9 (36)	3(75)
Sneeze +	1(10)	18(12)	4(12)	10(13)	1(8)	3(12)	0
Nose +	1(10)	16(11)	2(6)	10(13)	1(8)	3(12)	0
Throat +	2(20)	33(22)	5(15)	20(26)	3(25)	4(16)	1(25)
Chest +	0(0)	13(9)	2(1)	9(12)	1(8)	1(4)	0
SOB +	0(0)	20 (13)	4(12)	9(12)	1(8)	5(20)	1(25)
Eyes +	0(0)	3(2)	0 (0)	2(3)	0(0)	1(4)	0
Dizzy +	0(0)	0(0)	0 (0)	0	0(0)	0(0)	0
Flu +	3	0	0	0	0	0	0

It is evident that there is an appreciable burden of physical effects of the SO_2 exceedances on the exposed population. The comparison with the vanishing level of these effects in unexposed Oshakati is striking.

The predominant symptoms are cough and throat irritation which are upper respiratory system responses and compatible with respiratory irritation by SO_2. It is notable that the more severe lower respiratory symptoms such as shortness of breath and chest discomfort are considerably less prevalent. This is consistent with the mild to moderate impact on asthma-related symptoms discussed above. Other upper respiratory symptoms are nasal discomfort and sneezing. Itchy throat discomfort was very common and experienced by the author of this report on all field days in Tsumeb in 2016, particularly in Endombo at the northern end of Nomtsoub and in the northern part of town in the commercial district.

All these findings are compatible with the measured SO_2 levels from the air monitoring stations at Stadium and Information Centre. While not severe, they do however, impose some burden of discomfort on the residents in all areas of Tsumeb.

URINE ARSENIC LEVELS IN COMMUNITY RESIDENTS

Comparing Tsumeb and Oshakati

Table 18 shows findings from the biomonitoring of arsenic in urine for all the exposed groups in and around Tsumeb and an external control group from Oshakati who are not exposed to anthropogenic environmental arsenic.

There is no significant difference between all the exposed and Oshakati residents in either the arithmetic or geometric mean values or the 95th percentiles for total arsenic in the urine.

Table 18: Total urine arsenic by location

Location	n	Geometric mean µg/g	Arithmetic mean µg/g	95th percentile
Tsumeb town	172	20.6	29.2	96
Oshakati	40	18.0	24.5	100.1
USA[46]	2557	8.3	-	65.4
Belgium	235	15.9		

However, Table 19 shows that when inorganic arsenic in urine is compared the results are different. The arithmetic mean is still not significantly different for this comparison

[46] Representative sample from across the USA of non-exposed residents. Caldwell KL et al., Levels of urinary total and speciated arsenic in the US population: National Health and Nutrition Examination Survey 2003–2004. Journal of Exposure Science and Environmental Epidemiology (2009) 19, 59–68

between all the exposed areas of Tsumeb and Oshakati. However the geometric mean is significantly higher among the exposed ($p < 0.002$). The 95th percentile values are again very similar.

By comparison a 2009 study of a large number of non-exposed community residents in the USA showed an arithmetic mean value for total urine arsenic about 2.5 to 3 times lower than either Tsumeb or Oshakati, and a similar decrease in the 95th percentile or inorganic urine arsenic.

Table 19: Inorganic urine arsenic by location

Location	n	Geometric mean µg/g	95th percentile
Tsumeb town	172	15.2	52.2
Oshakati	40	10.3	50.4
USA[47]	2557	Not given	18.9
Belgium adults[48]	235	15.9	71.4 90th %ile
Belgium 14-15yrs	207	9.3	49.0 90th %ile
France adults	1515	11.96	61.3

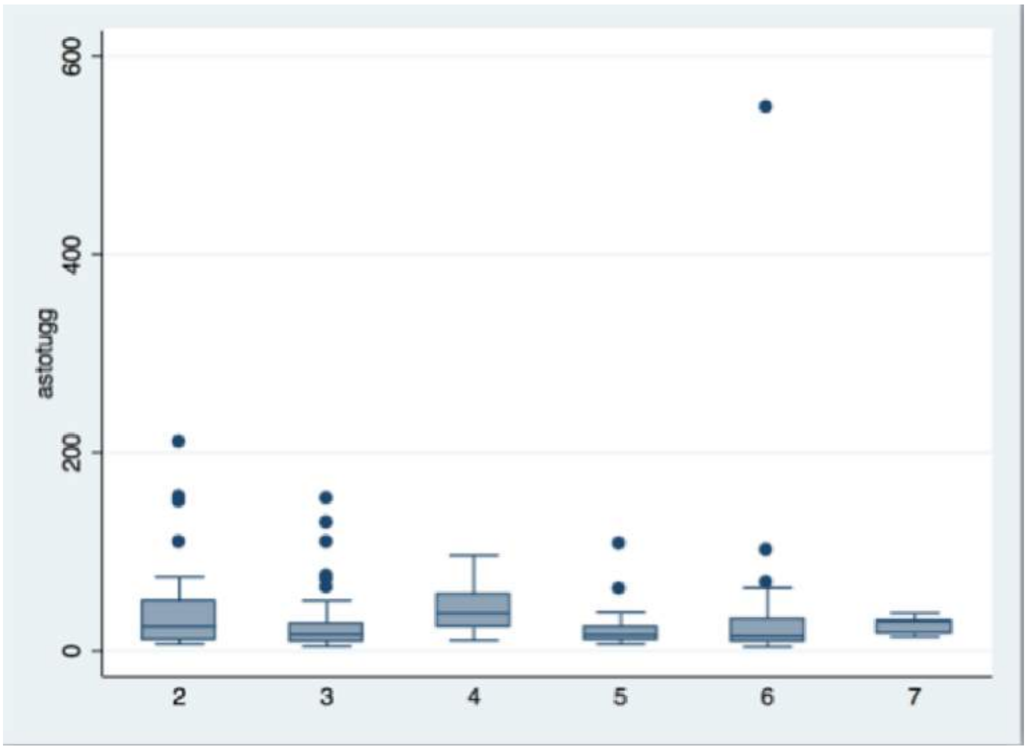
The total arsenic in urine measured by ICP-MS less the arsenic content of the organo-arsenic compound arsenobetaine was taken as the inorganic or anthropogenic and toxicologically relevant content of the total arsenic that is not dietary. It is also creatinine corrected.

47 Representative sample from across the USA of non-exposed residents. Caldwell KL et al., Levels of urinary total and speciated arsenic in the US population: National Health and Nutrition Examination Survey 2003–2004. Journal of Exposure Science and Environmental Epidemiology (2009) 19, 59–68
48 WHO 2015 Human biomonitoring facts and figures

Comparing Tsumeb suburbs and Oshakati

Graphic representation of total arsenic for all exposed areas within and around Tsumeb and Oshakati are shown as box and whisker plots in Figure 18 and 19. Two scales have been used to provide greater visibility. Figure 18 includes all data, while Figure 19 omits one high outlier in Oshakati which was entirely attributable to arsenobetaine. This was omitted to open up the scale for better viewing of the boxes. Figures 20 and 21 show the same plots for inorganic arsenic.

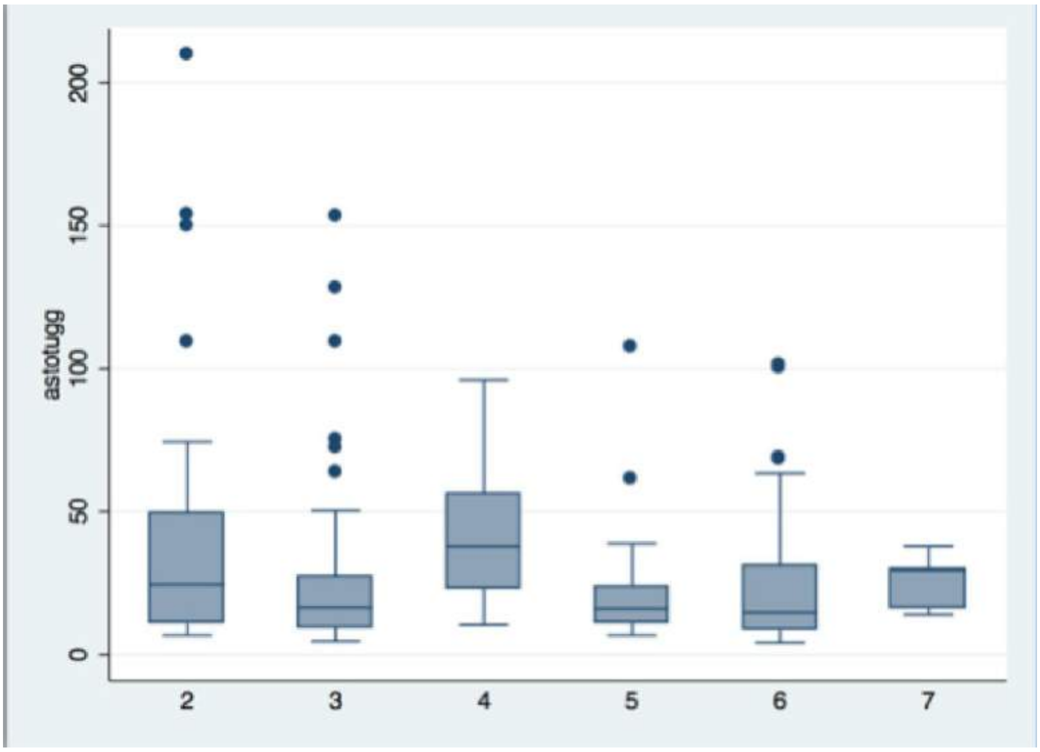
Figure 18: Total arsenic levels in µg/g by residential areas



Areas: 2 = Town North, 3 = Town Central, 4 = Town South, 5 = NAMFO,

6 = Oshakati, 7 = Remote Farms

Figure 19: Total arsenic levels in µg/g by residential areas with one outlier removed in Oshakati



Areas: 2 = Town North, 3 = Town Central, 4 = Town South, 5 = NAMFO,

6 = Oshakati, 7 = Remote Farms

Figure 20: Inorganic arsenic in µg/g by residential area

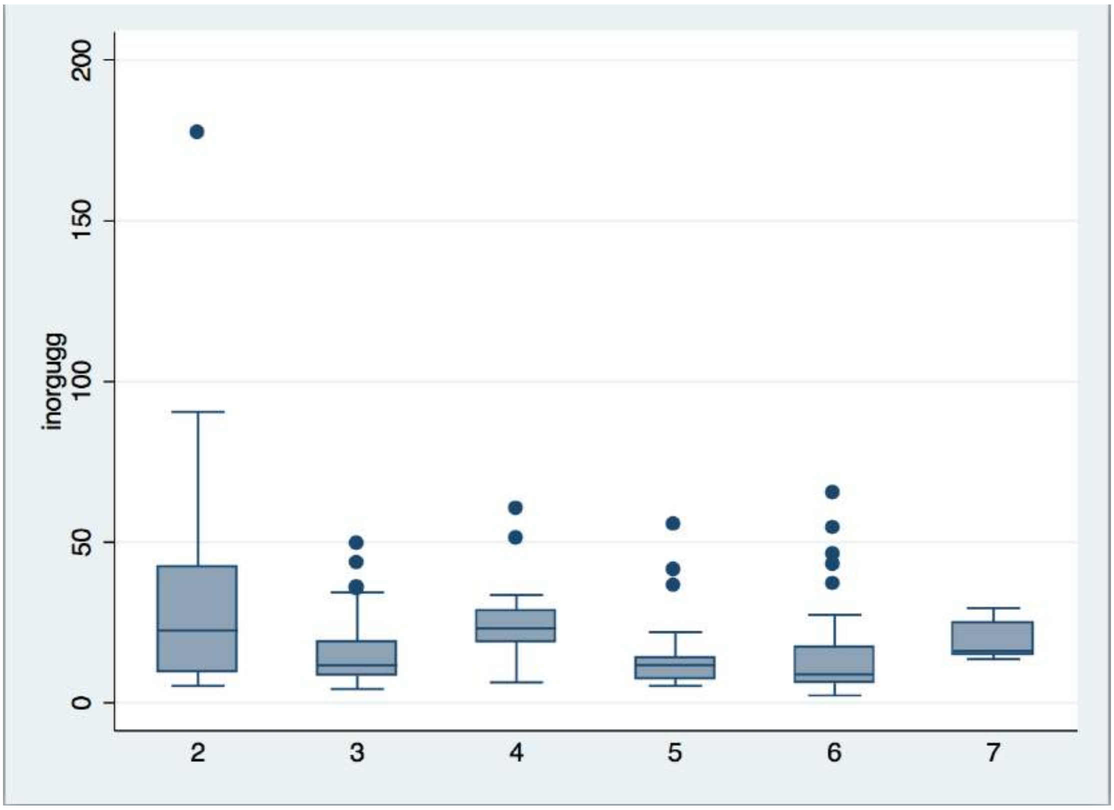
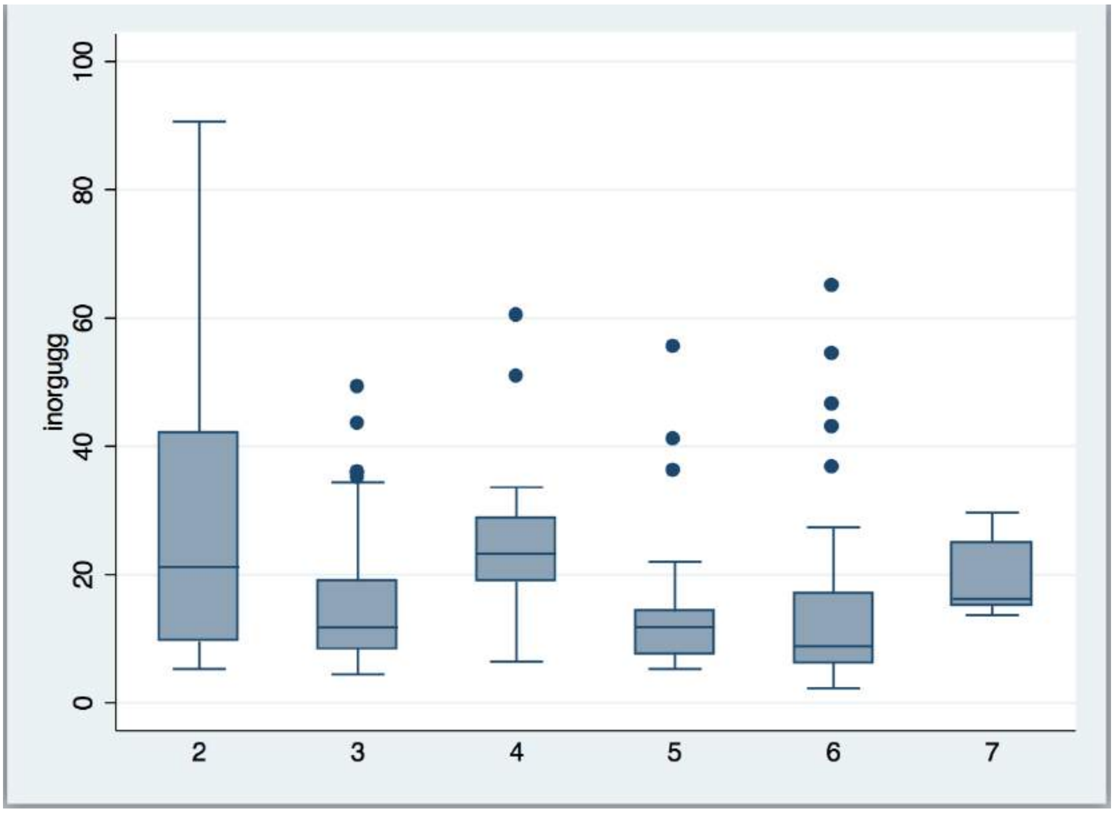


Figure 21: Inorganic arsenic in µg/g by residential area with one outlier removed from area 2 (Town North)



The data upon which Figures 18 - 21 are based are shown in Tables 20 and 21 below.

Table 20: Total arsenic µg/g by residential area

	Oshakati[49]	All exposed areas	Town North	Town Central	Town South	NAMFO near farms	Remote farms[50]
Area	**6**		**2**	**3**	**4**	**5**	**7**
n	**40**	**172**	**38**	**86**	**16**	**27**	**5**
Geometric Mean µg/g	**16.6**	**20.6 (NS)**	**26.4**	**17.5**	**35.16**	**17.46**	**23.81**
95th percentile µg/g	**83.1**	**95.6**	**154.4**	**72.2**	*	**61.6**	*
Arithmetic Mean µg/g	**24.5**	**29.2 (NS)**	**41.04**	**24.05**	**40.9**	**22.3**	**25.7**

***TOO FEW OBSERVATIONS NS = no significant differ**

Table 21: Inorganic arsenic ug/g by residential area

	Oshakati[51]	All exposed areas	Town North	Town Central	Town South	NAMFO near farms	Remote farms

49 Base for all statistical comparisons. NS = no significant difference at the 5% level

50 Note the small numbers in the remote farms column rendering these comparisons invalid

51 Oshakati is the base for comparison

Area	6		2	3	4	5	7
n	**40**	**172**	**37**	**86**	**16**	**27**	**5**
Geometric Mean µg/g	**10.2**	**15.2** **$p < 0.002$**	**21.34** **$p< 0.0001$**	**12.9** **NS**	**22.2** **$p < 0.0001$**	**12.3** **NS**	**19.1** **NS**
95th percentile µg/g	**50.4**	**52.2**	**90.9**	**35.5**	*****	**40.9**	*****
Arithmetic Mean µg/g	**14.8**	**20.2 NS**	**32.3**	**15.4**	**25.8**	**14.8**	**19.9**

It can be seen that the differences between Tsumeb as a whole and Oshakati are lesser in magnitude when considering total arsenic, and that the differences are more marked when considering the inorganic arsenic component. From here on, only the inorganic arsenic will be used in analysis to avoid confounding of the anthropogenic toxicologically relevant fraction by dietary sources of arsenic.

Taking Oshakati as the baseline, the geometric means (GM) for Town North and Town South are significantly higher. Moreover Town North is not significantly different from Town South while both of these are different from Town Central. Town North and Town South are also different from NAMFO which is not different from Town Central. Town Central and NAMFO are not however different from Oshakati.

The relationship between geometric means of the 2016 urinary arsenic species and the different residential areas were examined yielding Table 22. The MMA species is arguably the most precise measure of inorganic anthropogenic toxicologically relevant arsenic exposure. It is apparent that the MMA geometric mean for Oshakati, the external control area, is quite close to that obtained internationally[52] in large surveys of unexposed populations. It is also quite close to the MMA GM in Town Central, indicating that the latter area has low exposure to toxicologically relevant arsenic. This is consistent with the findings using inorganic arsenic. However all the other Tsumeb

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[52] USA[52] MMA GM = 0.45 – 0.49 (95th%ile = 1.61)and DMA = 3 – 4 based on the Fourth National Report on Human Exposure to Environmental Chemicals by the US CDC 2018.
Canadian MMA GM = BDL(95th%ile = 1.5) and DMA = 3-4 based on the Third Report on Human Biomonitoring of Environmental Chemicals in Canada 2018.

suburbs, with the exception of Endombo which is identical to Oshakati, have considerably raised mean MMA levels, even NAMFO where the mean for inorganic arsenic was close to that for Oshakati.

Table 22: Different Arsenic species and their relation to sources of Arsenic

	Oshakati	All exposed areas	Town North	Ondundu	Endombo	Kuvukiland	Town Central	NAMFO
	40	171	37	14	23	16	86	27
MMA AM	0.86	2.71	4.07	9.35	0.87	3.0	1.8	3.04
MMA GM	0.65	1.11	1.35	5.0	0.61	1.70	0.82	1.45
MMA 95%ile	2.8	11.1	25.3	34.2	2.3	12.1	6.3	11.1
DMA AM	0.92	7.99	15.90	27.41	8.89	6.75	5.79	4.71
ASB AM	9.775	9.03	8.75	14.91	5.0	15.11	8.69	7.5

(AM = arithmetic mean, GM = Geometric mean, MMA = monomethyl arsenic acid, DMA = dimethylarsinic acid, ASB = arsenobetaine)

Gender

Table 23: Female urine arsenic levels by residential areas

	Oshakati n	**All exposed areas**	**Town North**	**Ondundu**	**Endombo**
Females	**23**	**121**	**26**	**8**	**18**
Geometric mean µg/g	**12.3**	**15.5**	**22.7**	**48.4**	**16.1**

Table 24: Male urine arsenic levels by residential area

	Oshakati n	All exposed areas	Town North	Ondundu	Endombo
Males	**17**	**50**	**12**	**6**	**6**
Geometric mean μg/g	**8**	**15**	**19.1**	**34.8**	**9.2**

Females had higher levels than males in Oshakati, while having similar levels to males in Tsumeb. Within the exposed areas females had higher values than males within Tsumeb 26 Females had higher levels than 12 males in Town North.

Within Town North (the driver of high levels within Tsumeb as a whole) females had higher levels than 6 males in Ondundu (which in turn is the driver of high levels within Town North). Females had higher levels than 6 males in Endombo.

None of these differences were significant, and some of the numbers were small, but the direction of the differences indicate that for Tsumeb as a whole females and males had similar levels of urine arsenic.

However, within Town North levels, particularly in Ondundu, females had higher levels of urine arsenic than males. In Endombo females had slightly higher levels than Town Central, while male levels were low.

Age

Table 25: Child urine arsenic levels by residential areas

	Oshakati n	All exposed areas	Town North	Ondundu	Endombo
Children	**5**	**35**	**4**	**3**	**1**
Geometric mean μg/g	**7.2**	**16.8**	**42.1**	**37**	**62.2**

Table 26: Adult urine arsenic levels by residential area

	Oshakatin	**All exposed areas**	**Town North**	**Ondundu**	**Endombo**
Adults	**35**	**137**	**33**	**11**	**22**
Geometric mean µg/g	10.8	**14.9**	**20**	**43.4**	**13.3**

Similar considerations applied to age. The mean age for children (those under 18) was 12.8 years. For Oshakati, adults had a higher level than children, a non-significant difference, but the number of children at 5 was very small. For Tsumeb as a whole, 137 adults have a slightly lower level than 35 children. For Town North 33 adults had lower levels than 4 children. Within Town North 11 adults had higher values than 3 children in Ondundu, while a single child in Endombo had a higher value than 22 adults who in turn had lower values than adults in Ondundu.

None of these differences were significant, and some of the numbers were small, particularly for children, but the direction of the differences indicate that for Oshakati and Tsumeb as a whole, children and adults had similar levels of urine arsenic, with adults having slightly higher levels than children in Oshakati, and children having slightly higher levels than adults in Tsumeb. Within Town North, adults and children in Ondundu had similar levels. The numbers are too small for both Ondundu which has only 3 measurements for children, and Endombo which has only one measurement which is a very high outlier. Consequently no clear effect of age was found.

Gender and age combined

For Oshakati, urine arsenic levels for 22 adult females (12.8) were higher than for 13 adult males (8.1); and 4 male children were higher (7.8) than 1 female child (5.1). For Tsumeb as a whole, 99 adult female levels (15.2) were similar to 36 adult males (14.3), and 22 male children were similar (17.1) to 13 female children (16.1). Younger and older males and females all had similar levels for Tsumeb as a whole.

Within Town North both young females and young males had higher levels than older females and males respectively. Young males had the highest levels while older females had higher levels than older males.

None of these differences were significant, and some of the numbers were very small, particularly for children, but the direction of the differences indicate that for Tsumeb as a whole, young and old, female and male all had similar levels of urine arsenic.

However, within Town North, young females and young males had higher levels than adults, with old males having the lowest levels and young males the highest. The direction of these differences possibly points to behavioural differences between these groups. In particular, gardening with attendant soil contact, and housecleaning with attendant house and yard dust exposure promoting a higher level of arsenic absorption in the young (and males) who typically have more hand-mouth behavior, and young (and females) who typically do more housework and gardening work. Dietary differences may also be important. More measurements would be needed to investigate these differences more thoroughly.

Diet

There was a significant effect of eating fish in the past 2 days on urinary inorganic arsenic in both Tsumeb (a 45% increase in average level) and Oshakati (a 101% increase in average level). The latter increase is likely be due to DMA of dietary origin being a greater proportion of the total arsenic in the unexposed Oshakati. Females who eat fish tend to have higher urinary arsenic than do males who eat fish, and the gender difference is more pronounced in Oshakati and less pronounced in Tsumeb. However, none of these differences were significant due to small sample size.

There were no significant effects on levels of urinary arsenic for either rice eaters or cereal eaters, where the cereal is basically maize meal. No data were elicited for other dietary components such as green and leafy vegetables or root vegetables.

It is of interest to note the impact of eating fish on the different species of UAs.

For all the exposed in Tsumeb those eating fish had 22% lower MMA, a roughly 52% increase in DMA, 502% increase in ASB and a roughly 33% increase in inorganic UAs.

For the unexposed controls in Oshakati those eating fish had 5% lower MMA that nonfish-eaters, a 248% increase in DMA, 161% increase in ASB and a 100% increase in inorganic UAs.

For Town North these figures were 22% lower MMA, 93% increase in DMA, 320% increase in ASB and 50% increase in inorganic UAs.

For Town South/Kuvukiland we have 10% higher MMA, 8% higher DMA, 598% increase in ASB and 80% increase in inorganis UAs.

For Town Central 32% higher MMA, 43% higher DMA and 755% increase in ASB and 40% increase in inorganic UAs

It is evident that MMA has the least substantial relationship with fish in the diet (although somewhat inconsistently correlated ranging from 22% lower to 32% higher).

Nevertheless when compared to levels of other species, it is clear that MMA has the greatest promise as a more valid indicator of exposure to toxicologically relevant arsenic.

Other potential determinants of arsenic in urine

Smoking tobacco had no impact on urinary arsenic level.

Someone living in the household working at the smelter significantly raised the urine arsenic by 65% on average for other residents in that household.

Having visited the smelter precinct in the past 2 days raised the urine arsenic slightly but not significantly.

Growing one's own vegetables at home, and picking wild fruit and consuming it in the bush both significantly raised the average urine arsenic levels by 69% and 39% respectively. There was a tendency throughout for females to be more impacted than males, particularly in Town North, but this was not significant.

The smelter appears to be significant source of exposure in households where someone other than those included as subjects in this study works there. There were 28 (15%) of all Tsumeb househoulds such cases overall in the study, of which 10 (70%) were Ondundu households, 16 (19%) were Nomtsoub households, and 2 in an area of Southern Nomtsoub known as Soweto.

Exceedances of the upper limit of normal (the 95th percentile of the Oshakati distribution

Table 27: Arsenic exposures as geometric mean and 95th percentile by residential area

	Oshakati	All Tsumeb &surrounds	Town North	Town Central	Town South	NAMFO near farms	Remote farms
n	**41**	**171**	**37**	**86**	**16**	**27**	**5**
Geometric mean µg/g	**10.2**	**15.18**	**21.5**	**12.9**	**22.2**	**12.4**	**19.1**
95th percentile	**50.4**	**52.2**	**90.6**	**35.6**	*****	**41**	*****
n > 50 µg/g	**2**	**10**	**7**	**0**	**2**	**1**	**0**
% > 50 µg/g[53]	**4.8**	**6.4**	**18.9**	**0**	**12.5**	**3.7**	**0**

53 The number 50 is not to be confused with the Namibian BEI. Note that the Namibian BEI for arsenic is 50 µg/g for total arsenic while the analysis here makes use of inorganic arsenic. The 95th percentile for inorganic arsenic in

Maximum µg/g	**64.9**	**176.9**	**176.9**	**49.1**	**60.4**	**55.4**	**29.6**

***TOO FEW OBSERVATIONS**

For purposes of this comparison, normal[54] has been defined using the 95th percentile of the Oshakati values for inorganic arsenic in the urine. The expectation then is that for the other areas being compared a proportion exceeding 5% of that population would be considered to indicate overexposure to arsenic.

Table 27 above shows that Tsumeb as a whole has higher geometric mean levels of exposure than Oshakati as measured by inorganic As in urine. The geometric mean for Oshakati is quite close to the geometric means for both French adults and Belgian adolescents, while the Tsumeb geometric mean is the same as that for Belgian adults. The overall exceedance rate for Tsumeb as a whole is a mere 6.4% - very close to the 5% expected.

Within the Tsumeb exposed areas there is no clear gradient for the geometric mean from Town North to Town Central and Town South and NAMFO. Town Central while indeed lower than Town North, is similar to Namfo which are both close to Oshakati. All numbers of exceedances are small with Town South and remote farms being very small (Town South and remote farms have too few measurements to calculate 95th percentiles).

For both Oshakati and Tsumeb as a whole, the 95th percentile in the population is close to 50 µg/g creatinine, which coincidentally also happens to be the Namibian BEI for urine As. Which means that for inorganic As in urine there are only a few exceedances of this level, and there are similar proportions of both Tsumeb and Oshakati populations that are above this level. It is notable that the 95th percentiles for French and Belgian populations are higher than both those in Tsumeb and Oshakati.

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the urine in the unexposed controls in Oshakati was also 50 µg/g and was therefore taken as an upper acceptable limit of normal or expected for this study

When we look at exceedance proportions within Tsumeb against the 95th percentile for Oshakati, Table 27 shows that Town North and Town South are the only areas within Tsumeb that unequivocally have high outliers levels of urine arsenic. Nevertheless, the geometric means for Town North and Town South while raised at 21.5 and 22.2 respectively, are still below the ACGIH limit for inorganic arsenic in the urine of 35 µg/l. Town North also has the largest proportion of high outliers at 18.9% above the level of 50 µg/g. There are only 2 high outliers in Town South one of which is expected. Here given small numbers, the presence of an additional single outlier doubles the exceedance rate to 12.1%. It is evident here that there are too few Town South measurements here for confidence. Town Central data however are underpinned by a much large number of measurements and are in every respect on a par with Oshakati, viz. normal.

Town North is therefore the driver of the outlier exposures in Tsumeb. Even more notable is that the outliers in question are in Ondundu, and not in Endombo at the North western border of Nomtsoub. This is most likely due to proximity of Ondundu to the smelter as evidenced by the higher air concentrations at the sewerage works and plant hill stations. Since arsenic in PM_{10} and in drinking water are not responsible for elevated urine arsenic levels in Ondundu attention must be directed to arsenic in dust from roadways and garden soil, and arsenic in vegetables and fruit grown locally as well as edible insects in Ondundu, and hand to mouth behavior by both children and adults resulting in arsenic ingestion.

PAST COMPARATIVE DATA FOR TSUMEB (2011) AND GROOTFONTEIN (2012)

The 2011 study by Mapani et al.

In 2011 Mapani[55] et al. reported results of a medical test programme for Tsumeb residents but provided no details of methods or study population. They collected 154 urine samples with the assistance of Tsumeb hospital. They stated that "statistics show that every sixth surveyed person exceeds the WHO guideline value for arsenic concentration in urine. The highest detected arsenic concentration in urine of 443 µg/L exceeds the WHO limit of 50 µg/L by almost nine times". Following a citation trail from the 2011 article, it appears that these samples were collected some time before 2008[56], and that those results have never been published in the scientific literature.

Comparisons are rendered difficult by the imprecision in their article which provides no citation for a "WHO limit of 50 µg/L", Despite mention in the article of creatinine correction in the case of lead, urine arsenic level findings are presented, incompletely, as proportions exceeding the limit of 50 µg/L only, presumably in creatinine-uncorrected units of µg/L.

Two comparative tables are therefore presented below - one in uncorrected units (µg/L), and the other in creatinine-corrected units (µg/g).

[55] B.S. Mapani, S. Uugulu, R. L. Hahn, R. Ellmies, N. Mwananawa, William Amaambo, G. Schneider. Results of urine and blood from residents around the Copper Smelter Complex, Tsumeb, Namibia: An example of anthropogenic contamination IGCP/SIDA Project 594, Inaugural Workshop, Kitwe, Zambia, 2011, © Czech Geological Survey, ISBN 978-80-7075-119-0

[56] Hahn, R. L., Ellmies, R., Mapani, B.S., Schneider, G.,Mwananawa, N., Uugulu S. and William Amaambo (2008). Results of Blood and Urine Tests for Heavy Metals in Tsumeb:Environmental Monitoring Series N°12, Ministry of Mines and Energy, Namibia, Windhoek, January, 2008.

Table 28: Comparative findings for uncorrected total urine arsenic in µg/L in Tsumeb and Oshakati as exposure control area

Source	Location	Study population	Arsenic µg/L	#(%) of population exceeding 50 µg/L	Maximum value µg/L
Mapani et al. 2011	Tsumeb	154	Total	26 (16.7)	443
This study	Tsumeb	171	Total	63 (36.8)	351
	Tsumeb	171	Inorganic	38 (22.2)	241.4
	Oshakati	41	Total	8 (19.5)	101.3
	Oshakati	41	Inorganic	4 (9.8)	127

It is notable from Table 28 that the proportion exceeding a total urine arsenic value of 50 µg/L in the control population which was totally unexposed in Oshakati, was actually higher (19.5%) than the Mapani figure (16.7%) for the exposed population of Tsumeb. The Tsumeb proportion exceeding "the WHO limit" in our study using the uncorrected metric of µg/L was considerably higher .

Table 29 therefore compares the data expressed as creatinine corrected total urine arsenic in µg/g with Mapani et al. on the presumption that Mapani's data may well have been creatinine-corrected.

Table 29: Comparative findings for Tsumeb and Oshakati in µg/g (corrected total urine arsenic)

Source	Location	Study population	Arsenic	#(%) of population exceeding 50 µg/g	Maximum value for UAs
Mapani et al. 2011	Tsumeb	154	Total	26 (16.7)	443
This study	Tsumeb	171	Total	23 (13.5)	209.7
	Tsumeb	171	Inorganic	11 (6.4)	64.9
	Oshakati	41	Total	5 (12.5)	101.3
	Oshakati	41	Inorganic	2 (5.0)	64.9
Government Study 2012	Tsumeb	208	Total	43(21)	433
	Grootfontein	183	Total	42(23)	253

Expressed in creatinine-corrected units, the comparisons seem to make more sense as the unexposed Oshakati controls are now lower than Mapani et al.'s data for Tsumeb which is more expected. It is also notable that the proportions for Tsumeb in our study exceeding the "WHO limit" taken here in units of µg/g are also lower than the Mapani data. More importantly the proportions exceeding the limit are virtually identical when Tsumeb is compared to Oshakati in our study. The maximum value in our study is also much lower than Mapani's maximum.

Table 29 also shows clearly just how misleading the use of the total arsenic in urine can be, rather than using the inorganic component of arsenic in urine. In this table both distributions for Oshakati and Tsumeb in our study have 95% of their inorganic values below this level of 50 µg/g and both are consequently compliant with this limit.

The Namibian Government Study 2012

Table 30: Comparison of total arsenic (µg/g) in urine across studies

Source	Location	Study population	Arsenic	#(%) of population exceeding 26.5µg /g	#(%) of population exceeding 50 µg /g
MET UN 2012	Tsumeb	208	Total	97 (47)	43(21)
	Grootfontein	183	Total	105 (57)	42(23)
This study	Tsumeb	171	Total	58 (34)	23 (13.5)
	Oshakati	41	Total	11 (28)	5 (12.2)

The Namibia Custom Smelter Audit of 2012[57] commissioned by the Namibian Government Ministry of Environment and Tourism and the United Nations included a community health assessment study, and reported that when compared to Grootfontein, Tsumeb residents had lower values for urine total arsenic as arithmetic

[57] Namibia Custom Smelter Audit- Tsumeb December 2011 To January 2012
Volume II. JH Masinja, B Kistnasamy, D Rees, L Zungu, J Cornelissen, T Nghitila, FM Sikabongo.
12 April 2012 Undertaken With Support From The UNDP And The Ministry Of Health And Social Services

mean values, and also by the counts of numbers of subjects exceeding a cut-off value of 26.5 µg/g, as well as those exceeding the Namibian BEI of 50 µg/g.

The findings were similar for children who were not found to be more highly exposed than adults.

They also reported that "there were less significant differences in symptoms than expected particularly for acute exposure to Arsenic, and that this may be partly explained by the lack of expected difference in urinary arsenic levels between the two communities".

Table 31 also shows some improvement in 2016 of the arithmetic mean for Tsumeb compared with results dating back to before 2008 and again later on in 2012.

Table 31: Comparison of total arsenic in µg/g in urine with the Government Study 2012 with Grootfontein controls

	Oshakati This study 2016	**Tsumeb This study 2016**	**Tsumeb Government study 2012**	**Grootfontein Government study 2012**	**Tsumeb Mapani 2011/2008**
n	**40**	**171**	**208**	**183**	**154**
max	**101**	**209**	**433**	**253**	**443**
95^{th} percentile µg/g	**100.1**	**152.9**	**-**	**-**	**-**
Arithmetic Mean µg/g	**24.5**	**29.2**	**36.11**	**36.8**	**-**

These comparisons show that using total arsenic misleadingly shows no difference between the arsenic in urine levels between Tsumeb and an external control, Grootfontein, back in 2012; nor any difference currently between Tsumeb and another unexposed external control town, Oshakati in 2016.

Summary of urine arsenic findings in the community study

In summary there does not seem to be a general systemic overexposure problem based on urine inorganic arsenic for Tsumeb residents as a whole nor for those living on farms to the North West of the smelter. The geometric mean is actually below the most conservative occupational hygiene standard (ACGIH BEI[58]). There are a small number of high exposure outliers driven by location (Ondundu in Town North) and likely behaviours (hand to mouth with ingestion). Town Central which has a high population density shows a short transport distance and deposition of airborne arsenic particulates over time as the arsenic in urine exposure distribution here is virtually indistinguishable from that in Oshakati which is a completely unexposed distant control area from the point of view of arsenic. The entire town is therefore not contaminated apart from a small area of Ondundu and its resident population, which needs some further investigation. Specifically, more sampling is needed to characterise the arsenic levels in soil and locally consumed vegetables and fruit and edible insects in Ondundu. More sampling is also needed for Town South to increase the total sample size of urine arsenic measurements which was small in this study.

An important finding is that prior studies reporting arsenic in urine levels are unreliable and misleading as they did not conduct speciation in order to adjust for organic arsenic of dietary origin in the urine. Consequently, until this study in 2016 it has not be possible to estimate the absorption of toxicologically relevant arsenic of anthropogenic origin (the smelter) by Tsumeb residents.

Other determinants of inorganic arsenic in this study include contact with the smelter, especially having household members who work at the smelter. This means that some arsenic is being brought home on clothes, shoes, bags and vehicles and other

[58] ACGIH 2001. Recommended BEI: Arsenic and soluble inorganic compounds.

objects, and finding its way probably via the hand-to-mouth route and ingestion by household members. This applies to all areas of Tsumeb.

For Ondundu, growing vegetables and fruit, and picking wild fruit (and likely edible insects), also contributed to the urine arsenic burden among residents. The fact that eating fish still contributes to the inorganic arsenic burden indicates that there may be other organic arsenic components in the diet which are not being adjusted for sufficiently by simply subtracting arsenobetaine from total arsenic. If these components could be adjusted for, the inorganic arsenic measure might be expected to be somewhat lower than what is reported here in these results for all areas. Smoking tobacco did not contribute the arsenic body burden.

SUMMARY OF EXPOSURES FROM ALL PATHWAYS

Water pathway

This is not responsible for elevated urine arsenic levels as all measured values in drinking water were very low and well within the internationally accepted (WHO & EU) limit of 10 µg/l.

Air pathway

Arsenic in PM_{10} exposures are not, based on averages obtained at Stadium or at Information Centre monitoring stations, able to raise the average urine arsenic by more than 0.33 µg/l, a vanishingly small amount. Even if arsenic in air exposures were an order of magnitude higher than this, as they are at Sewerage or Hill monitoring stations, this could only raise the average urine arsenic by 3.3 µg/l – a small amount in relation to mean values for inorganic urine arsenic levels in Town North and Town Central. It is conceivable that the population of Ondundu are only exposed to arsenic in air midway between 0.06 and 0.5 µg/m^3 and this could not explain the elevation in urine arsenic in residents there.

Exposures at the two monitoring stations in the residential areas are, however, approximately one order of magnitude worse than the European Union limit of 6 ng/l. This latter limit is based on an acceptable excess lifetime risk of 1 case of lung cancer per 100 000 by the EU.

For SO_2 a big improvement has been noted in the air monitoring data since installation of the acid plant at end of 2015 with current level of exceedances of the WHO limits now about 4 per month. This was confirmed by the community respiratory survey responses and anecdotally in community consultations. There is considerable opportunity for improvement in reducing emissions going forward.

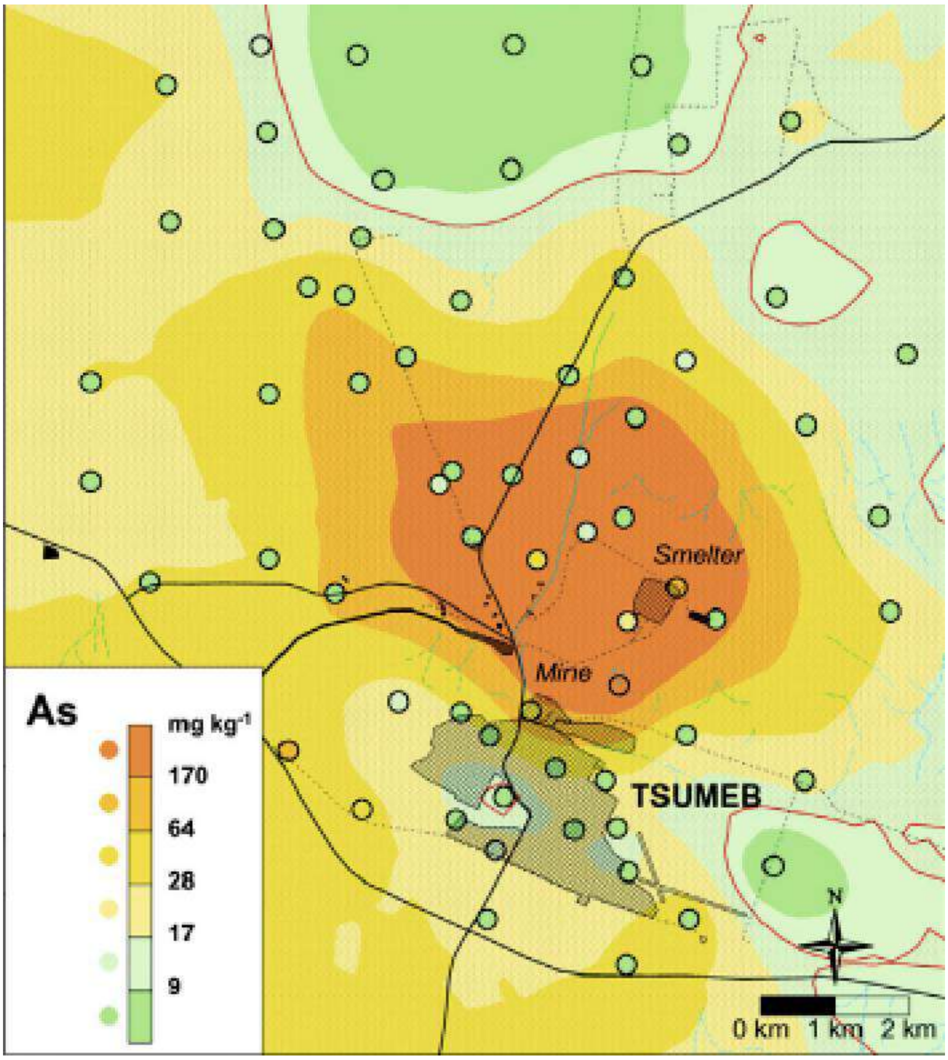
Soil pathway

There are few local data available for soil arsenic outside of the smelter precinct, and none that can be correlated with urine arsenic levels in this study. Recent soil data from the Contaminated Land Assessment provide a similar distribution to that in Figure 22. It is highly likely that the soil is a source of arsenic exposure both from legacy emissions and from current emissions, especially for Ondundu which is proximate to the waste disposal site. Substantial numbers of soil samples were taken in 2018 for residential areas outside the smelter precinct. These included Ondundu home and garden sites as well as other residential areas within Tsumeb. A final analysis of these soil samples are still to be published, but preliminary results indicate that there are historic mine and dump sites in the vicinity of Ondundu which may be contributing to the soil and air exposure pathways. Additional urine samples from more Ondundu households together with samples of household dust will complete the picture.

Kribek [59] et al., (2016) studied the arsenic concentration in the soils and grass and found high correlations between arsenic levels in topsoil and the rhizosphere and the arsenic content of grass in the same areas. They found that only the northern part of Tsumeb town was affected, principally the area around Ondundu. The granularity of his data was low and was based on very few measurements.

[59] Kríbek B et al., Contamination of soil and grass in the Tsumeb smelter area, Namibia: Modeling of contaminants dispersion and ground geochemical Verification. Applied Geochemistry 64 (2016): 75-91.

Figure 22: Extent of pollution with Arsenic in topsoil and the rhizosphere



Source: Kribek et al., 2016

Mileusnic[60] et al. (2014), studied the arsenic content of soil and its bioavailability in what they refer to as Nomtsoub. However, their study was actually done in Endombo a part of Tsumeb that is at the extreme northern tip of Nomtsoub and adjacent to the

60 Mileusnić M et al. Health risk assessment from the exposure of children to soil contaminated by copper mining and smelting, Nomtsoub township, Tsumeb, Namibia. IGCP/SIDA Projects 594 and 606, Closing workshop, Prague, Czech Republic, 2014, © Czech Geological Survey

Western Industrial Area. This is an area to the West of the exposed area of Ondundu which latter is on the North Eastern tip of Tsumeb. They conclude that " the estimated daily intake of arsenic elements from the Nomtsoub soil is low and does not exceed the allowable daily intake (TDI) for children weighing over 5 kg".

Our study found that Urinary levels in Endombo (20.6 µg/g) were lower than in Ondundu (53.1 µg/g) which is in agreement with the low bioavailability of arsenic in the soil found by Mileusic. Endombo is actually more similar in urine arsenic levels to Town Central and Oshakati.

While Mileusnic et al. concluded that "arsenic represent(s) a potential danger for children weighting less than 5 kg" and reported other adverse health effects relating to arsenic these are not supported by the available data in this HIA for cancer risk, nor was the image of a skin lesion in their Figure 5 arsenic-related.

Food pathway

There are few local data currently available which can be correlated with urine arsenic levels for vegetables and fruit grown at peoples' homes, nor for wild fruit, vegetables or edible insects picked near the smelter. This would be of particular importance in Ondundu. Results from this study show that those who grow their own vegetables at home in Ondundu show a significant difference in urinary arsenic (55.7 vs 17.3 µg/g) , $t = 3.57$, $p = 0.0005$.

Picking wild food is also highly significant in Town North, but sample numbers are small in these areas, and further sampling of arsenic in grown produce and urine is needed.

Kribek et al. also report that " in addition to the dust another source of intake of potentially toxic elements may be the consumption of contaminated fruits and vegetables." They cite Hasheela [61] et al. (2014), as showing high contents of metals

[61] Hasheela, I., Haidula, A., Leonard, R., Shaningwa, O., Mbidi, I., Kamanye, J., 2014.

in most fruits and vegetables (marula fruits, pumpkins, chilli, and tomato) which are grown in the northern district of the town of Tsumeb. This fits with data from our study regarding the growing of vegetables and fruits only in Ondundu, and not in Endombo.

The CLA collected data on edible plants (wild spinach) and fruit (Marula) as well as edible insects in the area surrounding the smelter precinct. Some plants and insects were found to contain elevated arsenic levels. While it was not possible to directly correlate individual urine arsenic levels and the history of consumption of these specific edible plants and insects in this health assessment, a correlation was, however, evident between elevated urine arsenic levels and individuals who indicated that they sourced wild fruits or planted their own vegetables (based on 2016 questionnaires). This was found to be significant for residents of the Ondundu community.

Bought fruit and vegetables produced at NAMFO farms are unlikely to be a sufficient source of arsenic via airborne arsenic or arsenic content of the farm water supply as water and urine arsenic samples were low for those living on the farms.

Hand to mouth data

No data were collected for this mechanism of exposure in this study. While age and gender differences suggest that children and female subjects may be more exposed than adults and male subjects based on urine arsenic values, these differences were neither large nor statistically significant.

Contamination mapping and land use categorization for Tsumeb, Namibia. In: Kríbek, B., Davies, T. (Eds.), Addressing Environmental and Health Impacts of Active and Abandoned Mines in Sub-Saharan Africa, Proceedings of the Closing Workshop of the IGCP/SIDA Projects 594 and 606, Prague, Czech Republic, May 26-28, 2014. Czech Geological Survey, Prague, pp. 53-56.

Integration of all pathways in urine arsenic

These latter 3 pathways are speculative given the absence of sufficient data for the appropriate areas which can be correlated with inorganic urine arsenic levels.
Further studies will need to be designed to obtain more relevant data to establish the role of these pathways. The emphasis will need to be on Ondundu and some control areas for comparison.

Total As by ICP-MS and especially inorganic As after subtracting arsenobetaine (inorganic As) show geometric means for Tsumeb and its suburbs which are all below the ACGIH BEI for inorganic As of 35 µg/l or 35 µg/g (the two metrics are similar in number at this level). For inorganic arsenic the 95^{th} percentile for Tsumeb as a whole is close to the unexposed control value for Oshakati which is also the Namibian BEI of 50 µg/g.

The ACGIH BEI is based on a number of well documented occupational epidemiological studies. The ACGIH does state that it should not be used for environmental purposes due to health differences in working age populations and the general community. However in the opinion of this author it could be heuristically applied to environmental considerations here, as it represents a final absorbed total arsenic dose integrated over 24 hours per day, seven days a week.

With average exposures of total arsenic and even more so of toxicologically relevant inorganic arsenic at this level there is no additional risk for lung cancer. Taking this approach then from the occupational cancer BEI and our data, the risk of lung cancer due to environmental arsenic exposure is low for Tsumeb overall. There is no risk above baseline occurrence of cancer for Tsumeb residents as a whole with the exception of Town North where the risk is low.

DUNDEE SMELTER EXPANSION ENVIRONMENTAL (AND OCCUPATIONAL) LUNG CANCER RISK ASSESSMENT

Occupational hygiene exposure measurements

Acceptable risk in the occupational context corresponds to a value between 1 lung cancer in 10, 000 and 1 in 1, 000 lifetime risk.

Average airborne exposure levels in the different business units of the smelter range from the lowest at 0.01 mg/m^3 in Administration to the highest at 0.6 mg/m^3 in the Arsenic Plant. For this range of airborne exposure in the workplace setting, the corresponding cancer risks shown in Figure 23 range from 1 x baseline (or no additional risk) to 3 x baseline (Medium risk) according to the ATSDR[62].

From the biomonitoring results at the smelter, for the plant as a whole at the current time of writing this report the average total arsenic in urine was 74 µg/g in 2016. For highly exposed groups the total arsenic in the urine is virtually all inorganic. Assuming this to be the case the ACGIH equation (1) yields a corresponding average air concentration of 0.25 mg/m^3, and the associated risk according to the ATSDR is about 2 fold which it categorises as low risk.

There is therefore an appreciable occupational lung cancer risk on average for the plant as a whole – more in some business units than in others depending upon the average air concentration in those units. The corresponding risks according to the ATSDR (2007) are mostly 2 (low) to 3 (medium) times the expected background risk for lung cancer at these levels of exposure.

[62] ATSDR 2007 &2016. Toxicology Profile for Arsenic (2007) and Addendum (2016)

Figure 23: Relative risks for lung cancer (ATSDR)

SMR ("Standardised Mortality Ratio") dose response line: (SMR of 100 = unexposed population) (data shown taken from multiple studies, published in the ATSDR (Aug 2007, pp 68-73)):

- Low: (0.05mg/m³)⇨SMR138; (0.213mg/m³)⇨SMR213; (0.29mg/m³)⇨SMR186. (0.05-0.30 = 2x risk)
- Medium: (0.3mg/m³)⇨SMR303; (0.564mg/m³)⇨SMR312; (0.58mg/m³)⇨SMR301. (0.30-0.60=3x risk)
- High: (1.487mg/m³)⇨SMR340; (2.75mg/m³)⇨SMR375; (1.5-3.0=3.5x risk)
- Very high: (5.0mg/m³)⇨SMR704 (5.0=7x risk)

Community exposures

From an airborne arsenic exposure perspective, the US EPA in 1984 issued a Unit Risk Factor (URF) of 0.0043 for exposure to 1 µg/m^3 of arsenic. This has not changed as of 2018. The URF means that for every 1 µg/m^3 increase in arsenic exposure, the lifetime risk of lung cancer increases by 0.0043.

We know from the monitoring station data (Stadium and Information Centre) for arsenic content of PM_{10} that average exposures within the residential areas of Tsumeb prior to 2016 have been around 0.1 µg/m^3. The 2016 averages for these two monitoring stations were 0.05 and 0.06 µg/m^3 respectively.

Based on current exposures of 0.06 µg/m^3, the excess lifetime risk will thus be 0.000258.

The lifetime risk for lung cancer in South Africa is estimated to be 0.007312[63].

Adding 0.000258 and 0.007312, the lung cancer risk for Tsumeb is estimated to be 0.00757. The excess lifetime risk of lung cancer due to arsenic is thus 3.5% of the baseline value without arsenic.

Using the WHO URF of 0.0015 following the EU methodology the excess lifetime risk

[63] Cancer association of South Africa. Fact sheet on the top ten cancers per population group, 2015.

of lung cancer due to arsenic is instead 1.2% of the baseline value without arsenic.

Assuming that the population of Tsumeb is 25 000, we could expect a background of 183 lifetme lung cancer cases, which would go up to 189, which is an additional 6 lifetime cases.

Using the WHO methodology 183 would increase by 2 cases to 185.

An increase of 2 to 6 lifetime cases on a base of 183 represents a very low additional risk for Tsumeb as a whole. However, airborne arsenic exposures for some people in some areas (e.g. Town North) may be somewhat higher than those measured by the two monitoring stations in North-Central town. They would, however, affect only a very small proportion of the total Tsumeb population.

It is important to remember at this point that these estimates are based purely upon airborne arsenic levels in PM_{10} as measured by the monitors. However we know from the arsenic levels in the urine or residents that they are being additionally exposed to arsenic from the soil, vegetables, fruits and edible insects, over and above their exposure to airborne arsenic.

So calculating the cancer risk purely from airborne arsenic will result in underestimating the real risk.

If we accept that the urine arsenic levels are a more accurate account of arsenic exposure for residents, we can assess the lung cancer risk from this starting point instead. Considering arsenic levels in urine in the community shown in Table 27 above, Tsumeb as a whole has a similar risk to Oshakati, the unexposed control population, where no excess cancer risk due to arsenic would be expected as average arsenic levels are well below the Namibian BEI of 50 µg/g as well as the ACGIH BEI of 35 µg/l. Also the 95^{th} percentiles of both Tsumeb and Oshakati are very near 50 µg/g.

However, Town North which is the most exposed Tsumeb suburb, has an elevated risk. It has a geometric mean value of 21.5 µg/g which is about double that of Oshakati (10.2 µg/g), and it has a high percentage, 18.9% (7 individuals), with urine inorganic arsenic levels exceeding the 95th percentile for the unexposed control area of Oshakati, which was 50.4 µg/g. For Ondundu in particular, the mean urine arsenic level for the 4 individuals exceeding the 95th percentile is 83.5 µg/g. For Endombo, the other area in Town North, the mean value of urine arsenic in those exceeding the 95th percentile is 58.8 µg/g. These urine arsenic levels correspond to about a doubling of abnormally high arsenic exposures from all sources including air, soil, plants and insects in Ondundu, but not in Endombo which is no different from the rest of Tsumeb. Assuming that this doubling of exposure in Ondundu translates to a doubling of cancer risk, there would be an appreciable cancer risk for Ondundu residents but this would apply to a very small population, resulting in a very small absolute number of excess cases.

These risks are then considered to be low for Tsumeb overall and low to medium, for Ondundu residents. However, given historical exposures these risks are likely underestimated.

The numbers in the above calculations were based upon average or arithmetic mean values for measures taken over the period 2011-2016. The US EPA would not use mean values but would look for the highest measured values by taking the 95th percentile value instead of the average in order to minimize risk.

MODELLING OF THE HEALTH IMPACT OF 54% INCREASED PRODUCTION THROUGHPUT

The nature of scaled up operations

Detailed pre-feasibility studies undertaken by Berakhah (2014) and WorleyParsons (2015) considered a number of different options for expanding and optimising the Tsumeb Smelter operations. Of the five processing alternatives considered, alternative 5 was recommended as the best option. This comprises constructing a rotary holding furnace and a third convertor (Peirce Smith converter). With this option, the mass balance showed that a throughput of 370 000 tpa new concentrate could be handled and that the Ausmelt would then limit throughput at 65% oxygen enrichment and 22 000 Nm^3/h gas flow through the lance system[3]. This constitutes a 54% increase of throughput relative to the current 240 000 tpa.

This alternative incorporates a third converter, thereby removing the bottleneck due to insufficient converting capacity, making a throughput of 370 000 tpa possible. The addition of a third converter would allow for the other two converters to be online while the third converter could be offline for maintenance. Due to limitations on the acid plant only one converter can be blowing at a time. The third converter would be similar to the existing two converters with some differences in the flux/reverts feed system arrangement due to the plant layout. The third converter would be located on the north side of the converter aisle between the two 13 ft x30 ft converters and the new RHF.

Matte tapped from the RHF would be transferred by ladle to the Peirce–Smith converters. High grade copper scrap and some crushed ladle skulls will also be treated in the converters. Slag from the converters would be skimmed into 5.7 m^3 (nominal) ladles and then transferred to the larger 12.6 m^3 slag pots by the converter aisle cranes. The slag pots would then be hauled to the slag slow cooling area. Blister copper would be tapped from the converters after the copper blow and cast into billets.

Should a third converter be installed, flux and reverts would be supplied to the new converter feed bins via two new inclined conveyors which would require some modification of the existing transfer tower. At the converter there is a flux feed bin and reverts feed bin. A diverter gate routes the feed to the appropriate bin. Belt feeders meter the flux and reverts onto a final feed conveyor that discharges into a feed chute that protrudes through the wall of the hood and discharges into the converter mouth.

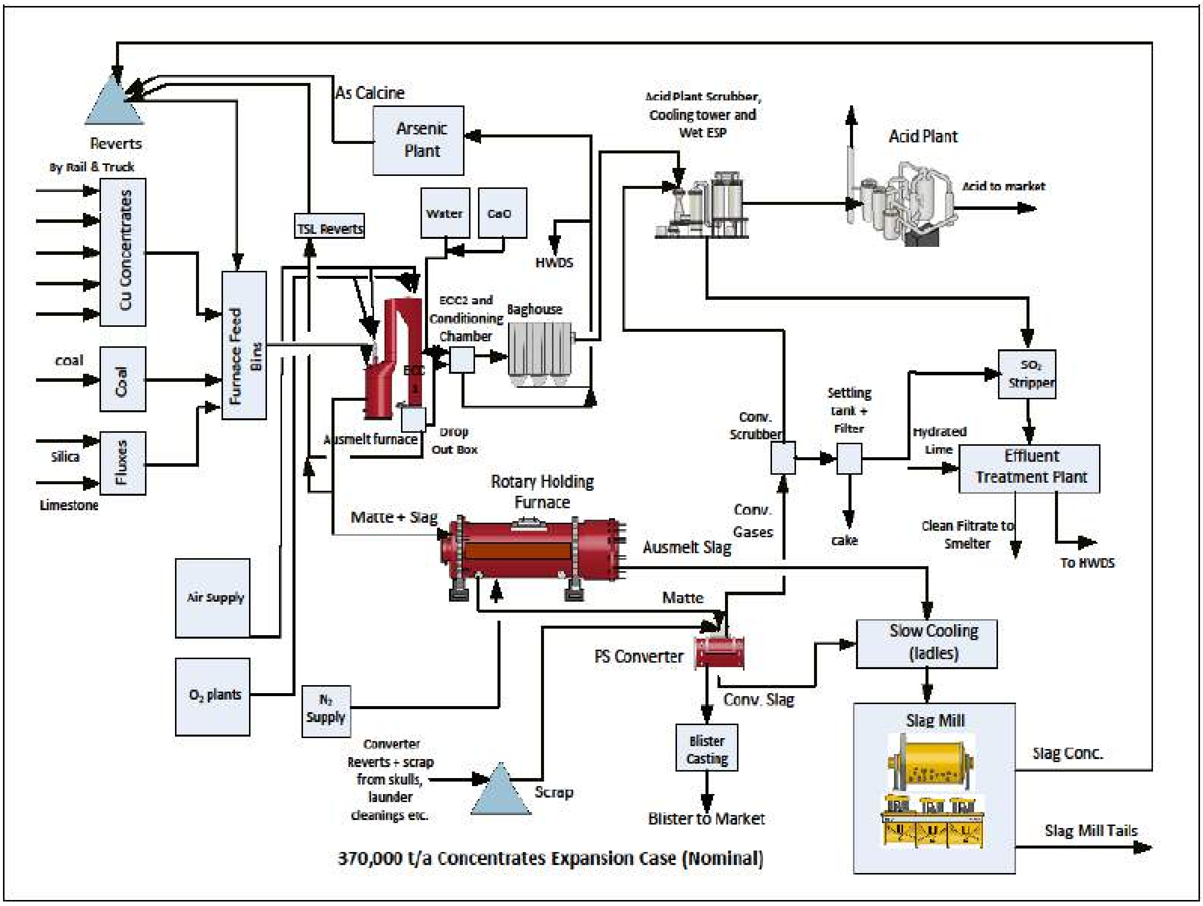
Since only one converter will be blowing at a time, there will be no increase to the required blast air demand with the addition of the third converter. Should the third converter option not be implemented, some oxygen enrichment may be required.

Converter primary off-gas will be collected in a water cooled hood and will flow through a drop out chamber before going through a wet scrubber and then to the acid plant gas cleaning circuit. The wet gas from the scrubber on the third converter will tie in to the duct from the other two 13 ft x 30 ft converters leading to the acid plant cooling tower. Weak acid bleed and solids collected from the gas cleaning section will be treated in an Outotec-supplied effluent treatment plant with lime slurry at pH 12. The treated water will go to the reclaim water pond. The gypsum from this plant is bagged and shipped to a hazardous landfill. Converter dust would be treated separately.

It is not expected that the addition of the third converter will increase the secondary gas flows to the existing hygiene system. This is due to the fact that only two of the three converters will be hot at any given time which is the design basis of the two converters being installed currently. Gas from the third converter secondary hood will be routed to the secondary gas header for the other two 13 ft x 30 ft converters.

The capacity of the cooling system would need to be increased in order to provide cooling water for the primary hood of the third converter

Figure 24: Diagram showing changes in the production process with the expansion



Occupational Health Impact

It is difficult to predict the impacts on employees of the increased throughputs, as there are a number of inherent uncertainties with such an operational shift, and furthermore the impacts are significantly affected by the presence of, and effectiveness of, the requisite controls. This section will pose two approaches by which such an estimation may be considered. Firstly, a qualitative assessment of the impacts will be presented, based on personal observations, a review of the recent EBRD report, and interviews with the smelter industrial hygienist. Secondly, the impacts will be modelled using statistical techniques.

Impacts based on qualitative assessments

It is understood that the capital upgrades will enable the smelter to handle the increased throughput volume. However, with increased production, key processes will become potential sources of increased emissions. Successful containment of these sources is critical for the successful implementation of the upgrade.

Materials handling: larger quantities of ore and smelter feedstock (including silica) will need to be received, stored and transferred in ways that do not generate dust.

Tapping, molten liquid handling and casting: this will take place at higher frequencies, with increased exposures to high ambient heat. In addition, the potential exposure to fugitive emissions associated with this task will increase, unless the extraction ventilation controls are in place.

Slow cooling of Rotary Holding Furnace and convertor slag: this is likely to increase exposure to these emissions.

The convertors: these are installed with modern extractor hoods but these are currently being by-passed when slag is transferred into them giving rise to emissions which are not captured by extraction. This will occur at greater frequency and a solution for avoiding this will have to be found.

The arsenic plant and arsenic waste generation: the decommissioning of the arsenic plant is likely to reduce the overall exposures for all personnel, because of the high quantities of fine airborne arsenic being generated there. However, it should be borne in mind that this will result in a demand for increased waste management, for which a solution will have to be found. Currently, closure and covering of the existing waste disposal site will only take place once the approved capacity has been reached after which waste would need to be transported to a site distant from Tsumeb.

The off-gases extraction pathways and baghouse collection points are focal areas of potential arsenic-laden dust generation, especially during episodes of intermittent malfunction: these points will be at increased risk during the transition phase to higher production.

General: It can be anticipated that the increased production will have initial teething problems, with a higher frequency of down-time and maintenance during the first few months of transition. During this period, the exposures to emissions and ergonomically risky tasks can be expected to increase temporarily. This could be exacerbated by prolonged working hours, with consequent worker fatigue. As the teething problems are resolved, the temporary increases in exposures to these hazards can be expected to improve, but the problem of increased ambient heat and noise is likely to remain.

A gratifying feature of the current situation is that the urinary arsenic levels have generally not reacted adversely to the already increased production levels over the past few years, including in 2016 (see next section); our analysis shows that, when adjusted for increased production, the levels of urinary arsenic showed a small improvement relative to 2015. However, this situation is unlikely to remain if production continues to increase to the 54% target, unless the issues described above are addressed.

Modelling of the impact of increased production on urine arsenic levels

Data used for statistical modelling included monthly quantities of total concentrate throughput all the way back to 2011, arsenic in urine data for smelter employees going back to 2011, as well as air quality data from the 5 monitoring stations for arsenic in PM_{10} going back to 2012. The data were analysed using multiple linear regression analysis in which quarterly urine arsenic levels taken as the integrated measure of arsenic absorption in smelter employees from all sources and pathways were regressed on quarterly tonnage of concentrated ore processed at the smelter.

The regression coefficients represent the unit increase in urine arsenic level per unit increase in ore tonnage, adjusted for varying arsenic content, and enable prediction of the anticipated levels of urine arsenic at any level of production throughput of ore including the current target of 240 000 tpa and the future target of 370 000 tpa for which this EIA is being conducted.

The urine arsenic data have been described above and DPMT supplied ore concentrate processed per month from 2012 along with its varying arsenic content. Separate regressions were carried out for each year. The context for total urine arsenic as discussed above and shown again in Table 32 is of significantly decreasing arithmetic mean concentrations from 2012 through 2016. This uniformly downward trend is statistically significant overall over the period 2012 to 2016 and each year on year decline is statistically significant as well, except for the decline between 2015 and 2016.

In the occupational context total arsenic is almost identical to inorganic arsenic due to the high levels of exposure compared with low level environmental exposures where organic arsenic can account for 25% or more of the total arsenic on average.

Table 32: Arithmetic mean for total Arsenic (creatinine corrected) in µg/g for the smelter as a whole

	n	Mean	Std Dev	Min	Max
2011	3047	177.7	168.7	2.9	2046
2012	1889	142.3	137	6.5	1004
2013	2133	151.3	132.1	1.8	1557
2014	3488	86.4	97.5	1.1	1451
2015	2518	79	71.2	2.8	1000
2016	2101	73.8	84.4	0.2	1553

Table 33 shows the annual production data for total ore concentrate

Table 33: Annual production data for total ore concentrate

Year	Tons of Ore concentrate
2012	101699
2013	152454
2014	198346
2015	195981
2016	139571 to 9/2016

Table 34 shows the results of the regressions by year for 2013, 2014 and 2015/2016 (insufficient data for calculation of quarterly urine arsenic value before 2013 due to pattern of urine sampling and combination of 2015 and 2016 for sufficient data points at different times) show different slopes of the equation $Y = bX + c$ where b is the slope or increase in urine arsenic (µg/g) per unit increase (ton) in total concentrate processed.

There is a qualitative but minor shift in 2015/2016 in which the more concentrate processed the lower the urinary arsenic actually is. However, the decrement is very small. This is most likely due to capital improvements which should continue into the future and are very likely to further reduce exposures, given the requisite attention to teething effects and continuous improvement plus aggressive management of high outlier urine arsenic levels. This is also despite some increased emissions of arsenic (and SO_2) at the new convertor hoods installed along with a new slow cooling method of processing slag outdoors, all since the beginning of 2016.

The planned closure of the arsenic plant will add to downward impetus in exposures going forward. Plans to eventually shut and cover the waste disposal site when its approved capacity is reached would also potentially make a big difference to arsenic levels in the smelter and its wider environment.

Looking at the smelter as a whole, and using the slopes for the relationship between concentrate processed and urine As levels, the Table 34 shows the predicted urine arsenic values at the actual throughputs for the past few years, the supposedly current target of 240 000, and the intended target of 370 000 tons.

Table 34: Regression of total arsenic in urine (µg/g) on total concentrate (tons) processed per quarter

Year	2013	2014	2015-2016
n	2133	3488	4619
Slope b	0.020473	0.0018923	-0.0002503
p	< 0.0001	< 0.0001	0.103
Constant c	-536.57	9.03	88.90
Average quarterly actual total concentrate put through (tons)	33600	40897	54275
Actual mean urine arsenic (µg/g)	151.1	86.4	73.9
Predicted mean urine arsenic at 240 000 tpa or 60 000 quarterly (µg/g)	691.8	122.6	73.9
Predicted mean urine arsenic at 370 000 tpa or 92500 quarterly (µg/g)	1357.18	184.1	65.7

Means are all arithmetic

Regression modelling on the basis of these data shows that, if continued improvement is maintained, there is little likelihood of increased exposure (increased urinary arsenic levels) going forward. It is anticipated that urine arsenic levels will decline further in the smelter as the capital improvements are completed in the near future, points of emissions are better controlled, the arsenic plant is shut, and the waste disposal site is eventually closed when the approved capacity is reached. Attention will need to be directed particularly towards the Materials Handling business unit and any other urinary arsenic spikes that are observed going forward. Continued monitoring will pick up any anomalous increases in exposure which can then be dealt with.

Any reduction of exposure going forward might be expected to be even more pronounced at the community level for residents.

Environmental health impact

Modelling of the impact of increased production on arsenic in PM_{10} measured at the monitoring stations

Regression analysis (not shown) indicates that there is no relationship between quantities of total concentrate put through the smelter monthly, and air quality as measured at any of the 5 monitoring stations (as arsenic in PM_{10}). There were no statistically significant regression coefficients and the magnitudes of these coefficients were vanishingly small either overall or for any year.

No significant increase in airborne arsenic exposures for residents should then be expected if throughput increases by 54%.

Summary of impact of a 54% production increase

No qualitatively new hazards are likely to be introduced as a result of increased production throughput.

On current data the impact on either employees at the smelter or Tsumeb residents is estimated to be negligible to very low.

It should be noted that the capital improvements are not yet fully implemented and these can be assumed to continue to result in reduced arsenic and SO_2 exposures going forward. Engineering down new arsenic and SO_2 exposures since January 2016 and which are associated with the introduction of new equipment (the new converters) and new methods (of slag cooling) may be expected to bring about further future reductions in exposure.

The shutdown of the arsenic plant in the first quarter of 2017 resulted in some reduction of occupational arsenic exposures below previous levels. These reductions have been substantial for certain areas within the smelter where exposures have been particularly high e.g. the arsenic plant and some other points where fugitive emissions currently arise.

Shutdown of the arsenic plant will result in some increase in waste destined for disposal. If this all ends up at the waste disposal site on the hill, the exposure situation there would continue and possibly increase proportionately by 54% as a worst case scenario, should the site not be efficiently managed. A recent external audit of the waste disposal site, however, showed that it was being operated to a high standard and in line with the operational specifications, thus limiting any spread of arsenic outside of the site boundaries.

Regression analysis of the throughput data and the results of the Hill monitoring station also do not predict a significant rise in airborne arsenic exposure at the waste site. Any future closure and covering of the waste disposal site will likely yield further reduction in environmental exposures to both smelter precinct and Tsumeb residents, particularly those in Ondundu in Town North.

Increasingly more efficient capture of SO_2 is likely, notwithstanding any production increase of 54%.

Given the presumptive predominance of the air pathway in determining the impact of the soil pathway on absorbed arsenic as measured by urine arsenic, the latter should decline with the closure of the arsenic plant and further engineering improvements removing fugitive emissions at the smelter.

Progress will be measurable in two ways - the monitoring stations and periodic arsenic level monitoring in soil, locally grown vegetables and fruit, house dust, edible insects, and urine of members of the community - in Ondundu in particular.

Occupational and environmental health surveillance should also continue. The former should focus on the principal adverse health outcome of lung cancer, while the latter should conduct periodic surveys of Tsumeb residents (particularly in Ondundu) and appropriate controls. Analysis of a follow-up survey during the last quarter of 2018 is still currently underway.

DPMT should consider setting up a post-employment medical examination and benefit scheme for past employees. The Namibian Government should consider setting up a cancer registry.

There are 2 likely scenarios based on the analysis in this report:

Scenario 1: The status quo continues with completion of the major capital developments. Based on historical exposure measurements particularly in recent quarters, the slow trend towards lower but still non-compliant exposures should continue given no production throughput increase.

Scenario 2: If in addition to Scenario 1 there is a 54% increase in production throughput, the worst case scenario is that exposures would increase pro rata. However, the statistical analysis suggests that exposures will improve slightly, or remain similar. This assumes that the planned capital improvements and improved industrial hygiene and attention to identifying and dealing with sources of fugitive emissions might be expected to result in a persistent slow decline of future exposures for SO_2 and arsenic (see recommendations above). Ultimately compliance should be achieved with Namibian and international standards.

SUMMARY OF HEALTH IMPACT ASSESSMENT

Table 35 : Criteria for Assessing Impacts

Note: Both the criteria used to assess the impacts and the methods of determining the significance of the impacts are outlined in the following table. Part A provides the definition for determining impact consequence (combining severity, spatial scale and duration) and impact significance (the overall rating of the impact). Impact consequence and significance are determined from Part B and C. The interpretation of the impact significance is given in Part D.

PART A: DEFINITION AND CRITERIA*		
Definition of SIGNIFICANCE		**Significance = consequence x probability**
Definition of CONSEQUENCE		**Consequence is a function of severity, spatial extent and duration**
Criteria for ranking of the SEVERITY/NATURE of environmental impacts	**H**	Substantial deterioration (death, illness or injury). Recommended level will often be violated. Vigorous community action. Irreplaceable loss of resources.
	M	Moderate/ measurable deterioration (discomfort). Recommended level will occasionally be violated. Widespread complaints. Noticeable loss of resources.
	L	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.
	L+	Minor improvement. Change not measurable/ will remain in the current range. Recommended level will never be violated. Sporadic complaints.
	M+	Moderate improvement. Will be within or better than the recommended level. No observed reaction.
	H+	Substantial improvement. Will be within or better than the recommended level. Favourable publicity.
Criteria for ranking the DURATION of impacts	**L**	Quickly reversible. Less than the project life. Short term
	M	Reversible over time. Life of the project. Medium term
	H	Permanent. Beyond closure. Long term.
Criteria for ranking the SPATIAL SCALE of impacts	**L**	Localised - Within the site boundary.
	M	Fairly widespread – Beyond the site boundary. Local
	H	Widespread – Far beyond site boundary. Regional/ national

PART B: DETERMINING CONSEQUENCE					
			SEVERITY = L		
DURATION	Long term	**H**	**Medium**	**Medium**	**Medium**
	Medium term	**M**	**Low**	**Low**	**Medium**
	Short term	**L**	**Low**	**Low**	**Medium**
			SEVERITY = M		
DURATION	Long term	**H**	**Medium**	**High**	**High**
	Medium term	**M**	**Medium**	**Medium**	**High**
	Short term	**L**	**Low**	**Medium**	**Medium**
			SEVERITY = 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/ national
				SPATIAL SCALE	

PART C: DETERMINING SIGNIFICANCE					
PROBABILITY (of exposure to impacts)	Definite/ Continuous	**H**	**Medium**	**Medium**	**High**
	Possible/ frequent	**M**	**Medium**	**Medium**	**High**
	Unlikely/ seldom	**L**	**Low**	**Low**	**Medium**
			L	**M**	**H**
				CONSEQUENCE	

PART D: INTERPRETATION OF SIGNIFICANCE	
Significance	**Decision guideline**
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.

Table 36: HIA Community Health Impact for Tsumeb as a whole with respect to arsenic exposure

Potential impact of the planned Dundee smelter expansion on the health of the community.	Severity	Duration	Spatial Scale	Consequence	Probability	Significance	Mitigation Measures	Severity	Duration	Spatial Scale	Consequence	Probability	Significance
Risk: Exposure to arsenic and lung cancer risk.							**Objective**						
Severity (of the health impacts) Baseline and increased production risks of lung cancer are infinitesimal	H						**Minimise the community's exposure to smelter inorganic arsenic as far as possible for Tsumeb community as a whole.**	H					
Duration (of the impacts) The impacts of arsenic exposure are permanent (cancer).		H					**Actions** Closure of arsenic plant (completed). Better control of fugitive emissions from the smelter Closure and covering the waste disposal site when it reaches its full approved capacity Ensure that all devices in monitoring stations are maintained in a functional state and rapid repaired if necessary. Include a $PM_{2.5}$ monitoring capacity (implemented since 2017) Further determination of arsenic levels in soil, vegetables/fruit, edible insects, hand to mouth behaviours and more urine arsenic sampling in most affected and specially undersampled areas within Tsumeb along with unexposed controls.		H				
Spatial Scale The evidence in the report indicates that the exposure beyond the smelter boundary is limited locally to Ondundu. More L than M.			L							L			
Consequence				H							H		
Probability (of lung cancer) The probability of lung cancer is very low at baseline exposures and will remain very low with 54% production increase.					L							L	
Significance						L	**Emergency Situations** Not applicable						L

Table 37: HIA Community Health Impact for Ondundu with respect to arsenic exposure

Potential impact of the planned Dundee smelter expansion on the health of the community.	Severity	Duration	Spatial Scale	Consequence	Probability	Significance	Mitigation Measures	Severity	Duration	Spatial Scale	Consequence	Probability	Significance
Risk: Exposure to arsenic and lung cancer risk.							**Objective** **Minimise the community's exposure to smelter inorganic arsenic as far as possible for residents of Ondundu.**						
Severity (of the health impacts) Baseline and increased production risks of lung cancer are infinitesimal	H							H					
Duration (of the impacts) The impacts of arsenic exposure are permanent (cancer).		H					**Actions** Closure of arsenic plant. Better control of fugitive emissions from the smelter Closure and covering the waste disposal site when it reaches its full approved capacity Ensure that all devices in monitoring stations are maintained in a functional state and rapid repaired if necessary. Include a PM2.5 monitoring capacity Further determination of arsenic levels in soil and vegetables/fruit, edible insects, hand to mouth behaviours and more urine arsenic sampling in Ondundu and Kuvukiland and Tsumeb and Oshakati controls. Should soil and homegrown food arsenic levels be high, initial prohibition of growing home crops, removal of topsoil layer and ultimately evacuation of Ondundu would be options.		H				
Spatial Scale The evidence in the report indicates that the exposure beyond the smelter boundary is limited locally to Ondundu. More L than M.			M				****NOTE THAT THE LOGIC OF THE CRITERIA IN TABLE 50 FORCE THE CONSEQUENCE TO BE HIGH, AND THEREFORE THE PROBABILITY AND SIGNIFICANCE WOULD BE MEDIUM, BUT POST MITIGATION THE PROBABILITY AND THE SIGNIFICANCE WLL ACTUALLY BE LOW**			L			
Consequence				H							H**		
Probability (of lung cancer) The probability of lung cancer is very low at baseline exposures and will remain very low with 54% production increase.					M							L**	
Significance						M	**Emergency Situations** Not applicable						L**

Table 38: Community Health Impact for Tsumeb as a whole with respect to SO_2 exposure

Potential impact of the planned Dundee smelter expansion on the health of the **community**.	**Severity**	**Duration**	**Spatial Scale**	**Consequence**	**Probability**	**Significance**	Mitigation Measures	**Severity**	**Duration**	**Spatial Scale**	**Consequence**	**Probability**	**Significance**
Risk: Exposure to SO_2 and respiratory effects.							**Objective**						
Severity Regular frequent upper and lower respiratory symptoms in all areas of Tsumeb.	M						**Reduce the community's exposure to SO_2 from the smelter to comply with WHO limits.**	M					
Duration (of the impacts) The impacts of SO_2 exposure seem to be irritative in nature, hence are short-lived and reversible over time.		L					**Actions** Better control of fugitive emissions at all points particularly capturing emissions at the converters and from slow cooling of slag . Ensure monitoring stations are all functional for SO_2.		L				
Spatial Scale The evidence in the report indicates that the exposure is fairly widespread (beyond the site boundary), but local to the Tsumeb area.			M							M			
Consequence				M							M		
Probability (of respiratory effects) The probability of respiratory effects is high at baseline exposures, and will remain at similar levels with a 54% production increase until planned capital improvements are completed and operating effectively.					M							L	
Significance						M	**Emergency Situations** Not applicable						L

APPENDICES

APPENDIX 1: TOXICOLOGY OF ARSENIC

General Chemistry

CAS No: 7440-38-2; arsenic is present in many forms, in nature as well as in industry. These have different CAS numbers, appearances and chemical properties. This CAS number is for elemental arsenic.

General Background

Arsenic (As) is a naturally occurring element, classified as a metalloid (properties of metal & non-metal) and which exists in 3 forms (ATSDR 2007):

- **Inorganic** As – combined with elements such as oxygen, chlorine and sulphur, commonly as "oxides" or "oxyacids". (this is the most common form, and is more toxic than the organic form)
- **Organic** As – combined with carbon & hydrogen
- **Elemental** As – steel grey solid material (rare in nature)

Most inorganic & organic As compounds are white or colourless, odourless, tasteless powders that do not evaporate.

Due to its toxicity and widespread occurrence, the presence and behaviour of arsenic in the environment has been the subject of substantial historical and ongoing research.

All humans are exposed to some amount of arsenic in food and drinking water, and smaller amounts from air and soil. For that reason, an understanding of the range of natural background arsenic exposures is important in providing a base against which increased exposures from specific sources can be assessed.

Sources of arsenic exposure

<u>Arsenic in Drinking Water</u>

Globally, the majority of individuals adversely impacted by arsenic are exposed through their drinking water. Countries and regions with well-documented high arsenic exposures in drinking water include West Bengal and Bangladesh, Cambodia, Taiwan, Chile, Argentina and Estonia (Amini et al. 2008). The arsenic drinking water standard set by the WHO (2016) is 10 µg/L.

Some rivers draining highly mineralized zones have much higher natural arsenic concentrations (Caceres et al. 1992). Arsenic in water is mostly present as arsenate, but can be reduced to arsenite under anaerobic conditions. High arsenic levels can be present in both oxidizing and reducing conditions, and almost universally restricted to aquifers in the uppermost 150 meters (JECFA 2011).

In Africa, levels of arsenic are generally higher in surface water than in groundwater (Ahoule et al. 2015). High levels of arsenic in surface waters are related to mining operations, agricultural drains, local sediments, and incineration and disposal of wastes. Arsenic measured at levels orders of magnitude above the WHO guideline (up to 10,000 µg/L) have been detected in areas of South Africa, Ghana, and other countries where gold and other mining occurs. Groundwater arsenic contamination, though less extensive, is still present and is mostly due to natural processes.

Arsenic in Soil and Dust

Arsenic is widely distributed in the Earth's crust, with concentrations ranging from 1-10 mg/kg in most rocks, but rocks in mining districts may contain up to 10,000 mg/kg (Polya and Lawson 2016). On a global scale, arsenic concentrations in soil are largely controlled by climate-dependent weathering processes and the composition and mineralogy of the underlying rock.

There are over 150 minerals containing arsenic, including sulphides and oxides in association with silver, lead, copper, nickel, antimony, cobalt and iron (ATSDR 2007, Polya and Lawson 2016). Consequently, on a global basis, areas enriched in these metals are co-located with areas with naturally high levels of arsenic in soil, surface water, and groundwater. Arsenic is released to the environment from both natural and anthropogenic sources. Man-made emissions arise from the smelting of metals (as is the case in

Tsumeb), the combustion of fuels, and the use of pesticides (USEPA 1998). Most anthropogenic releases are to land or soil, but substantial amounts are also released to air and water (ATSDR 2007).

In communities with copper smelters, much higher arsenic concentrations have been reported. The World Health Organization cites soil concentrations near copper smelters as ranging from 100 to 2,500 mg/kg (WHO 2000a). In the community of Mill Creek, near the Anaconda Smelter, arsenic concentrations in soil were found to range from 25 to 4,080 mg/kg, with a mean of 639 mg/kg (USEPA 1987). Concentrations in the town of Anaconda ranged from 29 to 345 mg/kg. In the town of Ruston (near the Tacoma Smelter), Polissar et al (1990) found a mean concentration of arsenic at 352 mg/kg. At La Oroya, the highest mean surface soil arsenic from any community was 1,109 mg/kg wet weight (Integral 2005).

Exposure to arsenic in soil and dust may occur when soil and dust is incidentally ingested by hand-to-mouth activities. Soil may be tracked into homes on shoes or feet or by pets. If soil is suspended by wind, it may be blown into homes. The absorption of arsenic ingested with soil or dust is usually fairly limited due to low solubility in the gastrointestinal tract (ATSDR 2007, USEPA 2012). The combination of low ingestion rates and low bioavailability generally makes soil ingestion a minor pathway of human exposure. However, when soil arsenic concentrations are elevated above 100-200 mg/kg, soil arsenic exposure may be similar to typical dietary exposure. Occupational settings where arsenic content in soil and dust is high may also result in elevated exposure to arsenic through incidental ingestion.

There is not a consensus EU soils guideline for inorganic arsenic. EU member countries have published standard/guideline values that range from 2 mg/kg (Norway) to 300 mg/kg (Belgium) although the “central tendency” value appears to be at the 50 mg/kg concentration. In the USA, risk-based soil concentrations for a residential setting, based on 1 x10E-5 carcinogenic endpoint, is 6.8 mg/kg.

Dietary Arsenic

Arsenic is naturally present in foods as a mixture of inorganic and organic arsenic compounds. Most market basket and diet surveys report total arsenic intake. Because most organic arsenic compounds have low toxicity, diet data must be carefully reviewed to focus only on intake of inorganic arsenic. The highest levels of total arsenic in food samples collected worldwide have been measured in seaweed, fish and shellfish, mushrooms and fungi, rice, and some meat products (JECFA 2011). However, the levels of inorganic arsenic in these foods vary considerably.

Terrestrial animal tissues typically have low concentrations of arsenic (Schoof et al. 1999, Xue et al. 2010a). Plants can take up arsenic via the roots (plants can also obtain arsenic through foliar absorption of dust containing arsenic). The highest arsenic concentrations are typically found in rice grains and leafy green plant parts (EFSA 2009, Schoof and Handziuk 2016, Schoof et al. 1999). Consistent with these reports, Hahn et al. (2007) found higher arsenic uptake in root and leafy vegetables sampled from agricultural fields west and southwest of Tsumeb, and low uptake in maize, chilli, tomato, beans, and fruit trees. In aquatic organisms, arsenic concentrations may be very high; however, most arsenic in fish and shellfish is present as organic arsenicals that have low toxicity (ATSDR 2007, EFSA 2009, Schoof and Yager 2007).

The levels of inorganic arsenic in various foods have been measured in a limited number of studies. A U.S.-based market basket survey found that about 10 percent of total arsenic present in foods is inorganic arsenic (Xue et al. 2010a). Multiple studies (Chung et al. 2014, Schoof et al. 1999, Xue et al. 2010a) have found vegetables are the largest source of inorganic arsenic in both Eastern and Western diets, contributing roughly 25 percent of total inorganic arsenic intake. From Xue et al. (2010b), fruits (18 percent), rice (17 percent), beer and wine (12 percent), and grains including flour, corn, and wheat (11 percent) are other important contributors, with meats and seafood contributing minimally (5 percent combined) to overall inorganic arsenic exposures.

The European Food Safety Authority (EFSA) estimates that the total dietary intake (food and water) of inorganic arsenic in European adults ranges from 0.13 to 0.56 µg/kg BW-day for average consumers, and 0.37 to 1.22 µg/kg BW-day for 95th percentile consumers. Dietary intake of inorganic arsenic by children under 3 years was roughly 2 to 3 times that of adults on a µg/kg body weight basis (EFSA 2009). The Joint FAO/WHO Expert Committee on Food Additives (JECFA) estimated a similar range of inorganic arsenic exposures for European adults, ranging from 0.21 to 0.61 µg/kg BW-day (JECFA 2011). The only countries outside of Europe and the U.S. that reported inorganic arsenic intake rates are Chile and Japan, which report much higher rates ranging from 2.08 to 21.48 µg/kg BW-day in Chile and 0.36 to 1.29 µg/kg BW-day in Japan (Díaz et al. 2004, JECFA 2011). Both studies assessed populations with high arsenic exposures, either through contaminated water (Chile) or high seaweed consumption (Japan).

Although variable, arsenic is generally well absorbed from most foods. EFSA (2009) recommends assuming 70 percent dietary absorption on average. Ongoing research on arsenic bioavailability from food is likely to clarify this issue over the next five to ten years (Yager et al. 2015).
In a review of the latest scientific evidence conducted in 2010, the Joint Food and Agriculture Organization of the United Nations (FAO)/WHO Expert Committee on Food Additives (JECFA) determined the lower limit on the benchmark dose for a 0.5% increased incidence of lung cancer ($BMDL_{0.5}$) from epidemiological data to be 3.0 µg/kg body weight per day (2–7 µg/kg body weight per day based on the range of estimated total dietary exposure).

Arsenic in Air

Ambient arsenic concentrations in the atmosphere vary in the range of 0.01 to 15 ng/m^3, with much lower concentrations occurring in uncontaminated rural areas (0.01-1 ng/m^3), in comparison to contaminated urban areas (up to 15 ng/m^3) (Polya and Lawson 2016). Average atmospheric arsenic is approximately five times greater in the northern hemisphere than the southern hemisphere. This is due to the greater concentration of anthropogenic and geogenic sources of arsenic in the northern continents (Polya and Lawson

2016). Typical ambient air arsenic concentrations are so low that inhaled arsenic does not contribute measurably to background exposures.

Airborne arsenic has been documented as a human health concern in a limited number of occupational and environmental settings, including copper smelters and indoor coal burning (Polya and Lawson 2016). Historical community air arsenic data are available for several U.S. copper smelters. In the community of Ruston, Washington, adjacent to the Tacoma Smelter, mean concentrations of arsenic in outdoor air in the 1980s were 0.09 $\mu g/m^3$ in fine particulate and 0.15 $\mu g/m^3$ in coarse particulate (Polissar et al. 1990). The Bunker Hill smelting complex in Idaho has reported a maximum quarterly average of 0.49 $\mu g/m^3$, similar to concentrations at Kennecott copper smelter (0.46 $\mu g/m^3$) in Utah and Anaconda Smelter (0.39 $\mu g/m^3$) in Montana (USEPA 1976). At La Oroya in Peru, air concentrations in the communities around the smelter ranged from a mean of 0.50 $\mu g/m^3$ to 4.2 $\mu g/m^3$ (Integral 2005).

The EU environmental exposure limit for arsenic in air of 6 ng/m^3 or 0.006 $\mu g/m^3$

The Occupational Exposure Limit (OEL) for Namibia is 0.1mg/m^3 (Labour Act, 1992), whereas the Threshold Limit Value (TLV) recommended by the American Conference for Governmental Industrial Hygienists (ACGIH) is 0.01mg/m^3 (100$\mu g/m^3$) (ACGIH, 2016).

Biomonitoring of exposure

The concentration of metabolites of inorganic arsenic in urine reflects the absorbed dose of inorganic arsenic on an individual level. Generally, non-industrially exposed background ranges from 5 to 20 µg/L (uncorrected for creatinine). Large population surveys in the USA (2011-12 most current data) showed a geometric mean of 6.85 ug/L urinary total arsenic.

The Biological Exposure Index (BEI) for Namibia for inorganic arsenic is 50µg/g creatinine in urine (Labour Act, 1992), whereas the BEI recommended by the American Conference for Governmental Industrial Hygienists (ACGIH) is 35 µg/L urine (ACGIH, 2016).

Toxicokinetics (the biological pathways which a chemical agent follows in the body)

When present in a water-soluble form, inorganic arsenic is well absorbed through the oral route; studies in humans demonstrate that greater than 95 percent of arsenic in this form may be absorbed (ATSDR 2007, Casarett et al. 2001). Oral bioavailability of inorganic arsenic is reduced when ingested as soil or dust (ATSDR 2016, USEPA 2012). Less soluble forms of arsenic are reported to be one-half to one-tenth as bioavailable as the more soluble forms of arsenic (Roberts et al. 2007). Bioaccessibility, or the solubility of arsenic in the gastrointestinal tract, accounts for the reduced bioavailability of soil arsenic. Physical and chemical factors of arsenic-bearing particles, such as morphology, arsenic mineralogy, and whether arsenic is on the surface or deeply embedded in the particle, affect the ability of the gastrointestinal tract to dissolve arsenic and ultimately its bioavailability (ATSDR 2016).

When inhaled, the water-soluble forms of arsenic are absorbed most rapidly and efficiently, whereas the absorption of particulate bound arsenic is greatly dependent on the dynamics of deposition and clearance of particles by the respiratory system (ATSDR 2007). The deposition and clearance of particles are influenced by the properties of the particles and exposure conditions. Dermal absorption of arsenic is low compared with other routes of exposure (ATSDR 2007), and dermal absorption from soil is negligible (ATSDR 2016, Roberts et al. 2007).

Following absorption, arsenic is distributed throughout the body. It does not show preferential accumulation in any internal organs, and can also transfer across the placenta (ATSDR 2007). Cellular uptake of arsenic depends on arsenic oxidation state and cell type. For passive diffusion, cell membranes are more permeable to As III than As V.

Metabolism of inorganic arsenic occurs in many tissues but principally in the liver; excretion principally in the urine. Inorganic arsenic is metabolized through a series of reduction and oxidative methylation reactions. In the first step of metabolism, inorganic arsenate (As V) is reduced to arsenite (As III). Following the initial reduction step, arsenite is methylated to MMA (V), which is reduced to MMA (III), and then methylated to the principal metabolite, DMA (V/III).

As (V) ⇨ As (III) ⇨ MMA*(V ⇨ MMA*(III) ⇨ DMA**(V) ⇨ excreted via kidneys mostly as DMA (60%). **reduction oxidative methylation reduction oxidative methylation**

(*MMA = "monomethyl arsenate"; **DMA = "dimethyl arsenate")

Metabolism of As_2O^3 results in inorganic As (20%); MMA (20%); DMA (60%)[64,65].

Although the process of methylation is saturable, under normal conditions the availability of methyl donors (methionine, choline, cysteine) is not limited and the process does not reach capacity. However, conditions including dietary deficiencies (e.g., restriction of methyl donor intake) can result in decreased methylating capacity (ATSDR 2007).

While earlier studies reported that stable pentavalent methyl derivatives of arsenic appeared to be less toxic than inorganic forms, recent studies evaluating multiple toxicity endpoints have suggested that the less stable trivalent methyl forms may have greater toxicity than inorganic arsenic forms. One study measuring toxicity in hepatocytes found that MMA (III) was more toxic than both arsenite (As III) and MMA (V). MMA (III) and DMA (III) have also been found to be more effective than As (III) in inducing DNA damage (Health Canada 2006). Further work is needed in order to confirm these findings and establish the role of various metabolites of inorganic arsenic in its toxicity (ATSDR 2007).

The primary pathway of elimination of arsenic is via urine. Approximately 75 percent of the absorbed dose of arsenic is eliminated by this pathway. Inorganic arsenic is rapidly excreted in urine, mostly within the first day following ingestion, whereas the methylated forms are mostly excreted within

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[64] Report No 70024547. Dundee Precious Metals Tsumeb Smelter Environmental & Social Due Diligence Report. September 2016.

[65] Dundee Precious Metals (DPM) 2016. Biomonitoring and Industrial Hygiene Data

2 to 3 days after exposure (Health Canada 2006, WHO 2000b). A small fraction of arsenic is excreted through faeces, bile, sweat, and breast milk (ATSDR 2007, Health Canada 2006).

Toxicodynamics (the effects of a chemical agent on organ systems)

The likelihood of experiencing adverse health effects (toxicity) is linked to: (ATSDR, 2007)

- Form: inorganic > organic. The organic forms in fish regarded to be nontoxic. (Humans cannot break the powerful molecular arsenic-carbon bond, thus inorganic As cannot be formed in its metabolism. Inorganic as is sequentially methylated in the liver, rendering it less toxic, prior to renal excretion.)
- Exposure route: inhalation/ ingestion > skin (inhalation most likely in occupational setting; ingestion for general public)
- Potency: valency III (arsenite) > valency V (arsenate). (with exception of arsine).
- Solubility: the more water soluble, the more toxic.

NB: whilst there is a great deal of data in the literature on the effects of ingested arsenic, there is very little on inhaled arsenic – therefore there is no published “minimum risk level” (“MRL”) for inhaled arsenic. The MRL (chronic effects) for ingested arsenic is 0.0003mg As/kg/day. (ATSDR, 2007)

Carcinogenic effects:

Arsenic and arsenic compounds are considered to be known human carcinogens. The International Agency for Research on Cancer (IARC) has classified arsenic and arsenic compounds as *carcinogenic to humans* (Group 1), which means that there is sufficient evidence for their carcinogenicity in humans.

Arsenic is considered to be a non-stochastic (characterized by a threshold dose below which effects do not occur) genotoxic (affects DNA) compound. Clastogenic damage (giving rise to or inducing disruption or breakages of chromosomes), was observed in different cell types of exposed humans and in mammalian cells *in vitro*. For point mutations, the results are largely negative. With regard to the mechanism which caused the genotoxic effects, there is evidence that DNA repair enzymes are inhibited by arsenicals. (ATSDR, 2007)

Long-term exposure to arsenic in **drinking water** is causally related to increased risks of cancer in the skin, liver, lungs, bladder and kidney, as well as other skin changes such as hyperkeratosis and pigmentation changes. The effects have been most thoroughly studied in Taiwan but there is considerable evidence from studies on populations in other countries as well. Increased risks of lung and bladder cancer and of arsenic-associated skin lesions have been reported to be associated with arsenic exposure categories of > 50 µg/L. (ATSDR, 2007)

Occupational exposure to arsenic by **inhalation** is causally associated with lung cancer. Exposure response relationships and high risks have been observed. Increased risks have been observed at relatively low cumulative exposure levels in smelter cohorts in Sweden (Rönnskär; arsenic exposure category of < 250 µg/m^3_ year) and in the USA (Tacoma; arsenic exposure category of < 750 µg/m^3_year). Studies indicated that smoking had a synergistic effect on the lung cancer effects of arsenic exposure. (ATSDR, 2007)

Because sufficient adequate human data on arsenic and arsenic compounds are available, human data are used for derivation of the occupational limit value.

SMR (“Standardised Mortality Ratio”) dose response line: (SMR of 100 = unexposed population) (data shown taken from multiple studies, published in the ATSDR (Aug 2007, pp 68-73)):

- Low increased risk: (0.05mg/m3)⇨SMR138; (0.213mg/m3)⇨SMR213; (0.29mg/m3)⇨SMR186. (0.05-0.30 = 2x risk)
- Medium increased risk: (0.3mg/m3)⇨SMR303; (0.564mg/m3)⇨SMR312; (0.58mg/m3)⇨SMR301. (0.30-0.60=3x risk)
- High increased risk: (1.487mg/m3)⇨SMR340; (2.75mg/m3)⇨SMR375; (1.5-3.0=3.5x risk)
- Very high increased risk: (5.0mg/m3)⇨SMR704 (5.0=7x risk)

Non-carcinogenic “toxic” effects. (ATSDR, 2007)

The skin is the most sensitive non cancer target organ, following ingestion. Arsenic has been shown to cause irritation (erythema & swelling), and may impair nail formation (so called Mee’s lines). Rarely, arsenic exposure has been linked to allergic contact dermatitis with sensitisation. In areas of high arsenic ingestion (Lowest Observable Adverse Effect Level (LOAEL 0.613mg/m^3)), arsenicosis may occur, which comprises a triad of hyperkeratinisation, hyperpigmentation and hypopigmentation.

The irritative effect of arsenic extends to exposures to the mucous membranes (conjunctivae, larynx, bronchi, and nose). In very high exposures, perforation of nasal septum may occur. The Respiratory NOAEL (non-malignancy) = 0.613mg As/m^3); reports include both restrictive and obstructive lung effects.

Mucosal irritation of the gastrointestinal tract may lead to diarrhoea.

Several studies have linked arsenic exposure to peripheral neuropathy (dying back axonopathy & demyelination). Lowest Observable Adverse Effect Level (LOAEL) approx. 0.31 mg As/m^3.

A number of studies have linked arsenic with peripheral vascular effects (elevated blood pressure), cardiotoxicity and diabetes mellitus, but these are generally in highly exposed populations. “Blackfoot disease”, a disease characterised by a progressive loss of circulation in the hands & feet, leading ultimately to necrosis & gangrene, has been described in a specific location in Taiwan.

Arsenic crosses the placenta & has been found in foetal tissues. Animal studies of oral inorganic arsenic exposure have reported developmental effects (LBW babies, foetal malformations, and even foetal death), but generally only at concentrations that also resulted in maternal toxicity. Chronic exposure of humans to inorganic arsenic in the drinking water has been associated with excess incidence of miscarriages, stillbirths, preterm births, and infants with low birth weights. (ATSDR, 2007)

Occupational exposure studies are not conclusive on a causal relationship between arsenic and reprotoxic effects.

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APPENDIX 2: SURVEY QUESTIONNAIRE

Please answer the following questions as accurately as possible. Please tick (✓) or circle your answer.

PERSONAL DETAILS

SURNAME: **FIRST NAME:**	**CODE**
SURVEY CODE NUMBER: WESTERN INDUSTRIAL (001-099); NORTHERN INDUSTRIAL (100-199); TOWN NORTH (200-299); TOWN CENTRAL (300-399); TOWN SOUTH (400-499); FARMS (500-599);OSHIKATI (600-699)	1□□□
GENDER: MALE / FEMALE	4□
DATE OF INTERVIEW & URINE SAMPLE COLLECTION (DAY/MONTH/YEAR): ____________________	5□□□□□ □
AGE IN YEARS: _____________	11□□
OCCUPATION: (WRITE A ONE LINE DESCRIPTION OF WHAT YOU DO AND FOR WHICH EMPLOYER) ____ ___	13□□
DO YOU WORK AT (1) DPMT (2) WESTERN INDUSTRIAL AREA (3) NORTHERN INDUSTRIAL/TOPSHOP AREA (4) TOWN NORTH (5) TOWN CENTRAL (6) TOWN SOUTH (7) FARMS (8) HOME (9) OTHER IF FARMS OR OTHER, PLEASE DESCRIBE ____	15□
DOES ANYONE ELSE IN YOUR HOME WORK AT DMPT? YES / NO	16□
NEAREST MONITORING STATION: 1. HILL 2. STADIUM 3. INFOCENTRE 4. SEWERAGE 5. MOBILE	17□

MEDICAL HISTORY

	Do you currently smoke tobacco, or chew tobacco, or use snuff? **YES / NO** If "Yes",	18□
1.1	Smoking: For how many years? .... Average daily number of cigarettes:	19□□ 21□□
1.2	Chew tobacco: For how many years? .... Average number of times per day:	23□□ 25□□
1.3	Snuff: For how many years?	27□□

	Average number of times per day: ……………………….	29□□
	Have you smoked, or chewed or taken snuff over the past 2 days **YES NO**	31□
	If "No" to question 1 or question 2, does anyone else in the household smoke tobacco? **YES NO**	32□
	Do you drink tap **water** from the taps, supplied by local municipal water? **YES NO**	33□
	Do you drink bottled water **YES NO** If "Yes", is bought from: 1. a shop, or 2. do you fill it from somewhere else in town?	34□ 35□
	Could you give an estimate of how much you drink from municipal tap water, and how much bottled water? % Municipal tap water ……………….. % Bottled water ………………..	36□□ 38□□
	Do you generally eat **food that is prepared with tap water**, supplied by local municipal water? **YES NO**	40□
	Have you eaten any fish in the past 2 days? **YES NO** If "Yes", what type of fish (e.g. Snoek, Angel, Breem, Pilchards, Hake, calamari, etc.)	41□ 42□
	Have you eaten any rice in the past 2 days? **YES NO** If "Yes" to eating rice, how many times? ___________________________	43□ 44□□
	Have you eaten any cereal in the past 2 days? E.g. pap, cornflakes, oats etc. **YES NO** If "Yes", how many times?	46□ 47□□
	If you live in Tsumeb, have you travelled out of Tsumeb in the last 2 days? **YES NO**	49□
	If you live on a farm outside Tsumeb, have you travelled to Tsumeb or visited the smelter site in the last week? **YES NO**	50□
	Have you worked at or visited the smelter in the last week? **YES NO**	51□
	Do you grow your own vegetables or herbs at home? **YES NO** If so what are you growing ? ____	52□
	Do you consume for food the vegetables or herbs that you grow at home? **YES NO**	53□
	Do you use the vegetables or herbs that you grow at home to sell to others or to make food products for others? **YES NO**	54□
	Do you pick or use or consume any wild vegetables? E.g. Majawa. **YES NO** If so what are they? ____ What do you use them for? ____ Where do you pick them?	55□

RESPIRATORY HISTORY

Please answer the following questions as accurately as possible. If you are unsure, indicate "NO" . Please tick (✓) or circle your answer.

	Have you had wheezing or whistling in your chest at any time in the last 12 months? **YES NO** **IF 'NO' GO TO QUESTION 2, IF 'YES':** How often have you had this? 1.1.1 Daily 1.1.2 At least once a week 1.1.3 At least once a month 1.1.4 Less frequently than this Have you been at all breathless when the wheezing noise was present? **YES NO** Have you had this wheezing or whistling when you did **not** have a cold? **YES NO** Have you had this wheezing or whistling during or after exercise **YES NO**	56☐ 57☐ 58☐ 59☐ 60☐
	Have you woken up with a feeling of tightness in your chest at any time in the last 12 months? **YES NO**	61☐
	Have you been woken up by an attack of shortness of breath at any time in the last 12 months **YES NO**	62☐
	Have you been woken by an attack of coughing at any time in the last 12 months **YES NO**	63☐
	Have you had an attack of asthma in the last 12 months? **YES NO**	64☐
	Are you currently taking any medicine (including inhalers, aerosols or tablets) for asthma? **YES NO**	65☐
	Do you have any nasal allergies including hay fever? **YES NO**	66☐
	Do you ever experience a strong unpleasant smell in the air ? **YES NO** If yes, how often ? 1. never 2. very infrequently 3. less than once a month, 4. more than once a month 5. at least once weekly, 6. daily	67☐ 68☐
	Compared with last year is this smell there as often, more often or less often than last year? 1 more 2 less	69☐

	When you smell this in the air does it ever affect you? **YES NO** Explain how?	70□

I hereby declare that all the information furnished above is, to the best of my knowledge, true and correct and that no information has been omitted or withheld.

______________________________ Date: ____________________________

Participant / Parent / Guardian

APPENDIX 3: GLOSSARY OF VARIABLES FROM COMMUNITY STUDY

VARIABLE NAME	VARIABLE DESCRIPTION	DATE CREATED
creatmol	creatinine (mmol/L)	
creatgl	creatinine (g/L)	
asbugl	AsB (µg/L)	
asinasbugl	Arsenic in AsB (µg/L)	
asbugg	AsB (µg/ g creatinine)	
asinasbugg	Arsenic in AsB (µg/ g creatinine)	
dmaugl	DMA (µg/L)	
asindmaugl	Arsenic in DMA (µg/L)	
dmaugg	DMA (µg/ g creatinine)	
asindmaugg	Arsenic in DMA (µg/ g creatinine)	
mmaugl	MMA (µg/L)	
asinmmaugl	Arsenic in MMA (µg/L)	
mmaugg	MMA (µg/ g creatinine)	
asinmmaugg	Arsenic in MMA (µg/ g creatinine)	
asiiiugl	As(III) (µg/L)	
asinasiiiugl	Arsenic in As(III) (µg/L)	
asiiiugg	As(III) (µg/ g creatinine)	
asinasiiiugg	Arsenic in As(III) (µg/ g	

	creatinine)	
asvugl	As(V) (µg/L)	
asinasvugl	Arsenic in As(V) (µg/L)	
asvugg	As(V) (µg/ g creatinine)	
asinasvugg	Arsenic in As(V) (µg/ g creatinine)	
unknownugl	Total of unknown arsenic species (µg/L) elemental arsenic	
unknownugg	Total of unknown arsenic species (µg/g creatinine) elemental arsenic	
totchromugl	Total of all column separated As species (µg/L) elemental arsenic	
totchromugg	Total of all column separated As species (µg/g creatinine) elemental arsenic	
astotugl	Total As (µg/L) by ICP-MS (no chromatography)	
astotugg	Total As by ICP-MS (µg/ g creatinine) (no chromatography)	
amalgugl	Amalgamated compounds (elemental arsenic in DMA+As(III)+MMA+As(V)) ug/L	
amalgugg	Amalgamated compounds (elemental arsenic in DMA+As(III)+MMA+As(V)) µg/g creatinine	
percasb	% AsB (as elemental Arsenic)	
validcreat	Urine Creatinine g/l < 0.34 or > 3.4 g/l	
logamalg		4/11/16

APPENDIX 4: LABORATORY ANALYTIC METHODS

Total arsenic in urine by ICP-MS

V&M method number: WIN-VM-085
ISO17025 accredited test method: Yes
Instrument: Agilent 7700x ICP-MS (helium mode)
Calibration: multi-level internal standard
Controls: ClinCheck and various in-house
Sample prep: urine sample is vortexed before a representative aliquot is removed for wet acid digestion

Arsenic speciation in urine by IC-ICP-MS and column chromatography

V&M method number WIN-VM-191
ISO17025 accredited test method: no (not frequently requested)
Instrument: Agilent 1100 HPLC utilizing a Dionex AS14 anion exchange column.
Gradient separation with TMAOH (2.6 mM) and ammonium carbonate (10 mM/ pH 10), 1 mL/min with effluent split.
Agilent 7700x ICP-MS (helium mode)
Calibration: multi-level external standard
Controls:in-house
Sample prep: urine sample is vortexed before centrifuging (8000 g), no dilution

APPENDIX 5: MAJOR OCCUPATIONAL HEALTH HAZARDS ASSOCIATED WITH PLANT OPERATIONS

Executive summary for occupational health.

Industrial hygiene personal sampling data for arsenic indicate that workplace concentrations are generally elevated above the Namibian occupational exposure limit, and substantially elevated above the most common European Union occupational exposure limits (OELs) or the American Conference of Governmental Industrial Hygienists Threshold Limit Value (ACGIH TLV). These data were obtained while the Arsenic Plant was still operational up to the third quarter of 2016, and show a slow longitudinal improvement for most business units up to the end of 2017.

The substantial biomonitoring programme at DPMT shows that while levels of arsenic in urine have declined significantly overall, and for most business units, some mean values, but particularly outliers (95^{th} percentiles) still exceed the Namibian Biological Exposure Index (BEI), and are well above the ACGIH BEI. The biomonitoring data generally demonstrate that the overall Personal Protective Equipment (PPE) programme is not working optimally. Specifically, the reduction brought about by the PPE falls substantially short of the protection factors able to reduce exposure below the OELs or BEIs. These factors are obtained in practice when environmental air levels of arsenic and urine arsenic levels are compared for similarly exposed groups of employees. A P3 reusable full face respirator should, conservatively, have an assigned protection factor (APF) of 30-40. Hence, if used perfectly by workers, the PPE should provide at least a 30-40 fold lowering of actual exposure. This level of performance is not achieved - instead the performance of the PPE is roughly an order of magnitude lower, in the range of 3-7. Suggested reasons for underperformance are provided. This confirms the well-known principle of non-reliance on personal protective devices for exposure reduction, while focussing on primary preventive occupational hygiene approaches to achieve compliance with occupational exposure limits and for guaranteeing safe working conditions. Occupational health surveillance should additionally focus on the principal adverse health effect of lung cancer. DPMT should consider setting up a post-employment medical examination and benefit scheme for past employees. The Namibian Government should consider setting up a cancer registry.

Principal Hazards

The main hazards associated with these processes include chemicals, noise, heat and ergonomics.

Chemicals

These include:

- Arsenic and sulphur dioxide, which are the main chemicals of concern. In particular, arsenic levels show exceedances above the Namibian occupational exposure limit[66].
- Lead, cadmium, copper, and mercury, which have been measured, and do not appear to be significant workforce drivers of exposure and risk.
- Sulphur dioxide (SO_2), for which exposures are historically extremely important and a major source of both plant and community exposure. However, since the installation of the new acid plant, SO_2 exposures have fallen substantially.
- Inhalable particulate matter exposures are a potential concern as the plant has a myriad fugitive dust generating sources.

[66] See Appendix 1: Toxicology of arsenic

Noise

Table 2: Summary of noise exposure across the main business units of the smelter

Noise Dosimetry — Includes all samples (shutdown and normal ops); Excludes invalid samples (too short etc.). Includes DPMT and contractors for total graph. Excludes contractors in other graphs, except in Oxygen Plant.

			Measured Exposure					Exposure Grouping						
Area	Sample Cycle	Numer of samples	Log. Average	Minimum	Maximum	50 %ile (Median)	95 %ile	Number above Limit	% over limit	< 80 dBA (Grp A)	80 - 84 dBA (Grp B)	84 - 94 dBA (Grp C)	94 - 100 dBA (Grp D)	> 100 dBA (Grp E)
Smelter All Noise Zones	2014	192	92.2	73.5	103.8	89.1	97.8	161	84%	6	16	137	30	3
Smelter All Noise Zones	2015	210	94.0	82.0	103.2	91.5	100.4	193	92%	0	9	145	44	12
Ausmelt	2014	46	91.6	76.4	99.1	89.9	95.0	39	85%	1	4	35	6	0
Ausmelt	2015	48	94.1	83.3	100.7	92.4	98.2	46	96%	0	1	31	15	1
Ausmelt	2016 YTD (End Sept)	29	90.2	78.1	96.6	88.5	95.2	22	76%	1	3	23	2	0
Convertors	2014	46	91.6	76.4	99.1	89.9	95.0	39	85%	1	4	35	6	0
Convertors	2015	50	96.7	85.5	103.2	91.9	102.3	50	100%	0	0	32	7	11
Convertors	2016 YTD (End Sept)	46	92.5	78.4	99.2	88.6	97.7	36	78%	1	8	25	12	0
Arsenic Plant	2014	41	92.1	74.8	102.2	88.3	97.3	36	88%	1	3	31	5	1
Arsenic Plant	2015	43	93.0	84.1	99.0	91.1	98.0	40	93%	0	0	31	12	0
Slag Mill	2014	19	92.5	79.6	98.9	87.6	97.0	15	79%	1	1	12	5	0
Slag Mill	2015	14	94.3	85.2	98.8	93.9	97.0	14	100%	0	0	7	7	0
Materials Handling	2014	28	91.0	78.3	98.8	87.7	95.6	21	75%	1	5	18	4	0
Materials Handling	2015	26	91.5	82.5	96.6	90.5	95.9	23	88%	0	3	20	3	0
Materials Handling	2016 YTD (End Sept)	23	94.7	70.7	105.9	89.3	97.6	16	70%	4	2	12	4	1
Laboratory	2014	2	86.8	85.7	87.6	86.7	87.5	2	100%	0	0	2	0	0
Power Plant	2015	11	89.2	83.5	93.0	86.1	92.8	9	82%	0	1	10	0	0
Power Plant	2016 YTD (End Sept)	11	102.1	80.8	111.6	91.1	107.1	8	73%	0	3	5	1	2
Oxygen Plant (Air Liquid	2016 YTD (End Sept)	4	88.9	85.4	91.3	87.8	91.1	4	100%	0	0	4	0	0

Source: DPMT, 2016.

As can be seen in Table 2, a total of 261 personal noise exposures were measured during 2015, of which 240 exceeded the 85 decibel exposure limit.

<u>Heat</u> the nature of some of the work tasks are arduous (especially plant maintenance and construction related tasks), coupled with a hot climate, which makes heat a potential hazard. Ambient heat exposure includes all occupations within the Converter and Ausmelt areas, as well as molten Slag Handling operations (prior to cooling and crushing) and molten metal handling (aisle). Heat sources are the Ausmelt furnace and launders, future RHF, converters, and steel covered structure (hot months), as well as molten material in ladles during slag and metal handling, and molten metal at the casting area. Exposure to heat also occurs during cleaning tasks involving hot liquid spills, e.g. after tapping.

<u>Ergonomics</u> a number of work tasks have ergonomic risk factors, such as manual handling and awkward posture, especially tasks associated with maintenance and construction work.

Fatigue is a problem because of shift work, pressing deadlines, combined with arduous tasks, awkward PPE and hot ambient conditions.

CONSEQUENCES OF EXPOSURE TO THESE HAZARDS

Notwithstanding this list of hazards, relatively few cases of occupational disease are identified.

In a large comprehensive health survey in 2012[67], the only findings were increased symptoms related to SO_2 exposure, increased skin rashes related to baghouse dust, and some cases of noise induced hearing loss (NIHL). There were no cases of work-related cancer identified, and no evidence of arsenic induced occupational disease.

Ongoing medical surveillance is conducted and this trend has continued since. To date three cases of nasal ulceration have been recorded.

In an independent review of audiograms in 2011, 63 cases of NIHL were identified in a sample of 554 audiograms (11.37%). (Source, DPMT).

Likely impacts of increased production on the nature of the hazards

The increase in production throughput is unlikely to introduce a new hazard, but may increase the exposures to hazards already present, including arsenic, SO_2, noise and fatigue. The likely impact of the scaled up operations on occupational health is discussed below.

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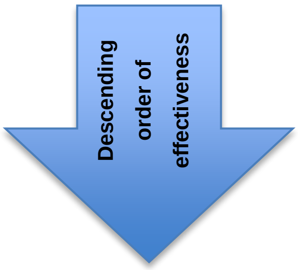
[67] Namibia Custom Smelter Audit- Tsumeb December 2011 To January 2012
Volume II. JH Masinja, B Kistnasamy, D Rees, L Zungu, J Cornelissen, T Nghitila, FM Sikabongo. 12 April 2012 Undertaken With Support From The UNDP And The Ministry Of Health And Social Services

DPMT Occupational Hygiene Management Programme

Overview

Industrial (Occupational) hygiene (IH) is the science of the anticipation, recognition, evaluation and control of hazards arising in or from the workplace, and which could impair the health and well-being of workers, also taking into account the possible impact on the surrounding communities and the general environment.[68] Measurements with the purpose of investigating the presence of agents and the patterns of exposure parameters in the work environment can be extremely useful for the planning and design of control measures and work practices. The objectives of such measurements include:

- hazard source identification and characterization
- spotting of critical points in closed systems or enclosures (e.g., leaks)
- determination of propagation paths in the work environment
- determining the efficacy of control measures



Ultimately, the purpose of IH monitoring is to recommend appropriate control of exposures; which may vary in effectiveness. The most effective control mechanism is the elimination of the hazard through stopping its use, or substituting it with a non-hazardous alternative. The next most effective controls comprise efforts aimed at reducing exposure. The following list shows these in descending order of effectiveness. This is known as the "hierarchy of controls".

- engineering controls
- employee education and safe work practices
- administrative controls (e.g. job rotation)
- correct use of protective equipment

As a general principle of IH, the most efficient hazard prevention approach is the application of engineering control measures which prevent occupational exposures by managing the work environment, thus decreasing the need for

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[68] ILO Encyclopaedia of Occupational Health and Safety. 2012. Chapter 30 Occupational Hygiene

initiatives on the part of workers or potentially exposed persons. Engineering measures usually require some process modifications or mechanical structures, and involve technical measures that eliminate or reduce the use, generation or release of hazardous agents at their source, or, when source elimination is not possible, engineering measures should be designed to prevent or reduce the spread of hazardous agents into the work environment by:

- containing them
- removing them immediately beyond the source
- interfering with their propagation
- reducing their concentration or intensity.

The efficiency of control measures is typically assessed by a combination of source or area sampling, alone or in addition to personal sampling. There is an existing Tsumeb plant database for both personal and area air samples.

In general, the Tsumeb plant personal samples are more systematic and longitudinally complete than the area samples. Personal sampling is typically executed by creating "similar exposure groups" (SEGs). A SEG is defined as a group of workers having the same general exposure profile for the agent(s) being studied because of the similarity and frequency of the tasks performed, the materials and processes with which they work, and the similarity of the way they perform tasks.

Personal Protective Equipment (PPE)

As is illustrated in the preceding section, personal protection is not the first choice, and is in fact the last, in the hierarchy of methods for controlling workplace hazards. From an IH perspective, PPE should only be used when standard, hazard reduction engineering controls (i.e., isolation, enclosure, ventilation, substitution, or other process changes) and administrative controls (such as reducing work time at risk for exposure) have been implemented[69]. Developing and implementing a PPE programme is complex and requires consistent changes in workplace behaviours and practices. This is inherently less efficient than protection which is built into the process at the source of the hazard.

Respiratory Protection

The whole Tsumeb plant, particularly in the arsenic plant area, is reliant upon the use of Respiratory Protection Equipment (RPE) in order to try and meet occupational exposure requirements.

A critical consideration for assessing the performance of a respiratory protection programme is the concept of respirator "assigned protection factor (APF)" and "nominal protection factor (NPF).

- The APF is based on workplace measurements that a trained operator is expected to achieve.
- The NPF is based on laboratory measurements; because the NPF does not represent true workplace conditions, in which the same RPE would perform less effectively, the NPF is regarded as the lowest performance value that a respirator must meet.

APF and NPF rating schemes have been developed and published in the USA and European Union, i.e., OSHA 29 CFR 1910.134 and EN-529. En-529 is the European Norm for Respiratory Protective Devices – Recommendations for Selection, Use, Care and Maintenance. Currently, there is no harmonised approach within the EU on the appropriate application of APFs for Respiratory Protective Equipment (RPE). The protection factor is used to select the respirator type only, not for selecting or changing filters. Simply put, the

[69] ILO Encyclopaedia of Occupational Health and Safety. 2012b Chapter 31 Personal Protection

protection factor is the difference between wearing a specific respirator type and wearing no respirator at all.

Table 3 presents a comparison of respirator type, APF, and NPF as rated by European and American authorities and are those respirator types that are currently used at DPMT.

Table 3: Respirator APF Comparison

Respirator Type	NPF	APF (Germany)	APF (Finland)	APF (Italy)	APF (Switzerland)	APF (UK)	APF (USA)
Filtering half mask (FFP2)	50	10	10	10	10	10	10
Half mask (P3)	48	30	N/A	30	N/A	20	10
Full face mask (P3)	1,000	400	500	400	500	40	50

Source: Drager, 2012. FF refers to disposable type, “P” refers to protection level class

As illustrated in Table 3, APFs are not always consistent across countries due to differences in respirator design, testing protocols, safety factors applied to NPF and professional judgement. Given the lack of a European consensus on APFs, it is appropriate to show a range rather than a point value, i.e., half mask(P3) 20-30; full face (P3) 40-500. There is general consensus that the disposable filtering half mask (FFP2) has a APF of 10. The dominant types of respirators at DPMT are the P3 level reusable half and full face respirators.

DPMT arsenic exposure monitoroing programme

DPMT’s industrial hygiene and occupational health programs consider and evaluate the workforce across the entire plant, in defined operational areas, e.g. arsenic plant, Ausmelt, laboratory, etc. Both IH and human biomonitoring data are collected within work areas and/or often across similar exposure groups (SEGs). IH data consists of personal and area monitoring. The biomonitoring database is substantially larger and more consistent than the IH sampling. The predominance of medical biomonitoring versus IH air sampling has been a general strategy since at least 2011, following the purchase of the plant by DPM.

The DPMT plant is undergoing a series of constant upgrades and engineering improvements, e.g. opening of a new acid plant, dust capture systems, and holding furnaces. Hence, longitudinal review of IH and/or biomonitoring data must be considered and analysed within a context of continuous engineering change, i.e. the exposure dynamic within a given work setting is constantly changing. In addition, there has been a substantial effort made by the occupational health and safety staff regarding the use of PPE, particularly respiratory protection.

DPMT exposure data

The DPMT IH and OH staff have extensive industrial hygiene air monitoring and biomonitoring data sets covering 2011 to the fourth of 2017 (4Q17) (DPM, 2018). The “raw data” for both data sets were provided by DPMT, for the purpose of independent analysis and reporting in this Health Impact Assessment. For industrial hygiene, the personal air sampling data were utilized.

For exposure data to be meaningful, they are compared with reference exposure values. Air monitoring exposure reference values in Namibia are known as Occupational Exposure Limits (“OELs”) and biomonitoring exposure reference values are known as Biological Exposure Indices (“BEIs”).

Occupational Exposure limits (OELs)

Occupational exposure limit values (OELs) are set to prevent occupational diseases or other adverse effects in workers exposed to hazardous chemicals in the workplace. OELs assume that exposed persons are healthy adult workers, although in some cases the OELs should also protect vulnerable groups – e.g. pregnant women or other more susceptible people [70]. OEL means the limit of the time-weighted average of the concentration of a chemical agent in the air within the breathing zone of a worker in relation to a specified reference period. Countries are not harmonized in terms of OELs and there are differences across the world.

Another widely cited list of chemical specific exposure limits is the ACGIH Threshold Limit Values[71] (TLVs). The ACGIH TLVs and most other OELs used in the United States and some other countries are limits which refer to airborne concentrations of substances and represent conditions under which “it is believed that nearly all workers may be repeatedly exposed day after day without adverse health effects” (ILO, 2012a[72]; ACGIH, 2016). While ACGIH TLVs do not have the force of law in the USA, they are highly regarded and recognized as benchmark worker exposure levels both in the USA and internationally. TLVs are based solely on health factors, i.e., there is no consideration given to economic or technical feasibility (ACGIH, 2016)

Table 4 (GESTIS, 2016) presents the most current (2016) summary of international OELs for inorganic arsenic exposures, including the ACGIH TLV. As shown in this table, the most common OEL for inorganic arsenic, both internationally and within the EU, is 0.01 mg/m^3 (10 ug/m^3), a concentration that matches the ACGIH recommendation.

Table 4 : Summary of Inorganic Arsenic OELs (2016)

Substance	Arsenic & Compounds [except arsine (as As) as Total Gas
CAS N0.	7440-38-2
Remarks	Classified as Known Human Carcinogen

[70] OSHwiki EU, 2016

[71] American Conference of Governmental Industrial Hygienists. ACGIH, 2016. TLV-BEI Guidelines, Documentation, Policy and Position Statements. http://www.acgih.org/tlv-bei-guidelines/policies-procedures

[72] ILO Encyclopaedia of Occupational Health and Safety. 2012a Chapter 30 Occupational Hygiene

Country	OEL- 8 hours (mg/m3)	Short-term Limit (mg/m3)
Australia	0.05	
Austria	0.1 (inhalable aerosol)	0.4 (inhalable aerosol)
Belgium	0.01	
Canada-Ontario	0.01	0.05 (1)
Denmark	0.01	0.02
Finland	0.01	
Germany	0.0083 (1)(3) 0.00083 (2)(3)	0.066 (1)(2)(3)
Hungary		0.01
Ireland	0.01	
Japan	0.003 (1) (2)	
New Zealand	0.05	
Poland	0.01	
Singapore	0.01	
South Korea	0.01	
Spain	0.01	
Sweden	0.01 (1)	
United Kingdom (UK)	0.1	
USA-NIOSH		0.002(1)
USA- OSHA	0.01	
USA-ACGIH	0.01	
Countries with Active Smelters Process Copper Concentrates with As>1%		
Canada- Quebec	0.1	
Chile	0.01	
China (PRC)	0.01	0.02 (1)
Namibia	0.1	

Source: GESTIS International Limit Values (2016)

European Union Countries are shaded

Notes: *Canada-Ontario*- (1) and organic compounds (only where both inorganic and organic compounds are present)*Germany (AGS)*- Workplace exposure concentration corresponding to the proposed tolerable cancer risk. (see background document: Germany AGS) (2) workplace exposure concentration corresponding to the proposed preliminary acceptable cancer risk . (see background document: Germany AGS) (3) inhalable fraction (4) 15 minutes average value

Japan- (1) Calculated as As (2) not GaAs

China PRC- (1) 15 minutes average value

Sweden- (1) Total dust USA-NIOSH- (1) Ceiling limit value (15min)

The ACGIH TLV[73] Committee and other groups which set OELs warn that these workplace values should not be directly used or extrapolated to predict safe levels of exposure for other exposure settings, i.e. different populations (community settings). A generally healthy adult workforce is not representative of a community which has a far more complex demographic population, i.e. children, newborns, the aged and potentially significant numbers of vulnerable individuals. Hence, modifying a workplace TLV and applying this adjusted value to a community setting is not recommended[74].

Biological Exposure Indices (BEIs)

Human biomonitoring (HBM) is a technique in common for both workplace and community assessments. HBM can be defined as the method for assessing human exposure to chemicals or their effects by measuring these chemicals, their metabolites or reaction products in human specimens (CDC, 2012; NRC, 2006). Biomonitoring involves measurements of biomarkers in bodily fluids, such as blood, urine, saliva, breast milk, sweat, and other specimens, such as faeces, hair, teeth, and nails. Biomonitoring data directly reflect the total body burden or biological effect resulting from all routes of exposure, and interindividual variability in exposure levels, metabolism and excretion rates[75].

The Biological Exposure Index is a reference value for assessing biological monitoring results, intended as a guideline for the likelihood of adverse health effects and generally represents the level of determinants that are most likely to be observed in specimens collected from healthy employees who have been exposed to chemicals with inhalation exposure at the Occupational Exposure Limit (ACGIH, 2016) .

[73] ACGIH, 2016; Policy Statement http://www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-policy-statement

[74] ILO Encyclopaedia of Occupational Health and Safety. 2012a Chapter 30 Occupational Hygiene

[75] Human biomonitoring: facts and figures: Copenhagen: WHO Regional Office for Europe, 2015.

Such data are often the most relevant metric for health impact assessment. For chemicals that are excreted relatively rapidly (e.g. arsenic), cross-sectional biomonitoring data reflect recent exposure rather than long-term chronic exposure, although they can be used as a proxy for long term exposure where the exposure is continuous.

HBM is a well-established strategy for both workplace and community exposure evaluations. Biomonitoring, however, usually does not reveal exposure sources and routes. Therefore, objective quantitative monitoring, e.g., industrial hygiene(occupational) and/or general environmental sampling is essential. The objectives of analysing HBM-based environmental health indicators include: (i) assessing temporal exposure trends, (ii) assessing effectiveness of workplace controls measures including personal protective equipment (PPE), (iii) characterizing geographic patterns of exposure in the workplace or community setting and (iv) comparing different worker or community subgroups and (v) identifying vulnerable subpopulations in either the workplace and/or community.

International standards and reference values for workplace HBM are available[76]. The BEI for Namibia for inorganic arsenic is 50 µg/g creatinine in urine (note – the arsenic level is corrected for creatinine). The BEI recommended by the ACGIH for inorganic arsenic is 35 µg/L urine (note – not corrected for creatinine).

The German equivalent (known as a BLW – Biologischen Leitwertes) is 50 µg/L uncorrected. At a recent international conference on "Arsenic in the Environment," the DPM HSE team presented their experience with corrected versus uncorrected urine arsenic biomonitoring[77] (Kew, 2016). Correcting the urine arsenic concentration matters when there is a likelihood of dehydration when working in hot ambient and working environments like Namibia. In a

[76] ACGIH, 2016. TLV-BEI Guidelines, Documentation, Policy and Position Statements. http://www.acgih.org/tlv-bei-guidelines/policies-procedures

[77] Kew GP et al. The ACGIH Biological exposure index for urinary arsenic: To adjust for urinary creatinine or not? Proceedings of the Arsenic in the Environment – Arsenic research and global sustainability, 2016

very narrow range near 35 ug/L, correcting for creatinine appears to make minimal difference.

In this analysis, all arsenic urines were corrected for creatinine.

The HBM program at the Tsumeb plant is primarily (and appropriately) focused on arsenic. Workplace HBM data are longitudinally available for virtually all workers and will be analysed in subsequent sections of this report.

Arsenic in air datasets

Tables 5 through 12 and Figures 8 through 15 below present the longitudinal personal IH sampling arsenic in air data by operational area or a specific defined group, i.e. “service providers” (contractors). The ACGIH arsenic TLV (0.01 mg/m^3) is shown as a dashed horizontal red line across the graphs. As previously discussed (See Table 4), the ACGIH TLV is a benchmark value and consistent with the most common EU country specific OELs. The current Namibia OEL (0.1 mg/m^3) is shown as a solid horizontal red line across the graphs. Other than the UK OEL, the Namibia standard is ten times (10x) higher than the ACGIH benchmark. Countries with operating copper smelters that receive high arsenic (>1%) concentrates are split between the 0.01 mg/m^3 OEL (China and Chile) and the 0.1 mg/m^3 standard (Canada- Quebec and Namibia).

Table 5: Total arsenic from personal air sampling mg/m^3

TOTAL ARSENIC (incl As_2O_3) (OEL=0.1mg/m^3) (TLV=0.01mg/m^3)	2011 Q4 2011, Q4	2012 Q1 2012, Q1	2012 Q2 2012, Q2	2012 Q3 2012, Q3	2012 Q4 2012, Q4	2013 Q1 2013, Q1	2013 Q2 2013, Q2	2013 Q3 2013, Q3	2013 Q4 2013, Q4	2014 Q1 2014, Q1	2014 Q2 2014, Q2
Total Smelter (Personal)											
Arithmetic Mean	**0.307**	**0.229**	**0.105**	**0.079**	**0.091**	**0.186**	**0.086**	**0.162**	**0.089**	**0.081**	**0.089**
Median	0.028	0.029	0.042	0.041	0.025	0.040	0.038	0.051	0.025	0.031	0.040
Minimum	0.002	0.001	0.001	0.002	0.001	0.001	0.005	0.002	0.001	0.001	0.005
Maximum	2.982	3.184	0.342	0.717	0.696	1.344	0.454	1.406	2.686	1.500	0.665
95th Percentile	1.824	0.833	0.302	0.185	0.412	0.851	0.336	0.737	0.295	0.242	0.366
Std Dev	0.681	0.572	0.112	0.133	0.148	0.314	0.110	0.258	0.306	0.188	0.147
Std error	0.101	0.098	0.025	0.025	0.019	0.047	0.016	0.032	0.034	0.021	0.025
Geometric Mean	0.047	0.040	0.040	0.039	0.026	0.050	0.044	0.060	0.025	0.033	0.040
Geometric Std Deviation	6.578	6.978	5.714	3.386	5.738	5.645	3.234	4.255	4.317	3.502	3.488
Samples	45	34	20	29	61	44	47	66	82	77	34

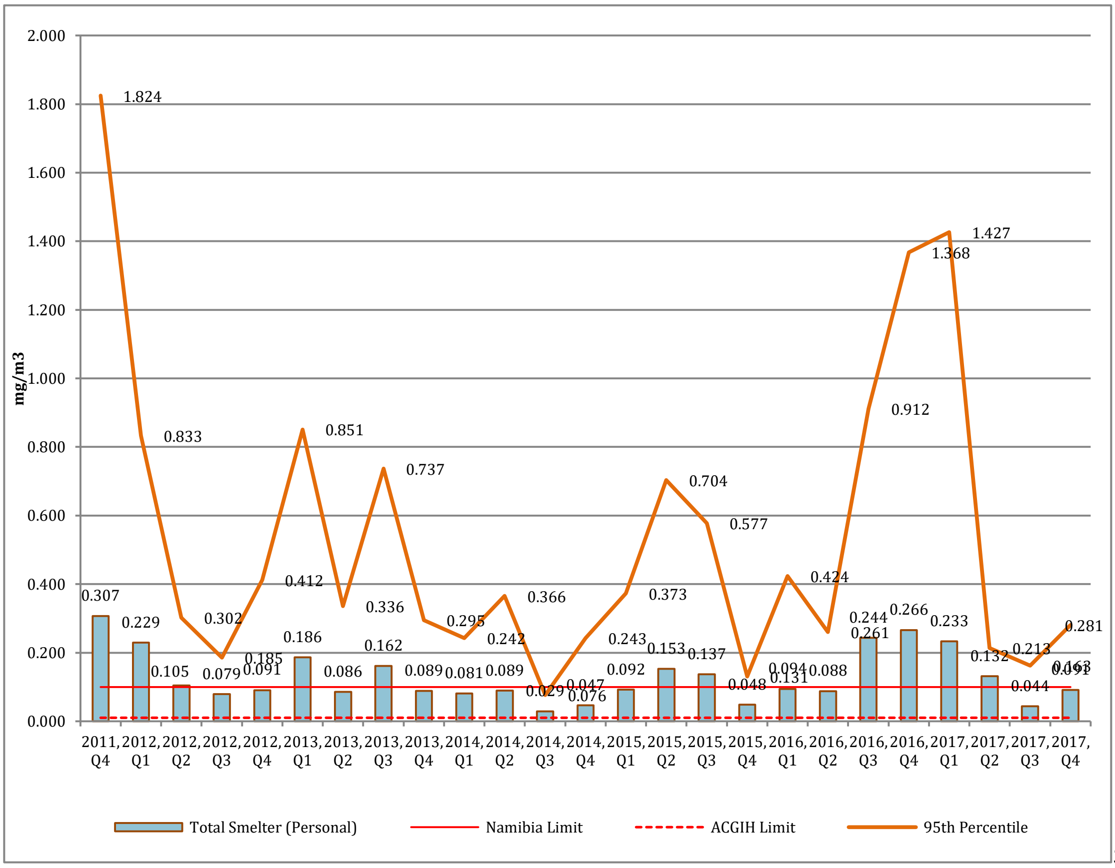
TOTAL ARSENIC (incl As_2O_3) (OEL=0.1mg/m^3) (TLV=0.01mg/m^3)	2014 Q3 2014, Q3	2014 Q4 2014, Q4	2015 Q1 2015, Q1	2015 Q2 2015, Q2	2015 Q3 2015, Q3	2015 Q4 2015, Q4	2016 Q1 2016, Q1	2016 Q2 2016, Q2	2016 Q3 2016, Q3	2016 Q4 2016, Q4	2017 Q1 2017, Q1	2017 Q2 2017, Q2	2017 Q3 2017, Q3	2017 Q4 2017, Q4
Total Smelter (Personal)														
Arithmetic Mean	**0.029**	**0.047**	**0.092**	**0.153**	**0.137**	**0.048**	**0.094**	**0.088**	**0.244**	**0.266**	**0.233**	**0.132**	**0.044**	**0.091**
Median	0.011	0.017	0.029	0.040	0.060	0.031	0.023	0.045	0.035	0.031	0.029	0.024	0.019	0.028
Minimum	0.001	0.000	0.001	0.002	0.001	0.005	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000
Maximum	0.528	0.570	0.870	2.850	1.142	0.190	1.130	1.248	4.127	2.445	3.698	5.264	0.388	2.545
95th Percentile	0.076	0.243	0.373	0.704	0.577	0.131	0.424	0.261	0.912	1.368	1.427	0.213	0.163	0.281
Std Dev	0.074	0.088	0.172	0.349	0.218	0.045	0.191	0.172	0.608	0.511	0.608	0.577	0.061	0.248
Std error	0.008	0.008	0.021	0.032	0.022	0.008	0.018	0.017	0.045	0.068	0.061	0.043	0.005	0.020
Geometric Mean	0.011	0.015	0.035	0.044	0.062	0.032	0.026	0.035	0.049	0.050	0.036	0.026	0.020	0.031
Geometric Std Deviation	3.436	6.552	3.967	4.569	3.887	2.710	5.042	4.148	5.595	7.427	6.496	4.143	3.939	3.949
Samples	91	125	69	117	95	32	109	103	185	56	101	176	150	155

Table 6: Total Plant personal sample sizes by year and quarter

4Q 11	1Q 12	2Q 12	3Q 12	4Q 12	1Q 13	2Q 13	3Q 13	4Q 13	1Q 14	2Q 14	3Q 14	4Q 14	1Q 15	2Q 15	3Q 15	4Q 15	1Q 16	2Q 16	3Q 16	4Q 16	1Q 17	2Q 17	3Q 17	4Q 17
45	34	20	29	61	44	47	66	82	77	34	91	125	69	117	95	32	109	103	185	56	101	176	150	155

Source: DPMT, 2017

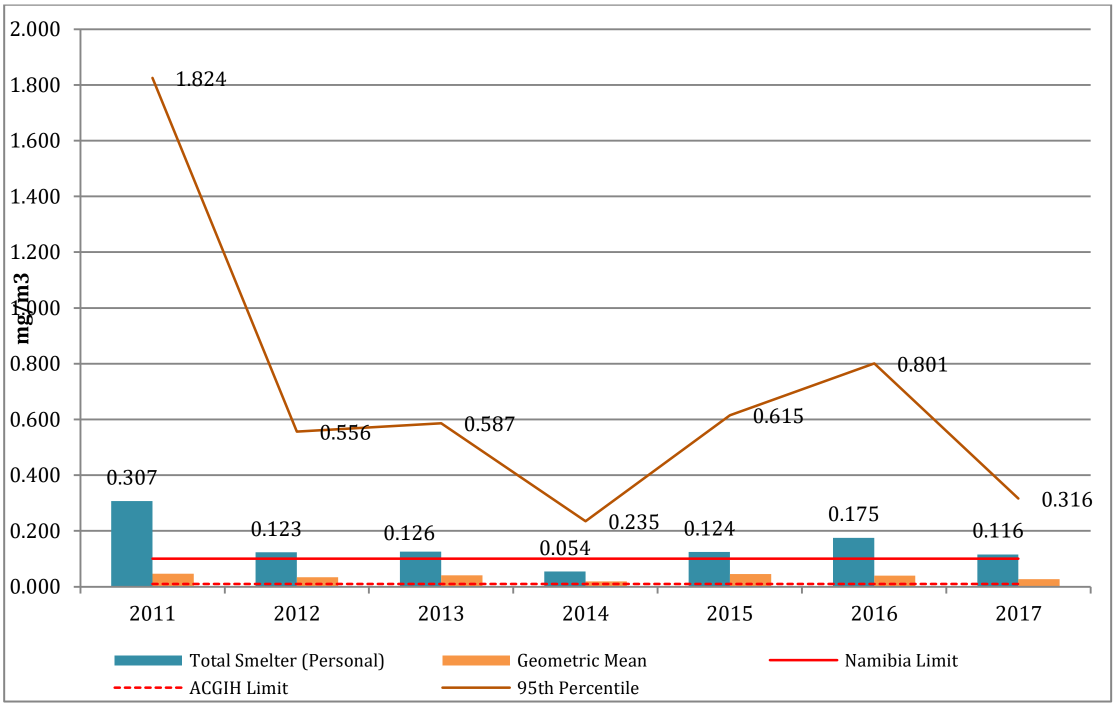
Figure 8: Total plant personal air samples means and 95th percentile by quarter



Source DPMT, 2017

The air sampling data of the Total Plant shows a variable course over time, but the trend suggests a slight general improvement over time. Until recently, three consecutive quarters have been below the Namibian OEL. Whilst the value approximated the TLV once in 2014, at no time has the mean value been below the ACGIH TLV.

Figure 9: Total plant personal air sample means and 95th percentiles by year



Source: DPMT, 2017

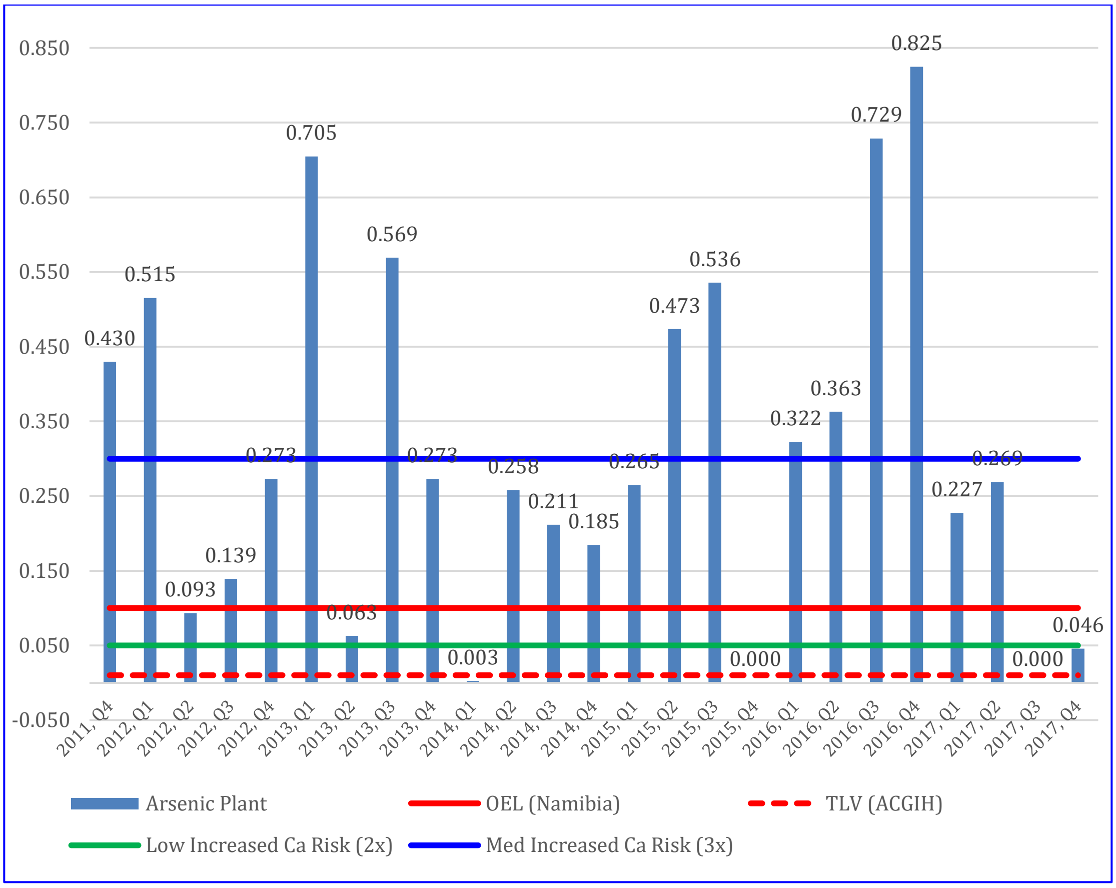
Arsenic Plant Air monitoring

Table 7: Arsenic plant personal sample sizes 2011 to 2016

4Q 11	1Q 12	2Q 12	3Q 12	4Q 12	1Q 13	2Q 13	3Q 13	4Q 13	1Q 14	2Q 14	3Q 14	4Q 14	1Q 15	2Q 15	3Q 15	4Q 15	1Q 16	2Q 16	3Q 16	4Q 16	1Q 17	2Q 17	3Q 17	4Q 17
28	8	5	2	7	9	2	11	5	1	7	4	14	17	31	11	0	25	8	55	15	22	15	0	6

Source: DPMT, 2017

Figure 10: Arsenic plant personal air sample arithmetic means



Source: DPMT, 2017

Air sampling data (arithmetic means) are consistently and substantially greater (30x) than ACGIH TLV or EU OELs. With a few exceptions, air data are also greater than the Namibia OEL by a factor of 2-3 times.

These data do not mean that workers actually experienced these exposure concentrations in terms of uptake as there was a respiratory protection programme in place. However, as will be shown by the biomonitoring data, the respiratory protection programme did not, in practice, achieve full protection, i.e. the assumed applied protection factor (APF) for a full face respirator of 40-500 ideally would have reduced the air exposure concentration to well below the ACGIH TLV. Assuming a conservative APF of 30-40 for a P3 full face respirator, the "effective" worker arsenic air exposure would have nominally been:

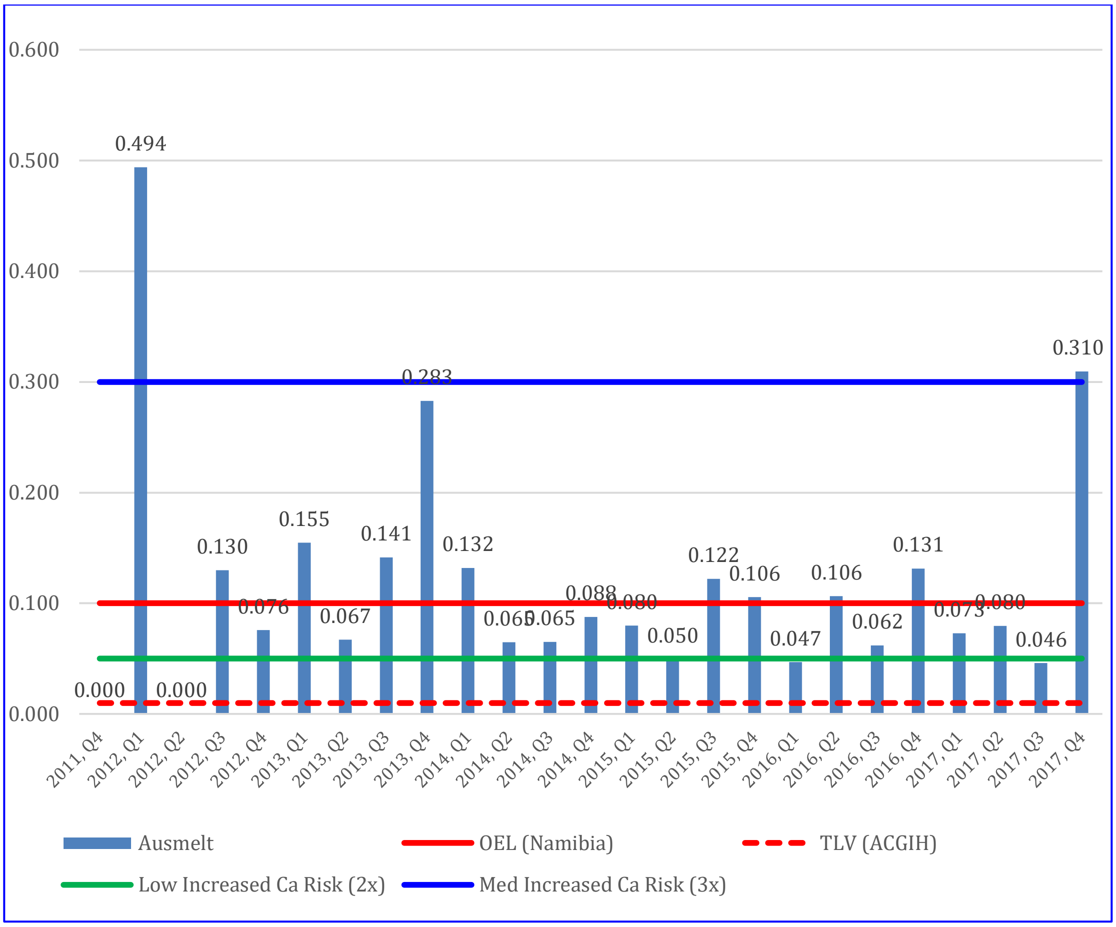
0.363mg/m^3 (second quarter 2016 concentration) / 30-40 = 0.012-0.009 mg/m^3

As will be shown in subsequent sections this level of exposure protection did not occur.

Ausmelt Air monitoring

Figure 11 presents the Ausmelt arsenic air concentrations. Air concentrations are generally 3-10 times lower than the arsenic plant. There is partial compliance with Namibian OEL, however, the air measurements are consistently above the arsenic ACGIH TLV.

Figure 11: Ausmelt personal air sample arithmetic means



Source: DPMT, 2017

Table 8 presents the air monitoring sample sizes for the Ausmelt, which are extremely variable and compromise a consistent ability to calculate standard statistical parameters. Ausmelt biomonitoring and respiratory protection analysis will be presented in subsequent sections.

Table 8: Ausmelt Arsenic Personal Sample Sizes 4Q11- 2Q16

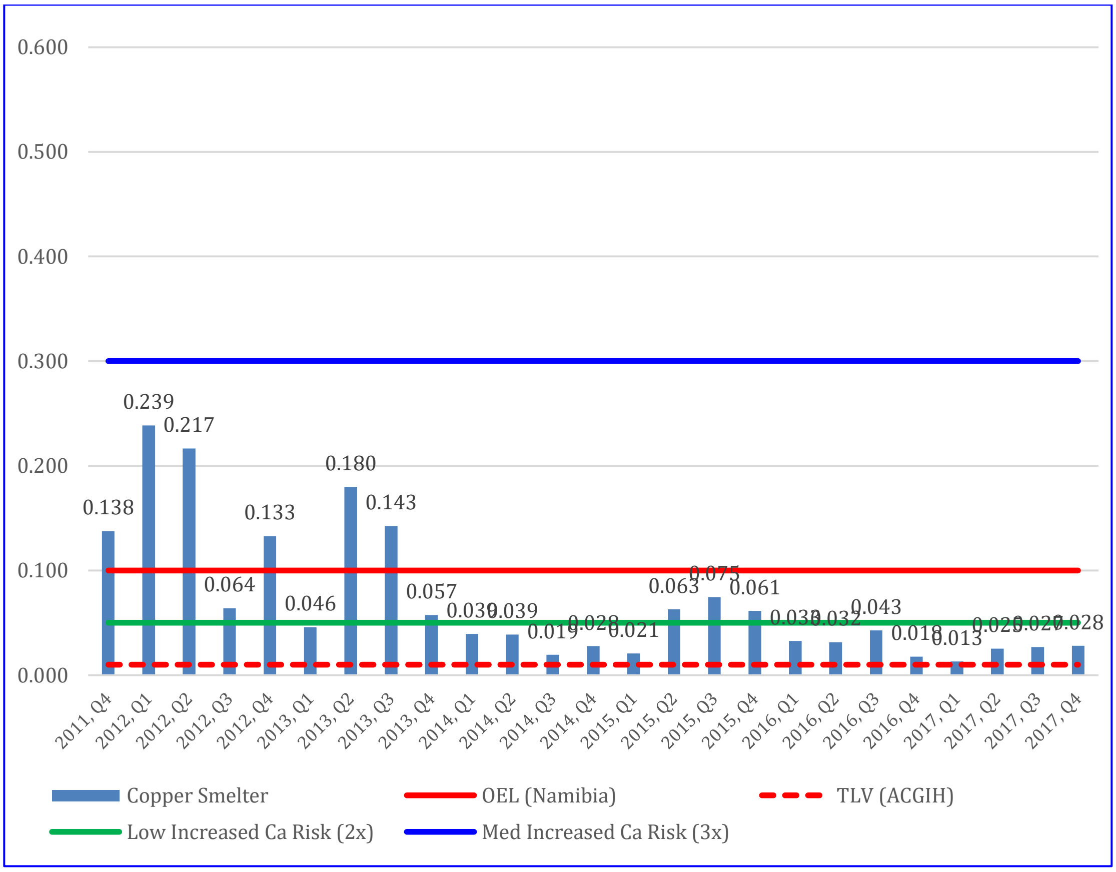
4Q 11	1Q 12	2Q 12	3Q 12	4Q 12	1Q 13	2Q 13	3Q 13	4Q 13	1Q 14	2Q 14	3Q 14	4Q 14	1Q 15	2Q 15	3Q 15	4Q 15	1Q 16	2Q 16	3Q 16	4Q 16	1Q 17	2Q 17	3Q 17	4Q 17
0	3	0	10	9	6	9	11	12	35	12	11	20	13	20	25	3	9	17	21	7	6	23	20	18

Source: DPMT, 2017

Copper Smelter Air monitoring

Figure 12 presents the copper smelter arsenic air concentrations and illustrates that air concentrations are generally in compliance with Namibian OEL, but consistently above arsenic ACGIH TLV.

Figure 12: Copper smelter personal air sample arithmetic means



Source: DPMT, 2017

Table 9 presents the air monitoring sample sizes for the copper Smelter, which are extremely variable and compromise a consistent ability to calculate standard statistical parameters.

Table 9: Copper Smelter Arsenic Personal Sample Sizes 4Q11- 2Q16

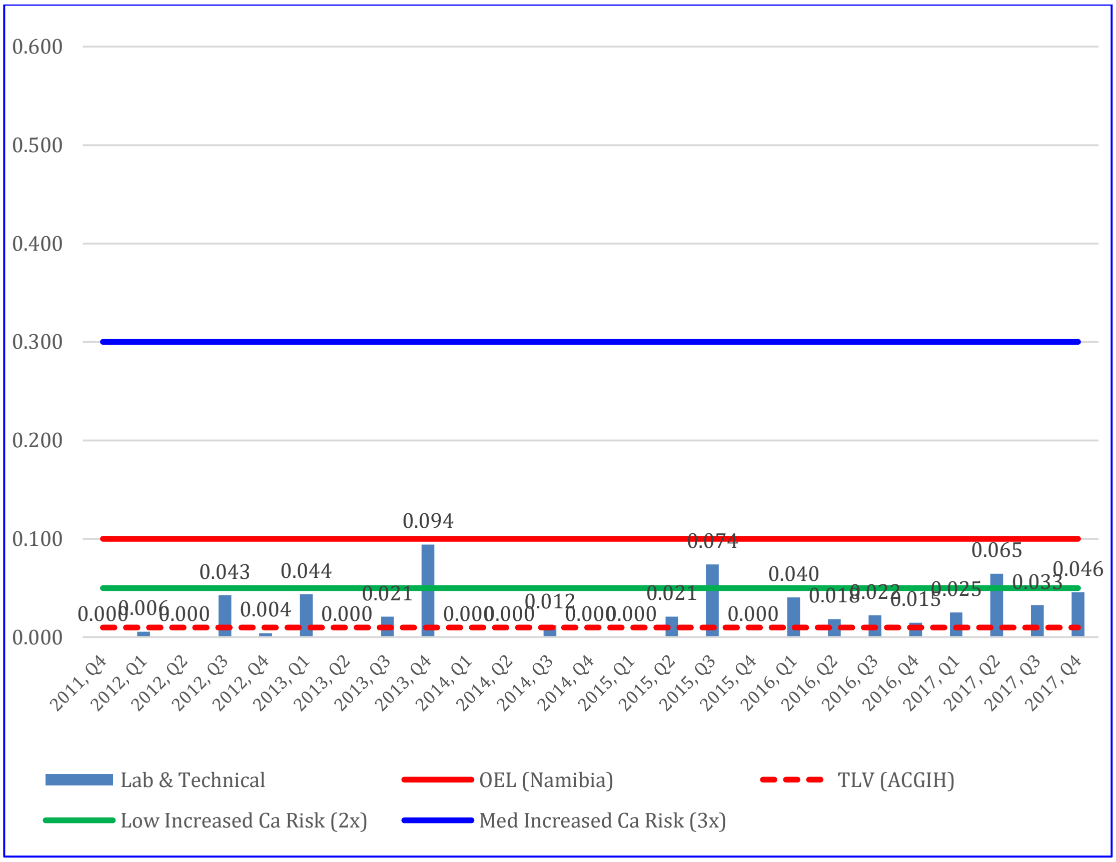
4Q 11	1Q 12	2Q 12	3Q 12	4Q 12	1Q 13	2Q 13	3Q 13	4Q 13	1Q 14	2Q 14	3Q 14	4Q 14	1Q 15	2Q 15	3Q 15	4Q 15	1Q 16	2Q 16	3Q 16	4Q 16	1Q 17	2Q 17	3Q 17	4Q 17
12	8	7	5	4	4	14	10	21	41	8	10	27	12	21	25	6	13	12	21	3	9	20	17	21

Source: DPMT, 2017

Laboratory / Technical Air monitoring

Figure 13 presents the laboratory/technical area arsenic air concentrations and illustrates that air concentrations are in compliance with Namibian OEL and are occasionally below the ACGIH TLV.

Figure 13: Laboratory/technical area personal air sample arithmetic means



Source: DPMT, 2017

Table 10 : Laboratory/technical area arsenic personal sample sizes

4Q 11	1Q 12	2Q 12	3Q 12	4Q 12	1Q 13	2Q 13	3Q 13	4Q 13	1Q 14	2Q 14	3Q 14	4Q 14	1Q 15	2Q 15	3Q 15	4Q 15	1Q 16	2Q 16	3Q 16	4Q 16	1Q 17	2Q 17	3Q 17	4Q 17
0	1	0	2	5	8	0	2	4	0	0	3	0	0	5	7	0	2	4	14	2	2	18	22	10

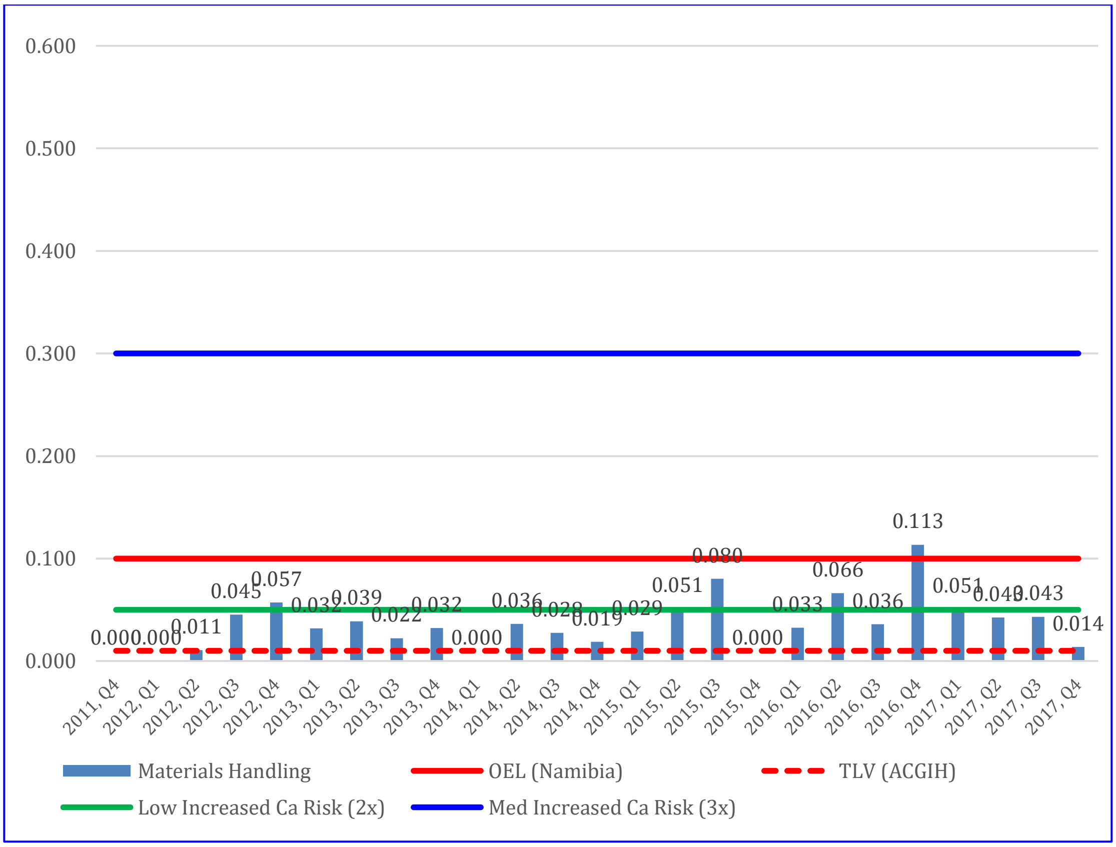
Source: DPMT, 2017

Sample sizes for the laboratory/technical area are extremely small and generally less than five; hence, these data should be interpreted cautiously. The laboratory/technical area air data do indicate that air concentrations are higher than typically seen in a laboratory setting and strongly suggest that further IH investigation of lab processes and procedures would be appropriate.

Materials Handling Air monitoring

Figure 14 presents the materials handling arsenic air concentrations and illustrates that air concentrations are in compliance with Namibian OEL but consistently above arsenic ACGIH TLV.

Figure14: Materials handling personal air sample arithmetic means



Source: DPMT, 2017

Table 113: Materials handling area Arsenic Personal Sample Sizes

4Q 11	1Q 12	2Q 12	3Q 12	4Q 12	1Q 13	2Q 13	3Q 13	4Q 13	1Q 14	2Q 14	3Q 14	4Q 14	1Q 15	2Q 15	3Q 15	4Q 15	1Q 16	2Q 16	3Q 16	4Q 16	1Q 17	2Q 17	3Q 17	4Q 17
0	0	2	1	3	4	3	8	15	0	3	3	15	12	7	17	0	15	16	12	7	7	21	11	3

Source: DPMT, 2017

Sample sizes are extremely variable but more robust since 4Q14 to 2Q16. Further IH investigation of material handling processes and procedures would be appropriate.

Service Providers Air monitoring

Figure 15 presents the service providers arsenic air concentrations and illustrates that air concentrations are in compliance with Namibian OEL but generally above the arsenic ACGIH TLV. However, service providers are all contract employees, and industrial hygiene monitoring is not done routinely on them.

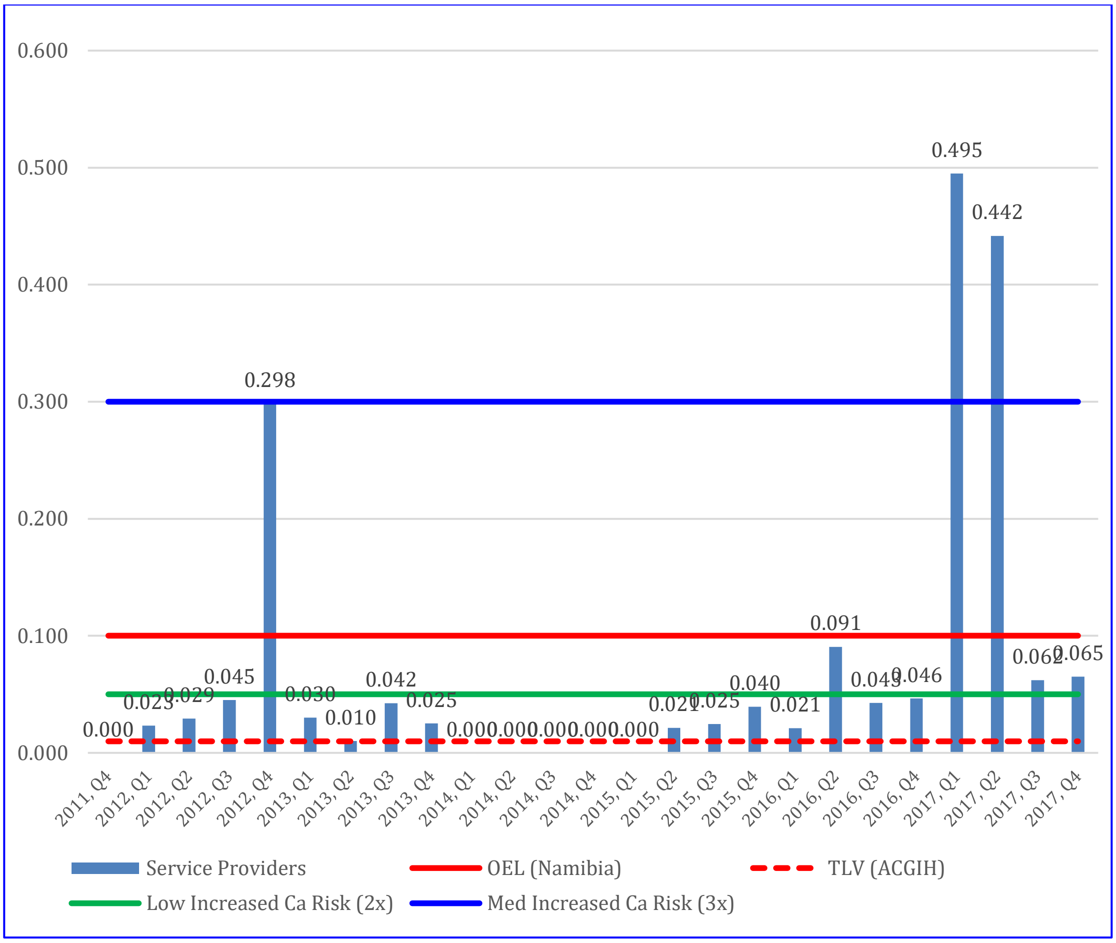
Table 12: Service Providers Arsenic Personal Sample Sizes

4Q 11	1Q 12	2Q 12	3Q 12	4Q 12	1Q 13	2Q 13	3Q 13	4Q 13	1Q 14	2Q 14	3Q 14	4Q 14	1Q 15	2Q 15	3Q 15	4Q 15	1Q 16	2Q 16	3Q 16	4Q 16	1Q 17	2Q 17	3Q 17	4Q 17
0	4	1	5	5	3	1	13	16	0	0	0	0	0	7	3	16	26	29	34	14	35	31	56	65

Source: DPMT, 2017

The sample sizes on this study group are generally small, and extremely variable.

Figure 15: Service providers personal air sample arithmetic means



Source: DPMT, 2017

Summary of Industrial Hygiene data

Overall, the IH personal sampling arsenic data indicate that workplace concentrations are generally elevated above Namibian OELs and substantially elevated above either the most common EU OELs or the ACGIH TLV. In general, the IH air data indicates a slow longitudinal improvement for some work areas, however, sample sizes are extremely variable quarter to quarter; therefore, these data should not be over interpreted.

As previously noted, an elevated air concentration does not immediately translate into a significant worker exposure concentration or dose. The role of PPE/respiratory protection is critical as it can, and should, ameliorate the ‘true” exposure concentration experienced by workers. An objective “test” of the success or failure of the IH efforts is the analysis of the arsenic biomonitoring data.

Arsenic biomonitoring data

DPMT has an extensive arsenic biomonitoring programme that includes longitudinal surveillance data from 2005 to 2017. This analysis focuses on the 2011-2017 datasets as this time period covers DPM ownership and management, including reliable laboratory data. In general, there are extremely large sample sizes covering the critical business units.

Key statistical parameters are shown in Table 13 below, including arithmetic and geometric means, the median, and the 75^{th} and 95^{th} percentile values.

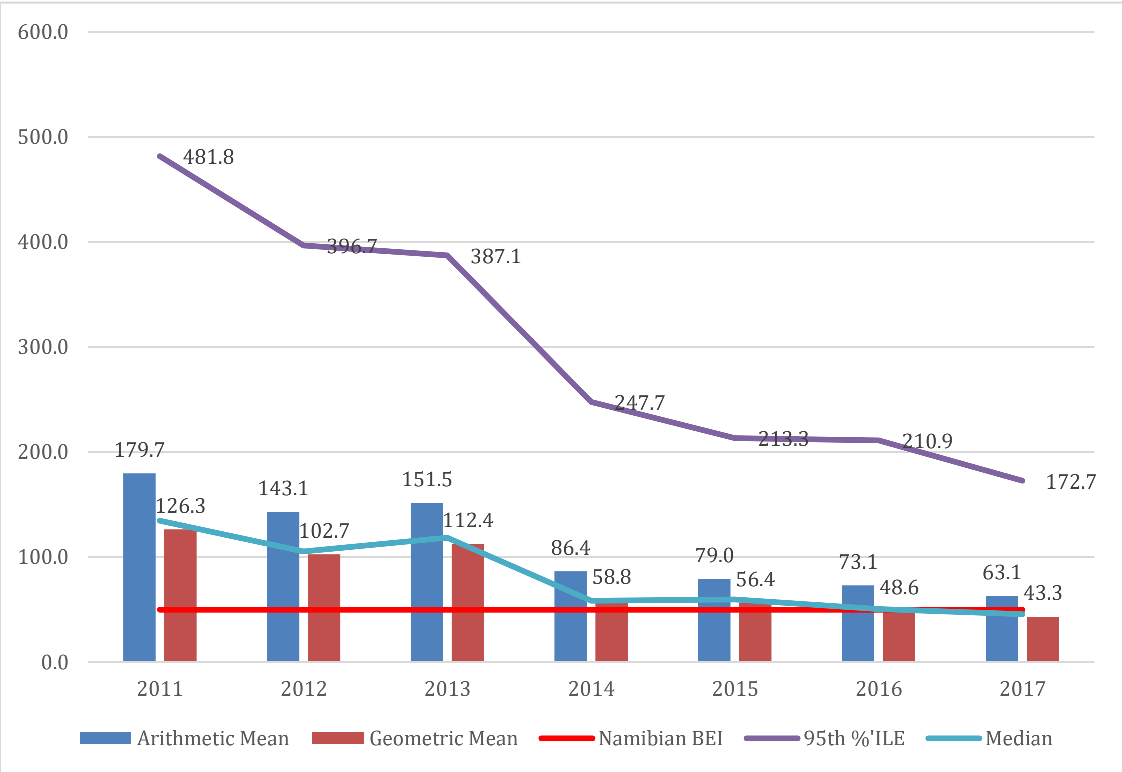
Table 13 presents the overall yearly biomonitoring sample sizes covering all the DPMT business units.

Total Smelter biomonitoring

Table 13: Arsenic Biomonitoring Data 2011-2017: Total plant

TOTAL SMELTER	2011	2012	2013	2014	2015	2016	2017
No. of samples	2988	1846	2115	3488	2515	2475	4788
Arithmetic Mean	179.7	143.1	151.5	86.4	79.0	73.1	63.1
Geometric Mean	126.3	102.7	112.4	58.8	56.4	48.6	43.3
95th %'ILE	481.8	396.7	387.1	247.7	213.3	210.9	172.7
75th %'ILE	225.8	174.7	191.9	104.4	100.9	91.2	82.6
Median	134.6	105.5	118.4	58.5	59.6	50.4	45.5

Figure 16: Total smelter biomonitoring Total arsenic in urine means



Source: DPMT, 2017

A highly significant trend with an average decline of 20 per year (p= 0.0016) is evident between 2011 – 2017. This was accompanied by a similar trend in the 95th percentile values over this period.

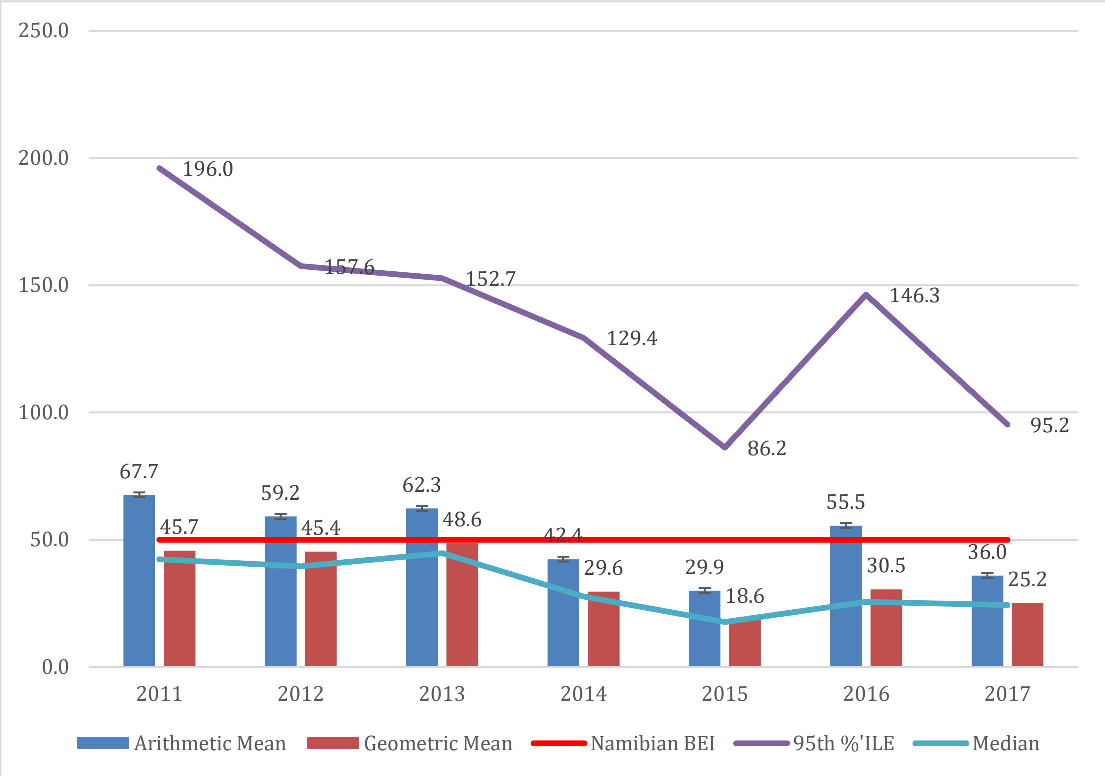
Overall, the most significant change took place during 2014, during which a plant-wide concerted drive for improved safety behaviour was led by the Safety Manager, along with improved engineering controls consequent to the capital development.

Admin employees biomonitoring

Table 14: Arsenic Biomonitoring Data 2011-2017: Admin employees

Admin	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
No. of samples	237	120	150	293	156	255	512
Arithmetic Mean	67.7	59.2	62.3	42.4	29.9	55.5	36.0
Geometric Mean	45.7	45.4	48.6	29.6	18.6	30.5	25.2
95th %'ILE	196.0	157.6	152.7	129.4	86.2	146.3	95.2
75th %'ILE	80.7	68.2	73.0	46.0	29.6	63.8	47.2
Median	42.3	39.5	44.7	27.7	17.6	25.6	24.3

Figure17: Admin Employees biomonitoring total arsenic in urine means



Source: DPMT, 2017

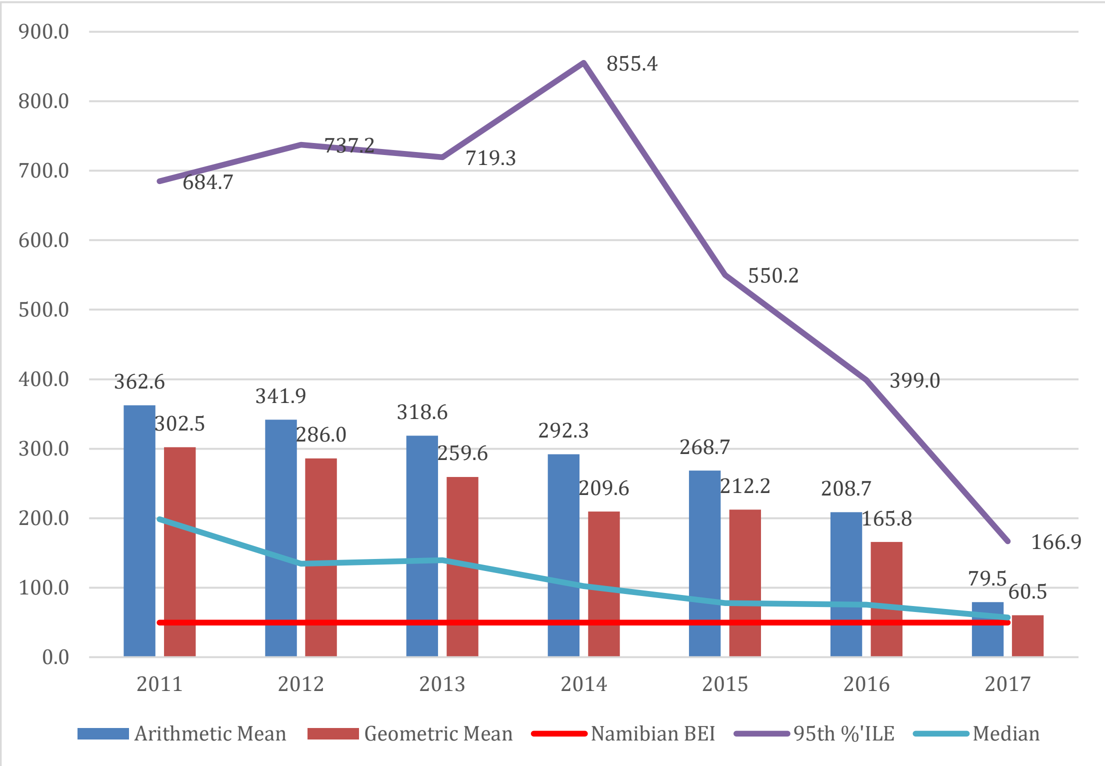
As illustrated in Figure 17, the admin employees' urine biomonitoring data has a borderline significant ($p < 0.07$) downward trend with an annual average decline of 4.8 from 2011 to 2017. This is due to an unexplained spike in 2016 which by 2017 is still higher than in 2015. While the means in 2014, 2015 and 2017 were below the Namibian standard of 50 µg/g creatinine, the 95th percentiles are still consistently elevated above either international or Namibian standards, as a number of these employees are required to enter into the operational area of the plant from time to time. Stratification into Similar Exposure Groups ("SEG's") has been done by the OH team. It may be of value to conduct arsenic speciation on these lesser exposed employees with unexplained elevations of total arsenic, to exclude dietary contributions.

Arsenic Plant employees biomonitoring

Table 15: Arsenic Plant Biomonitoring Data 2011-2017: Arsenic plant employees

Arsenic Plant	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
No. of samples	106	63	48	49	38	59	38
Arithmetic Mean	362.6	341.9	318.6	292.3	268.7	208.7	79.5
Geometric Mean	302.5	286.0	259.6	209.6	212.2	165.8	60.5
95th %'ILE	684.7	737.2	719.3	855.4	550.2	399.0	166.9
75th %'ILE	471.1	455.6	402.2	327.8	373.1	283.1	107.2
Median	351.9	285.2	259.1	206.8	257.4	197.1	69.5

Figure 18: Arsenic Plant employees biomonitoring total arsenic in urine means



Source: DPMT, 2017

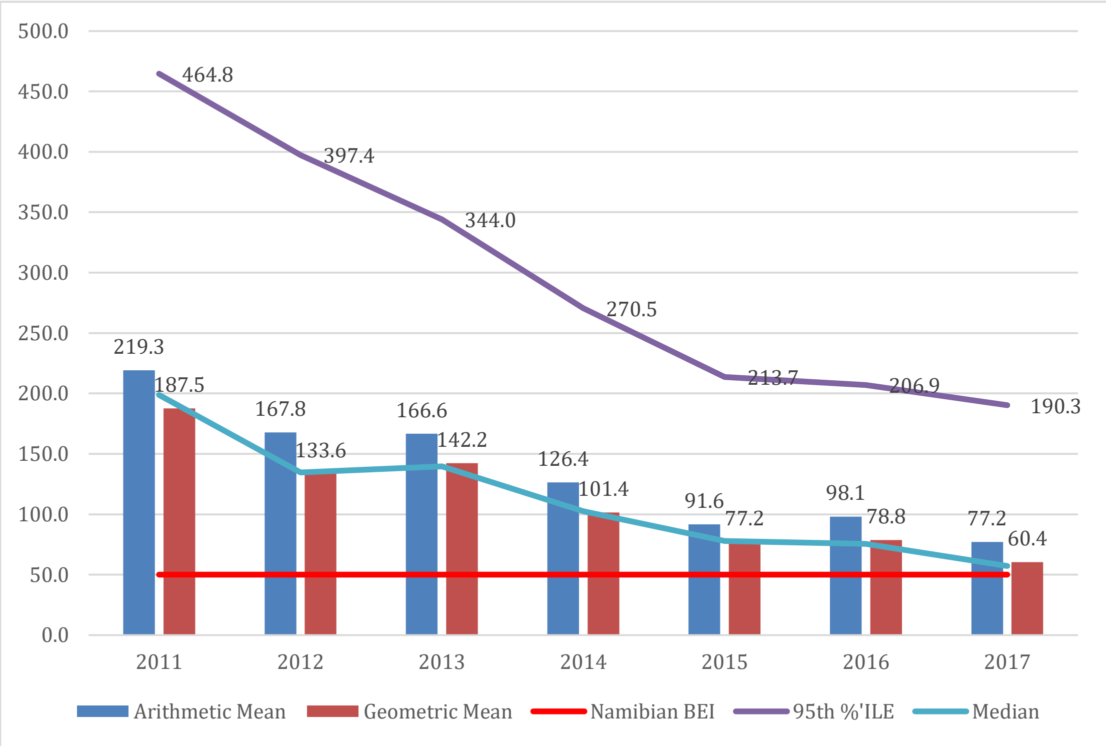
As illustrated in Figure 18, the arsenic plant urine biomonitoring data are generally far higher (2 – 3 X) than the levels for the rest of the plant. The means show a significant ($p < 0.003$) decline between the years 2011 – 2017 with an annual average decline of 42. The step change in 2017 is the consequence of closure of the arsenic plant; these data are from employees involved in closing down the plant.

Ausmelt employees biomonitoring

Table 16: Arsenic Biomonitoring Data 2011-2017: Ausmelt employees

Ausmelt	2011	2012	2013	2014	2015	2016	2017
No. of samples	249	137	130	129	69	134	192
Arithmetic Mean	219.3	167.8	166.6	126.4	91.6	98.1	77.2
Geometric Mean	187.5	133.6	142.2	101.4	77.2	78.8	60.4
95th %'ILE	464.8	397.4	344.0	270.5	213.7	206.9	190.3
75th %'ILE	277.5	196.9	209.1	145.8	113.1	118.3	97.2
Median	198.7	134.7	139.8	102.6	77.9	75.6	57.2

Figure 19: Ausmelt Employees Biomonitoring Total arsenic in urine means



Source: DPMT, 2017

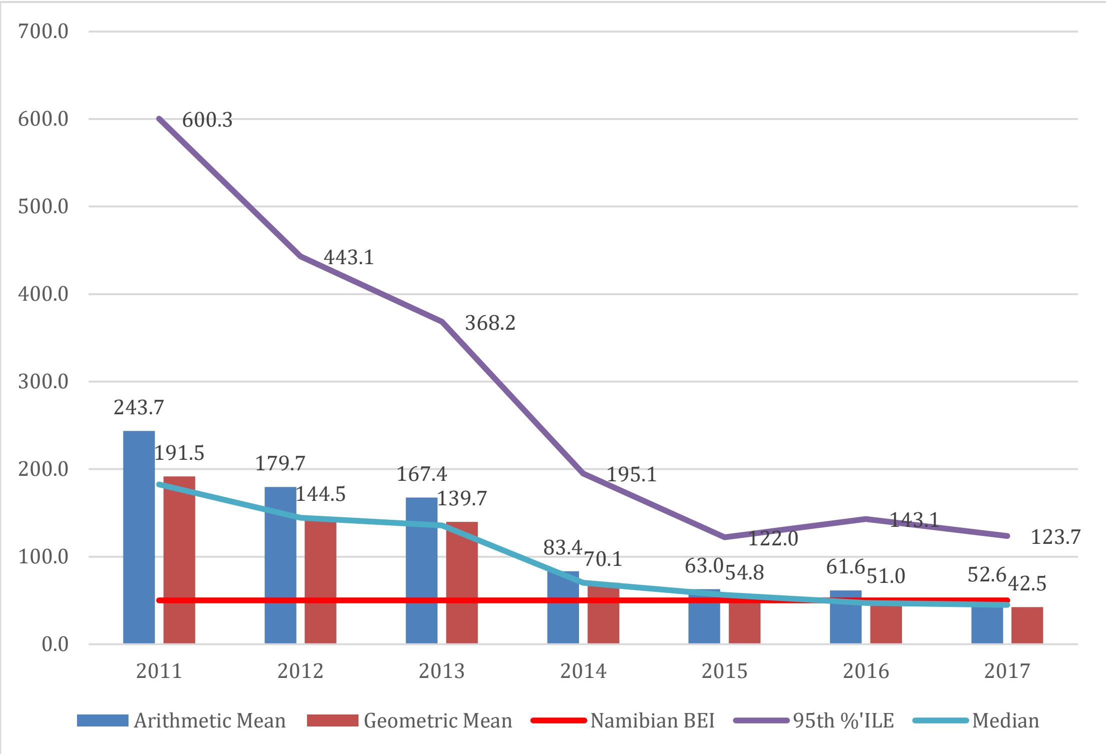
As illustrated in Figure 19, the Ausmelt employees' urine biomonitoring data shows a significant overall decline (p=0.0005) with an annual average decline of 23 between 2011 to 2017, with a slowing of the rate of decline since 2015. The 95th percentiles show a similar pattern of decline.

Copper Smelter employees biomonitoring

Table 4:Arsenic Biomonitoring Data 2011-2017: Copper smelter employees (converter)

Copper Smelter	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
No. of samples	418	213	217	154	69	120	251
Arithmetic Mean	243.7	179.7	167.4	83.4	63.0	61.6	52.6
Geometric Mean	191.5	144.5	139.7	70.1	54.8	51.0	42.5
95th %'ILE	600.3	443.1	368.2	195.1	122.0	143.1	123.7
75th %'ILE	282.5	205.7	215.5	102.6	75.4	73.2	69.8
Median	182.7	144.6	135.6	70.3	56.2	47.1	45.1

Figure 20: Copper smelter employees biomonitoring total arsenic in urine means



Source: DPMT, 2017

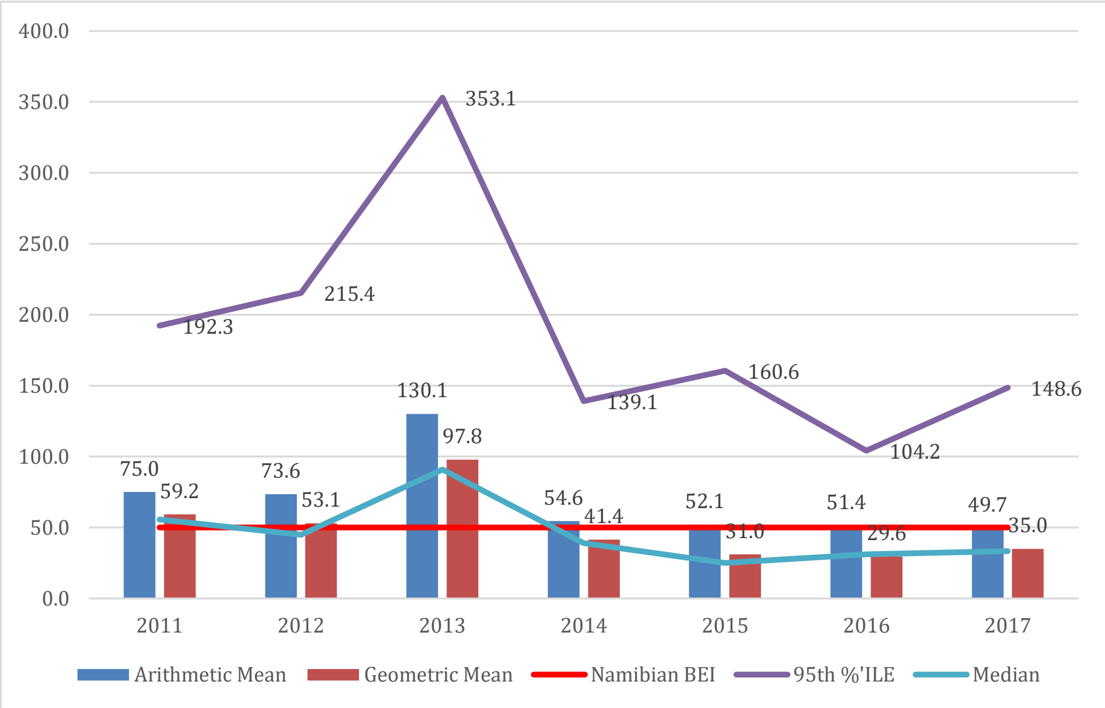
As illustrated in Figure 20, the Copper Smelter employees' urine biomonitoring data shows a significant (=0.0015) decline with an annual average of 33 between 2011 and 2017. The decline has tailed off since 2015.

Laboratory & Technical employees biomonitoring

Table 18: Arsenic Biomonitoring Data 2011-2017: Laboratory & Technical employees

Lab & Technical	2011	2012	2013	2014	2015	2016	2017
No. of samples	85	45	35	47	33	57	148
Arithmetic Mean	75.0	73.6	130.1	54.6	52.1	51.4	49.7
Geometric Mean	59.2	53.1	97.8	41.4	31.0	29.6	35.0
95th %'ILE	192.3	215.4	353.1	139.1	160.6	104.2	148.6
75th %'ILE	85.7	70.8	167.2	78.7	69.6	48.0	61.7
Median	55.8	44.8	90.8	39.1	25.1	31.1	33.4

Figure 21: Laboratory and technical employees biomonitoring total arsenic in urine means



Source: DPMT, 2017

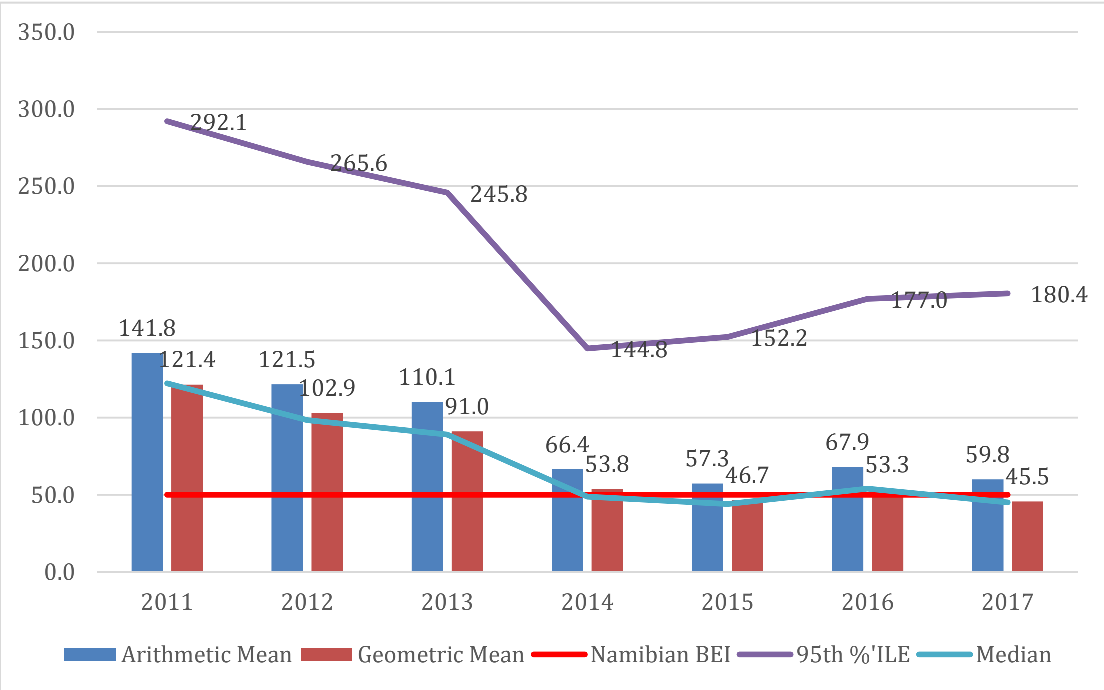
As illustrated in Figure 21, the Laboratory & Technical employees' urine biomonitoring data shows a non-significant slight decline with an annual average drop of 7 between 2011 to 2017, with a spike in 2013, related to three lab employees who had spikes into the 300's and 400's, twice during the year. No explanation was found, and these cases returned to previous levels in subsequent test cycles.

Materials Handling employees biomonitoring

Table 19: Arsenic Biomonitoring Data 2011-2017: Materials Handling employees

Materials Handling	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
No. of samples	236	127	118	116	42	70	178
Arithmetic Mean	141.8	121.5	110.1	66.4	57.3	67.9	59.8
Geometric Mean	121.4	102.9	91.0	53.8	46.7	53.3	45.5
95th %'ILE	292.1	265.6	245.8	144.8	152.2	177.0	180.4
75th %'ILE	172.0	143.8	150.0	75.0	62.6	76.3	77.3
Median	122.2	98.2	89.0	48.8	43.9	53.9	44.9

Figure 22: Materials handling employees biomonitoring total arsenic in urine means



Source: DPMT, 2017

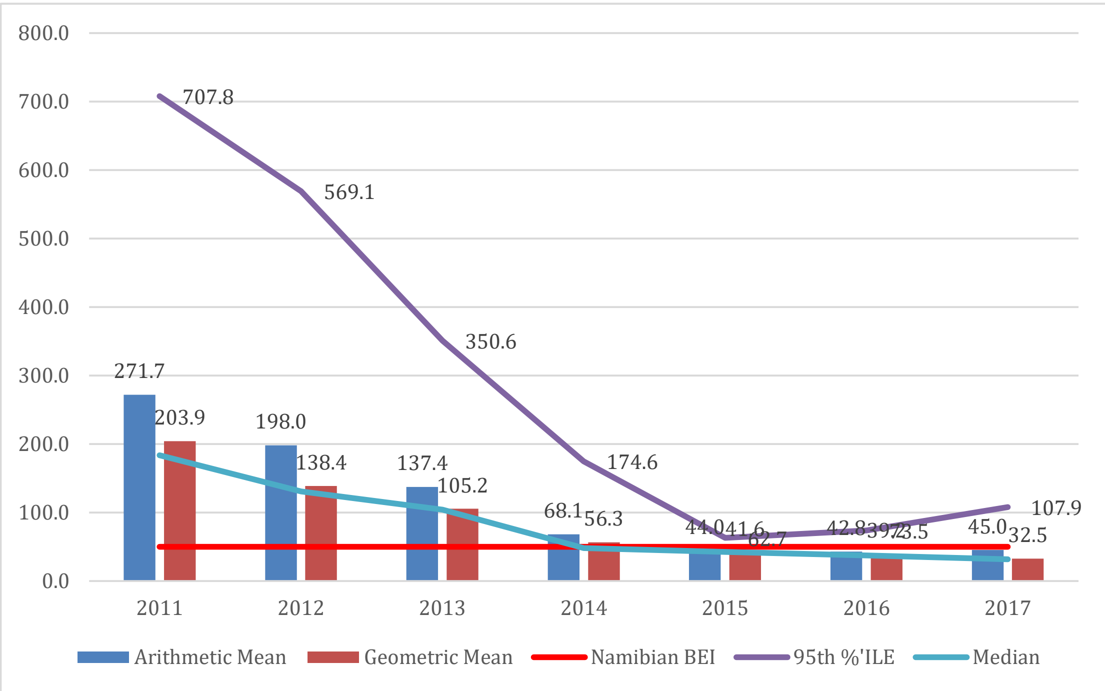
As illustrated in Figure 22, the Materials Handling employees' urine biomonitoring data shows a significant decline ($p<0.05$) with an average annual decrease of 15 between 2011 and 2017. However, a disconcerting pattern is observable in that the decline only took place before 2014 after which urine arsenic levels have increased for each year since then. The 95th percentiles have similarly been rising steadily. This is a red flag and might be the result of increased production volume or some change in production process, and further investigation is warranted.

Power Plant employees biomonitoring

Table 20: Arsenic Biomonitoring Data 2011-2016: Power Plant employees

Power Plant	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
No. of samples	30	11	14	12	8	17	38
Arithmetic Mean	271.7	198.0	137.4	68.1	44.0	42.8	45.0
Geometric Mean	203.9	138.4	105.2	56.3	41.6	39.2	32.5
95th %'ILE	707.8	569.1	350.6	174.6	62.7	73.5	107.9
75th %'ILE	306.3	180.7	169.2	67.2	55.0	53.3	49.8
Median	183.3	130.7	104.2	48.1	42.5	37.3	31.5

Figure 23: Power Plant Employees – Biomonitoring – Total arsenic in urine means



Source: DPMT, 2017

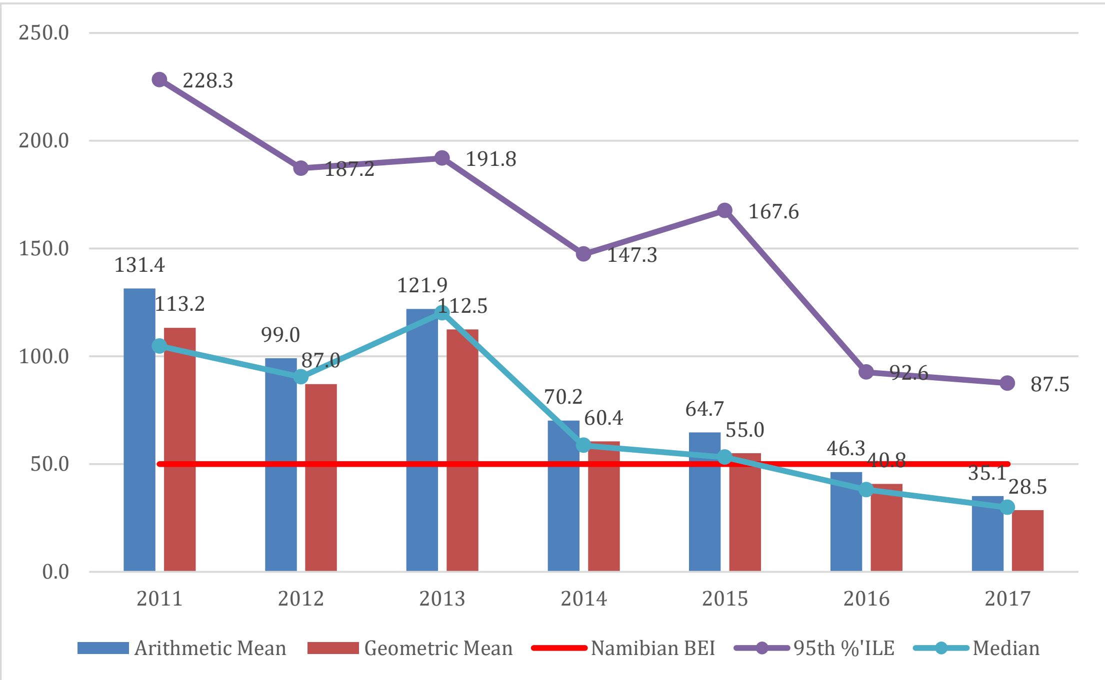
As illustrated in Figure 23, the Power Plant employees' urine biomonitoring data shows a significant ($p < 0.005$) decline from 2011 to 2017 with annual average drop of 39. The 95th percentiles, however, have started to increase again since 2015 which indicates the need for further investigation.

Slag Mill employees biomonitoring

Table 21: Arsenic Biomonitoring Data 2011-2017: Slag Mill employees

Slag mill	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
No. of samples	74	42	45	48	24	43	104
Arithmetic Mean	131.4	99.0	121.9	70.2	64.7	46.3	35.1
Geometric Mean	113.2	87.0	112.5	60.4	55.0	40.8	28.5
95th %'ILE	228.3	187.2	191.8	147.3	167.6	92.6	87.5
75th %'ILE	186.7	129.8	144.1	78.5	68.7	60.1	42.0
Median	104.7	90.4	120.1	58.6	53.2	38.1	29.9

Figure 24: Slag Mill Employees – Biomonitoring – Total arsenic in urine means



Source: DPMT, 2017

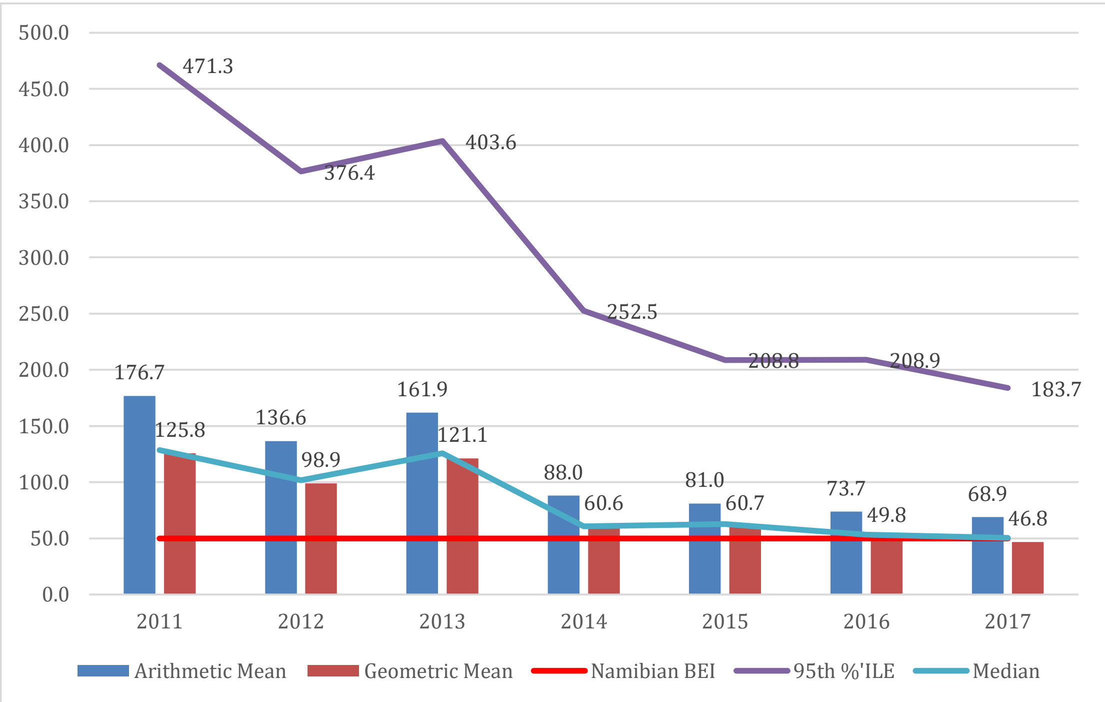
As illustrated in Figure 24, the Slag Mill employees' urine biomonitoring data shows a significant ($p < 0.005$) decline from 2011 to 2017, with an average annual decline of 16.

Service Provider employees biomonitoring

Table 22: Arsenic Biomonitoring Data 2011-2017: Service Providers (engineering related tasks)

Service Providers	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
No. of samples	1419	911	1119	2593	2027	1586	2708
Arithmetic Mean	176.7	136.6	161.9	88.0	81.0	73.7	68.9
Geometric Mean	125.8	98.9	121.1	60.6	60.7	49.8	46.8
95th %'ILE	471.3	376.4	403.6	252.5	208.8	208.9	183.7
75th %'ILE	225.6	168.7	201.6	106.8	105.4	94.4	90.0
Median	128.6	101.9	125.6	60.7	62.8	53.2	50.5

Figure 25: Service Provider Employees – Biomonitoring – Total arsenic in urine means



Source: DPMT, 2017

As illustrated in Figure 25, the Service Providers' employees' urine biomonitoring data shows a significant ($p < 0.005$) decline from 2011 to 2017, with an average annual decline of 18.

It is notable that overall, and with respect to most business units, there was significant and sustained reduction of urine arsenic arithmetic means throughout the period 2011 to 2017. Notable exceptions were the laboratory and technical, and administrative business units. A red flag was raised for materials handling where levels have worsened since 2014. The arithmetic mean patterns were echoed in the main by the 95th percentiles which are, however, still substantially above both the Namibian and international BEI limits indicating that there is still some way to go to achieve compliance with safe exposure levels. The slowing rate of decline of urine arsenic levels in most business units illustrates the increasing difficulty in bringing exposures down. For administration and laboratory workers who have not shown significant reductions in urine arsenic levels, this may be due to complacency, while increasing urine arsenic levels for materials handling workers may be due to increased production volumes.

There has been a recent reorganisation of the business units which made the incorporation of 2017 data an onerous task for purposes of this analysis. It is important that going forward the new business units are sufficiently differentiated to continue to be able to focus on identifying areas of high exposure risk in the smelter as a whole. There is a suggestion from 2018 data that this trend is continuing overall and for most business units with few exceptions.

The effectiveness of PPE

As previously discussed, the biomonitoring data indicates that the PPE/respiratory protection programme is having a positive impact; however, the critical question is whether the impact is sufficient. To further analyse the impact of the PPE programme, this section will consider the relationship between arsenic in urine and arsenic in air. ACGIH (2001) has previously described the urine:air relationship and published a number of predictive equations based on published data from previously operating arsenic plants. Based on these field studies, ACGIH described a variety of predictive equations. As a simple screening exercise, this report will use the ACGIH published equation:

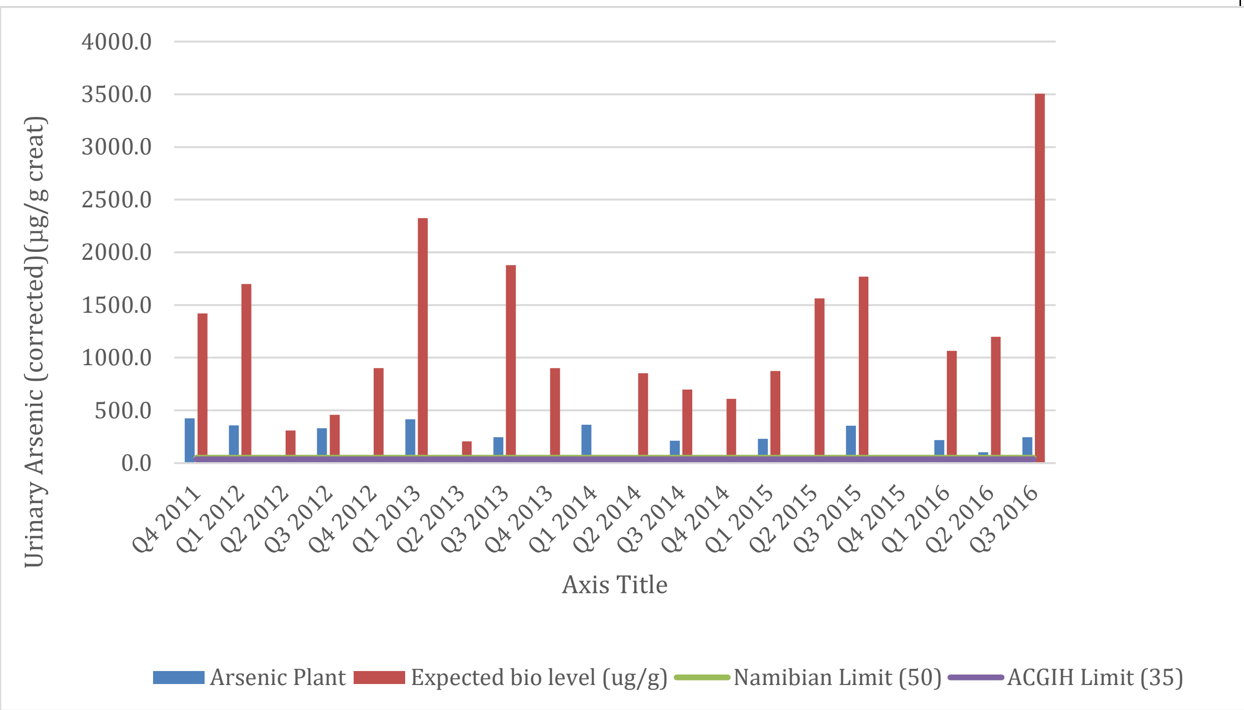
Equation 1: Arsenic in urine (ug/L) = 3.3 arsenic in air (ug/m3).

The relationship between expected urinary arsenic and actual urinary arsenic, in the context of the DPMT smelter, has been studied in a recent report[78] by the European Bank for Reconstruction and Development (EBRD).

For the purposes of this report, only the Arsenic Plant and Ausmelt analysis will be shown, by way of illustration of the key findings of the EBRD report.

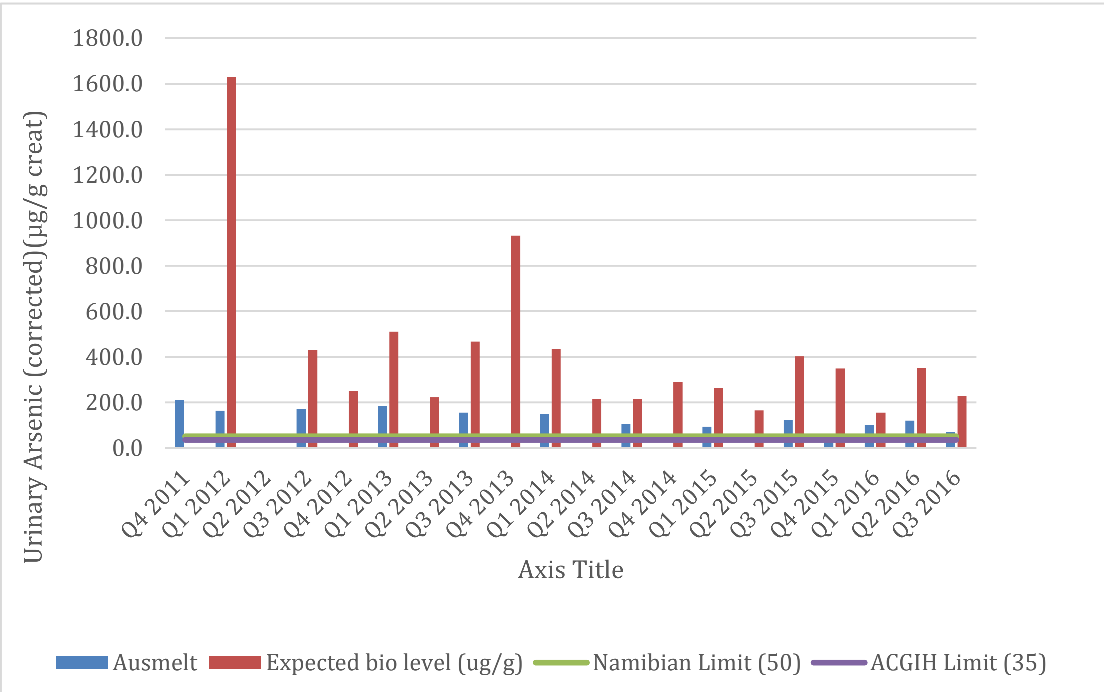
[78] Report No 70024547; Dundee Precious Metals Tsumeb Smelter Environmental & Social Due Diligence. September 2016

Figure 1: Expected versus Actual Urine Arsenic- Arsenic Plant



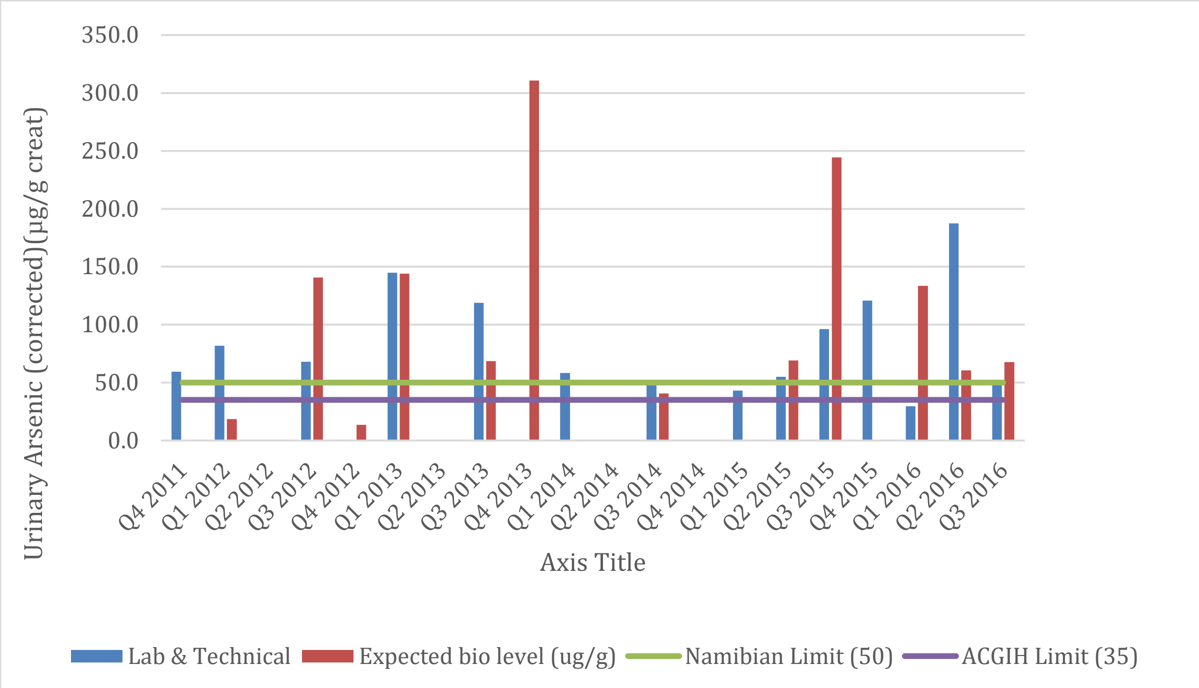
Source: DPMT, 2016.

Figure 2: Expected versus Actual Urine Arsenic- Ausmelt



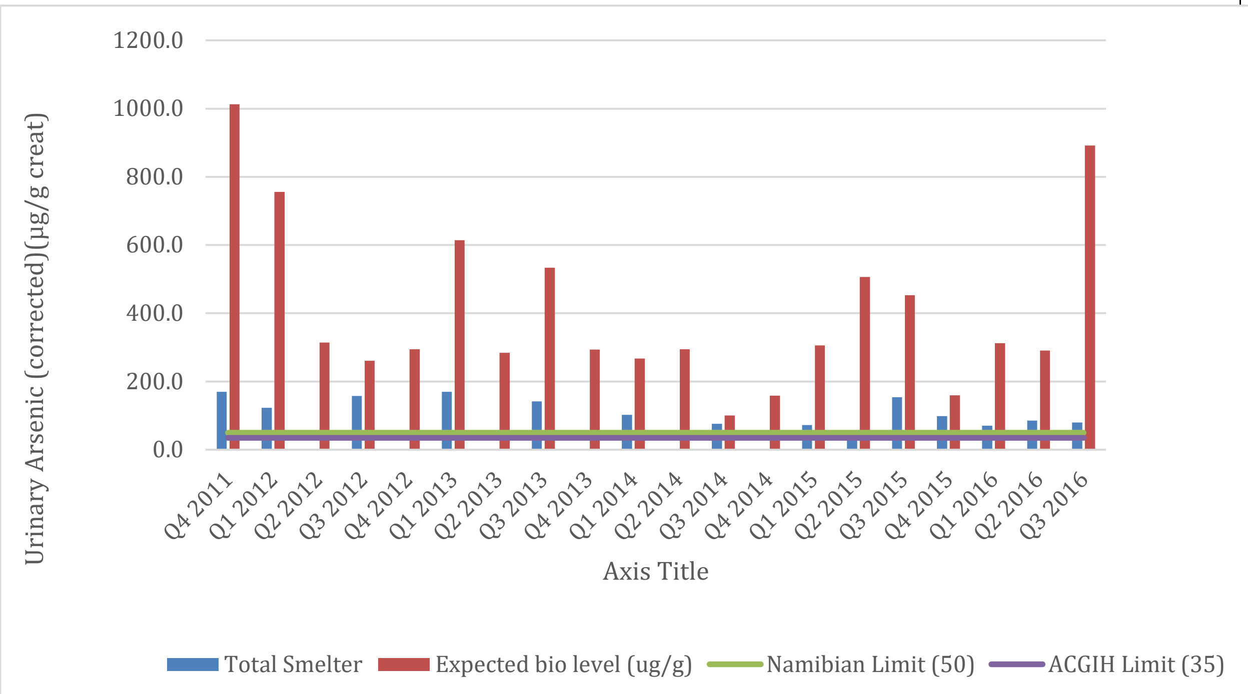
Source: DPMT, 2016

Figure 28: Expected versus Actual Urine Arsenic- Lab & Technical



Source: DPMT data, 2016

Figure 29: Expected versus Actual Urine Arsenic – Total Smelter



Source: DPMT, 2016

In order to be consistent with the previous analysis of the DPM urine arsenic data, all urine comparisons made were using corrected mean values.

Based on the observed quarterly air concentration (from personal samples) an "expected" urine arsenic (creatinine corrected) value was calculated and compared to the actual measured mean creatinine corrected arsenic biomonitoring data from the same time period. The "difference" between the observed (measured) and the "calculated" urine arsenic value provides a general indication of the impact/efficiency of PPE.

A P3 reusable full face respirator should, conservatively, have an APF of 30-40. In addition to a full face respirator, workers in the arsenic plant also use Tyvek suits and gloves. Hence, if "perfectly used" by workers, the PPE should provide at least a 30-40 fold lowering of actual exposure, such that urine arsenic concentrations would be expected to be below Namibian and German 50 ug/L (uncorrected) standards and likely well below ACGIH 35 ug/L recommendations.

As shown in the preceding figures, this level of performance is not achieved; instead, the performance of the PPE is in the order of 3-7, rather than 30-40.

There is likely a multi-factorial explanation for why the PPE is not achieving full protection:

- Full face respirators and Tyvek suits are cumbersome and extremely hot in a work setting/environment that is already extremely hot; hence, full worker compliance is less likely. In fact, during the site visit to the arsenic plant, the EBRD team observed numerous workers not fully complying with PPE requirements.
- Arsenic particulates are probably less than 2.5 µm in size which would facilitate pulmonary absorption.
- Respirator fit may be suboptimal, i.e. air leakage is a real potential, especially under working conditions.
- Post-work personal hygiene, i.e. uniform change out and showering may not be fully eliminating inadvertent exposures.
- The general administrative urine arsenic biomonitoring data is greater than the ACGIH BEI of 35 µg/L but slightly less than the Namibia standard of 50 µg/L indicating that working at DPMT, in any capacity, generates a non-trivial level of arsenic exposure.

Summary of arsenic biomonitoring programme

In general, the arsenic biomonitoring programme at DPMT is substantial.

While urine arsenics have declined significantly and in some business units substantially, in most areas means and particularly outliers still exceed the Namibian BEI and are well above the ACGIH BEI.

The biomonitoring data generally demonstrate that the overall PPE programme is not working optimally.

The main conclusions regarding occupational risk from arsenic are as follows:

- While there has been longitudinal improvement in exposures since 2011, the general level of improvement, with a few exceptions (Power Plant), is not sufficient to meet either (i) international or Namibian standards for arsenic workplace exposures. However, many units are now close to these exposure limits.
- Significant ongoing overexposures to arsenic are occurring in some business units (Arsenic Plant [now decommissioned] and Ausmelt).
- The general strategy of utilizing PPE/respiratory protection as a substitute for engineering control is a failure. The urine arsenic biomonitoring data unequivocally demonstrates that PPE is not providing a sufficient level of worker protection.
    - This failure is not due to the inherent inadequacy of PPE but rather due to the underestimation by DPMT of the difficulty of fully executing a PPE/respiratory protection programme in a complex environment/workplace setting like Tsumeb.
    - PPE/respiratory protection is NOT a substitute for engineering control and management.
- The industrial hygiene programme has remained seriously undercapacitated and the complexity of the Tsumeb smelter makes this a daunting task.
    - The plant is quite old and encumbered, in many locations (e.g. arsenic plant), by antiquated technology and equipment that generates significant exposures.
    - Relative to the magnitude and complexity of the exposure problem, the IH staff is under resourced.
- The current IH strategy needs a complete overhaul, i.e. a primary focus on rigorous, systematic sampling utilizing both personal and area monitoring strategies.
    - Relative to the biomonitoring programme, the IH sampling is inadequate in size and scale.
    - The IH sampling must be better coordinated with the medical programme. Biomonitoring cannot tell how or why a worker is exposed,

only an IH programme can objectively document what, where and how exposures are occurring.

- In general, the balance between IH and medical is overly dependent upon medical at the expense of IH. This is not standard industrial practice, i.e. IH must lead and medical follows.

- The current exposure situation at the plant is incrementally and consistently generating and accumulating future risks and liabilities that are significant and far in excess of what would be tolerated in European and North American jurisdictions.
  - There is a potential burden of future adverse medical outcomes, i.e. lung cancer, that should neither be minimized nor ignored.
  - Arsenic OELs are based on human exposure data at historic smelters.
  - Whether work-related lung cancer cases have occurred is unknown and probably unknowable due to limitations in the Namibian medical surveillance system.
  - Future worker claims for arsenic-related disease is a significant risk.

SUMMARY OF OCCUPATIONAL HEALTH IMPACT ASSESSMENT

Table 23 : Criteria for Assessing Impacts

Note: Both the criteria used to assess the impacts and the methods of determining the significance of the impacts are outlined in the following table. Part A provides the definition for determining impact consequence (combining severity, spatial scale and duration) and impact significance (the overall rating of the impact). Impact consequence and significance are determined from Part B and C. The interpretation of the impact significance is given in Part D.

PART A: DEFINITION AND CRITERIA*		
Definition of SIGNIFICANCE		**Significance = consequence x probability**
Definition of CONSEQUENCE		**Consequence is a function of severity, spatial extent and duration**
Criteria for ranking of the SEVERITY/NATURE of environmental impacts	**H**	Substantial deterioration (death, illness or injury). Recommended level will often be violated. Vigorous community action. Irreplaceable loss of resources.
	M	Moderate/ measurable deterioration (discomfort). Recommended level will occasionally be violated. Widespread complaints. Noticeable loss of resources.
	L	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.
	L+	Minor improvement. Change not measurable/ will remain in the current range. Recommended level will never be violated. Sporadic complaints.
	M+	Moderate improvement. Will be within or better than the recommended level. No observed reaction.
	H+	Substantial improvement. Will be within or better than the recommended level. Favourable publicity.
Criteria for ranking the DURATION of impacts	**L**	Quickly reversible. Less than the project life. Short term
	M	Reversible over time. Life of the project. Medium term
	H	Permanent. Beyond closure. Long term.
Criteria for ranking the SPATIAL SCALE of impacts	**L**	Localised - Within the site boundary.
	M	Fairly widespread – Beyond the site boundary. Local
	H	Widespread – Far beyond site boundary. Regional/ national

PART B: DETERMINING CONSEQUENCE					
				SEVERITY = L	
DURATION	Long term	**H**	**Medium**	**Medium**	**Medium**
	Medium term	**M**	**Low**	**Low**	**Medium**
	Short term	**L**	**Low**	**Low**	**Medium**
				SEVERITY = M	
DURATION	Long term	**H**	**Medium**	**High**	**High**
	Medium term	**M**	**Medium**	**Medium**	**High**
	Short term	**L**	**Low**	**Medium**	**Medium**
				SEVERITY = 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/ national
				SPATIAL SCALE	

PART C: DETERMINING SIGNIFICANCE					
PROBABILITY (of exposure to impacts)	Definite/ Continuous	**H**	**Medium**	**Medium**	**High**
	Possible/ frequent	**M**	**Medium**	**Medium**	**High**
	Unlikely/ seldom	**L**	**Low**	**Low**	**Medium**
			L	**M**	**H**
				CONSEQUENCE	

PART D: INTERPRETATION OF SIGNIFICANCE	
Significance	**Decision guideline**
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.

Table 24: Employee Health Impact from exposure to arsenic in the smelter

Potential impact of the planned Dundee smelter expansion on the health of the community.	Severity	Duration	Spatial Scale	Consequence	Probability	Significance	Mitigation Measures	Severity	Duration	Spatial Scale	Consequence	Probability	Significance
Risk: Exposure to arsenic and lung cancer risk.							**Objective**						
Severity (of the health impacts) Baseline and increased production risks of lung cancer are similar and substantial.	H						**Reduce the workforce exposure to smelter inorganic arsenic to within acceptable occupational exposure limits.**	H					
Duration (of the impacts) The impacts of arsenic exposure are permanent (cancer).		H					**Actions** Closure of arsenic plant (completed) Better control of fugitive emissions especially at the converters Better control of fugitive emissions from slow cooling of slag Engineering solutions remain a priority for the above and more generally Industrial hygiene programme needs to be considerably strengthened More emphasis on IH led exposure control rather than biomonitoring Improve the PPE programme Less reliance on PPE Continue job rotations but at lower cut-off values of 150 and 125 by end of 2017 Improved safe work practices		H				
Spatial Scale			L							L			
Consequence				H							H**		
Probability (of lung cancer) Baseline risk is raised between 1.5 and 2 X background for smelter as a whole and up to 3 X for the arsenic plant					M		****NOTE THAT THE LOGIC OF THE CRITERIA IN TABLE 50 FORCE THE CONSEQUENCE TO BE HIGH, AND THEREFORE THE PROBABILITY AND SIGNIFICANCE WOULD BE MEDIUM, BUT POST MITIGATION THE PROBABILITY AND THE SIGNIFICANCE WLL ACTUALLY BE LOW**					L**	
Significance						H	**Emergency Situations** Not applicable						L**