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Assessment of Bacteria, Morphological Characteristics, and Elemental Composition of Dust Fallout

Priskila N. Mweendi, Festus S. Shafodino, Zivuku Munyaradzi, Lamech M. Mwapagha*

Department of Biology, Chemistry and Physics, Namibia University of Science and Technology, Windhoek, Namibia
Email: *lmwapa@gmail.com

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Abstract

Dust fallout can have diverse impacts ranging from major health problems to environmental concerns. It can harbour disease-causing microorganisms and toxic heavy metals, and it is therefore critical to establish the microbial and the mineral compositions of the dust fallout in a particular site and elucidate the possible related health implications for humans and the entire environment. In this study, dust fallout samples were collected from Arandis, a town in the Erongo region (Namibia), using the American Society for Testing and Materials standard method (ASTM D1739) for collection and analysis of dust fallout (settleable particulate matter). The identification of present viable bacteria was done through culturing and isolation techniques and the morphological characteristics, and the elemental composition of the dust fallout were determined using the Stereomicroscope and the X-ray fluorescence, respectively. The results showed that the most dominant bacteria contained in the fallout dust were the *Bacillus* species. The morphological characterisation revealed that the present particles were mixed black, brownish, greenish, and crystal particles with irregular, cubical, flocks and flake shapes. The elemental investigations indicated that the dust fallout contained Hg, As, Fe, Ni, Cr, Mn, Al and Pb occurring in varying concentrations and the status of pollution of the dust fallout ranged from low to severe concerning the inconsistent heavy metal indices that are the contamination factor, pollution load index and the enrichment factor.

Keywords

Dust fallout, Arandis, Microbial Composition, Heavy Metals, and Pollution Indices

1. Introduction

Air pollution is rated among the major global concerns especially in urban centres. Urban dust samples are normally associated with more negative health impacts than those collected from rural areas, and this is attributed to the high rate of development and massive traffic. Substances present in the air include but not limited to particulate matter (i.e., dust, liquid droplets, and smoke), gaseous pollutants (i.e., nitrogen oxides, volatile organic compounds, oxone, ammonia, and carbon monoxide), heavy metals and culturable bacteria which all lead to the depreciation of the air quality, and they are an indication of the air quality state with respect to a particular site (Canha et al., 2021; Durant et al., 2009; Kgabi et al., 2012).

Particulate matter refers to a mixture of atmospheric solid and liquid particles that vary in number, morphology (size, shape, and surface features), chemical composition, density, solubility, and origin. Particulate matter also represents suspended dust that is settleable or can be deposited at a particular site in the atmosphere and referred to then as dust fallout (Dudu et al., 2018; Liebenberg-Enslin et al., 2020; Pope & Dockery, 2006). Dust fallout or dust in general is constantly emitted into the ambient air from a variety of activities and sources that can be natural or anthropogenic. Natural sources include but not limited to dust episodes due to wind, veld fire, atmospheric-based photochemical reactions, and volcanoes. On the other hand, the anthropogenic sources involve traffic emissions (i.e., cars, trains, and aircrafts), burning of wood and coal for power generation, and industrial processes (i.e., smelters and waste incineration) among others that are known to be prevalent in urban dust samples and their environments (Addo et al., 2012; Canha et al., 2021; Mugudamani et al., 2022; Sebaiwa, 2016).

Dust can be a nuisance as it can settle on tree leaves, open surfaces such as roads and streets, on roof tops of buildings, and even inside buildings. A wide variety of pollutants and/or microbial diversity has been associated with dust and/or dust fallout particles (Al-Barakah et al., 2014; Gonzalez-Martin et al., 2014). Chemical pollutants that are of concern that can be absorbed or incorporated into dust of a given location (with respect to their origin) include a variety of trace metals (i.e., arsenic, chromium, nickel, lead, copper, cadmium, and mercury) (Kgabi, 2010; Kgabi et al., 2012; Lanzerstorfer, 2021; Popoola et al., 2012), radionuclides mostly linked to mining sites and its associated processes (i.e., radium and thorium) (Dudu et al., 2018) as well as other contaminants. Previous studies have shown that dust and/or dust fallout particles have been correlated with viable microorganisms or cells (i.e., non-pathogenic, and pathogenic bacteria, viruses, and fungi) which can emanate from humans and plants in addition to other sources such as pets (Babu et al., 2017; Chen et al., 2023; Malli Mohan et al., 2019). Furthermore, the concentrations of bacteria are reported to range from 10^3 to -10^9 microorganisms per gram of soil. Some of the microorganisms present in dust can be transported for long distances away from their sources. The problem is further compounded when these microorganisms are in the aerosol form and viable. Some bacteria can even remain in the latent stage or form spores until ideal conditions are favourable for their development, whereas others can be in the dominancy stage, which allows them to be resistant to UV light and ensures continuity of life (Gonzalez-Martin et al., 2014).

The problems associated with dust fallout in local communities have been ignored or neglected, leading to a poor underestimation of the dust concentrations, morphological characterisation, and its impact on human health. Particulate bound toxic metals can be carcinogenic and are likely to be persistent or accumulate in the environment as well as endanger other living species (Addo et al., 2012; Popoola et al., 2012). Dust as a particulate matter has also been linked with health complications such as respiratory diseases (i.e., tuberculosis) (Canha et al., 2021), scar lungs and tissues, renal failure, high blood pressure, impairment of visual and hearing abilities due to compromised environmental air quality, and has subsequently increased premature death in communities where it is prominent (Mugudamani et al., 2022). Dust particles along with their constituents (i.e., heavy metals among others) enter the human body through inhalation or ingestion (Kgabi, 2010; Nyashanu et al., 2023) and are carried through the respiratory system's alveolar linings, where they have a negative impact such as respiratory complications. The most lethal particles present in dust are the fine particles (i.e., particulate matter with an aerodynamic diameter less than 2.5 µm ($PM_{2.5}$)) which can easily pass through the alveolar linings and be transported to other organs via the blood stream (Pope & Dockery, 2006). According to Al-Awadhi et al. (2014), fallout dust particles size maybe attributed to land activities and land degradation within a specific area.

Some regions of Namibia such as the Erongo region are semi-arid. The region is characterised by lack of ambient air quality or ambient monitoring data and its towns are prone to dust episodes due to strong easterly winds (Liebenberg-Enslin et al., 2020) and, these have an impact on human health and the environment. Therefore, the main objective of this study was to evaluate the chemical and morphological composition including assessment of bacteria in dust fallout in Arandis town. Previous studies conducted in Namibia have focused on the toxic chemical and morphological characterisation of dust from roads and urban streets (Kgabi et al., 2012; Liebenberg-Enslin et al., 2017; Liebenberg-Enslin et al., 2020). However, most of these researchers did not address the presence of pathogenic bacteria in dust fallout. This study provides complementary data that can be used to establish a baseline for the composition of dust fallout in Arandis. Furthermore, the findings of this study can be used in health risk assessment, such as assessing population exposure to dust fallout (Dudu et al., 2018).

2. Material and Methods

2.1. Study Area

Arandis is a town that is located in the Erongo region of Namibia which was established in 1994 and it lies between 22˚25'0" South and 14˚58'0" East. It is located less than 10 km away from the largest open pit of Rössing Uranium Mine's main entrance gate and hence, it is also known as the Uranium capital of the world. Arandis has a population of about 8000 residents and this number may fluctuate depending on the opening and closing of the vocational training centres that are situated in the town (RUL, 2021). Because of its location and associated mining activities, this has therefore pointed out the need to study and investigate related environmental pollutants that humans are exposed to unintentionally.

2.2. Sampling of Dust Fallout

About 21 single bucket monitors were deployed in Arandis town according to the American Society for Testing and Materials standard method (ASTM D1739) for collection and analysis of dust fallout (settleable particulate matter). The ASTM D1739 is an accepted procedure for monitoring fallout dust from a variety of sources (Kgabi et al., 2012). The buckets were placed in an open area with no obstruction from buildings and trees at each sampling site. The cylindrical buckets were tied to a metal pole and raised at least 1.5 m above the ground. The buckets were filled with deionised water and treated with biocide to prevent algal growth. The amount of deionised water to be filled in the bucket varied depending on the prevailing conditions. The sampling areas were marked with a geographical position system (GPS) and these buckets remained at their respective positions for a month before they were transported to the Namibia University of Science and Technology Physics laboratory for analysis.

2.3. Bacteria Isolation and Identification

The buckets containing fallout dust samples were filtered with a Buchner filtration system. After filtration, the samples were attached to filter paper, air dried and placed in a desiccator to allow the mass to stabilise before weighing to determine the exact amount of settled particulate matter (PM) using gravitational calculations. The samples were further transferred to 1.5 ml centrifuge tubes. In each centrifuge tube, 1 ml of 85% saline solution was added, and the content of each tube was centrifuged and vortexed. This was followed by pipetting out 50 μL onto fresh nutrient agar plates. The plates were then incubated at 37˚C ± 2˚C for 24 hours. Different colonies that grew onto the nutrient agar were sub-cultured on MacConkey and Mannitol salt agar plates and, were subsequently incubated at 37˚C ± 2˚C for 24 hours. Both MacConkey and Mannitol agar bacterial growth were further inoculated into tryptone water for indole test confirmation and incubated for 48 hours at 37˚C ± 2˚C. After incubation, 1 ml of Kovacs reagent was added to each sample to determine the ability of present bacteria to split indole from tryptophan molecule respectively. Gram staining was done on all the bacterial samples to determine their morphological characteristics.

2.4. Morphological Characterisation

The morphological characteristics of the fallout dust were visually examined with a Stereo Microscope. About 0.05 g of each dust fallout sample was placed onto the microscopic slide, observed under the microscope and the morphological characteristics (different colours and sizes) were observed on the computer screen.

2.5. Analysis of Elemental Contents in the Dust Fallout by Using the X-Ray Fluorescence (XRF)

The concentrations of heavy metals (namely, Hg, As, Fe, Ni, Cr, Mn, Al and Pb) in the fallout dust sample were directly determined by using the XRF. Prior to that, the fallout dust samples were first dried at 25˚C -27˚C up to a constant weight and then grinded so that the particles are homogenous. The homogenised samples with fine dust particles were then transferred to pre-weighed cups, compressed with a PANA press compressor for 1 minute at 300 Nm and weighed again. The weight of samples was obtained by subtracting the final weight of the sample plus the XRF cup and the initial weight of the XRF cup only. The samples were then placed in XRF for analysis. This procedure was repeated three times for each measured sample.

2.6. Dust Quality Assessments

Parameters that were used to determine the degree of contamination by heavy metal dust fallout are namely, the contamination factor (CF), pollution load index (PLI) and the enrichment factor (EF), which have been widely used by numerous researchers (Antoniadis et al., 2017; Dudu et al., 2018; Mugudamani et al., 2022; Onjefu et al., 2020; Singovszká & Bálintová, 2014).

The CF was obtained by using the following Equation (1)

$$\mathrm{CF} = C_{\text{metal}} / C_{\text{backgroung value}} \tag{1}$$

where C_{metal} = metal concentration in a polluted sample while $C_{\text{background value}}$ = background value of that metal. Based on the outcome, CF is classified into the following categories: CF < 1 = low contamination, CF ranged from 1 - 3 = moderate contamination, CF ranged from 3 - 6 = considerable contamination and CF > 6 = very high contamination (Addo et al., 2012; El-Amier et al., 2017).

The PLI was obtained by using the following Equation (2)

$$\mathrm{PLI} = \left(\mathrm{CF}_{\mathrm{Hg}} \times \mathrm{CF}_{\mathrm{As}} \times \mathrm{CF}_{\mathrm{Fe}} \times \cdots \times \mathrm{CF}_{\mathrm{Pb}}\right)\frac{1}{n} \tag{2}$$

where n = number of metals under study while CF = contamination factor of each metal. The PLI value > 1 indicates pollution, whereas PLI < 1 indicates no pollution (Addo et al., 2012; El-Amier et al., 2017).

The EF was calculated by using the following Equation (3)

$$\mathrm{EF} = \left[\left(C_x / \mathrm{CF}_e\right)_{\text{sample}}\right] \Big/ \left[\left(C_x / \mathrm{CF}_e\right)_{\text{background}}\right] \tag{3}$$

where, Fe (iron) is selected as a natural element of reference; (C_x/CF$_e$) sample is the ratio between the concentration of the element “X” and that of Fe in the dust fallout sample; and (C_x/CF$_e$) the background (Earth’s crust) is the ratio between the concentration of the element "X" and that of Fe in unpolluted reference baseline. Based on the obtained EF, the degree of enrichment is assessed using recognised contamination categories: EF < 2 shows minimal enrichment; EF = 2 - 5 represents moderate; EF = 5 - 20 represents significant enrichment; EF = 20 - 40 indicates very high enrichment; and EF > 40 implies extremely high enrichment (Addo et al., 2012; El-Amier et al., 2017).

3. Results and Discussion

3.1. Identification of Bacteria by Culture-Based Analysis

The viable bacteria attached to the dust fallout were cultured and isolated on nutrient agar. The results showed white-creamy, creamy-yellow, and orange-colored colonies, as shown in **Figure 1**.

The characteristics of characterized and isolated bacteria are shown in **Table 1**, and the most dominant bacteria were *Bacillus* species. The colonies were further characterized by streaking them on MacConkey (MAC) agar and Mannitol salt agar (MSA) which is both differential and selective medias. The result gave a pink and pale pink-coloured colonies in MacConkey and yellow colonies on Mannitol salt agar with no growth observed on a few plates. All colonies from MAC and MSA were inoculated in tryptone water for indole test conformation. The results as shown in **Figure 2** revealed that all species are indole negative, and this implies that the present bacteria are likely not to be *Escherichia coli.* The indole classic test (specific diagnostic test) is mostly utilized to differentiate classical *E. coli* (indole-positive) from other genera (i.e., *Klebsiella* and *Enterobacter* species) that are indole negative (MacWilliams, 2009; Ramirez & Giron, 2022).

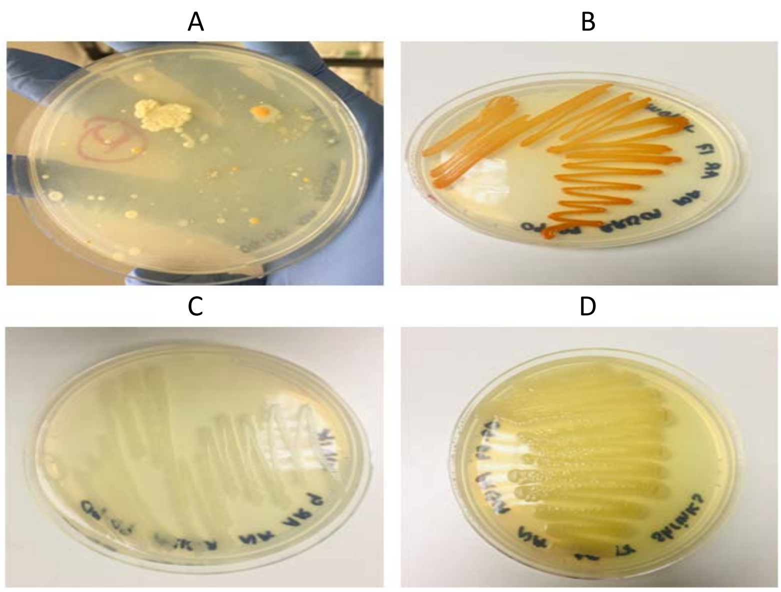

Figure 1. Bacterial colony plates. (A) Nutrient agar plate showing all bacteria present in the dust sample. (B) Orange bacterial growth. (C) Creamy-white bacterial growth. (D) Creamy-yellow bacterial growth.

Table 1. The observed characteristics of bacteria and colony.

Sample Id	Colony colour on NA	Colony colour on Mac	Colony colour on MSA	Positive or negative mannitol	Indole test	Gram Staining	Colony shape
AR 2	Creamy yellow	Pale pink	Clear colonies	Negative	Negative	Positive	Bacilli
	Orange	pale pink	Yellow	Positive	Negative	Negative	Bacilli
AR 3	creamy White	Pale pink	no growth	Positive	Negative	Positive	Bacilli
	Orange	Pale pink	Yellow	Positive	Negative	Negative	Bacilli
AR 5	Creamy White	No growth	Yellow	Positive	Negative	Positive	Streptobacilli
	Orange	Pale pink to yellow	Yellow	Positive	Negative	Positive	Coccus
AR 7	Creamy yellow	Pink	Yellow	Positive	Negative	Positive	Coccus
	Orange	Pink	Yellow	Positive	Negative	Negative	Coccus
AR 8	Creamy yellow	Pale pink	no growth	Positive	Negative	Negative	Coccus
	Creamy White	Pale pink	no growth	Positive	Negative	Negative	Diplococcus
AR 10	Orange	Pale pink	Yellow	Positive	Negative	Positive	Bacilli
	Creamy yellow	Pink	Clear colony	Negative	Negative	Positive	Bacilli
AR 11	Orange	No growth	Clear colony	Negative	Negative	Negative	Streptobacilli
	Orange	Pale pink	No Growth	Positive	Negative	Negative	Coccus
AR 14	Creamy yellow	Pale pink	Yellow	Positive	Negative	Negative	Streptobacilli
AR 16	Creamy White	Pink	White, big colonies	Positive	Negative	Negative	Bacilli
	Creamy yellow	Pale pink	Yellow	Positive	Negative	Positive	Bacilli
AR 17	Orange	Pale pink	Yellow	Positive	Negative	Positive	Bacilli
	Orange	Pale pink	Yellow	Positive	Negative	Positive	Coccus
AR 18	Creamy yellow	Pale pink	No growth	Positive	Negative	Positive	Streptobacilli
AR 19	Orange	Pale pink	No growth	Positive	Negative	Negative	Bacilli
	Orange	Pink	Clear colony	Negative	Negative	Negative	Bacilli
AR 23	Creamy White	Pale pink	Yellow	Positive	Negative	Positive	Bacilli
	Creamy yellow	Pale pink	Clear colony	Negative	Negative	Negative	Bacilli
AR 24	Orange	Pale pink	Clear colony	Negative	Negative	Negative	Coccus
	Creamy White	Pale pink	Clear colony	Negative	Negative	Positive	Bacilli
AR25	Orange	Pale pink	Yellow	Positive	Negative	Positive	Bacilli

The colonies on MSA and MAC were subculture on blood agar, which showed no growth of MSA colonies. Gram staining shown in **Figure 3** was done to differentiate gram positive from gram negative species and assist to distinguish their unique characteristics (Gonzalez-Martin et al., 2014).

The results showed that gram-positive and gram-negative *Bacillus* species dominated at most of the sites sampled in Arandis town, with only few of other species whose presence decreasing order is *Cocci* > *Streptococcus* > *Streptobacilli.* From these results, it can be inferred that the colonies on Nutrient agar and

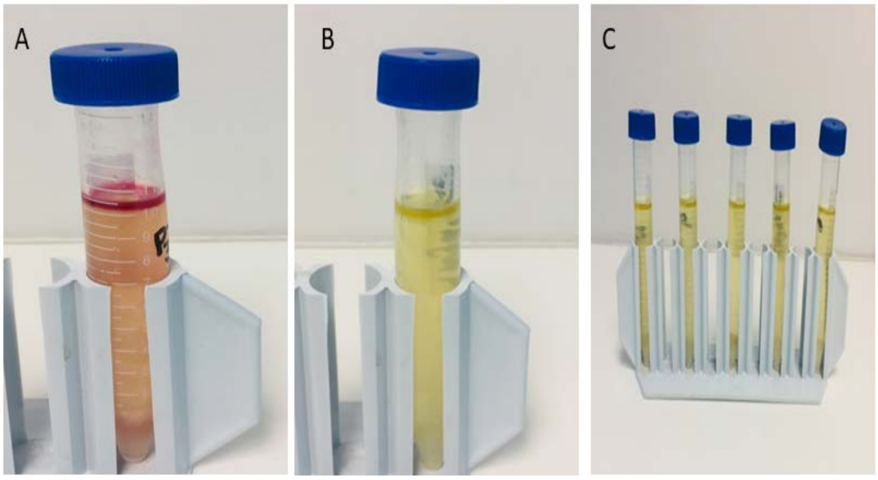

Figure 2. Indole test. (A) Positive control of *Escherichia coli.* (B) Negative control of *Klebsiella pneunomiae.* (C) Negative indole results of the samples.

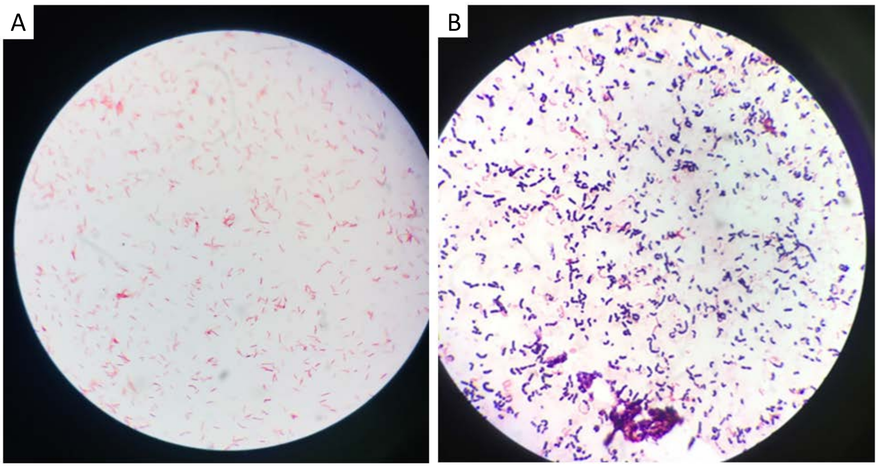

Figure 3. Gram staining. (A) Gram negative *bacillus* and (B) Gram positive *bacillus.*

MacConkey agar are likely to be gram-negative *Bacillus* and *Streptobacillus* species (Jung & Hoilat, 2022). Ramirez and Giron (2022) reported that *Enterobacter* (gram-negative bacilli) can widely be spread and is resident in soil, water and sewage among other sources and hence, they can also be present in the dust fallout samples which can exist as composite of dust from a variety of sources in and/or around Arandis town. These results of bacterial identification by cultivation analysis are in agreement with similar studies done by Al-Barakah et al. (2014) and Al Salameen et al. (2020) who also reported that *Bacillus* species were the most encountered among other species in the samples obtained from the study areas. The survival of the *Bacillus* group during transportation in the environment can be attributed to their special ability to form aerobic spores under prevailing favourable seasons or climatic conditions. Bacteria that belong to the *Bacillus* group (such as the *P. aeruginosa*) are considered as opportunistic human pathogens and are known to count for various chronic and respiratory diseases, and toxicity (Al-Barakah et al., 2014; Al Salameen et al., 2020; Salin et al., 2021). Another study done by Yamaguchi et al. (2012) on aeolian dust showed the affiliation of more than 20 classes of bacteria of which *Actinobacteria*, *Bacilli and Sphingobacteria* dominated. It was also indicated that these bacteria are commonly found in African Dust.

Members of the coccus family, which include *Streptococcus* and *Pneumococcus*, can lead to many skin infections and pneumonia, respectively (Henriques-Normark & Tuomanen, 2013). In addition, some species of *Streptococcus* (a gram-positive coccus) can be pathogenic while others are commensals and hence, their presence in the respiratory pathways does not compromise human health (Henriques-Normark & Normark, 2010). This study therefore raises a distinct probability that the dust fallout in Arandis contains a variety of potential pathogenic bacterial species that belong to the bacilli and cocci family, and these can easily be inhaled during breathing. This finding is in line with the notion that airborne microbes are often associated with dust or dust fallout particles which are directly proportional to the high concentrations of particles suspended in the air and the subsequent likely hood of the increased load of microbes (Al Salameen et al., 2020). It can therefore be inferred from the present study and previous findings that bacteria carried within the fallout dust can have harmful effects and may constitute possible source of opportunistic infections with potential allergens (Yamaguchi et al., 2012).

3.2. The Microphotographs of Fallout Dust

The microphotographs of dust fallout observed at four different sites around Arandis are shown in **Figure 4** and close investigations revealed a combination

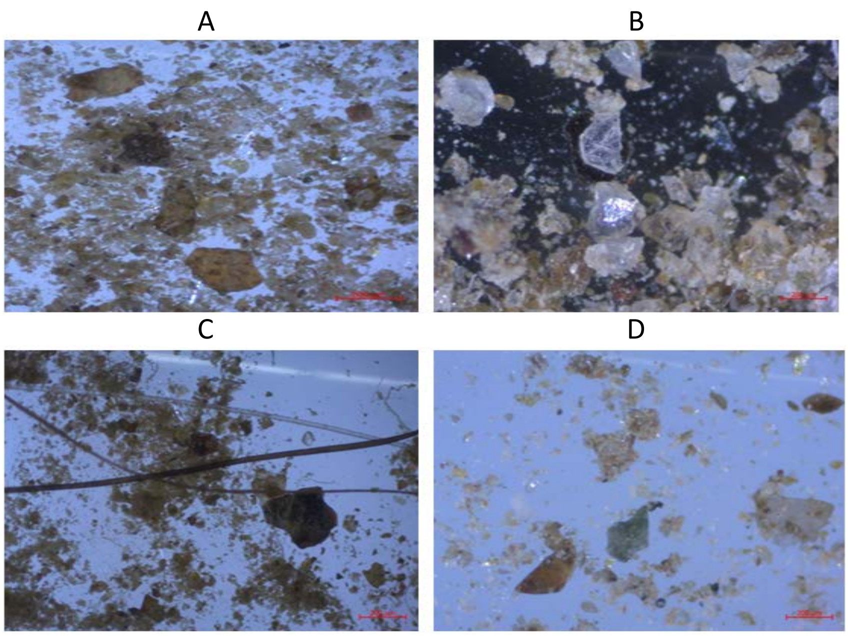

Figure 4. Microphotographs of dust samples magnified at ×25. (A) Brownish irregular particles. (B) Crystal particles. (C) Long thread-like clear and brownish particles. (D) Brownish and greenish irregular particles.

of irregular brownish, black-grey, greenish, thread like with sharp edges and crystal-clear particles. The brown-reddish particles were found in all samples, and this can be a result of high Fe concentration at all sampling sites as evidenced by **Table 2**. Kgabi et al. (2012) also observed similar findings based on the morphological analysis of dust fallout particles from three locations situated in Windhoek, and it was further reported that minerals are normally linked with particles that are like flakes, whereas spherical particles can be fly-ash and pollen grains.

The colour of the dust particles is indicative of the metals and their complexes that are associated with dust. Black-grey particles imply the presence of lead-sulphur compounds, while particles that appear red, orange, and yellow are known to contain the oxides of Fe. On the other hand, white or crystal-clear particles can be due to carbonates of Fe and Ca, whereas black particles may imply the presence carbon compounds (Kgabi et al., 2012).

Table 2. The average concentration of elements presents in the fallout dust samples obtained by XRF analysis.

Town: Arandis	**Concentration (mg/kg)**							
Sample ID	**Hg**	**As**	**Fe**	**Ni**	**Cr**	**Mn**	**Al**	**Pb**
AR2	6.93	73.40	18136.00	20.70	139.20	276.00	20140.00	51.80
AR3	13.00	13.80	18451.00	25.60	41.70	298.00	18311.00	59.80
AR5	0.00	50.30	9445.00	11.70	12.20	159.00	7329.00	52.40
AR7	8.23	23.30	24761.00	22.50	91.30	563.00	47669.00	55.10
AR8	9.23	18.50	28704.00	26.50	99.60	705.00	47579.00	57.60
AR9	NA	6.54	21239.00	32.30	71.20	475.00	58151.00	57.10
AR10	NA	10.95	38560.00	42.30	99.20	670.00	53040.00	70.00
AR11	NA	10.57	35545.00	42.30	88.20	696.00	53040.00	47.50
AR13	20.70	8.11	20562.00	26.70	47.40	320.00	37630.00	89.10
AR14	8.13	5.95	12562.00	15.10	17.60	168.00	8205.00	63.00
AR15	3.87	8.68	4084.00	5.93	26.50	90.60	33612.00	10.03
AR16	NA	1.85	29498.00	7.56	17.20	441.00	42288.00	20.28
AR17	NA	8.35	37026.00	38.80	99.00	627.00	60624.00	62.70
AR18	NA	10.38	31912.00	32.30	78.10	592.00	52384.00	78.10
AR19	19.90	7.72	31274.00	35.40	67.40	579.00	47118.00	71.20
AR20	NA	11.20	27034.00	26.80	61.10	439.00	38799.00	61.40
AR23	NA	7.54	17105.00	22.20	23.80	252.00	7018.00	53.50
AR24	NA	16.70	43585.00	48.40	126.00	682.00	61911.00	78.70
AR25	10.50	5.82	25522.00	26.00	64.30	481.00	39643.00	10.50
Min	0.00	1.85	4084.00	5.93	12.20	90.60	7018.00	10.03
Max	20.70	73.40	43585.00	48.40	139.20	705.00	61911.00	89.10
Average	6.61	13.19	26480.11	28.08	68.29	476.46	42091.11	54.72

3.3. The Heavy Metal Composition of Fallout Dust

Minimum, maximum, and average concentrations of the heavy metals associated with fallout dust around Arandis town were determined per sampling location as summarised in **Table 2**. The results showed high concentrations of Al, Fe and Mn among all sampling sites or dust fallout samples, whereas Pb, Cr, and Ni showed moderate concentrations in comparison to Hg which occurred at none to lower concentrations in the individual samples. On average and almost with respect to the minimum and maximum concentrations, the varied magnitude of contamination by the target elements in the dust fallout samples followed the decreasing order of Al > Fe > Mn > Cr > Pb > As > Ni > Hg. When there is great variability in the ranges of all the tested heavy metals distributions in comparison to their respective means (**Table 2**), Addo et al. (2012) reported that it implies pollution with respect to that particular metal ion. Most of the studied heavy metals (i.e., Cr, As, Pb, Ni and Hg) are considered toxic and they have no significant benefit to humans, animals and the environment, with the exception to others such as Fe, which is dangerous when its content is above the permissible limits (El-Amier et al., 2017).

Iron and manganese play prominent roles in the life cycle of animals and plants and hence, they tend to be the main elements in most environmental samples. Their elevated level can be due to their presence in the organic wastes and sewage wastes that are associated with towns (El-Amier et al., 2017). In addition, the load of Fe, Al and Mn as well as that of the rest of the tested heavy metals in the dust fallout can be contributed by natural sources (i.e., water, rocks and soil) (Sebaiwa, 2016) and anthropogenic activities (i.e., unpaved roads and mining activities) within Erongo region particularly in the coastal towns such as Arandis due to wind episodes (Liebenberg-Enslin et al., 2017; Liebenberg-Enslin et al., 2020). Based on a similar study done on fallout dust in Rehoboth, a high concentrations of arsenic (As) Iron, (Fe), manganese (Mn) and nickel (Ni) were reported and these elevated concentrations were linked to anthropogenic activities in the area such as corrosion of vehicular parts, automobile exhaust, improper handling of waste among others (Onjefu et al., 2016).

3.4. Contamination Factor, Pollution Load Index and Enrichment Factor Parameters

Pollution levels and their variation among sampling sites were determined using contamination factor, pollution load index and enrichment factor parameters. The CF results in **Table 3** showed that all the tested sites in Arandis are highly contaminated (CF > 6) with Fe, Al, & Hg whereas, the same sites are uniformly less contaminated (CF < 1) with respect to Ni and Mn. For Pb, the CF values fall in the moderate and considerable contamination categories. As (for example, location AR9 - AR25) and Cr showed variable categories of contamination by the individual heavy metals in the individual samples per sampling site and, on average, most of them fall in the low contamination (CF < 1) category with

Table 3. Contamination factor and pollution load index for the fallout dust samples in Arandis.

Sample ID	Contamination factor								PLI *index*
	Hg	As	Fe	Ni	Cr	Mn	Al	Pb	
AR2	38.50	5.65	3842.37	0.41	1.55	0.32	2288.64	2.59	13.38
AR3	72.22	1.06	3909.11	0.51	0.46	0.35	2080.80	2.99	10.56
AR5	-	3.87	2001.06	0.23	0.14	0.19	832.84	2.62	0.00
AR7	45.72	1.79	5245.97	0.45	1.01	0.66	5416.93	2.76	14.49
AR8	51.28	1.42	6081.36	0.53	1.11	0.83	5406.70	2.88	15.52
AR9	-	0.50	4499.79	0.65	0.79	0.56	6608.07	2.86	0.00
AR10	-	0.84	8169.49	0.85	1.10	0.79	6027.27	3.50	0.00
AR11	-	0.81	7530.72	0.85	0.98	0.82	6027.27	2.38	0.00
AR13	115.00	0.62	4356.36	0.53	0.53	0.38	4276.14	4.46	12.59
AR14	45.17	0.46	2661.44	0.30	0.20	0.20	932.39	3.15	6.09
AR15	21.50	0.67	865.25	0.12	0.29	0.11	3819.55	0.50	4.15
AR16	-	0.14	6249.58	0.15	0.19	0.52	4805.45	1.01	0.00
AR17	-	0.64	7844.49	0.78	1.10	0.74	6889.09	3.14	0.00
AR18	-	0.80	6761.02	0.65	0.87	0.70	5952.73	3.91	0.00
AR19	110.56	0.59	6625.85	0.71	0.75	0.68	5354.32	3.56	15.29
AR20	-	0.86	5727.54	0.54	0.68	0.52	4408.98	3.07	0.00
AR23	-	0.58	3623.94	0.44	0.26	0.30	797.50	2.68	0.00
AR24	-	1.28	9234.11	0.97	1.40	0.80	7035.34	3.94	0.00
AR25	58.33	0.45	5407.20	0.52	0.71	0.57	4504.89	0.53	9.57

exceptions to a few samples that are moderately and considerably contaminated with these respective elements. On average, the CF values of the heavy metals follow the decreasing order where Fe > Al > Hg > Pb > As > Cr > Ni > Mn.

Similarly, the PLI values (**Table 3**) affirmed the deterioration of the quality of dust fallout from Arandis, which varied in different samples with AR2, AR3, AR7, AR8, AR13, AR14, AR15, AR19 and AR25 having the highest pollution index (PLI > 1, 47.4%) compared to the rest of the samples per site that have lower values of PLI (PLI < 1, 52.6%) with no significant pollution.

With respect to the enrichment factor determinations shown in (**Table 4**), minimal enrichment with respect to all the target heavy metals (namely, Hg, As, Ni, Cr, Mn, Fe and Al) was observed and therefore, local enrichment factors within Arandis can be negated. Since all the values are uniformly lower than 2.0, it is evident that the presence of the studied elements can be ascribed to materials from natural processes rather than the contribution from anthropogenic sources (Ahmadfazeli et al., 2018; El-Amier et al., 2017; Puławska et al., 2021).

Table 4. Enrichment factor for the fallout dust samples in Arandis. All the EF values are below 2 which imply minimal enrichment. The sign (-) indicate not applicable.

Arandis town	($\times 10^{-3}$)							
sample ID	Hg	As	Fe	Ni	Cr	Mn	Al	Pb
AR2	0.260	0.260	0.260	0.260	0.260	0.260	0.260	0.260
AR3	0.256	0.256	0.256	0.256	0.256	0.256	0.256	0.256
AR5	-	0.500	0.500	0.500	0.500	0.500	0.500	0.500
AR7	0.191	0.191	0.191	0.191	0.191	0.191	0.191	0.191
AR8	0.164	0.164	0.164	0.164	0.164	0.164	0.164	0.164
AR9	-	0.222	0.222	0.222	0.222	0.222	0.222	0.222
AR10	-	0.122	0.122	0.122	0.122	0.122	0.122	0.122
AR11	-	0.133	0.133	0.133	0.133	0.133	0.133	0.133
AR13	0.230	0.230	0.230	0.230	0.230	0.230	0.230	0.230
AR14	0.376	0.376	0.376	0.376	0.376	0.376	0.376	0.376
AR15	1.160	1.160	1.160	1.160	1.160	1.160	1.160	1.160
AR16	-	0.160	0.160	0.160	0.160	0.160	0.160	0.160
AR17	-	0.127	0.127	0.127	0.127	0.127	0.127	0.127
AR18	-	0.148	0.148	0.148	0.148	0.148	0.148	0.148
AR19	0.151	0.151	0.151	0.151	0.151	0.151	0.151	0.151
AR20	-	0.175	0.175	0.175	0.175	0.175	0.175	0.175
AR23	-	0.276	0.276	0.276	0.276	0.276	0.276	0.276
AR24	-	0.108	0.108	0.108	0.108	0.108	0.108	0.108
AR25	0.185	0.185	0.185	0.185	0.185	0.185	0.185	0.185

4. Conclusion

The common particles observed in Arandis dust are brownish, black, irregular-shaped, and clear, crystal-like, sharp edged. Based on the photomicrographs, the possible sources of fallout dust in Arandis can be linked to road/traffic dust, coal grinding or abrading activities, possibly from building construction and mining. The contents of the selected metals, namely Fe, Pb, Cr, Hg, Mn, Ni, Al, and As (determined using the XRF) showed variable, less, and appreciable extent of pollution with respect to the site and some of the individual elements. This is with respect to the average concentrations (as well as maximum and minimum concentrations) and the inconsistent heavy metals indices (especially CF and PLI in comparison to EF). Regular monitoring may be required to reduce further increases in the heavy metal load in the dust fallout within Arandis to minimize the potential health risks, since even small concentrations of these heavy metals such as mercury (Hg) are a danger to humans. On bacteria assessment, gram positive *Bacillus* species dominated, with only a few species remaining gram-negative cocci and *Streptococci*. There is a high likelihood that some of these bacterial species can be pathogenic, however, this needs to be confirmed further by carrying out biochemical tests and DNA sequencing on dust fallout samples from Arandis to fully identify the species present in the dust fallout and elucidate their harmful effects on humans and other living species with great specificity. To give more details on particle size, shape, and colour (that indicate metals and their relative metal complexes present), it is recommendable that the results obtained with a Stereo Microscope method can be further explored with other methods of analysis such as the X-ray diffraction and Scanning Electron Microscopy with Energy Dispersive X-ray spectroscopy (SEM/EDX).

Ethics Approval and Consent to Participate

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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