

**Quantification of potential elemental impact of a munitions
production and testing facility on its immediate surroundings**

U Janse van Rensburg

**Dissertation submitted in fulfilment of the requirements for the degree Master of
Environmental Science and Management in Zoology at the Potchefstroom Campus
of the North-West University**

Supervisor: Prof L van Rensburg

2010

ACKNOWLEDGEMENTS

I would hereby like to thank all the people that helped me to make this possible. Firstly, and most importantly, I would like to give all thanks to God for the opportunity and talent to achieve this.

- I would like to thank Prof Leon van Rensburg for the supervision of this dissertation.
- Mr George Jacobs at Rheinmetal Denel Munitions for all the help with the sampling of the data.
- Mrs Yvonne Visagie and colleagues at the ECO REHAB who did the analyses of the samples.
- Prof Johan Jerling and colleagues at the Pharmacy department who help me with the freeze-drying of the organ tissue.
- Prof Faans Steyn who helped with the statistical analysis of the results.
- South Africa's Weather Services (SAWS) for providing the precipitation data of the Boskopdam Nature Reserve.
- I would like to give special thanks to my parents for all the support, love and interest you took in this dissertation.
- The final thanks to my best friend, Liezl du Plessis, for all the support, encouragement and interest you took in my work and ideas.

ABSTRACT

The study attempted to quantify the elemental concentrations and possible accumulation levels in the antelope's organ tissue at Rheinmetal Denel Munitions (RDM), as well as to correlate the findings with the surrounding environment. To achieve this, the elemental concentrations within the kidney, liver and lung tissue of the antelope, and environmental factors such as the soil, vegetation and waterholes were quantified. STATISTICA was used to determine meaningful differences between variables and Canoco to determine the relationship between the different datasets. PCA analyses of the vegetation confirmed that the natural slope at RDM could have contributed to the distribution and variation of the elemental concentration. It became apparent that positive associations existed between the liver tissue and the K, the kidney tissue and Ni and Cd, and the lung tissue had a positive association with Mg, Mn, V, Rb and Co elemental concentrations. It became evident in this study that the elemental concentrations of Al and Ni were higher in the liver and kidney tissue of the antelope than the recommended concentration for livestock (Puls, 1994). The elemental concentration of Al, Ca, Fe and Mn also exceeded the recommended elemental concentration for livestock, in the water sampled at RDM (Puls, 1994). Four distinct areas were identified within the study area, the area above the factory, the area under the factory, the testing area and the area under the factory. Significant differences between the testing area and the area under the factory were found regarding the Tl, Ag, Hg and B elemental concentrations in the vegetation. Furthermore, it became apparent that the amount of precipitation could have contributed to the variation of the elemental concentrations and distribution in the study area as well as in the organ tissue of the antelope.

Keywords: Antelope, munitions, vegetation, organs, metal, elements, accumulation

OPSOMMING

In hierdie studie is daar gepoog om die elementkonsentrasies en moontlike akkumulasie van elemente in die organe van die bokke by Rheinmetal Denel Munitions (RDM) te kwantifiseer, asook om die bevindinge met die nabye omgewing te korreleer. Om hierdie doel te bereik, is die elementkonsentrasies in die nier-, long- en lewerweefsel gekwantifiseer, sowel as in die grond, plantegroei en water. STATISTICA is gebruik om die betekenisvolle verskille tussen die veranderlikes te bepaal, en Canoco om assosiasies tussen die resultate te vind. Hoofkomponentanalise (PCA) van die plantegroei het bevind dat die natuurlike helling wat teenwoordig is by RDM 'n moontlike rol kan speel in die verspreiding en variasie in elementkonsentrasies van die studie-area. Daar is gevind dat daar 'n positiewe assosiasie tussen die elementkonsentrasies van die lewer en K is, tussen die niere en Ni en Cd, sowel as tussen die longweefsel en die Mg-, Mn-, V-, Rb- en Co-elementkonsentrasies. Daar is ook gevind dat die elementkonsentrasies van Al en Ni hoër was in die lewer- en nierweefsel van die bokke as wat Puls (1994) voorstel vir vee. Die elementkonsentrasies van Al, Ca, Fe en Mn was ook hoër in die watergate by RDM as wat voorgestel word vir vee (Puls, 1994). Vier verskillende areas in die studie-area is geïdentifiseer om met mekaar te vergelyk, die area is as volg die fabrieksarea, die toetsarea, die area bokant die fabriek en die area wat onder die fabrieksarea geleë is. Betekenisvolle verskille tussen die toetsarea en die area onder fabriek is gevind ten opsigte van die Tl-, Ag-, Hg- en B-elemente se konsentrasies. Verder het dit geblyk dat die hoeveelheid reënval van die area 'n moontlike rol kon speel in die verskil en verspreiding van die elemente in die studie-area, sowel as in die organe van die bokke en moet dus inag geneem word tydens die vergelyking van die data.

Sleuteltermes: Bokke, wapens, plantegroei, grond, elementkonsentrasies, reënval, organe, niere, lewer, longe, plofstowwe, vuurwapens, akkumulering, ammunisie

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Chapter layout

Chapter 1, contains an introduction to the study and an overview of the objectives to be achieved during the study. The elemental occurrences associated with the production of the ammunition at Rheinmetal Denel munitions (RDM) were investigated in the areas surrounding the factory area.

In Chapter 2, the materials and methods used to achieve the objectives are described. These include the sampling methods of the soil, vegetation, water and the different organs of the antelope, the chemical analyses of the samples and finally the statistical analyses of the results obtained. An area description of Rheinmetal Denel Munitions (RDM) and the activities taking place in the area are explained and described.

Chapter 3, the results and discussions of the obtained results from the methods mentioned above are shown. These include each of the sampled variables results as well as discussions of the occurrences of certain elemental results that were obtained by the chemical analyses.

Concluding remarks from the previously mentioned chapters are documented in Chapter 4.

CHAPTER 1

Introduction, objectives, problem

1.1 Introduction

Increased industrialisation worldwide during the last decade, 1993 to 2003, has led to elevated levels of metallic elements and toxic pollutants within the environment that seriously threaten the habitat quality and health of wildlife species (Parker, 2003:23).

Although certain measures, such as implementing environmental laws, have been put in place to restrict industry's emission into the environment, preceding years' emissions were not controlled and still have an influence on the surroundings. It was only in the last 10 to 20 years that awareness of environmental health has really started to receive more and much needed attention. The problem is that it still persists, although it is being controlled by implemented laws these days, and has for years before.

Cadmium (Cd) represents a typical example of a non-essential element prevailing in the environment due to industrial activities, as it is mostly distributed through food and drinking water and preferentially accumulates in the liver and kidneys of the organisms consuming the affected water and vegetation (Min *et al.*, 2007:85; Lind *et al.*, 1997:892). Cd can be considered as a very mobile element, and is introduced into the environment by several means such as agricultural activities, sewage sludge and various fertilizers (Lind *et al.*, 1997; Prankel *et al.*, 2004.).

A vast amount of research (Cardellicchio *et al.*, 2002; Ciesielski *et al.*, 2006; Rueles-Inzunza & Paez-Osuma, 2002; Bustamante *et al.*, 2002; Seixas *et al.*, 2007; Saeki *et al.*, 2001) has been done on marine systems and the influences of rudiments on the organisms in the aquatic food webs. But there is much less known on the subject of the terrestrial systems and the influences on these organisms (Horai *et al.*, 2006:658).

To the present, a lot of the focus has been placed on the larger industries, which have greater and more noticeable impacts on the environment. Therefore, not much can be said about the munitions industry and its influences on the surroundings. Regardless of what is known about the munitions

industry and what is not, any influence will, despite the quantity, directly or indirectly have an influence on its immediate surroundings.

According to Bausinger (2007:259), with the contamination of areas such as Rhein Metal Denel (RDM) where ammunition and explosives are manufactured and tested, most contamination of the soil will occur in the upper 20cm of the top soil. This renders it more accessible to plant life and prone to surface runoff to lower areas. Munitions that are left in the testing areas often serve as another source of contamination. Elevated concentrations of lead (Pb), copper (Cu) and zinc (Zn) can be expected in the soil of areas similar to that described by Bausinger (2007:260).

A large elemental fraction becomes airborne during the testing of ammunition and explosives (Martiny *et al.*, 2007). According to Martiny *et al.* (2007), 5% (approximately 141 000 tons) of the global Pb utilisation can be ascribed to the ammunition industry, and one can foresee the extent of Pb pollution during the testing and manufacturing of such products. Pb is primarily used in projectiles and priming mixes and is released into the air when these projectiles hit the backstop after being shot.

According to Martiny *et al.* (2007:9), ammunition testing and production residue consist mainly of potassium, silicon and calcium. Previous studies suggest that elements such as Pb, barium (Ba) and antimony (Sb) should also be investigated in comparable situations, as these elements will remain in the area until dispersed or until it is broken up by natural processes. Dispersion can be caused by floods and annual burning of the fields (Bausinger, 2007:260). During the burning process, elements are discharged from the area in gas form and carried to areas downwind. Bacteria also play an important role in the mineralisation of the elements in an area (Ernst, 1996:164). Other pathways, such as natural disintegrating of the residues, which remain in an area after ammunition testing took place, may take several years.

The presence of the elements in a specific environment can be traced via the quantification of the concentrations of those elements present in the soil, within the organisms and their diet, such as the vegetation in the study area. Not only are elements accessible by the organisms through their diet and water intake, they can also be obtained by means of inhalation. According to Rogival (2006:516), accumulation of certain elements by inhalation is much more acute than those acquired through the gastrointestinal tract, although it is the most likely route of uptake by antelope roaming similar areas. Airborne elements are not only inhaled, but can also be ingested when grooming themselves. These methods of intake could be some of the major uptake routes present at RDM,

due to the testing of ammunition and explosives in the area. Min *et al.* (2007:85) mentioned few factors that could influence the transfer of elements to various compartments within food and its ultimate host. These include factors such as the type of metal, whether it is essential or non-essential, the total concentration and distribution of the elements, the edaphic factors such as pH of the area, route of exposure and the demographic properties of the species influenced.

According to Rude *et al* and Gruber (2007:313), metallic elements of concern in the freshwater environment are Cd and Cu, which have contributed to serious problems in freshwater settings. Obvious differences between these element's properties exist, and will therefore have different, but noticeable effects on the environment and the organisms utilising it. Shallow water bodies such as the waterholes at RDM might facilitate considerable sediment re-suspension (Das *et al.*, 2008:2497). Enrichment of metallic elements in similar shallow water bodies has been found to be controlled by factors such as the pH, phytoplankton concentration and composition of the water body and the amount of organic matter contained within. Any changes in these controlling factors could, according to Das *et al* (2008:2497), initiate a series of geochemical processes that will affect the elemental accumulation in the sediments.

Similarly, according to Bausinger (2007:260), some soil characteristics such as pH, clay concentration, mineral content and organic matter influence the mobility, solubility and potential bioavailability of elements to the plant life (Smith, 2008:1). This will subsequently have an effect on the elemental concentration and the absorption of these elements into the system.

The availability of elements in the soil to plants is also dependant on the nature of the chemical association between the metallic elements itself and the soil matrix, the pH value, concentration of the elements in the area and the regulating ability of the plant when the uptake of elements occurs (Smith, 2008:12). A critical influencing factor of the available elemental uptake is that of the soil's pH, as mentioned above. This not only influences the metallic element's availability, but also the potential transfer of elements to the plants. In theory, pH has a tendency to decrease as the concentration of the metallic elements in the soil increases. Therefore, an increase in the elemental uptake by the vegetation will be eminent (Smith, 2008:13; Morton-Bermea *et al.*, 2008:7).

The other factor that will directly affect the elemental availability is that of the clay content of the soil (Smith, 2008:8). In a study on the mobility and bioavailability of trace elements in soil, Ne'el *et al.* (2006) found that clay minerals in the soil immobilise more than 30% of elements, such as Ni, while more than 20% of Zn is immobilised by the organic matter in the soil. Hence, the role of the soil

type in an area plays a far greater role than expected in the bioavailability and uptake of the elements from the surroundings.

Aspects such as the plant's ability to uptake elements from the environment and the binding strength of the elements with the soil (Smith, 2008:8) play an important role in the dispersion thereof for a particular area. For example, Zn is very mobile and readily transferred to plant tissues. On the other hand, Cu has a tendency to be strongly sorbed in the soil and its uptake is more effectively regulated by the plant itself. Therefore, the Zn concentration in the plant tissue will be higher than that of Cu under similar conditions. Another example is that of iron, of which the availability is subject to the sodium (Na) and bicarbonate (HCO_3) ions in the soil (Rabhi *et al.*, 2007:779).

From the above-mentioned examples, it is clear that complex interactions exist between the soil, the metallic elements in it as well as the plants that absorb it, and that these interactions are not always as predictable as one would like them to be. These interactions of the elements and soil play an important role in the remediation of areas contaminated with metallic elements and have an indirect effect on all organisms living in similar areas.

Pollution in an area can be monitored by studying the plants and organisms in the specific area. Environmental contamination could affect the vegetation negatively. For example, the species richness could decline as species in the area are replaced by limited species that are more tolerant to the pollutants in the area (Bausinger, 2007:269). An elevation in the metallic elemental concentrations in the plant could be due to changes in the distribution of elements in the soil as well as an overall increase in the elemental concentrations in the environment. These rising levels have generally been reported to cause an increase in the metallic elemental concentrations in the tissue of plants growing in these contaminated soils (Ke, 2007:62).

Plants that are restricted to highly contaminated soils over extended periods of time may develop, through natural selection, a resistance to high concentrations of certain elements (Liu *et al.*, 2005), as quoted by Ke *et al.* (2007). Finally some plants could evolve to have two metallic element tolerance strategies, either exclusion or accumulation. Exclusion by plants can be done by cell wall thickening or higher mucilage production by the plant's border cells. In the process, the metallic elements are immobilised in the cell wall, or limited ions are transported through the endodermic casparian strips. Different from exclusion is accumulation or hyper-accumulation. In this case, metallic elements can be accumulated in large amounts in the aerial tissue of the plant. These

elements are transported to different compartments, such as vacuoles, where they are detoxified by organic acids, amino acids and elemental binding peptides (Ke *et al.*, 2005:60).

Ne'el *et al.* (2006:734) found that 90-99% of the effective the phyto-available fractions of trace elements in the soil are available for absorption by plants in an area, thereby exclaiming even more the effect that possible residues of similar test areas to RDM could have as a result.

Elemental concentration in a given environment could be a good indicator of the elements organisms are exposed to in a certain polluted ecological unit. Metallic elements in an organism's body can have toxic effects and disrupting results on the natural functions of enzymes, proteins as well as the tissue, such as the kidneys, brain and the reproductive systems. These potential effects depend on the exposure and concentration of the elements they are exposed to (Ciesielski *et al.*, 2004:381).

The bio-availability of these elements is determined by the natural resources in the surroundings of the organism and includes the water, food and air that are utilised. According to Ciesielski *et al.* (2004:381), bioaccumulation occurs when the rate of elemental uptake exceeds the rate of excretion. Naturally, the elements that are not excreted will remain in the organism and stored in the organs. Another complicating factor typical to organisms is the regulation of the elemental concentration by homeostasis. The levels of elements ingested through the natural resources will, despite fluctuations in the foliage, be maintained as stable as possible by the organism (Ciesielski *et al.*, 2004:381). Metallic elements cannot be produced by the animal and have to be obtained through the diet. The remaining elements will be excreted from the body as soon as the function has been fulfilled (Peixoto *et al.*, 2008:1327). The liver plays a vital role in most of the homeostasis mechanisms that occur in mammalian bodies.

Different elements have different accumulative characteristics and functions in the organism's body. For example, elements such as Cd and nickel (Ni) accumulate very effectively in the tissue of vertebrates, even at low exposure levels, while others are less accessible due to the bioavailability of the element itself (Parker, 2003:28). Furthermore, elements such as Cu, tin (Sn) and Zn demonstrate signs of organ-specific accumulative behaviour in the liver, while Cd has a tendency to accumulate in the kidneys (Cardellicchio, 2002:85). The mechanisms of elemental uptake, regulation and elimination in the body of an organism, vary between species (Carriquiriborde & Ronco 2007:313-314).

Elements such as Cu, Zn, iron (Fe), magnesium (Mg) and manganese (Mn) play an important part in the normal functioning of mammals and other organisms by maintaining organism health. It is accomplished by acting as cofactors and coenzymes of various enzymes and may include the structural functions of the enzymes (Peixoto *et al.*, 2008:1327). Magnesium, for example, plays an essential role in enzymatic reactions, interactions related to the energy availability and also plays an important role as catalyst in different enzymatic reactions (Rude *et al.*, 2007:710).

Essential elements, including the metallic elements, fulfil important functions in the respiratory chain, transport and storage of oxygen, elimination of toxic oxygen forms, neuromuscular activities, immune system etc. The list is endless and serves to indicate how important some of these elements are, but in tolerable concentrations.

The concentrations in which the elements are required vary according to the function they fulfil, for example, certain elements will be needed in higher concentrations during the growth and development phases of organisms. In these cases, Fe, Cu and Zn play important roles and could easily result in deficiencies in organisms.

After reviewing all these important aspects of elemental distribution, availability, regulation and functions in soil, vegetation and the organisms itself, it should be clear that in order to act environmentally responsibly, a thorough understanding of the potential environmental impact of a situation similar to RDM's and other munitions factories is essential. It is therefore important to identify the effect that testing of explosives and ammunitions has on the environment. This can be revealed by comparing the test sites with other areas surrounding the factory that are not affected by the testing.

A significant lack of specific literature on the normal metallic elemental concentration found in the tissue of antelope severely hampered the interpretation of the results obtained. Although limited, the data provided in this thesis do provide some much-needed baseline data in this regard.

1.2 Objectives

- 1) This study attempted to quantify the potential environmental impact of munitions testing at RDM. This was achieved by the quantification of the elemental concentrations in soil, watering holes, vegetation and the tissue of the antelope roaming RDM.
- 2) Furthermore, the potential impact of the natural gradient as well as the role it played in the distribution of the elements was considered. In order to evaluate the potential dilution and / or concentration effect of seasonal rainfall variation on the above-mentioned data, sampling was conducted during one “dry” season and one “wet” year.
- 3) It became apparent that the seasonal rainfall may have influenced the elemental concentration in the area, as well as in the organ tissue of the antelope at RDM. Comparisons and associations regarding the precipitation of a wet and a dry rainfall season were made to examine this hypothesis.

1.3 Problem statement

A vast amount of elements are distributed during the production and testing of munitions. These elements are distributed further through various mechanisms throughout the immediate surroundings of the factory area. Depending on the retention time of the different elements, elements could remain in an area for different periods during which it could continue to affect the surroundings. Not only will the microbial organisms in the soil be affected, but it could also have a negative effect on the growth of the vegetation as well as the overall health of the organisms. Furthermore, physiological processes of organisms, including mammals, could be interrupted and could finally influence humans as well.

CHAPTER 2

Materials and methods

Area description, sampling methods, chemical analysis and statistical analysis

Due to a significant lack of specific data and literature on the normal metallic elemental concentrations found in the tissue of the antelope, the interpretation of the results obtained was hampered. Although the data obtained in this dissertation was limited, it did provide some much-needed baseline data.

2.1 Area description

The study was conducted at the RDM factory in the North West Province of South Africa. The factory is situated approximately 20km Northeast of Potchefstroom towards Carletonville. RDM's main objective is to develop and manufacture various explosives and ammunition. These explosives were tested at the grounds under different conditions, such as extreme temperatures, different levels of pressure, etc. This is done to determine the explosives' durability and stability during transportation in and to the field in order to make improvements when necessary.

RDM consists of a factory (Figure 2), which is separated from the surrounding area where the game is kept by means of wiring; this is also done for safety reasons. The area surrounding the factory is used to test the explosives under the mentioned conditions and is located in the highest region of the area. The RDM area is approximately 1300ha, of which 1200ha provides a home for 16 antelope species and includes the testing area (Figure 2). The game is kept for its aesthetic value and is utilised for hunting by the stakeholders of the company. The animals in the area have free access to the testing grounds (Figure 2) of the explosives and are only kept from entering the factory area (Figure 2) by the wiring. Although these animals are free to enter the testing area, they are usually not found there, due to the activities taking place.

The sampling area included the whole area around the factory. The test area is located to the east of the factory, on higher grounds. A natural slope persists from east to the southwest (Figure 1) through the study area. Within this gradient, three watering holes (Figure 3) were formed and are fed with surface runoff water.

This area was divided into 13 sampling sites (Figure 1) relatively similar in size (approximately 100ha each) in which different samples were taken to determine the elemental concentrations in the specific area and their distribution in the area. During the study, site 5 could not be accessed and were thus excluded from the study.

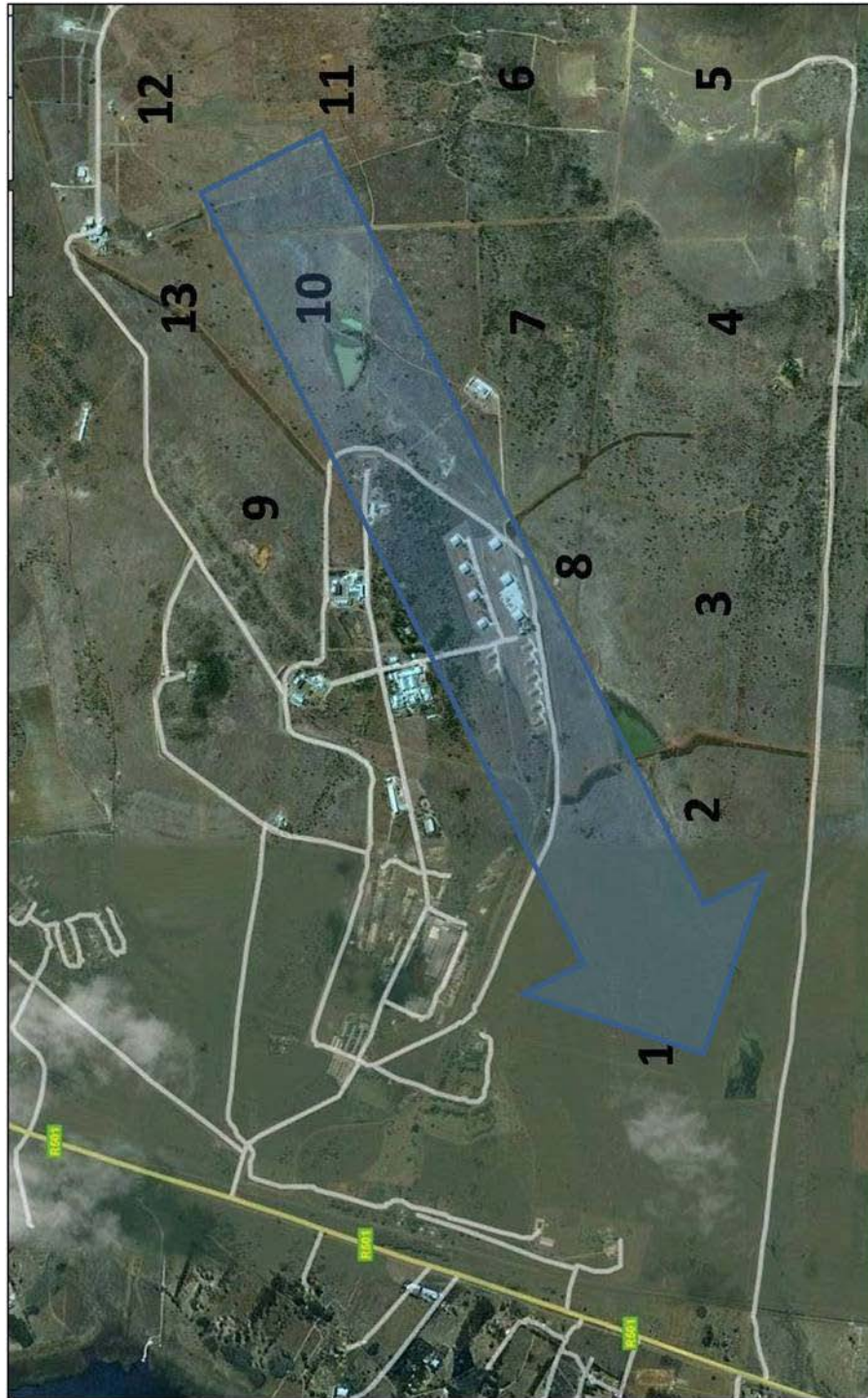


Figure 1: Sampling sites in the study area, RDM as well as the natural gradient in the area, indicated with the arrow

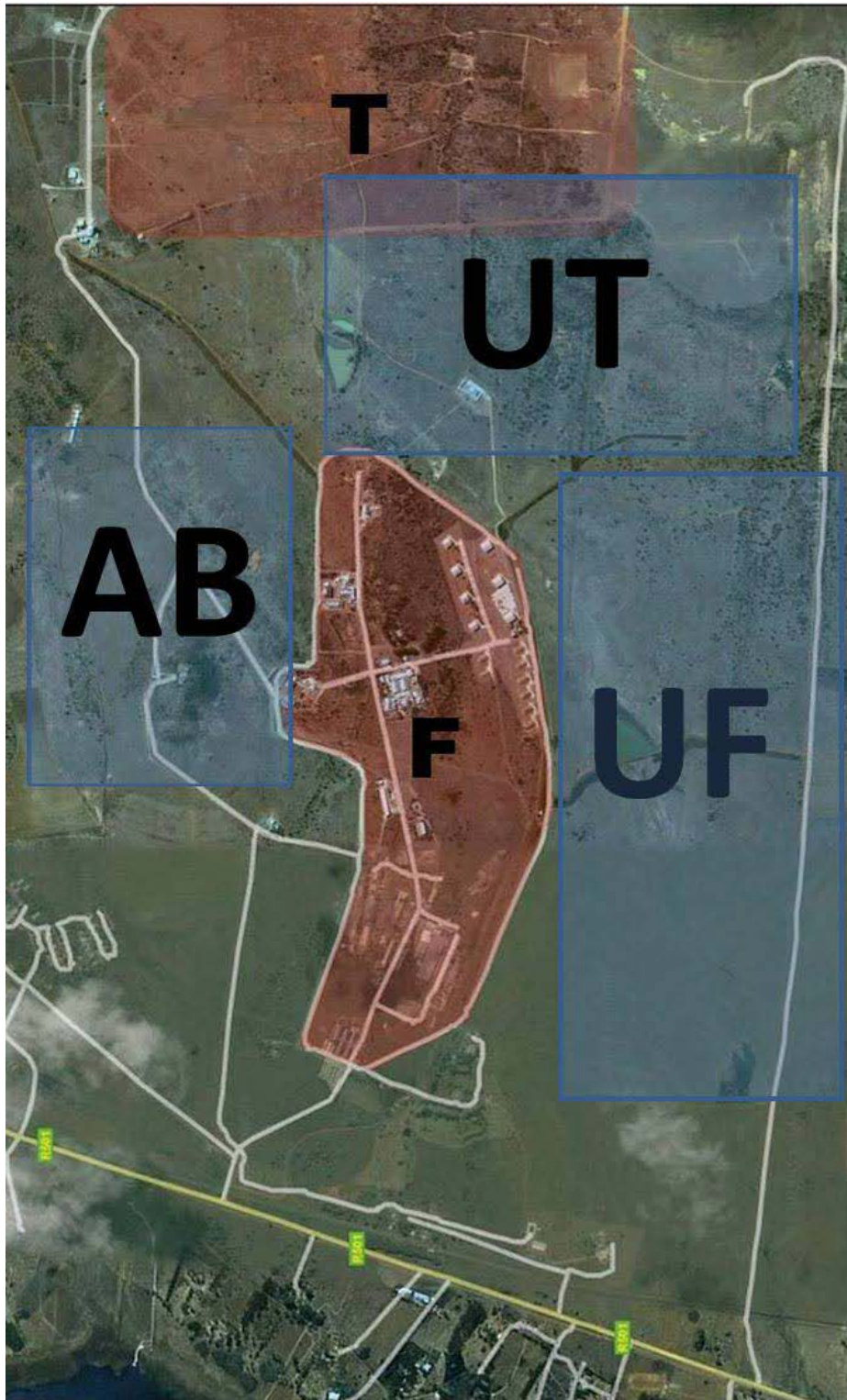


Figure 2: The test area (T), the area under the test area (UT), the area under the factory (UF), the area above the factory (AB) and the factory area (F) at the study area, RDM

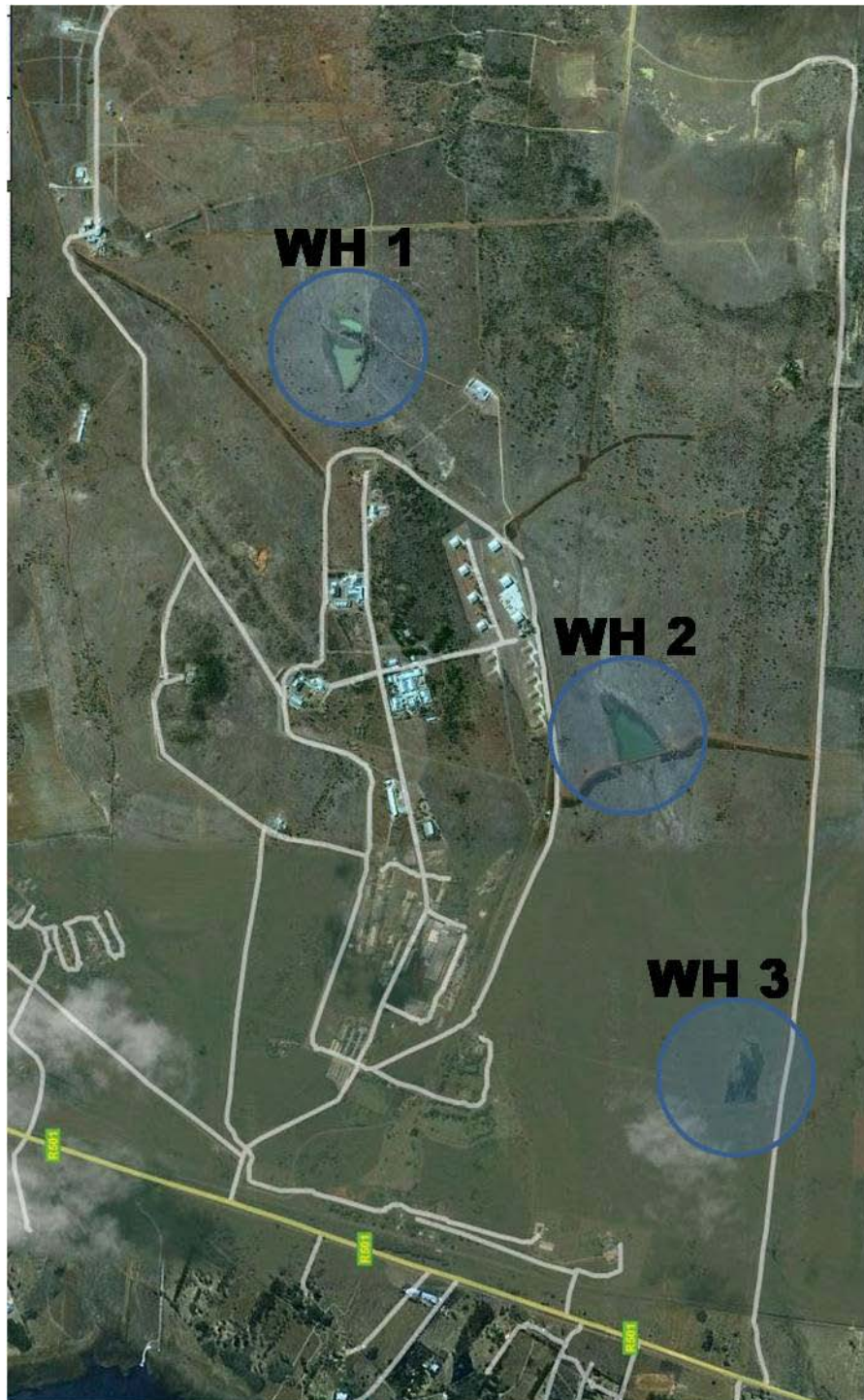


Figure 3: Watering holes at the study area, RDM

2.2 Sampling methods

2.2.1 Soil

A ground auger was used to take two samples at each of the designated sites at the study area. The sites where the samples were taken were cleared from organic matter and the soil sampled to approximately 20cm below the topsoil level of 5cm. The samples were added together and 500g were weighed off to obtain a composite representative sample of each of the sites at RDM.

2.2.2 Tissue

Tissue sampling took place annually during the hunting season from May to July for two consecutive years. Approximately 100g of the kidneys, liver and lungs were collected during the skinning of the animals. The collected samples were immediately frozen. Tissue samples of various species were collected and analysed. The species consisted of blesbuck, oryx, eland, springbuck, black wildebeest and blue wildebeest. The tissue samples collected in 2007 consisted of two blue wildebeest, four eland, one black wildebeest and one blesbuck. The tissue samples collected in 2008 consisted of three oryx, three black wildebeest, two eland, one springbuck, one blue wildebeest and one blesbuck. The tissue samples were pooled and will be referred to as *antelope* onwards. Since no statistical differences could be detected between the respective antelope species with regard to the kidney, lung and liver tissue, the results of the analyses were pooled and would from here on be referred to as *antelope* in this study.

2.2.3 Vegetation

Samples of the dominant grass species, as mentioned later, at each of the sites were collected for analysis. Sampling took place during March, as it is during this period that active growth would have taken place and elements would have been more likely to be detected (Macnae *et al.*, 1995:6). Approximately 100g of the grass were sampled at each of the sites, although only two grams of the vegetation sampled at the different sites were used during the analyses.

2.2.4 Water

Approximately 500ml water was sampled at each of the waterholes. Two samples were taken approximately 3m into the waterhole just beneath the surface of the water mass and pooled together. The sampling of the watering holes was only done once, in 2007.

2.2.5 Rainfall data

The rainfall data was supplied by the South African Weather Service's Boskopdam nature reserve's data station. Sampling mainly took place during the hunting season, which usually starts in May and ends in July, therefore any influences on the antelope and the surroundings that took place before the hunting season will most likely be included in the sampled results. Therefore, the rainfall recorded in January to April might have had the most significant influence on the concentrations of the elements in the area itself and eventually on the concentrations of the elements in the tissue of the antelope.

2.3 Chemical analysis

All sampled items – the vegetation, tissue, water and soil samples – were prepped separately, as required to enable analysis with an Inductively Coupled Plasma mass spectrometer (ICP-MS) (Agilent 7500, Chemetrix, 2003). Preparation of the tissue and the vegetation was done by freeze drying the samples in a freeze drier for different periods depending on the density of the sampled product. For example, the tissue samples' densities are higher than that of the vegetation and were therefore dried for seven to 10 days. As for the vegetation, it was dried for two to four days. The soil and catchments samples were air dried in order for dry weight measurement to be conducted.

2.3.1 Soil

The sampled soil was air dried after which it was grinded until it was able to fit through a 2mm sieve. The grinded soil samples were thoroughly mixed to ensure that the distribution of the elements in the samples was evenly distributed throughout the sample before it was prepped for the various analyses. The various analyses were done to determine the elemental concentration,

exchangeable cations, cation exchange capacity, pH, electric conductivity, phosphate (PO_4), sand, silt, clay and particle size distribution, ammonium (NH_3), Ba, HCO_3 and the total sorbed metals within the soil samples.

2.3.1.1 Exchangeable cations

Ammonium acetate has the ability to exchange with other cations available in the soil particles, and these included particles such as Ca, Mg, Na and K. By measuring the concentration of the exchanged cations, the concentration of the elements in the soil can be determined. The cations were extracted with a 1:10 g/ml soil: extractor (SpectrAA 250 Plus, Varian, 2000).

Five grams of the prepared soil was weighed into a Schott bottle and 50ml of ammonium acetate was added. The mixture was mixed for 15 minutes at 180 rpm, after which two to three drops of super flock (1%) were added to the suspension and mixed lightly. The top liquid was filtered off into another clean Schott bottle. Ten millilitres of the filtrate was transferred into a 50ml volumetric flask with a pipette. Ten millilitres of Lanthanum (500 ppm) was added and filled up to volume of the flask with ammonium acetate.

2.3.1.2 Cation exchange capacity (CEC)

Colloidal particles, such as clay, have a negative charge and are neutralised by the absorption of cations on the surface of the particles. Cation exchange capacity is the ability of the soil to absorb more cations and therefore influences the number of cations it can hold until the soil is saturated.

Five grams of the prepared soil was weighed of into a Schott bottle, and 50ml sodium acetate added. The suspension was mixed for 15 minutes at 180 rpm. The filter flock was placed into leaching tubes and compacted tightly with a glass tube. The suspension was carried over to the leaching tubes quantitatively by washing the soil into the Schott bottle with sodium acetate.

The excessive sodium was washed out by adding approximately 50ml ethanol: dH₂O (1:1) to the soil in the leaching tubes. The excessive ethanol was gathered in a separate bin and disposed. The suspension was washed five times with 50 ml ethanol. The excessive liquid was removed from the leaching tubes by added air pressure and by washing it three times with 30ml ammonium acetate to remove the sodium. The liquid that passed through was caught in a 100ml volumetric

flask. The flask was filled up to volume with ammonium acetate and mixed well. The mixture was diluted 10 times. This was done by taking 5ml of the mixture in the 100ml volumetric flask and transferring it to another 50ml volumetric flask where ammonium acetate was added to fill the flask to volume. The sodium concentration was determined with the AA (SpectrAA 250 Plus, Varion, 2000).

2.3.1.3 pH (H₂O)

Twenty grams of the prepared soil (<2 mm) was weighed off into a 100ml plastic cup and 50ml deionised water (dH₂O) was added. The suspension was stirred for five seconds with a glass tube. The suspension was left to set for four hours and stirred again with the glass tube, after which it was left for another 10 minutes. The pH of the top fluid was measured with a pH meter (PHM 80, Radiometer Copenhagen, 2002) after the pH meter had stabilised for three minutes.

2.3.1.4 Electric conductivity (EG)

Fifty grams of the prepared soil was weighed off into an EG tube and just enough dH₂O was added to form a muddy paste when stirred with a glass tube. The mixture was left to stand for seven hours. The mixture was then centrifuged for 10 minutes at 2000 rpm. The EG was determined with an EG meter (LF 92, WTW, 2002). The electrode of the EG meter (LF 92, WTW, 2002) was placed into the sample and stirred. The electrode was allowed to stabilise and the EG of the solution was measured and noted. Note that the measurements taken were in mS/cm. The electrode was rinsed and dried between the samples.

2.3.1.5 Phosphate: p-bray 1

Ten grams of the prepared soil was measured into a Schott bottle and 75ml p-bray 1 solution added and immediately stirred for precisely 40 seconds. Two drops of super flock were added to the mixture and lightly centrifuged. The top liquid was filtered off into a clean Schott bottle. The phosphate concentration of the liquid was measured with an auto analyser (AA) (SpectrAA 250 Plus, Varion, 2000).

2.3.1.6 Sand, silt, clay and particle size distribution

One hundred grams of the prepared soil was weighed off and sieved through a 2mm sieve from which the fraction greater than 2mm was noted. Fifty grams of the sieved soil was weighed off into a glass beaker to which 500ml of dH₂O was added and left for 10 minutes after it had been mixed thoroughly. Ten millilitres of hydrogen peroxide was added to the mixture and left for 10 minutes after which the mixture was thoroughly stirred and placed on a heated stove. The suspension was covered with a watch glass to prevent it from boiling over. The mixture was heated for four hours and left to cool down. Hundred-twenty-five millilitres of Calgon was added to the suspension and thoroughly stirred. The suspension was carried through a 53µm sieve to a sedimentation cylinder. The soil was washed with running tap water and a brush. The fractions smaller than 53µm were washed into a sediment cylinder. It is important to note that less than one litre of water should be used when washing the suspension.

The fraction that was left on the sieve was dried in an oven and measured after exactly 40 seconds with a hydrometer. The amount and temperature were noted. The second measurement took place only after seven hours, without stirring the suspension. The dried fraction was sieved with an electric sieve for three minutes through a 53µm sieve to another pan. This fraction was weighed and noted.

To determine the particle size distribution of the soil, the dried soil was sieved with the electrical sieve for three minutes with a 2000mm, 1000mm, 500mm, 250mm, 100mm and a 53µm sieve, respectively. The fractions left on the sieve afterwards were weighed and noted.

2.3.1.7 Extraction method

Two hundred millilitres of dH₂O was placed in a plastic bottle and two to three drops of super flock were added. One hundred millilitres of soil was systematically added into the bottle and was shook for 30 minutes. The overlying fluid was decanted into an Erlenmeyer flask and the EG was measured with an EG meter (LF 92, WTW, 2002). The liquid was centrifuged for 12 minutes at 16500 rpm and filtered into one of the brown bottles. The bicarbonate HCO₃ concentration was determined by means of a titration. The cations (Ca, Mg, K and Na) and the micro-elements (Fe, Mn, Cu and Zn) were determined with the AA. (SpectrAA 250 Plus, Varion, 2000).

The concentration of the Cl , NO_3 , NO_2 , F , SO_4 and PO_4 was determined with an integrated circuit. The colometric was determined with the spectrophotometer, and the p-bray concentration with the scalar auto-analyser (AA) (SpectrAA 250 Plus, Varion, 2000).

2.3.1.8 Ammonium

Before measurement took place, the instrument (Photometer, SA-120 skalar, 2000) was allowed to stabilise and at least three standards from low to high were taken to ensure that the readings were accurate and 0.5ml sodium hydroxide (NaOH) was added, and the measurement taken. The electrode was cleaned with dH_2O and dried after each sample was measured.

2.3.1.9 Boron

One millilitre of the standard sample was measured into a tube and 2ml Boron (B) buffer was added, the cap was replaced and the mixture shook. Two millilitres Azomethien-H was added. The solution was left for exactly 30 minutes and measured. The concentration of the boron was determined by using a graph.

2.3.1.10 Phosphate

Before any measurements took place, the samples were arranged in numerical order, and were machine-washed for 30 minutes with a weak sulphuric acid (HNO_3) solution. The ascorbic acid tube was placed into the ascorbic acid bottle, and the molibdate tube into the molibdate bottle. The other two tubes were placed into the five-litre lauryl sulphate flask. The chemicals were sucked through the tubes for five to 10 minutes and the author noted the reading of the three samples. The machine (SpectrAA 250 Plus, Varion, 2000) was rinsed for another 30 minutes.

2.3.1.11 pH and bicarbonate

Firstly, the temperature was set and the pH was allowed to stabilise in the buffer while stirring the electrode from time to time. Five millilitres of the sample were placed into the pH jug with a pipette and the pH reading noted after it stabilised. Afterwards, a titration was done with 0.005m hydrochloric acid (HCl) to a pH of 4.5. The titration volume of the HCO_3 was noted. The electrode had to be cleaned and dried before every sample.

2.3.1.12 Total sorbed metals

Two grams of the sampled soil was weighed into a 150ml beaker and 15ml concentrated HNO_3 was added and covered with a watch glass. It was placed on a sand bath with and heated to $\pm 95^\circ\text{C}$. Care was taken that the solution did not boil. The solution was refluxed for one hour and the watch glass removed as soon as the solution was dissolved to let the acid evaporate. The solution was heated until the volume declined to a volume of $\pm 5\text{ml}$. Three millilitres of the 30% hydrogen peroxide (H_2O_2) were added after the solution was completely cooled down. Ten millilitres of 3N HCl were added and the solution was covered with a watch glass and placed on the heated sand stove to reflux. It was removed after one hour and left to cool. The sample was filtered through a Whatmann 40 filter paper ($0.22\mu\text{m}$) into a 50ml volumetric flask and washed and filled up to volume with dH_2O .

2.3.2 Tissue

The liver, kidney and lung tissue samples were freeze dried for seven to 10 days, depending on the density of the samples. The dried tissue samples were powdered and 1g digested with concentrated HNO_3 . The ICP-MS (Agilent 7500, Chemetrix, 2003) was used to determine the concentration of the elements present in the tissue samples. For comparative purposes, the data on the elemental concentration of the cattle were given in wet weight and were multiplied with 80% to enable comparison with the dry weight concentrations of this study. The data only represented the liver and kidney tissue of cattle, therefore the concentrations found in the lung tissue of the antelope will only be compared to the values found in the liver and kidney tissue.

2.3.3 Water

All the water samples were analysed with the ICP-MS (Agilent 7500, Chemetrix, 2003) to reveal the elemental concentrations present within each sample, which was a representative of each of the waterholes.

2.3.4 Vegetation

Two grams of the freeze-dried foliage was weighed off into a 150ml beaker and 15ml concentrated HNO_3 was added and covered with a watch glass. It was placed on a sand bath and heated to

$\pm 95^{\circ}\text{C}$. Care was taken to ensure that the solution did not boil. The solution was refluxed for one hour and the watch glass removed as soon as the solution was dissolved to let the acid evaporate. The solution was heated until the volume declined to a volume of $\pm 5\text{ml}$. Three millilitres of the 30% hydrogen peroxide (H_2O_2) were added after the solution was completely cooled down. Ten millimetres of 3N hydrochloric acid (HCl) were added and the solution was covered with a watch glass and placed on the heated sand stove to reflux. It was removed after one hour and left to cool. The sample was filtered through a Whatmann 40 filter paper into a 50ml volumetric flask and washed with and filled up to volume with deionised water (dH_2O).

2.4 Statistical analysis

Analyses were done with STATISTICA version 8, CANOCO 4.5 for Windows and EXCEL. STATISTICA was used to determine the variation, deviations, mean values and averages of the elemental concentrations in the specific areas. CANOCO was used to do principle component analyses (PCA). The results of a PCA analysis would indicate the similarity and dissimilarity of the different samples according to the different scores they receive during the procedure. These analyses identified the correlations and contrasts between the variables and the sampling sites in the area. After all the statistical analyses took place, the results were interpreted separately and as a whole.

CHAPTER 3

Results and discussion

Vegetation, soil, waterholes, catchments, rainfall and antelope

The results acquired through the analyses as described, were used to study the distribution, elemental concentrations within the different sampled entities at the study area as well as the elemental composition within those entities to finally address the objectives of this study.

3.1 Vegetation

Due to the lack in specific literature on the elemental concentration of vegetation and proposed intake of elements for antelope, the standards provided by Puls (1994) were used to provide a guideline for the measured values in the study area, as analysis of different organs in various animals were done. Although limited, the data obtained and compared in this dissertation provide some much-needed baseline data in this regard.

Table 1: The suggested elemental concentration in the diet of cattle (Puls, 1994)

Elements	Diet	Units
Al	<300	ppm dry weight
Ba	0.5-20	ppm
B	1.0-50	ppm
Br	5.0-20	ppm dry weight
Cd	0.01-0.5	ppm dry weight
Ca	0.38-0.81	%
Cl	<0.04	%
Cr	0.1-0.5	ppm
Co	0.1-1.0	ppm
F	10.0-20.0	ppm
I	0.5-2.0	ppm
Fe	100-500	ppm
Pb	<1.0	ppm
Mg	0.25-0.35	%
Mn	40-200	ppm dry weight
Hg	<0.01-0.1	ppm dry weight
Mo	0.5-3.5	ppm
Ni	1.0-10.0	ppm dry weight
P	0.35-0.45	%
K	0.8-2.45	%

Se	0.3-1.00	ppm dry weight
Na	0.18-0.67	%
Tl	<0.5	ppm
U	<0.1	ppm dry weight
V	<50	ppm
Zn	50-100	ppm dry weight

These are the minimum and maximum values of the elemental concentrations (Table 1) provided by Puls (1994).

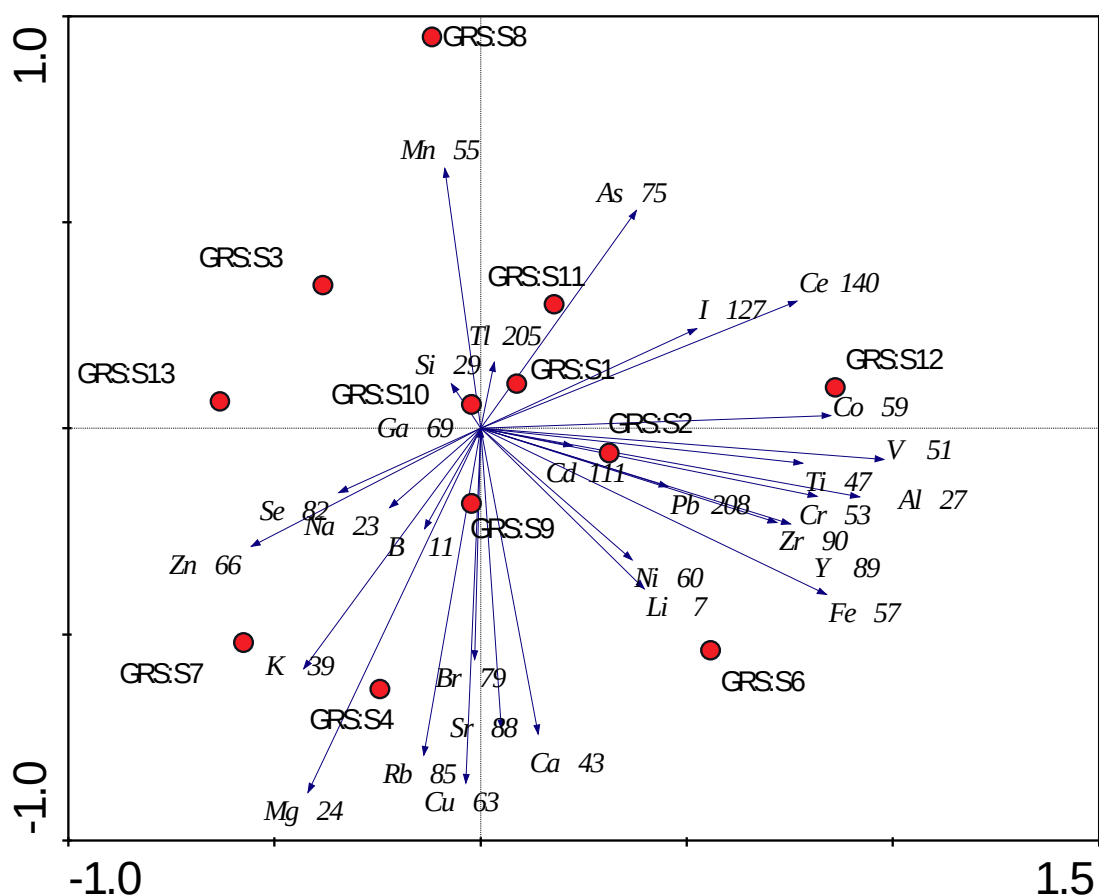


Figure 4: PCA on the elemental concentration of the pooled vegetation, sampled at each of the different sites at RDM. GRS = grass, the sites at which the samples were taken are represented by 'S'. Abbreviations of the elements mentioned are available in the appendix (page I).

PCA ordinations examine the principle components present at each of the sites and focus on the associations in terms of the elemental concentration, distribution and composition in the grass. By

examining each of the sites and their association separately and as a whole, differences and comparisons were definitely noticeable and important.

Firstly, GRS: S8 positioned at the top of the diagram indicates that no similarity in the elemental composition and elemental concentration in the grass sampled in GRS: S8 existed. This positioning of GRS: S8 in Figure 4 might be ascribed to the high Mn concentration and the low concentrations of K and Mg present at the site. This site showed the greatest difference with regard to its positioning in Figure 4 when it was compared to the sites GRS: S4, GRS: S6 and GRS: S7. The positioning of GRS: S8 on the diagram could be due to the differences in the elemental concentrations of specifically Mg, Mn and K. GRS: S8 was situated just below (in terms of the gradient) waterhole 1 and also below the testing area (Figure 2), which could have influenced the elemental composition and concentrations that typify it. Explosive residues in the test area, which remained on the site, could have washed down towards the sites below, influencing the elemental concentration and distribution of these areas, which might explain the difference between the positioning of the sites, as illustrated in Figure 4 above.

A clear association was evident between sites GRS: S1, GRS: S10 and GRS: S11, which could primarily be attributed to the presence of the elements Tl, Si and Ga. In the area where GRS: S10 and GRS: S11 were situated, explosives were tested under different pressures and extreme temperature conditions. All test residues, explosives and ammunition shells were left in the area. As for GRS: S1, it was located at the very lowest point of the area near waterhole 3 (Figure 3). The significance of this is that one would actually expect a closer association between GRS: S2 and GRS: 8 that are situated under the factory area and downhill of all possible pollution areas.

The positioning of sites GRS: S4, GRS: S6 and GRS: S7 was positively associated with the presence of the following elements: Ca, Br, K, Mg, Rb, Cu and Fe. These three sites were located just below the testing area of the factory. All residues and elements present in this area would be washed down with the surface runoff, among others, to these three sites. These sites were grouped and the elemental composition compared to other areas. These three sites represented the “under test area” (UT) in subsequent statistical analyses. Therefore, some clear degree of association can already be seen to exist between these three sites. Another interesting observation was the association of Li, Fe and Ni specifically with GRS: S6 (Figure 4).

It is also worth mentioning that the sites GRS: S3 and GRS: S13, that are grouped together, showed no specific relation to any of the elements measured. It is also worth mentioning that the sites GRS: S3 and GRS: S13, that are grouped together, had a definite negative association with

the sites GRS: S6 and GRS: S12, representing the sites that were firstly unaffected by any activities taking place at the area and secondly, situated outside the runoff route towards the lower areas. To aid further statistical analysis, the areas sampled were grouped into four distinctive groupings, namely:

Under the factory (UF): S1, S2, S3 and S8,

Under the test area (UT): S4, S6 and S7,

Test area (T): S10, S11, S12 and S13, and

Above the factory (AB): S9.

As mentioned earlier, site 5 was excluded from the study, due to inaccessibility.

The natural gradient played a major role in the determination of the four groupings as well as the potential elemental concentrations and their distribution in the study area. Surface runoff was mostly responsible for the distribution of the elements to the lower situated regions. The degree of activities and therefore potential environmental impact differ greatly between the four areas. The test area, where the explosives and ammunition were tested, represented the highest point of the study area and it was here that most of the activities took place (Figure 2). Explosive residue and impacts of the explosives on the surrounding area would be expected to be the highest there. Any surface runoff through this area could carry components and elements left in the area after testing took place, to areas lower down the gradient. The area directly under the test area ought to have been the first to be influenced by the test area, although slightly out of the direct runoff route. The “under the factory area” represented the lowest point of the natural gradient. This area would have been influenced by the factory itself. The area represented by site 9 was situated neither in the testing area nor in the runoff route of the testing site or the factory, and was therefore expected to be the least impacted. This grouping of the sites remained the same for all the relevant analyses further on.

The following elements were identified from the results of the vegetation analyses as elements with potential significant differences between the distinguished areas, mentioned above. These elements were B, Hg, Pt, Ti, Ag and Cd (see appendix for abbreviations – page I).

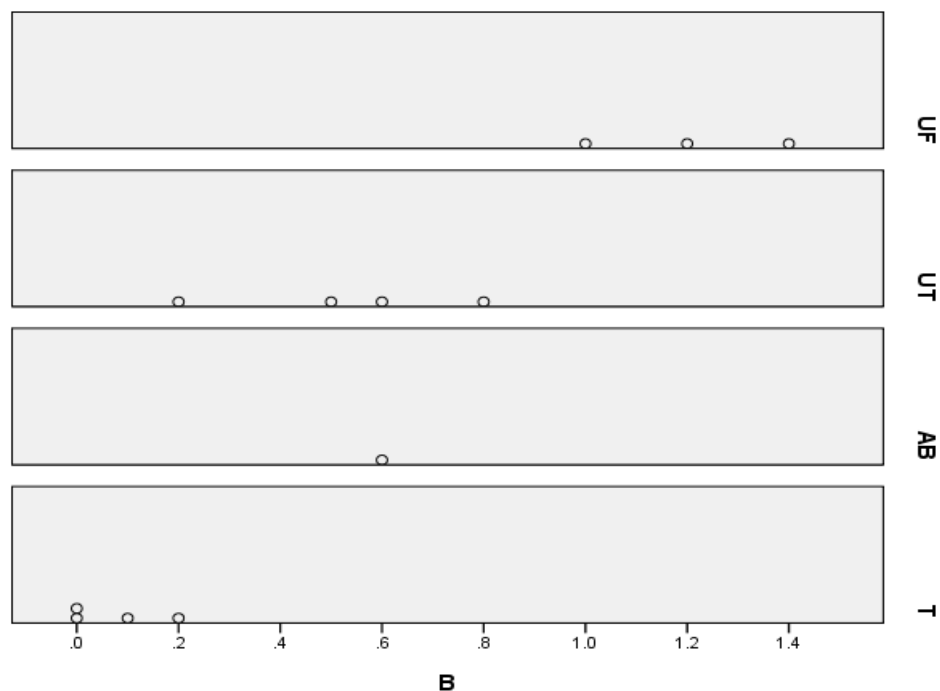


Figure 5: The elemental distribution according to the average elemental concentration of B in the vegetation in the area above the factory (AB), test area (T), the area under the factory (UF) and the area under the test area (UT). The concentration in ppm (mg/l) is presented on the x-axis and the grouped sites on the y-axis. Each of the dots represents samples taken from the area.

The variation in the B concentration between the four groupings is presented in Figure 5. Differences can be seen especially between the testing area (T) and the under factory area (UF). The grouping was done to determine if there was any significant difference in terms of the concentration of B in the different sites. From the data presented it is clear that the testing area (T) differed markedly from the under the factory area (UF), for example.

Table 2: A comparison of the significance of B in the different grouped sampling sites

	UF (R:11.000)	UT (R:6.7500)	AB (R:7.5000)	T (R:2.6250)
UF		0.736504	1.000000	0.014135
UT	0.736504		1.000000	0.634030
AB	1.000000	1.000000		1.000000
T	0.014135	0.634030	1.000000	

Table 2 provides the statistical quantification to support the above-mentioned statement, since a comparison between T and UF yielded a value of less than 0.05. UT also differed from T, but not significantly.

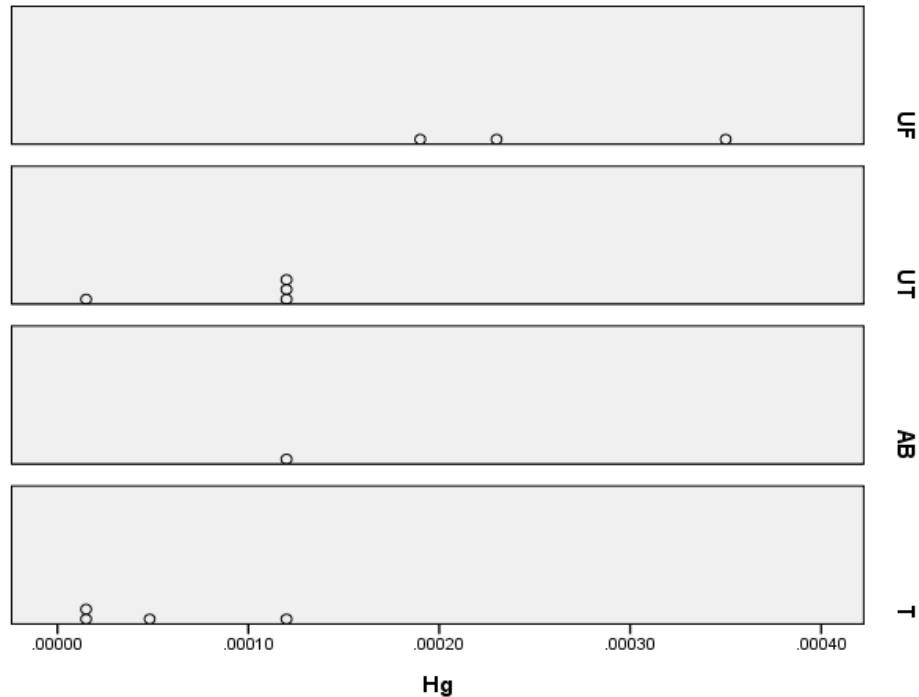


Figure 6: The elemental distribution according to the elemental concentration of Hg in the vegetation in the area above the factory (AB), test area (T), the area under the factory (UF) and the area under the test area (UT). The concentration in ppm (mg/l) is presented on the x-axis and the grouped sites on the y-axis. Each of the dots represents samples taken from the area.

Table 3: A comparison of the significance of Hg in the different grouped sampling sites

	UF (R:11.000)	UT (R:6.0000)	AB (R:7.0000)	T (R:3.5000)
UF		0.416514	1.000000	0.038754
UT	0.416514		1.000000	1.000000
AB	1.000000	1.000000		1.000000
T	0.038754	1.000000	1.000000	

As was the case with the B concentration, some variation in the Hg concentration in the sampled vegetation at each of the experimental sites did occur. However, as can be seen from the statistical data presented in Table 3, a statistically significant variation (0.05) only occurred between the groupings T and UF, while groupings AB, UT and T showed similar concentrations of Hg in the vegetation sampled.

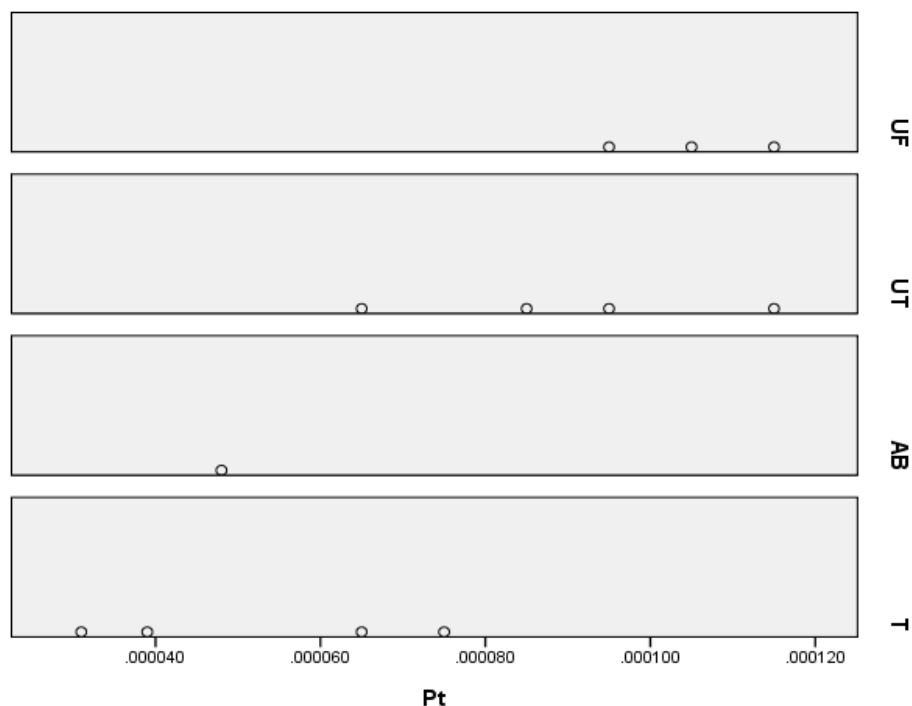


Figure 7: The elemental distribution according to the elemental concentration of Pt in the vegetation in the area above the factory (AB), test area (T), the area under the factory (UF) and the area under the test area (UT). The concentration in ppm (mg/l) is presented on the x-axis and the grouped sites on the y-axis. Each of the dots represents samples taken from the area.

From the data presented in Figure 7 it became clear that differences in the concentrations of Pt in the sampled vegetation did exist, especially when T, UT and UF were compared, despite the low concentrations found to be present in the vegetation.

Table 4: A comparison of the significance of Pt in the different grouped sampling sites

	UF (R:10.000)	UT (R:7.8750)	AB (R:3.0000)	T (R:3.3750)
UF		1.000000	0.556175	0.096828
UT	1.000000		1.000000	0.465337
AB	0.556175	1.000000		1.000000
T	0.096828	0.465337	1.000000	

Table 4 provides the statistical proof that significant differences between the test area (T) and the under the factory area (UF) existed in terms of the Pt concentrations found in the vegetation sampled. Differences in the Pt concentrations of the vegetation sampled were also found to exist, but these differences were not statistically significant (>0.05 , see Table 4).

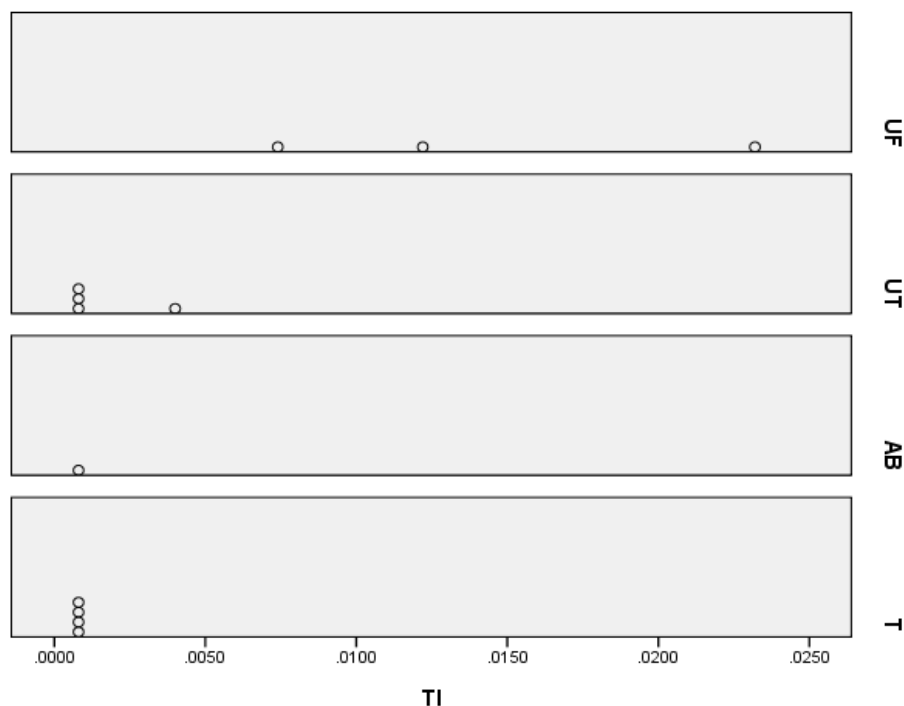


Figure 8: The elemental distribution according to the elemental concentration of TI in the vegetation in the area above the factory (AB), test area (T), the area under the factory (UF) and the area under the test area (UT). The concentration in ppm (mg/l) is presented on the x-axis and the grouped sites on the y-axis. Each of the dots represents samples taken from the area.

The concentrations of TI at the different sites were found to be rather constant throughout the study area, except for those sampled in the under the factory area (UF). The TI concentrations in the samples representing the UF area were scattered and typified by higher concentrations than those in the UT, T and AB groups (Figure 8).

Table 5: A comparison of the significance of TI in the different grouped sampling sites

	UF (R:11.000)	UT (R:7.0000)	AB (R:3.0000)	T (R:3.5000)
UF		0.878099	0.327984	0.038754
UT	0.878099		1.000000	1.000000
AB	0.327984	1.000000		1.000000
T	0.038754	1.000000	1.000000	

Again, statistically significant differences (0.03) were found to exist between the concentrations of TI in the vegetation sampled at the T and UF sites. The differences in the TI concentrations in the

vegetation sampled at the respective sites, UT and UF as well as between AB and UF, were found not to be statistically significant (Table 5).

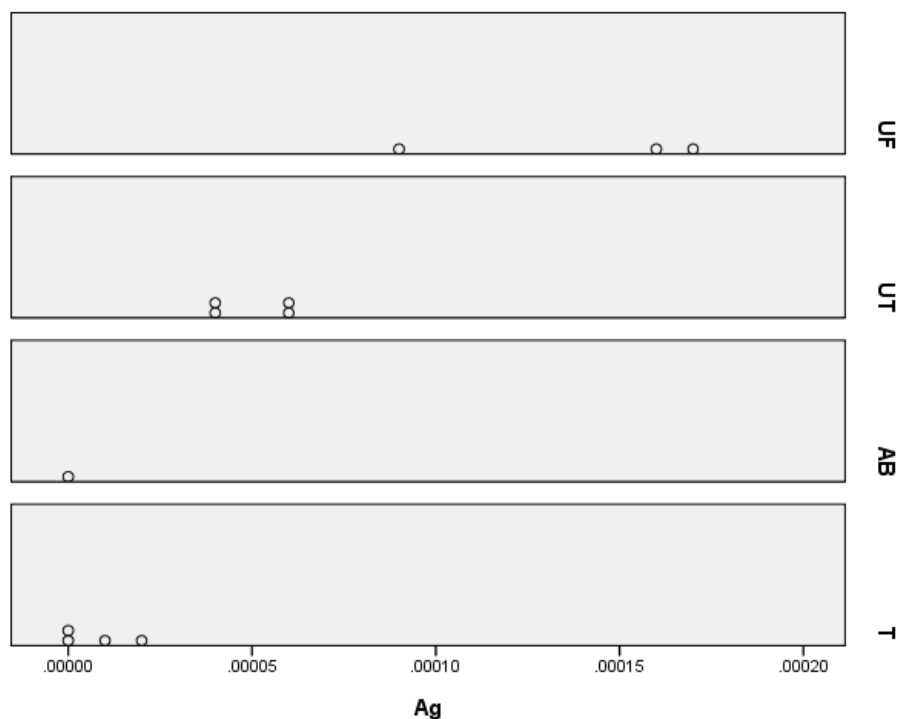


Figure 9: The elemental distribution according to the elemental concentration of Ag in the vegetation in the area above the factory (AB), test area (T), the area under the factory (UF) and the area under the test area (UT). The concentration in ppm (mg/l) is presented on the x-axis and the grouped sites on the y-axis. Each of the dots represents samples taken from the area.

Although the concentration in which the differences were identified was very small, differences in concentration between the sites still existed. This difference could be seen when UF and T was compared.

Table 6: A comparison of the significance of Ag in the different grouped sampling sites

	UF (R:11.000)	UT (R:7.5000)	AB (R:2.0000)	T (R:3.2500)
UF		1.000000	0.183834	0.029329
UT	1.000000		1.000000	0.573102
AB	0.183834	1.000000		1.000000
T	0.029329	0.573102	1.000000	

As was the case with the other elemental concentrations presented, a statistically significant (0.02) difference in the Ag concentration in the vegetation sampled was found to exist between the UF

and T groupings, and although differences did exist in terms of this parameter between the other groupings, it was not statistically significant (Table 6).

Table 7: A comparison of the significance of Cd in the different grouped sampling sites

	UF (R:10.833)	UT (R:4.1250)	AB (R:9.5000)	T (R:4.8750)
UF		0.089094	1.000000	0.182930
UT	0.089094		1.000000	1.000000
AB	1.000000	1.000000		1.000000
T	0.182930	1.000000	1.000000	

In contrast with the previous comparisons reported on, in the case of the Cd concentration in the vegetation at the respective sites, an important difference between UT and UF existed. Although differences in terms of the Cd concentrations were found between the T and UF groupings, it was not statistically significant (0.18), but was found to vary significantly between the UF and UT groupings (0.08) (Table 7).

From the results of the comparison of the specific elemental concentrations in the vegetation sampled at the respective sampling sites, it became clear that in all but one of the elements statistically significant differences were found to exist between the T and UF groupings. These differences in some specific elemental concentrations in the sampled vegetation might, as previously been alluded to, probably be ascribed to the differences in activities occurring at each site. For example, the UF grouping consisted of sites 1, 2, 3 and 8, and all these sites were situated under the factory area and were subject to the runoff of the factory itself as well as the testing area to a lesser extent, for example, T: sites 10, 11, 12 and 13, located at the highest point of the study area and subject to the testing of ammunition and explosives. These sites were expected to differ from each other before the elemental composition and concentration were compared, as a result of the activities associated with each.

Besides the statistically significant differences in the elemental concentrations in the vegetation sampled, differences between the UT and T groupings also existed when the concentrations of B, Pt and Ag were compared, although not as significant as the others. The concentrations of Hg, B and Tl in the vegetation also differed between the UT and UF groupings, as did the concentrations of Pt, Tl and Ag in the UF and AB groupings.

3.1.1 Discussion

During the comparison of the elements measured in the study area with the recommended concentration provided by Puls (1994), it became apparent that the concentrations of Mg and K were higher than the recommended levels for cattle. A number of elements had concentrations less than recommended. These included Br, Ca, Cr, Co, I, Fe, Mn, Se and Zn. Implications of the occurrence are not clear, due to the amount of variables and lack of sufficient data, as mentioned earlier.

Firstly, differences in the elemental concentrations between the identified sites, as well as between the identified grouped sites in the area became clear. An example of this was the higher elemental concentration of K present in the downhill areas, and the higher elemental concentration of Fe in the testing area and the area underneath it, when compared to the remaining sampled sites at RDM.

The PCA analysis results of the elemental concentration in the vegetation, confirmed the hypothesis that a variation in the elemental concentration and distribution along the natural slope did occur. Not only was it due to the natural slope in the area, but it could also be assumed that the different activities in the area lead to the variation of elemental concentrations and distribution along the gradient. The grouping of the elements according to the association of the elements with certain sites (PCA analysis) helped to identify the following groups within the sampled area. These groups were the test area (T), the area underneath the test area (UT), the area under the factory area (UF) and the site that was situated above the factory (AB).

After these areas were identified and the vegetation present at each studied, it became clear that significant differences were at hand. Significant differences of various elements stated that the activities in the areas have different impacts on those areas surrounding it, with regard to the associated elemental distribution. Distinct dissimilarities between the T and UF were identified, specifically with regard to the elemental B, Hg, Pt, Tl, Ag and Cd concentrations within the vegetation sampled at the respective sampling points.

As a final point of interest, it can be noted that, as mentioned by Bausinger (2007:269), there could be a decline in the species richness. If there is a specific impact on an area, species with an

exceptional tolerance for high elemental concentrations could for example be dominating such an area (Bausinger, 2007:269). The activities in the T area and annual burning could have been responsible for this phenomenon, as it was noted that the dominant species at these sites were *Themeda triandra* and *Eragrostis curcula*.

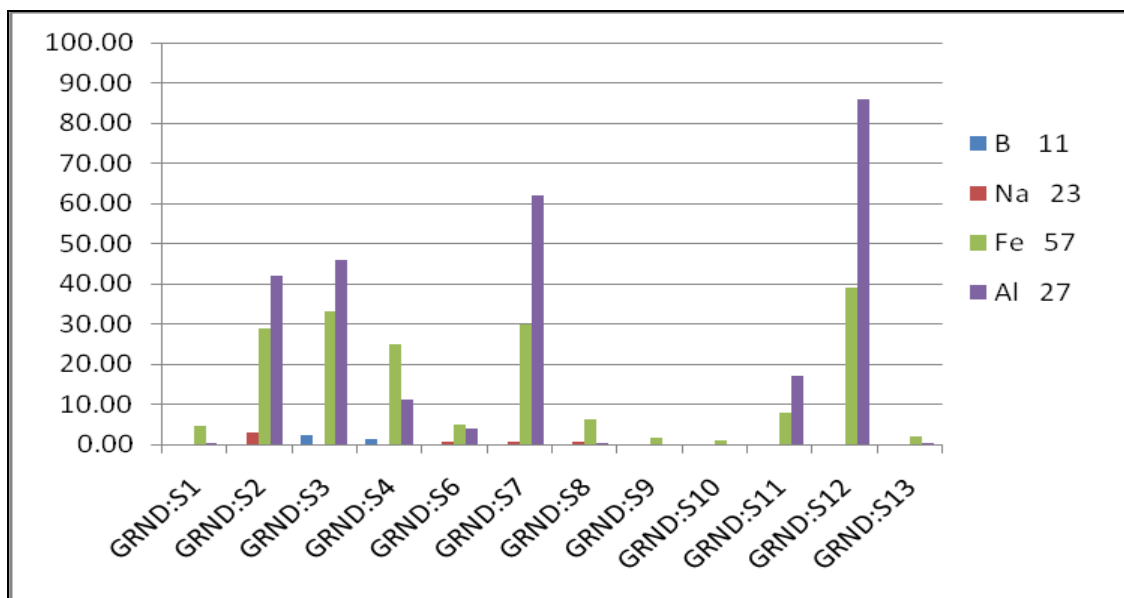
From the results regarding the vegetation presented above, it is clear that the different areas, particularly the T site, have a distinct impact on the area surrounding it. However, it is highly likely that the impact will not be confined to this specific area, but could and probably have affected the areas lower down the gradient as well.

Major differences were seen in the elemental concentrations of the vegetation of the area, as expected, between the different grouped sites in the area at RDM. Areas of importance are the T and UF areas. As mentioned earlier, vegetation and the elements in it could be indicators of the elemental concentration in the soil and the rest of the surroundings (Ne'el *et al.*, 2006:734). Therefore, the results presented already gave an idea of the elements in the surroundings area and the possible impact it could have on the rest of the area.

3.2 Soil

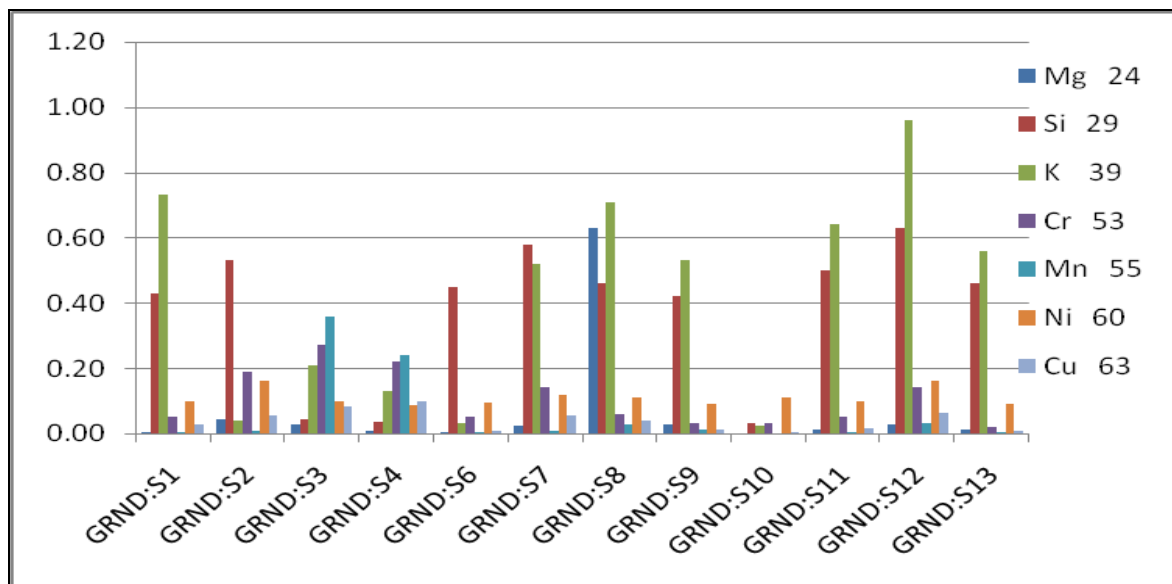
Although no sufficient comparative soil standard data of similar studies was found during this study to compare with the measured elements in the study area, it was compared within and across the sampling area to indicate possible influential activities present in an area or grouping. This allowed the study of the elements in the area and comparisons between the areas where certain activities such as the testing of the ammunition took place.

The concentration of the elements in the soil can be seen as a direct result of any pollution in or around the area. Sampling sites were grouped into the four groups, as previously mentioned (UF, UT, T, AB) to enable further comparisons, and to predict the source of the elemental concentration. The analysed elements were divided into those with higher values and those with lower values in order to aid presentation; all were part of the same sampled soil. This ordering made the comparison between the elements and the sites possible.



Graph 1: The elemental concentration and distribution of B, Na, Al and Fe in the soil at RDM. Sampling sites are identified as GRND=soil, and S1=the specific sites at the facility. The x-axis is represented by the sampling sites and the y-axis by the elemental concentration in ppm (mg/l).

In four of the sampled sites, i.e. GRND: S2, GRND: S3, GRND: S7 and GRND: S12, the Al concentration was the highest followed by Fe in each of the four sites. The highest concentration of Fe was measured in GRND: S12, with a value of 39 ppm. The highest concentration of Al was also measured in GRND: S12, 86ppm. These high concentrations were in all probability specific to the location of the site. GRND: S12 was located in the testing area of the explosives and ammunition. The high concentration of Al in GRND: S7 could be due to the surface runoff that carried components from the T area to the lower areas. In this case, GRND: S7 was situated directly below the testing site and was therefore probably influenced by the runoff.



Graph 2: The elemental concentration and distribution of the elements in the soil sampled at RDM. The x-axis is represented by the sampling sites and the y-axis by the elemental concentration in ppm (mg/l) (abbreviations in appendix, page i).

In Graph 2, the elements with lower concentrations are presented. These elemental concentrations varied between 0 and 1.00 ppm. The elements that drew the most attention, because of the higher concentrations among the rest, were K, Si, Mg and Mn.

The absolute K concentration was the highest of this grouping of elements in all three of the sites, being GRND: S1, GRND: S8, GRND: S9, GRND: S11, GRND: S12 and GRND: 13. These sampling sites were located below the testing (T) and factory areas (F). The sampling site GRND: S10 was located among the sites that constituted part of the testing area (T). Similarly, the Si concentration had higher concentrations in GRND: S2, GRND: S6 and GRND: S7. The concentration of Mg was the highest in sampling site GRND: S8.

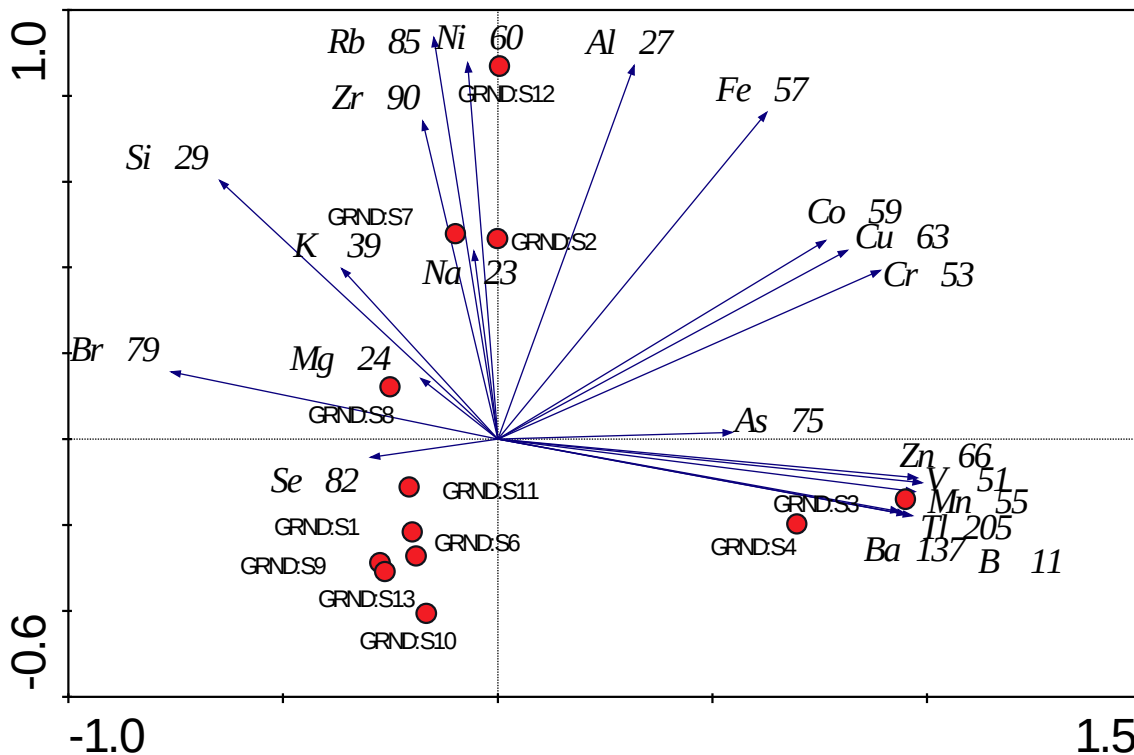


Figure 10: A principle component analysis of the soil's elemental composition, as a result of the ICP-MS measurement, and distribution among the sites at RDM

From the distribution of the elements and the association that each of the sites had with certain elements, it was clear that five definite associations could be identified. These five grouping areas were as follows: GRND: S3 and GRND: S4; GRND: S12, GRND: S7 and GRND: S2; GRND: S8 and finally GRND: S1, GRND: S6, GRND: S9, GRND: S10, GRND: S11 and GRND: S13.

The elements that typified the different sites were Ni, Rb, Al, Zr and Fe in GRND: S12 with a particularly positive association with Ni. The grouping of sites GRND: S1, GRND: S6, GRND: S9, GRND: S10, GRND: S11 and GRND: S13 showed no association with any of the measured elements, except for a slight association of GRND: S1 with Se. It would thus be plausible to assume that a negative association existed with Co, Cu, Cr, Fe and Al.

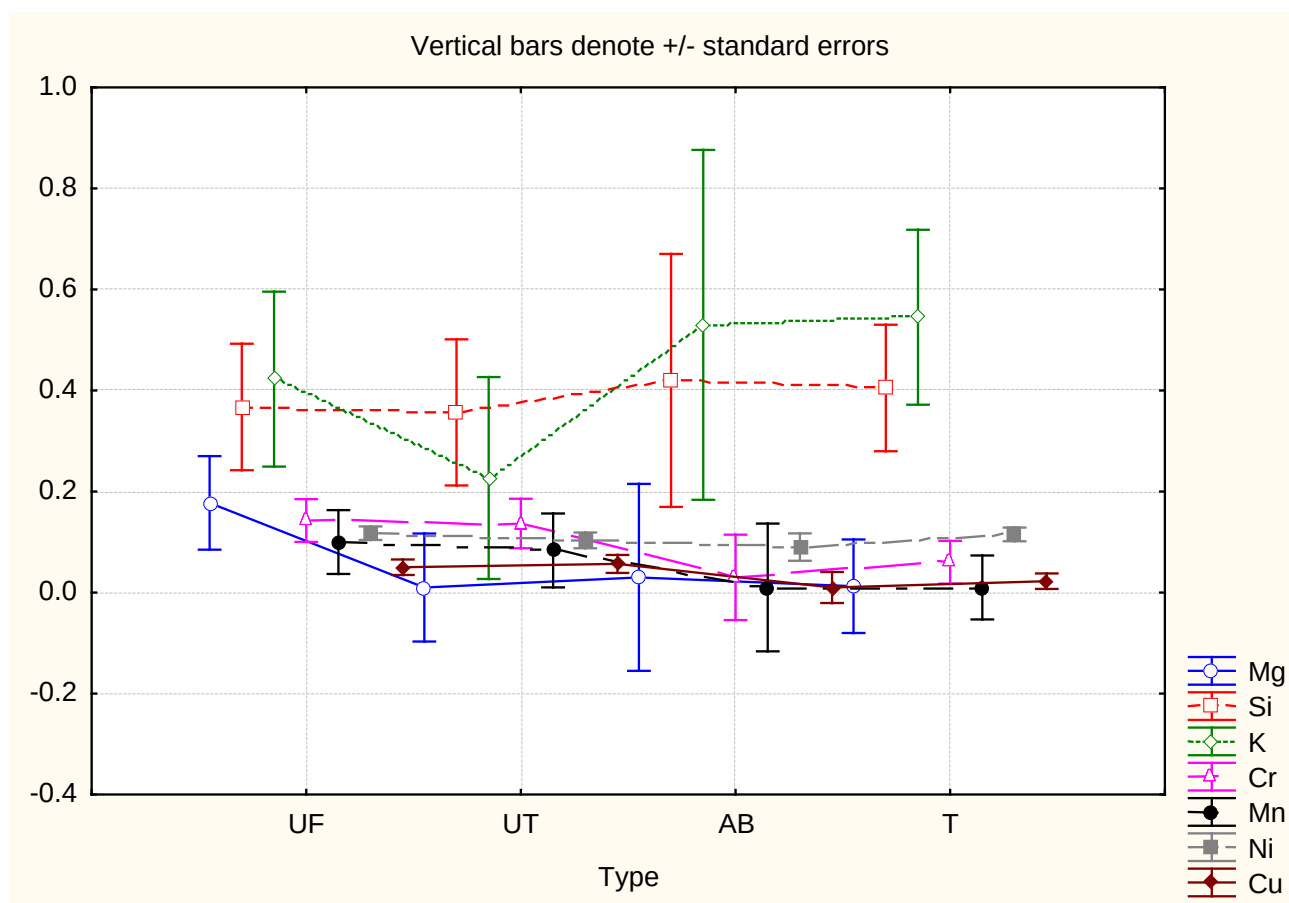
As mentioned previously, a positive association between GRND: S8 and Mg existed. The Na concentration revealed a positive correlation with both GRND: S2 and GRND: S7.

The groupings of the sites, as mentioned earlier, could also be seen in the associations. This further emphasizes the importance and difference in the activities that take place at RDM and the correlations they have with specific elemental compositions (Figure 10).

Table 8: The average elemental concentrations of the elements as measured in the soil at RDM in ppm

	Mg 24	Si 29	K 39	Cr 53	Mn 55	Ni 60	Cu 63
UF							
GRND:S1	0.01	0.43	0.73	0.05	0.00	0.10	0.03
GRND:S2	0.04	0.53	0.04	0.19	0.01	0.16	0.05
GRND:S3	0.03	0.05	0.21	0.27	0.36	0.10	0.08
GRND:S8	0.63	0.46	0.71	0.06	0.03	0.11	0.04
UT							
GRND:S4	0.01	0.04	0.13	0.22	0.24	0.09	0.10
GRND:S6	0.00	0.45	0.03	0.05	0.00	0.10	0.01
GRND:S7	0.02	0.58	0.52	0.14	0.01	0.12	0.06
AB							
GRND:S9	0.03	0.42	0.53	0.03	0.01	0.09	0.01
T							
GRND:S10	0.00	0.03	0.02	0.03	0.00	0.11	0.00
GRND:S11	0.01	0.50	0.64	0.05	0.01	0.10	0.02
GRND:S12	0.03	0.63	0.96	0.14	0.03	0.16	0.06
GRND:S13	0.01	0.46	0.56	0.02	0.00	0.09	0.01

The absolute concentrations of the elements of these groupings were much lower than that of the elemental concentrations in Table 9. Consequently, the differences between the elemental concentrations were small. In order to present this more clearly, the data, as presented in Graph 3, give a much better visual representation of the distribution of the elements in the different groupings.



Graph 3: The standard errors of the elements and the elemental distribution in the soil at RDM sampled at the testing area (T), the area under the factory (UF), the area above the factory (AB) and the area under the testing area (UT)

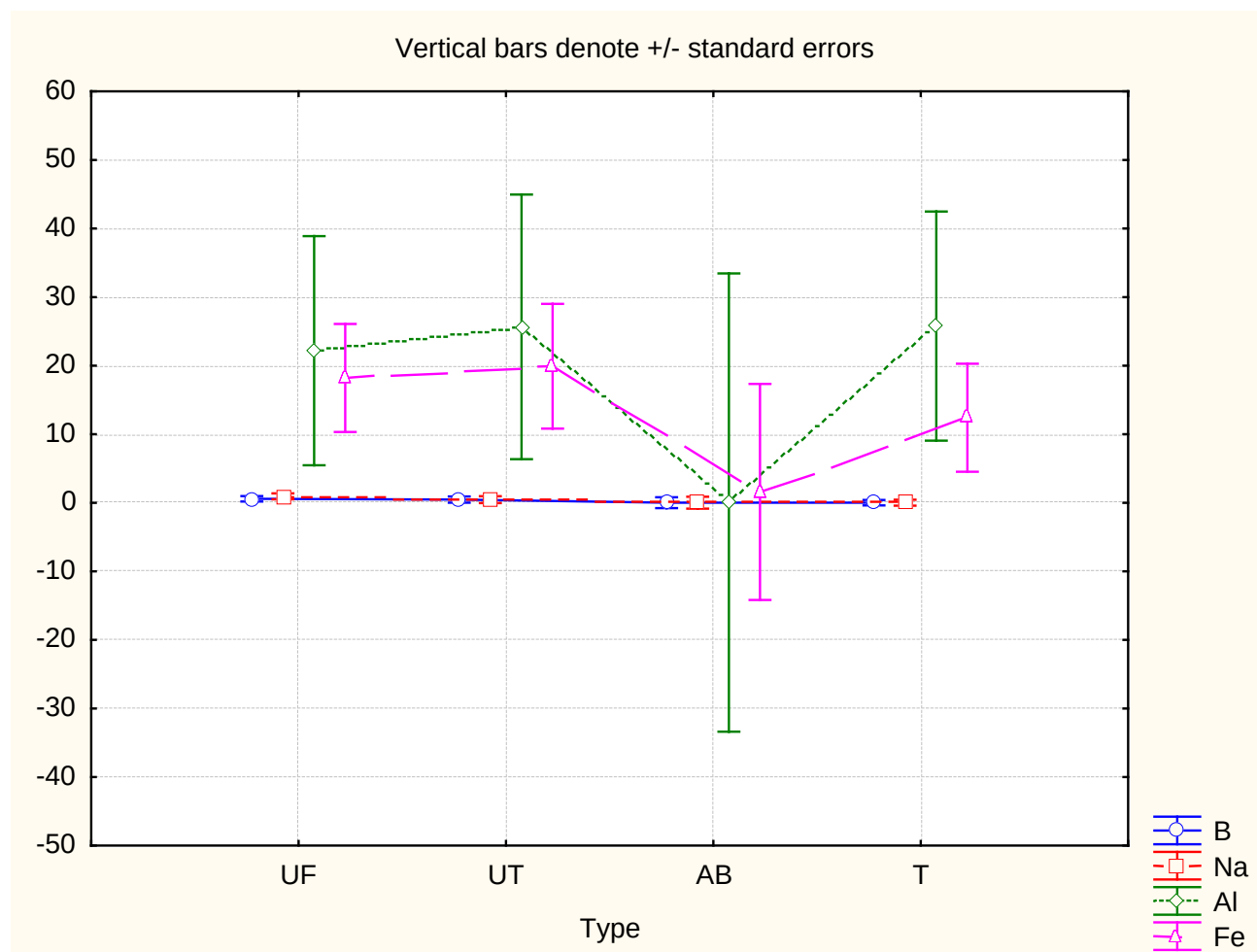
From the data presented in Graph 3, Si was relatively equally distributed across all the sampling sites, that the Mg concentration in the UF area was higher than the rest of the groupings and that the K concentration revealed a difference when UT and T was compared.

Table 9: Average elemental concentration in the soil sampled at RDM

	B	Na	Al	Fe
UF				
GRND:S1	0.04	0.03	0.39	4.60
GRND:S2	0.04	3.00	42.00	29.00
GRND:S3	2.30	0.12	46.00	33.00
GRND:S8	0.04	0.70	0.43	6.30
UT				
GRND:S4	1.40	0.11	11.00	25.00
GRND:S6	0.03	0.58	4.00	4.80
GRND:S7	0.02	0.76	62.00	30.00
AB				

GRND:S9	0.03	0.04	0.05	1.60
T				
GRND:S10	0.01	0.02	0.00	1.00
GRND:S11	0.04	0.03	17.00	7.80
GRND:S12	0.04	0.02	86.00	39.00
GRND:S13	0.03	0.03	0.17	1.90

When the concentrations of the elements present at each of the sites were examined, a relevant difference between the different areas of interest existed.



Graph 4: The standard deviation of the elemental concentrations in the soil at the different grouped sites, the testing area (T), the area under the factory (UF), the area above the factory (AB) and the area under the testing area (UT)

As can be seen from the data presented in Graph 4, which visually represents the average elemental concentration of B, Na, Fe and Al in the four groupings, it is clear that differences in the

concentrations existed when the groupings were compared. It became clear that higher concentrations of the mentioned elements were found in the groupings associated with the testing (T) and the under the testing area (UT) as well as the area under the factory (UF). The lowest concentrations of the elements were found in the area above the factory (AB), which could indicate that these elements might be associated with the testing and manufacturing of munitions at RDM.

Table 10: The significant differences of Na in the soil of the different groups, the testing area (T), the area under the factory (UF), the area above the factory (AB) and the area under the testing area (UT) sampled at RDM

	UF (R:8.0000)	UT (R:9.2500)	AB (R:6.0000)	T (R:2.7500)
UF		1.000000	1.000000	0.339538
UT	1.000000		1.000000	0.064725
AB	1.000000	1.000000		1.000000
T	0.339538	0.064725	1.000000	

The elemental Na concentration was the only elemental concentration among the elements in the soil samples that were analysed that differed statistically significantly within the different identified groupings, specifically between the testing area (T) and the area under the testing area (UT). The concentration of Na in T also differed from UF, but not statistically significantly.

3.2.1 Discussion

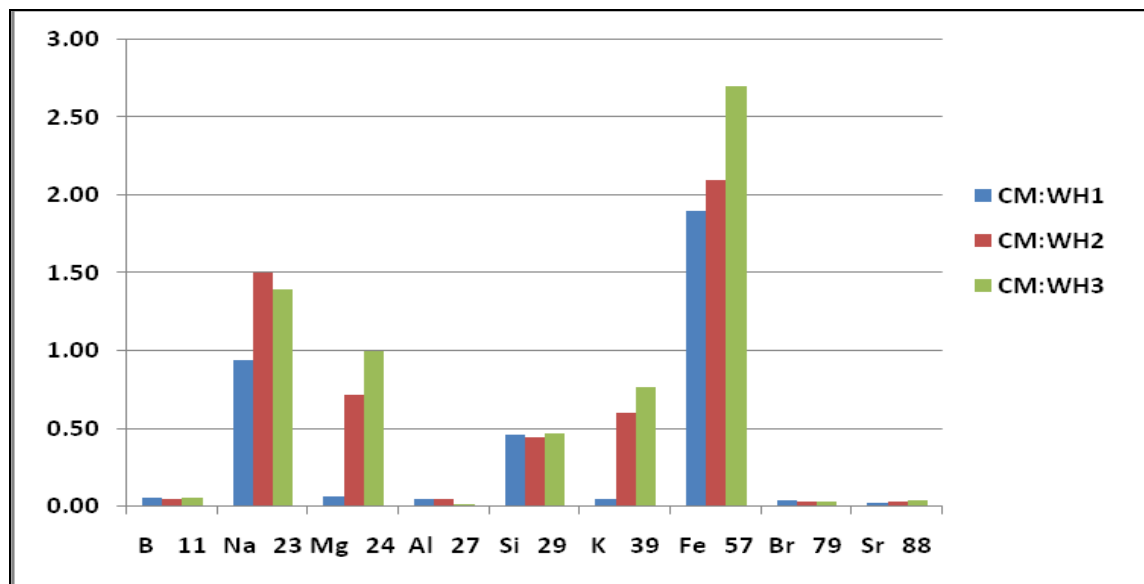
Higher concentrations of Fe and Al were identified in the analyses of the soil samples taken from the study area. According to the grouping of the sites associated with the location of the sites, higher concentrations of Al were present in the area under the factory (UF) as well as in the testing area (T). As for Fe, a similar occurrence could be seen and was also present in the testing area (T), the area under the factory (UF) as well as the area under the testing area (UT). Therefore, the assumption could be made that the testing area (T), under the testing area (UT) and the under the factory area (UF) could be the areas accountable for the elemental occurrences and distribution in the lower regions of RDM. It also became clear within the PCA analysis of the elemental concentrations, that there is a positive association between GRND: S3, GRND: S4 and GRND: S12. As mentioned earlier, GRND: S3 and GRND: S4 are associated with the area under the factory (UF), and GRND: S12 is associated with the testing area (T). The grouping of the study

sites aids in the comparison of the distribution and occurrence of elemental concentrations identified within the sites.

During the comparison of the grouped sites, UT, UF, AB and T, statistically significant differences between the following elements were found in the identified areas – K, Mg, Al and Fe. Therefore, the assumption could be made that the activities associated with the testing and manufacturing of the munitions could play an important role in the distribution of these elements within the study area.

The differences in the elemental concentration and distribution within the different groupings of the sampling sites at RDM could be seen as an indication of the result of the activities taking place. Depending on the bioavailability of these elements, it could be distributed into the food web of the area and exposed the organisms utilising the area to it, which could have a negative effect on the natural processes of the environment itself and the organisms exposed to it.

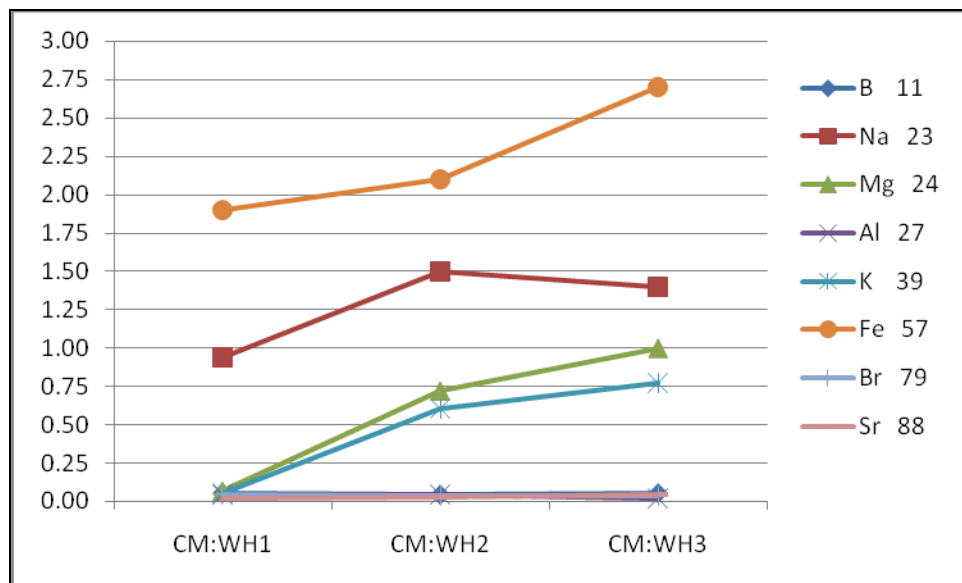
3.3 Catchment areas



Graph 5: The elemental concentration of the catchments of the different waterholes at RDM. Elemental concentration is measured in part per million (ppm). Different catchments are referred to as CM: WH1, indicating that the results are from the catchments area of waterhole 1 and the same for CM: WH2 and CM: WH3. The x-axis represents the elements and the y-axis the elemental concentration in ppm (mg/l).

From the results presented in Graph 5, it would seem as if a gradient of elemental concentration existed when looking at the Fe (2.70mg/l; 1.90mg/l), K (0.77mg/l; 0.05mg/l) and Mg (1.00mg/l;

0.07mg/l) concentrations. All of the highest concentrations were located at the catchment area of waterhole 1 and the lowest at the catchment area of waterhole 3. From the data presented above (and Graph 6 that is visually possibly easier to interpret), it should be clear that the Fe, K and Mg concentrations in the catchments were the highest in the catchment area of watering hole 3. In contrast, the Si, Al and Ni concentrations in the catchments did not seem to differ significantly between the respective catchments of the watering holes. The Na concentration in the catchment area of watering hole 2 was the highest when compared to the catchment areas of watering hole 1 and the catchment of watering hole 3.



Graph 6: The elemental concentration gradient of the elements in the catchments of the different waterholes at RDM. CM=Catchment WH1=waterhole 1. The x-axis represents the sampling sites and the y-axis represents the concentration of the elements in ppm (mg/l).

Despite the fact that Fe had the highest water soluble elemental concentration of the measured elements, it clearly increased the catchment area of watering hole 1 to the catchment area of watering hole 3. Although typified by the lower absolute concentrations, both Mg and K displayed a similar occurrence within the elemental concentrations of the catchments of the different watering holes. If it is realised that all three these elements are highly water soluble, it could serve as circumstantial evidence of some transportation down the natural gradient in the study area of RDM (Figure 1).

Therefore, T, situated in the highest on the gradient, could potentially have impacted the lower regions of the study area. The activities associated with the T and the UF grouping areas could be

responsible for the elements found in CM: WH3, since elemental dispersal takes place through surface runoff in the area.

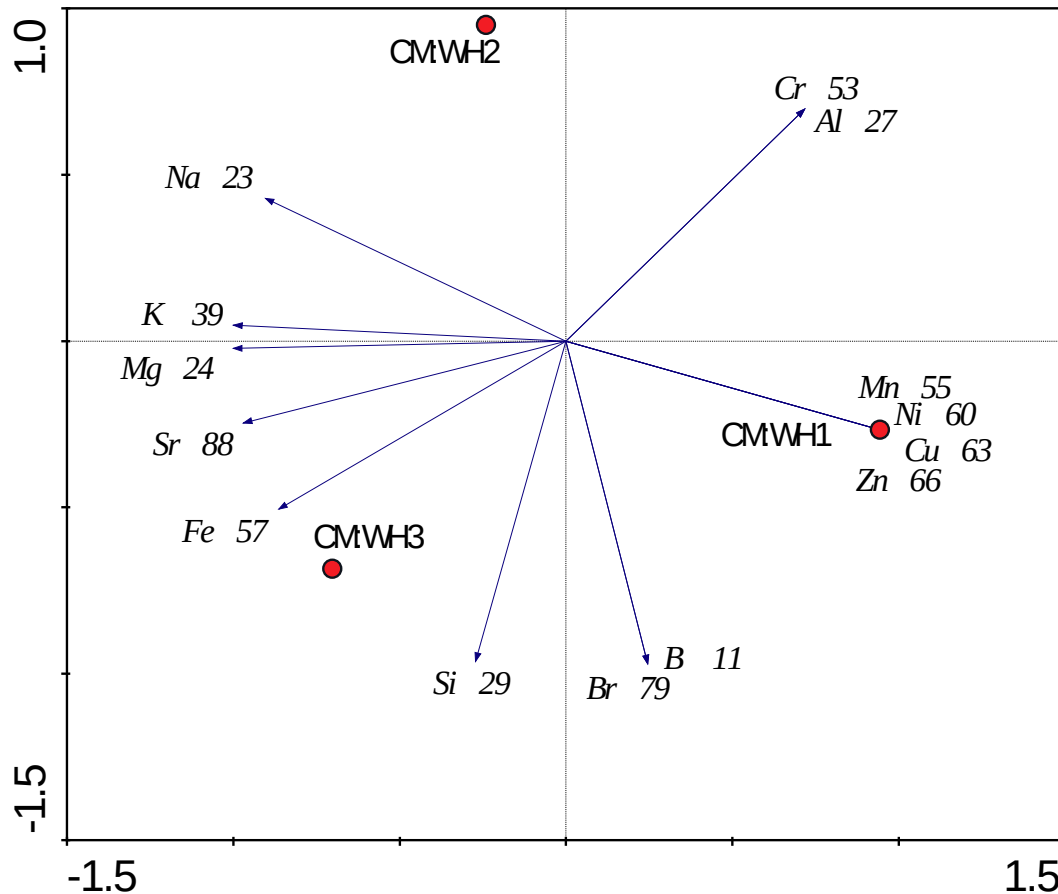


Figure 11: PCA of the catchments of the different waterholes. The abbreviations CM: WH1 to CM: WH3 identify the catchments of the different waterholes

From the PCA ordination data of the concentrations of the different elements quantified in the three respective catchment areas of the watering holes (Figure 11), it is clear that there was almost no resemblance between the three catchments.

The elemental Mn, Zn, Cu and Ni concentrations were more closely associated with the catchments of WH1 than with the other catchments. This catchment also showed a negative association with especially Na, Mg and K. CM: WH3 had a positive association with Fe and Si. As for CM: WH2, it showed a negative association with the B, Br and Si concentrations.

3.3.1 Discussion

Among the elements quantified, the Fe, Na, Mg and K concentrations were found to be elevated compared to the other elements identified at the sites. It is noteworthy that these elevated elemental concentrations were all located in the catchment of watering hole 3. With the exception of Na, these elements were found to typify the catchment of watering hole 1. If the elements were distributed by the surface runoff towards the lower regions, additional elements from the factory and the testing area could have contributed to the higher concentrations of these elements found to be present in the groupings lower down the slope.

According to the PCA ordination conducted for the catchments, there was no resemblance between the three sampled areas. The site with the greatest difference was the catchment of waterhole 2. There were also no distinct elemental concentrations associated with this specific site.

The concentrations of Mn, Ni, Cu and Zn showed a positive association with waterhole 1's catchment. This waterhole was also associated with the T area of RDM and was located directly underneath and in the surface runoff route of that specific area. Therefore, it was not totally unexpected that the elemental concentration and distribution in this area would have differed from the rest. No individual elemental concentration associated with the catchment area of waterhole 3 was found to exist.

After consideration, it became apparent that the T area and the factory area might be the areas responsible for introducing some of the elements into the area, from where it is dispersed to the lower area along the slope.

3.4 Waterholes

It would be fair to assume that the largest fraction of the elemental concentrations found to be present in the water of the waterholes could be the result of activities elsewhere, probably higher up the gradient. These three waterholes were formed and sustained by natural processes, such as rainfall and surface runoff. During the surface runoff of the water, elements were in all probability carried to the lower located areas and gathered in the waterholes. It was expected that the three waterholes' elemental composition and concentrations would not be the same. Waterhole 1 (WH1)

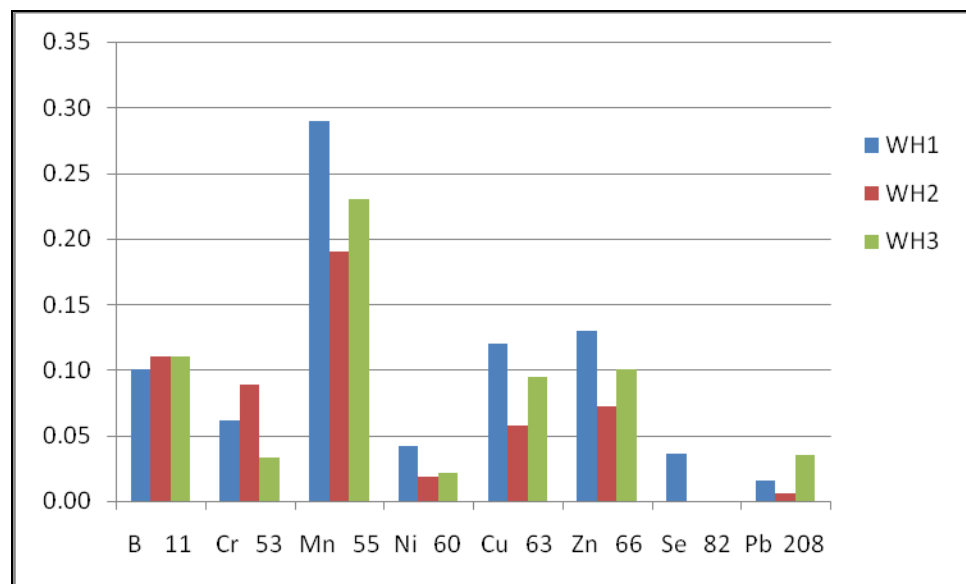
was situated under the T area, waterhole 2 (WH2) is located in the UF area and the lowest of the three waterholes was waterhole 3 (WH3) (Figures 2 and 3).

Table 11: Recommended maximum levels of elemental concentrations in the drinking water of livestock (Puls, 1994).

	Livestock	Units
Alkalinity	<2.0	mg/L
Aluminium	<5.0	mg/L
Ammonia	-	mg/L
Antimony	-	mg/L
Arsenic	<0.05-0.2	mg/L
Barium	<1.0	mg/L
Beryllium	<1.0	mg/L
Bicarbonate (HCO₃)	<1.0	mg/L
Boron	<5.0-3.0	mg/L
Cadmium	<0.05	mg/L
Calcium	<1.0	mg/L
Caesium	-	Bq/L
Chloride	<1.0	mg/L
Chromium	<0.1	mg/L
Cobalt	<1.0	mg/L
Copper	<0.5	mg/L
Cyanide	<0.2	mg/L
Fluoride	<1.2-2.0	mg/L
Hardness (CaCO₃)	<2.0	mg/L
Iodine	1	mg/L
Iron	<0.4	mg/L
Lead	<0.05-0.1	mg/L
Magnesium	<90-250	mg/L
Manganese	<0.05	mg/L
Mercury	<0.003-0.01	mg/L
Molybdenum	<0.06	mg/L
Nickel	<1.0	mg/L
Nitrogen	<23	mg/L
Nitrate	<100	mg/L
pH	5.5-8.3	mg/L
Phosphate	<0.7	mg/L
Potassium	<20	mg/L
Radium	<1.0	Bq/L
Selenium	<0.01-0.05	mg/L
Silver	-	mg/L

Sodium	<150-800	mg/L
Strontium	<10	Bq/L
Sulphate	<500	mg/L
Uranium	<0.2	mg/L
Vanadium	<0.1	mg/L
Zinc	<5.0-25	mg/L

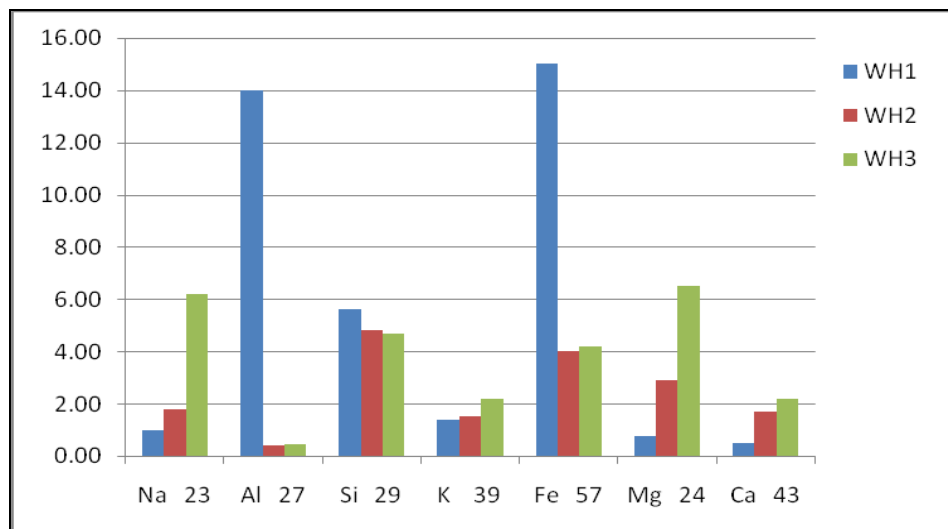
During the comparison of the study area's watering holes' elemental concentrations with that of the recommended maximum levels provided by Puls (1994), as presented in Table 11, it became apparent that the majority of the elemental concentrations fell well within the allowed margins proposed by Puls (1994). The Fe, Ca, Al and Mn exceeded the recommended concentrations, while the K, MG and B concentrations were lower than the proposed maximum level. Although these elements occurred in higher concentration than the maximum allowance, it is unclear what the effects of this might be on the antelope with varied daily and seasonal intake, but with long-term exposure. As has been previously described in section 3.2, the results of the watering holes' elemental concentrations were ordered to aid in providing a more visual comparison of the elements present in the study area.



Graph 7: The elemental concentrations and distribution in the waterholes in the RDM area. The x-axis represents the elements and the y-axis the elemental concentration in ppm (mg/l).

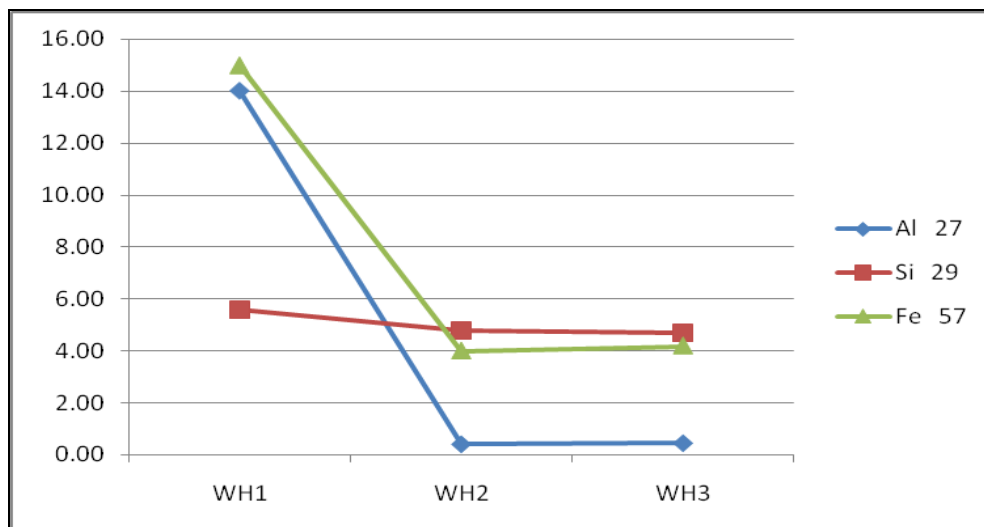
From the results presented in Graph 7, that quantified the concentrations of the elements within the watering holes in the study area, it became clear that in the first grouping the Mn concentration was the highest in all three watering holes. The highest Cu and Zn elemental concentrations were also measured in WH1. An unexpected finding was that the elemental concentration at the sites had a

tendency to be the highest in WH1, the lowest in WH2 and a higher value than the lowest would be measured in WH3. Se had a noticeably higher concentration in WH1 in comparison with the other watering holes.



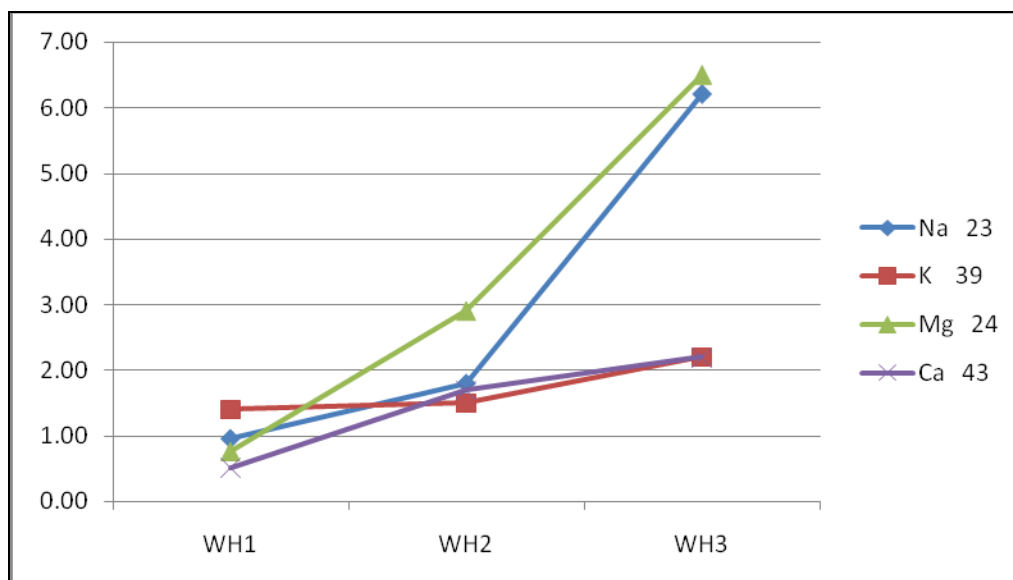
Graph 8: The elemental concentration of the elements with the higher absolute concentration and distribution in the waterholes in the RDM area. The x-axis represents the elements and the y-axis the elemental concentration in ppm (mg/l).

The data presented in Graph 8 represents the elemental concentration within the watering holes in RDM with higher absolute concentrations than the elemental concentration in the watering holes presented in Graph 7. Clearly noticeable was the elevated AL and Fe concentrations that typified WH1. The Al concentration in WH1 was measured on average to be ± 14 ppm, in contrast to concentrations of less than 1 ppm found to be present in the other two watering holes. The highest Na, Ca and Mg elemental concentrations were found to be presented in WH3. With careful scrutiny, the existence of possible concentration gradients in terms of the Na, Si, K, Mg and Ca elemental concentrations from WH1 to WH3 became evident. This trend is visually presented in Graph 10 and discussed in more detail later on.



Graph 9: The elemental concentration gradient that shows a decrease from WH1 to WH3. The x-axis represents the sampling sites and the y-axis the elemental concentration in ppm (mg/l).

The elemental Al, Fe and to a lesser extent Si concentrations decreased from WH1 to WH3 (Graph 9). The highest elemental concentration was measured at WH1 and the lowest Al, Si and Fe elemental concentrations were measured at WH3. This indicated that an elemental concentration of the mentioned elements decreased as the distance between the testing area (T) and the watering holes increased (Figures 2 and 3).



Graph 10: Elemental concentration gradient present at the waterholes of RDM factory ground. X-axis represents the sampling sites and the y-axis the elemental concentration in ppm (mg/l).

According to Graph 10, an increase in the Na, K, Mg and Ca elemental concentrations measured within the watering holes at RDM showed an increase in the mentioned element's concentration as the distance between the T area increased.

Possible explanations for the elemental gradients present in the waterholes could firstly be due to the immobility of certain elements and their inability to be distributed further along the way to the waterholes at the lower areas of RDM. Secondly, the possible uptake of elements by the vegetation might decrease the concentration of the elements present in the waterholes towards the lower regions. Thirdly, an accumulation of elements in the waterholes towards the lower areas might result in an increase in the elemental concentration towards WH3. Lastly, the effective management of the elements introduced into the area during the production and testing processes that took place at RDM might also have an effect on the elemental concentrations present in the areas, either way resulting in different elemental concentrations in the waterholes.

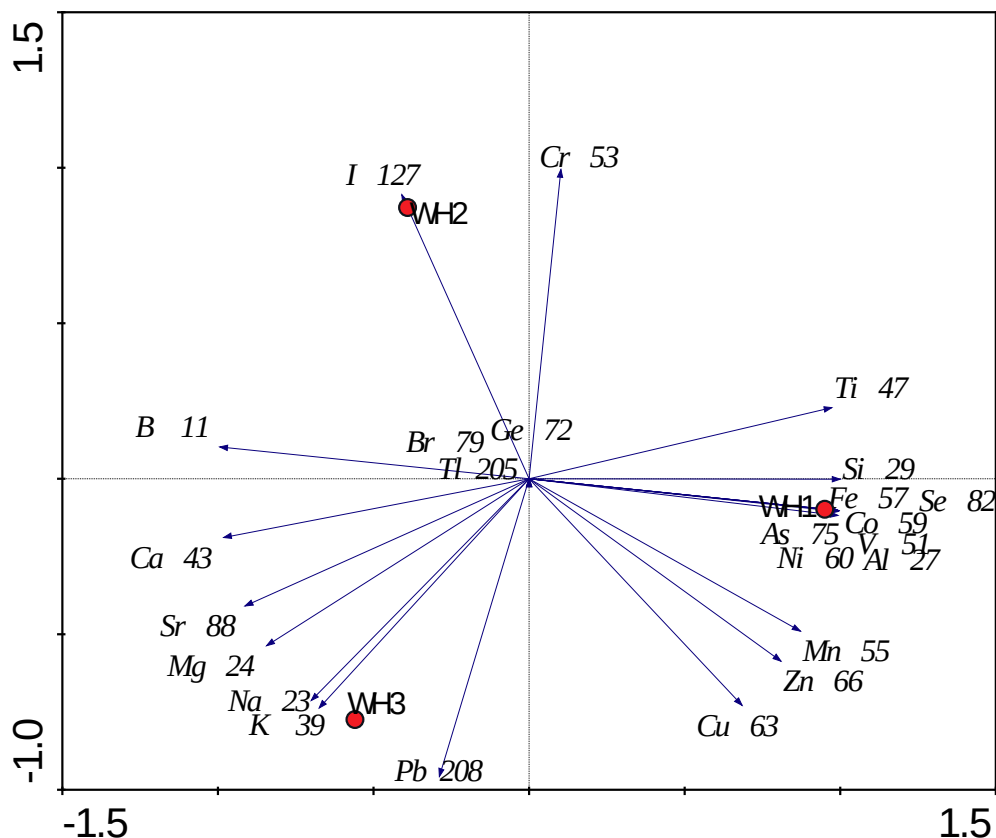


Figure 12: Principle component analysis of the waterholes and associated elemental concentrations at RDM. WH1, WH2 and WH3 are the different waterholes in the area.

The three waterholes on the RDM site clearly differ significantly in terms of their water soluble elemental concentrations, as can be seen from the PCA data presented in Figure 12. In broad terms, WH1 was found to be positively associated with the Fe, Al, Si, Co, As, V, Se and Ni elemental concentrations, WH2 with the Cr and I elemental concentrations and WH3 with the K, Na, Pb and Mg elemental concentrations.

In the comparison of the watering holes and their catchments' elemental concentrations and distributions according to the PCA analyses, it became apparent that the Ni elemental concentrations had a positive association with WH1 and its catchment area (CM: WH1), and the Cr elemental concentration had a positive association with WH2 and its catchment area (CM: WH2). Similar to this, Na, K, Mg, Al and Fe elemental concentrations showed an increase in the watering holes as well as in the catchment areas associated with each of the watering holes at RDM, from watering hole 1 to watering hole 3.

3.4.1 Discussion

During the comparison made with the recommended maximum levels of elements in the drinking water of livestock (Puls, 1994), it became clear that concentrations of Al, Ca, Fe and Mn were higher than the elemental concentrations as recommended by Puls (1994). As for the B, Mg and K elemental concentrations, they were lower than the recommended concentrations in the tissue of the livestock as recommended by Puls (1994).

Higher concentrations of Mn, Cu and Zn were found in waterhole 1 than in the other watering holes. Waterhole 1, according to the areas with distinct activities, was located directly underneath the T area of the ammunitions and explosives (Figures 2 and 3). Due to the specific location of WH1, it is possible that it could be exposed to more elemental residue than some of the other areas. The elements could be distributed by natural processes, such as the surface runoff during rains, annual burning as well as by the antelope in the area.

According to the results of the waterholes analysed, it became apparent that an elemental gradient exists within the watering holes, with the Na, K, Mg and Ca elemental concentrations increasing from watering hole 1 to watering hole 3. In contrast with this, the Al, Si and Fe elemental concentrations decreased from watering hole 1 to watering hole 3. Therefore, the only waterhole

that was not directly affected by the activities taking place at RDM's factory area or testing area, was waterhole 3.

The elements associated with waterhole 1 were Fe, Si, Co, Ni and Al. The significance of the associations of these elements with waterhole 1 was that these elements were also associated with ammunition and explosives (Bausinger, 2007:260). It can therefore be assumed that the surface runoff in the area may have carried elements to the lower areas, and in this case collected at lower areas to form the waterholes. Waterhole 2 had a positive association with I and Cr, while waterhole 3 had a positive association with K, Na and Pb.

The distribution of the elements in the waterholes made it clear that the activities surrounding the T area and the factory could have been responsible for the distribution of the elements in this specific area. In a comparison of the elemental concentrations in the vegetation and the soil, according to the groupings mentioned above, it became clear that some similarities existed between the groupings of the soil and vegetation. The average highest Cu and Fe elemental concentrations were measured in the UT area's vegetation and showed a similar pattern in the soil of the UT area. The highest average B elemental concentration was measured in the vegetation and soil of the UF area, and measured the second highest average concentration in both the soil and vegetation in the UT area. As for the average Al elemental concentration, it became clear that the highest measurements were also made in the T area within the vegetation and the soil at RDM.

3.5 Tissue analysis

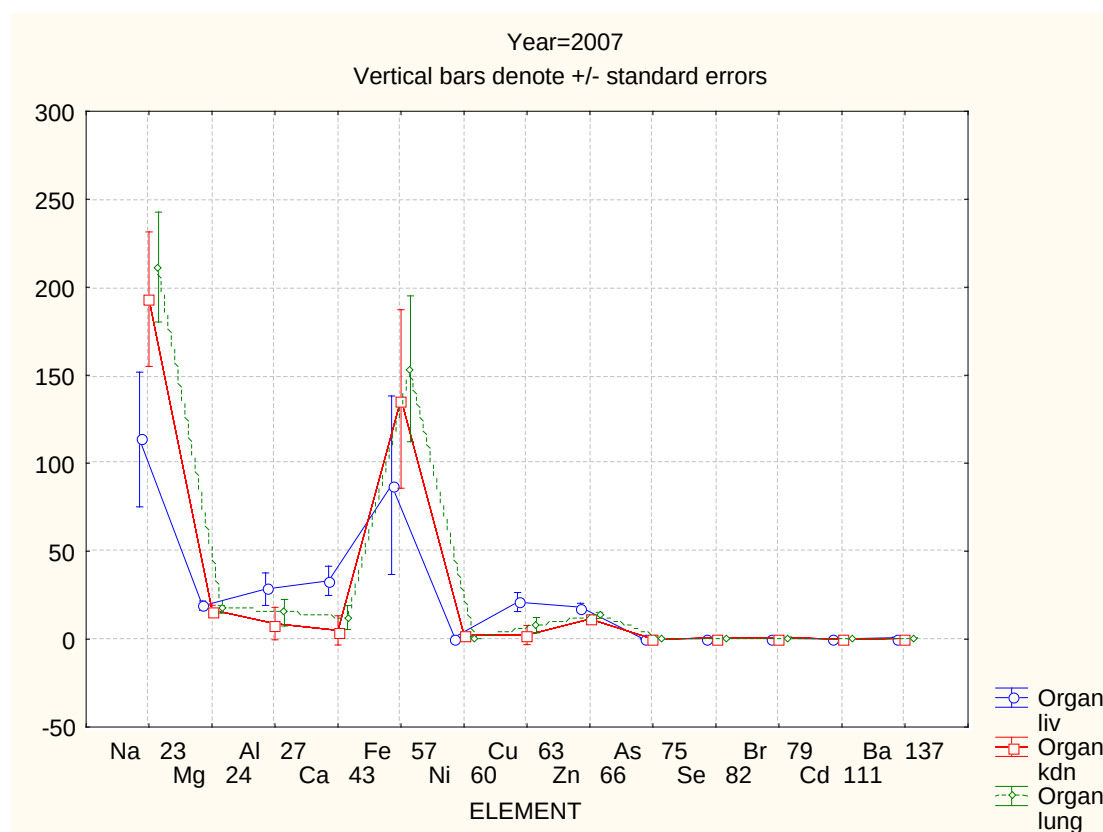
Since no antelope specific elemental concentration data per element, species or per organ could be found, the data as presented by Puls (1994) was used as some point of reference to compare the data for the antelope on the RDM site with. The study was done for two years. In the first year, the study was accompanied with lower rainfall (an average rainfall of 32.8mm per month was measured in 2007), and in the second year in which samples were collected, a higher rainfall season of 38.55mm per month was measured at the Boskopdam weather centre. Even though the difference in the overall average rainfall per month does not differ greatly, a higher average was measured during January to April in 2008 than in 2007, which is the period of active growth for vegetation.

Table 12: The normal elemental concentrations found to be present in cattle (Puls, 1994)

Element	Liver	Kidney	Units
Al	<1.0-5.0	<2.0-6.0	ppm wet weight
As	0.004-0.4	0.018-0.4	ppm wet weight
Ba	-	-	ppm wet weight
B	0.5-6.0	4	ppm dry weight
Br	4.0-20	30-90	ppm dry weight
Cd	0.02-1.0	0.05-1.5	ppm wet weight
Ca	30-200	45-200	ppm wet weight
Cl	-	-	
Cr	0.04-3.8	0.05-6.2	ppm wet weight
Co	<0.02-0.085	0.071	ppm wet weight
Cu	25-100	4.0-6.0	ppm wet weight
F	-	-	
I	<0.094	-	ppm wet weight
Fe	45-300	30-150	ppm wet weight
Pb	0.1-1.0	0.2-2.0	ppm wet weight
Li	6.3-7.0	9.4-19.1	ppm wet weight
Mg	100-250	50-200	ppm wet weight
Mn	2.5-6.0	1.2-2.0	ppm wet weight
Hg	0.0007-0.06	0.008-0.09	ppm wet weight
Mo	0.14-1.4	0.22-0.57	ppm wet weight
Ni	0.1-0.6	0.15-0.50	ppm wet weight
P	2.0-4.0 (ppm wet weight)	8.0-13.0 (ppm dry weight)	
K	-	-	
Se	0.25	1.00-1.50	ppm wet weight
Na	900-1800	-	ppm wet weight
Sr	0.19	0.52	ppm dry weight
Tl	<0.05	0.05-0.06	ppm wet weight
U	0.008	-	ppm dry weight
V	0.006-0.007	-	ppm wet weight
Zn	25-100	18-25	ppm wet weight
W	0.0005	-	ppm wet weight

Table 13: Average elemental concentrations quantified for the liver, kidney and lung tissue of the antelope in the study area, measured in ppm dry weight

Elements	Liver	Kidney	Lung	Units
Na	113.50	193.25	211.50	ppm dry weight
Mg	19.00	16.65	17.00	ppm dry weight
Al	28.43	8.85	15.00	ppm dry weight
Fe	87.50	136.50	153.67	ppm dry weight
Ca	33.18	4.98	12.35	ppm dry weight
Cu	21.08	2.35	7.93	ppm dry weight
Zn	18.25	11.45	13.50	ppm dry weight
Ni	1.12	2.33	1.14	ppm dry weight
As	0.04	0.04	0.03	ppm dry weight
Se	0.26	0.64	0.46	ppm dry weight
Br	0.54	0.85	1.01	ppm dry weight
Cd	0.04	0.11	0.03	ppm dry weight
Ba	0.83	0.45	0.59	ppm dry weight



Graph 11: The standard errors of the elemental concentrations in the three different tissue types from tissue of the antelope sampled at RDM. The x-axis represents the elements measured and the y-axis represents the elemental concentrations of the elements measured in 2007.

During the comparison of the elemental concentration in the tissue of the antelope with that of the cattle as presented by Puls (1994), it became apparent that, for the most part, the elemental concentrations fell well inside the normal concentration range proposed for cattle.

From the elemental concentrations quantified in the different organ tissues of the antelope on the RDM site (Table 13 and Graph 11) it became evident that both the Al and Ni concentrations were higher in the liver and kidney tissue in the antelope than that proposed by Puls (1994). Furthermore, the As and Fe concentrations in the kidney tissue of the antelope also exceeded the proposed normal range in cattle. Despite this, it should be noted that both the Na and Fe concentrations in this tissue was, on average, higher than that found in the liver and kidney tissue.

In order to make proper comparisons, the different organ tissue results of the different antelope species were pooled together and referred to as group data, *antelope*. The concentrations of the other elements quantified in the lung tissue did not differ statistically significantly from that measured in the other tissue. For the most part, it was less than the elemental concentration in the liver, but a higher elemental concentration was measured than in the kidney tissue.

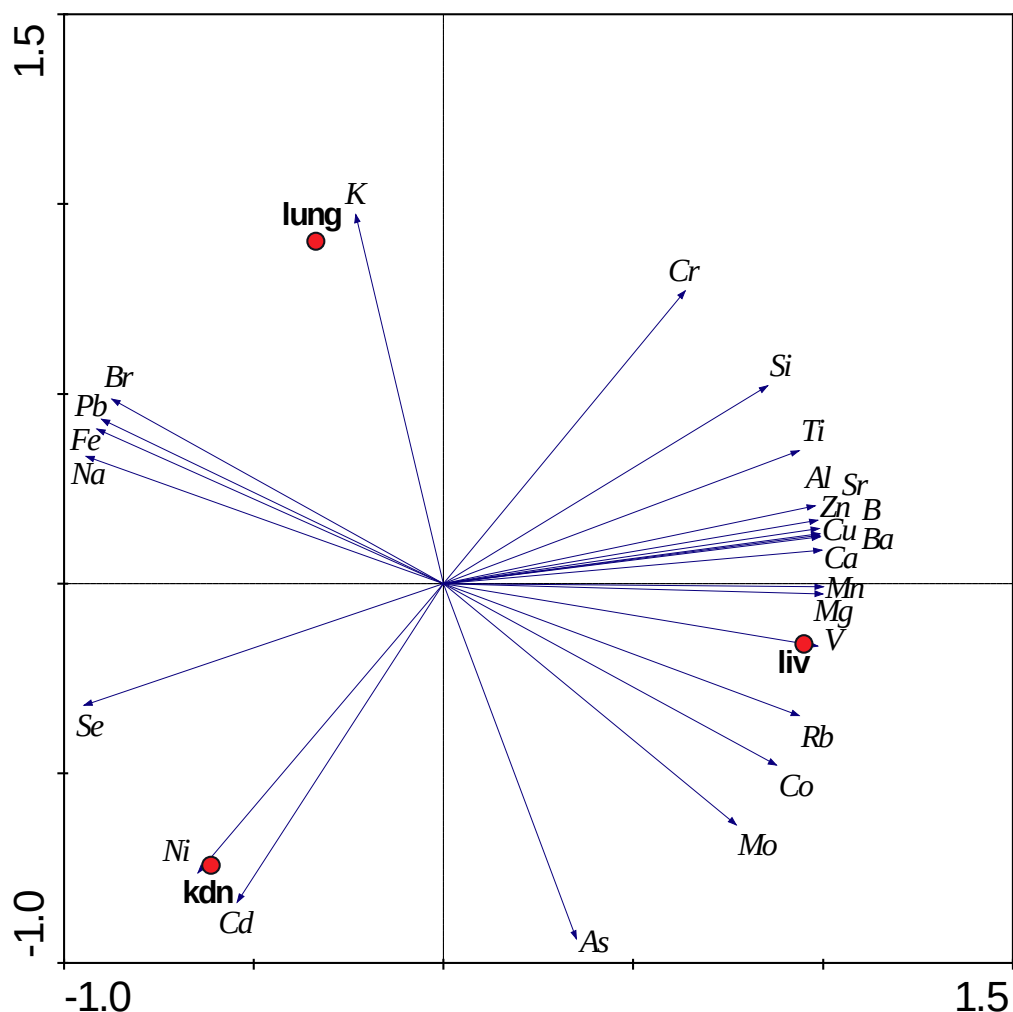


Figure 13: PCA analysis of the elemental concentration and distribution among the kidney (kdn), liver (liv) and lung tissue of antelope sampled and analysed in 2007

Four distinct groupings were identified when a PCA ordination (Figure 13) was conducted on the elemental concentrations quantified in the different organ tissue for the antelope at the RDM site. The three different tissue types and a grouping of the elements (Br, Pb, Fe and Na) became apparent. The lung tissue was found to be strongly positively associated with the K concentration, the kidney tissue with the Ni and Cd concentrations and the liver tissue with the Mg, Mn, V, Rb and Co concentrations, while the three tissue types clearly had negative associations with the As, Mo and Co elemental concentrations in the case of the lung tissue, with the Cr, Si, and Ti elemental concentration in terms of the kidney tissue and with the Pb, Br, Fe and Na elemental concentrations in the case of the liver tissue.

A comparative statistical analysis of the Mn, Ni and As concentrations in the different tissue types revealed that, despite obvious concentration differences between the Mn concentrations in the liver and kidney tissue (Table 14) in terms of the Ni concentration between the kidney and lung tissue (Table 15) and in terms of the As concentrations between the kidney and lung tissue (Table 16), none of these differences were statistically significant.

Table 14: A comparison between the Mn concentrations in the tissue of the antelope sampled in 2007

	Liver (R:11.500)	Kidney (R:5.5000)	Lungs (R:6.1667)
Liver		0.1276	0.1448
Kidney	0.1276		1.0000
Lungs	0.1448	1.0000	

Table 15: A comparison between the Ni concentrations in the tissue of the antelope sampled in 2007

	Liver (R:6.7500)	Kidney (R:10.500)	Lungs (R:6.00)
Liver		0.6147	1.0000
Kidney	0.6147		0.2869
Lungs	1.0000	0.2869	

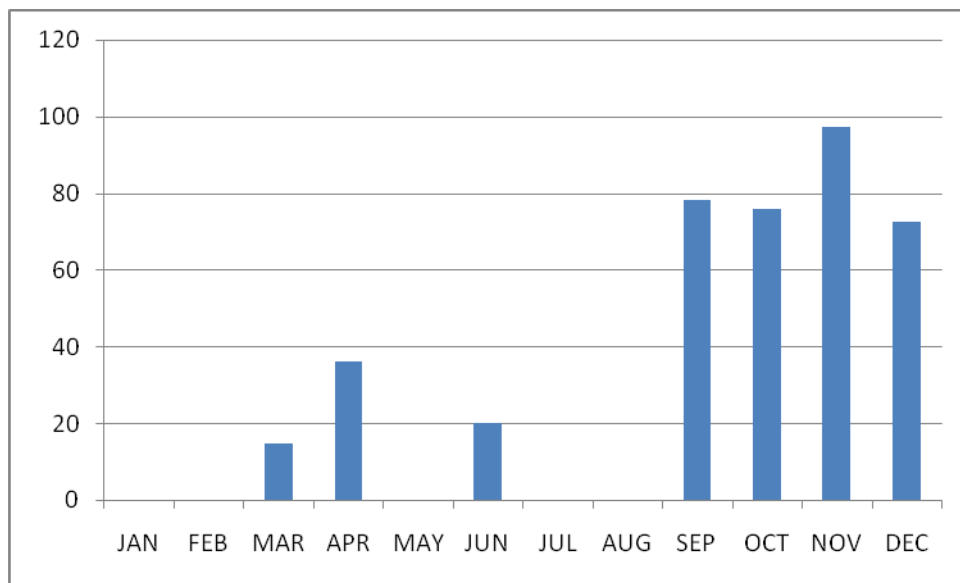
Table 16: A comparison between the As concentrations in the tissue of the antelope sampled in 2007

	Liver (R:7.500)	Kidney (R:9.3750)	Lungs (R:6.2500)
Liver		1.0000	1.0000
Kidney	1.0000		0.7415
Lungs	1.0000	0.7415	

It seemed as if an additional factor could have had an influence on the elemental concentration within the organ tissue of the antelope at the RDM site, assuming that the activities taking place at RDM stayed relatively constant. It became apparent that the rainfall during the study time differed in the two consecutive years, and could influence the concentrations of the exposed elements due to the dilution effect.

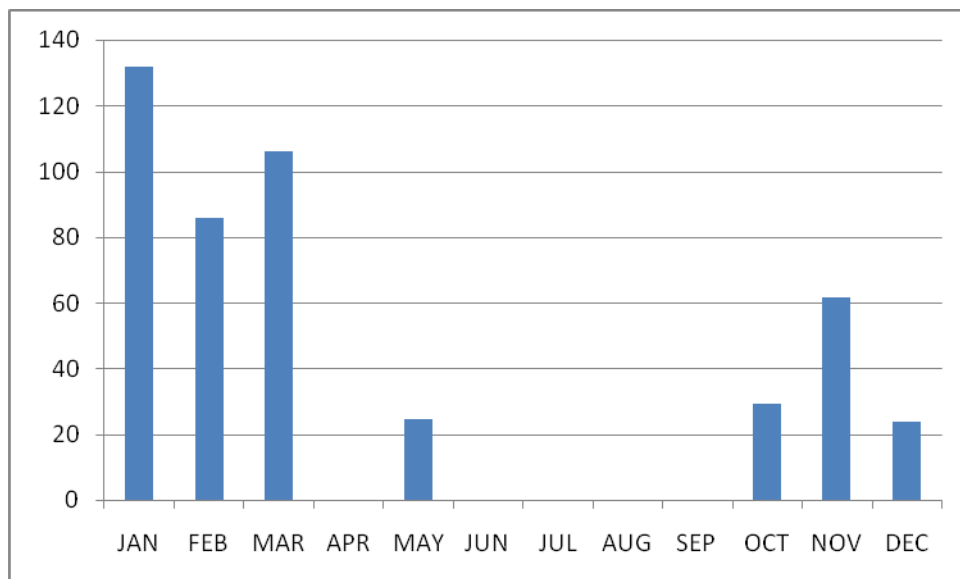
In order to evaluate the potential effect of the different rainfall regimes on the elemental content in the organ tissue at the RDM site, it was hypothesised that a decrease in elemental concentration would take place with the increase in rainfall. The number of elements is fixed, but their concentrations can differ. This could also influence the elemental concentrations' availability to the antelope.

The elemental concentration within the vegetation might be lower or there might simply be more biomass available. During the periods of lower rainfall, less biomass will be produced by the more tolerant plant species in the area.



Graph 12: Monthly rainfall (mm) recorded in the Boskopdam area in 2007, provided by the South African Weather Services

From the rainfall data presented in Graphs 12 and 13, it can be seen that a higher average rainfall was measured during September to December and a lower average during January to April of 2007. As explained above, the rainfall period studied would be from January to April prior to the hunting season. Therefore, a lower rainfall season will hypothetically result in elevated elemental concentrations in the vegetation and finally in the antelope.

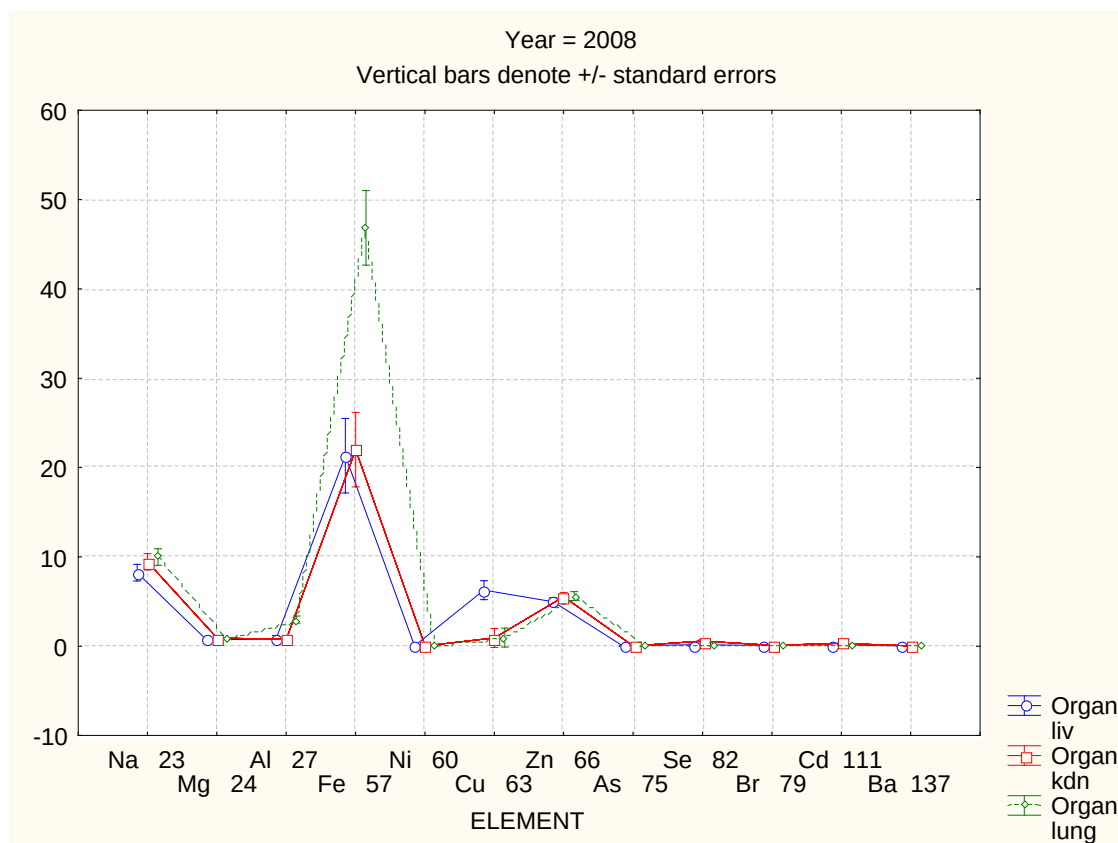


Graph 13: Monthly rainfall (mm) recorded in the Boskopdam area in 2008, provided by the South African Weather Services

A clear difference in the total amount of rainfall that occurred during the 2007 growing period (Graph 12) and 2008 growing period (Graph 13) is apparent from the rainfall data supplied by the South African Weather Services. The study area at RDM is situated in the Boskopdam area, therefore it is relevant to use the rainfall data measured at the Boskopdam weather station located approximately 5km from the study area.

Table 17: Average elemental concentration of the tissue sampled in 2008

Elements	Kidney	Liver	Lung	Units
Na	9.45	8.23	9.98	ppm dry weight
Mg	0.94	0.72	0.83	ppm dry weight
Al	0.77	0.79	2.97	ppm dry weight
Fe	22.00	21.33	46.83	ppm dry weight
Si	0.08	0.08	0.08	ppm dry weight
K	6.83	6.82	7.65	ppm dry weight
Cu	0.92	6.28	0.97	ppm dry weight
Zn	5.53	4.97	5.62	ppm dry weight
B	0.40	0.42	0.41	ppm dry weight
Ni	0.04	0.03	0.05	ppm dry weight
Mn	0.33	0.53	0.21	ppm dry weight
Cr	0.53	0.43	0.47	ppm dry weight
Co	0.02	0.02	0.02	ppm dry weight
As	0.10	0.09	0.09	ppm dry weight
Se	0.32	0.17	0.06	ppm dry weight
Br	0.05	0.03	0.05	ppm dry weight
Rb	0.01	0.02	0.02	ppm dry weight
Cd	0.04	0.03	0.01	ppm dry weight
Ba	0.58	0.17	0.19	ppm dry weight
V	0.15	0.13	0.14	ppm dry weight



Graph 14: The standard error of the elemental concentration in the organ tissue sampled in 2008. The x-axis represents the elements measured and the y-axis represents the elemental concentration in ppm dry weight.

With the exception of the V concentration that was 0.06ppm higher in the liver than that measured in the cattle, the elemental concentrations quantified in the organ tissue sampled during the wetter 2008 growing season were well in accordance with that proposed by Puls (1994). Similar to the data for the drier growing period, the concentration in the lung tissue was found to be higher than in the other organ tissue sampled.

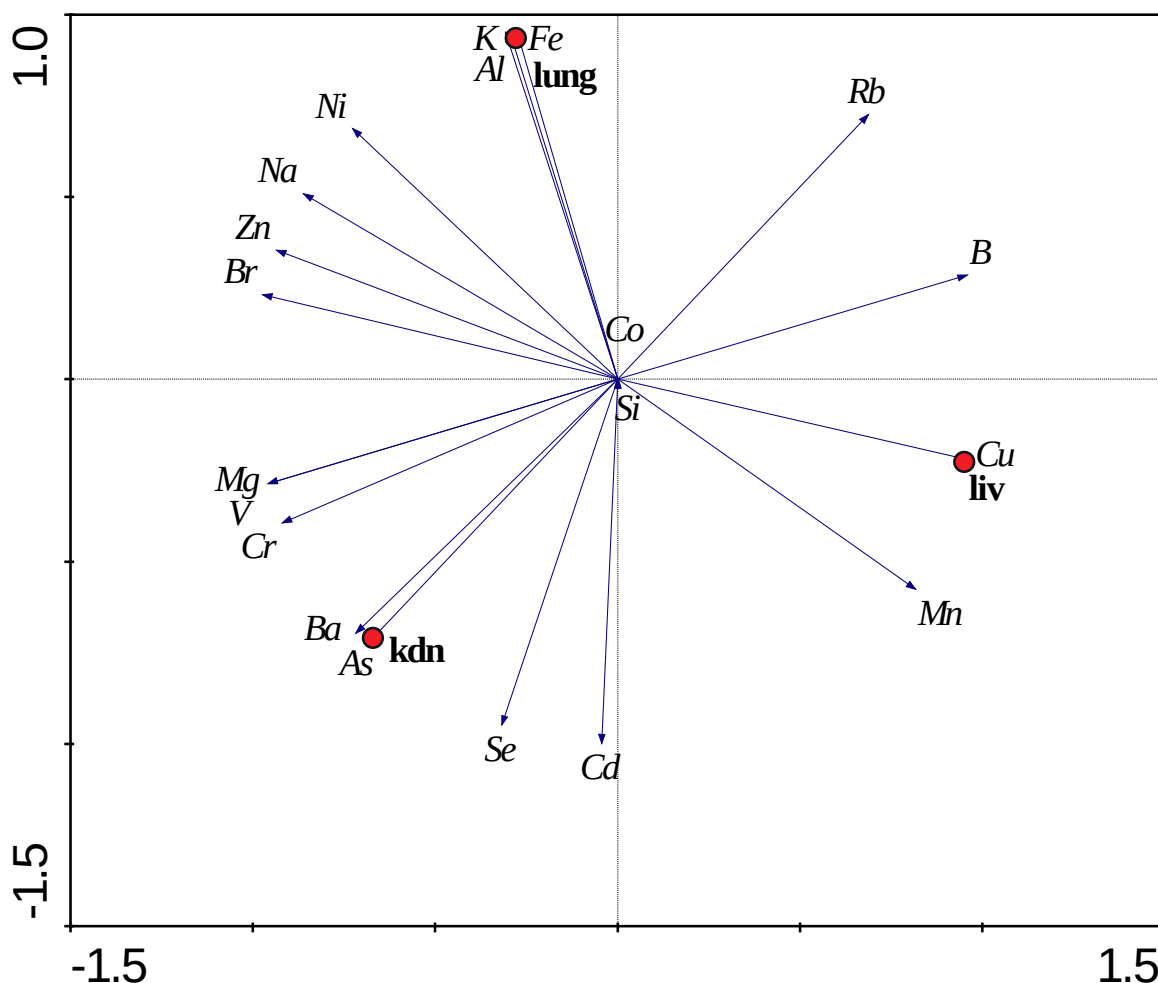


Figure 14: PCA analysis of the elemental concentration in the tissue of antelope sampled in 2008 at Denel. Kdn=Kidney, liv=liver, lung=lungs of the antelope.

There was a significant difference according to the distribution of elements and their associations with the different tissue of the antelope sampled in 2008 at RDM. Similar to the data sampled in 2007, three distinct groupings of organs – the kidney, lung and liver tissue – could be distinguished as well as a grouping of the elements Ni, Na, Zn and Br in Figure 14.

From the PCA ordination (Figure 14), it could be seen that K, Al and Fe had a definite association with the lungs of the antelope. Similar to the PCA ordination of the organ tissue data sampled in 2007, K had a positive association with the lung tissue (Figure 13), but not with Al and Fe. It also became apparent that a difference exists between the lung tissue and the liver and kidney tissue according to the PCA ordination.

The kidney showed a positive association with As and Ba in Figure 14. This is contrary to a positive association that existed between Ci, Cd and the kidney tissue in organ tissue sampled in 2007 (Figure 13), while Cu and Mn had a positive association with the liver tissue in 2008. Similarly, Mn had a positive association with the liver tissue in 2007 (Figure 13).

Table 18: Comparison of the elemental concentration and distribution thereof in the tissue of the antelope sampled in the 2007 hunting season and 2008 hunting season

Compared aspects	2007	2008
Association		
Kidney	Ni, Cd, Se	Ba, As, Se, Cr
Liver	V, Mg, Mn, Rb, Co, Ca	Cu, Mn, B
Lung	K	K, Al, Fe
Negative correlation		
Kidney	Cr, Si, Tl	Rb, B
Liver	Br, Pb, Fe, Na	Ni, Na, Zn, Br
Lung	As, Mo, Co	Cd, Se, Mn

When comparing the elemental concentration in the tissue samples of the dry and wet periods, it became clear that only a few constants were present, for example the association with the Se concentration in the kidney tissue, Mn concentration in the liver tissue and K concentration in the lung tissue of the antelope. In contrast with that were the large differences between the different years. Take for example Cr in the kidney, which had a positive association in 2008, but a negative association in 2007.

There were no similarities when the negative associations of the different years were compared. Other than that, there were differences in the composition of the associated and negatively associated elements in the tissue of the antelope. Therefore, a definite difference was visible in the comparison of the different years of sampling's elemental concentrations as well as distribution among the tissue.

Table 19: A comparison between the Mn concentrations in the tissue of the antelope sampled in 2008

	Liver (R:14.667)	Kidney (R:9.1667)	Lungs (R:4.6667)
Liver		0.223059	0.003531
Kidney	0.223059		0.432876
Lungs	0.003531	0.432876	

Differences between all the Mn concentrations of the tissue sampled in 2008 were measured. The Mn concentration was found to differ statistically significantly between the 2008 sampling period.

Table 20: A comparison between the Ni concentrations in the tissue of the antelope sampled in 2008

	Liver (R:5.9167)	Kidney (R:9.2500)	Lungs (R:13.333)
Liver		0.838456	0.048347
Kidney	0.838456		0.555704
Lungs	0.048347	0.555704	

Statistically significant (0.04) differences in the Ni elemental concentration in the lungs and liver were measured in the 2008 sampling period.

Table 21: A comparison between the As concentrations in the tissue of the antelope sampled in 2008

	Liver (R:9.333)	Kidney (11.667)	Lungs (7.500)
Liver		1.0000	1.0000
Kidney	1.0000		0.5298
Lungs	1.0000	0.5293	

There were no differences of importance in the comparison of the As concentration in the tissue of the antelope.

As was the case during the 2007 sampling period, no statistically significant differences (Table 16) were found to exist in the As concentration in the organ tissue at the RDM site.

Table 22: A comparison between the different years of sampling as well as the elements that were of importance

	Fe	Cu	Se
Year	0.000463	0.006834	0.004021
Organ	0.298326	0.003197	0.045921
Year*Organ	0.691646	0.151512	0.318480

Statistically significant differences were present in the Cu, Fe and Se concentrations in the comparison between 2007 and 2008. The differences are, in fact, large, if it was taken into consideration that a difference was classified as significant if the value is 0.05 between the compared components, and in this case it was 0,004 to 0,006. Significant differences existed between the tissue regarding Cu and Se. However, the interaction between the different years and the tissue had no distinct differences.

3.5.1 Discussion

During both 2007 and 2008, a dry and wet growth season, elevated elemental concentrations of Na, Fe and K were present in the organ tissue of the antelope. The order of these elemental concentrations in the tissue of the antelope was the highest in the lungs > kidneys > liver. Even though similar elevated elemental concentrations in the specific tissue were apparent, these concentrations varied between the different years of sampling and their presence. The Fe concentration could serve as a good example in this regard as it was found to have the highest concentration in the lung tissue in relation with the other measured tissues; this concentration was 153.8 mg/l in 2007 and only 46 mg/l in 2008. A similar pattern was observed with regard to the concentration of Mn in the liver tissue, as well as the Ni elemental concentration in the kidney tissue. Although the patterns of accumulation were similar, other factors probably also played an important role in the uptake and accumulation of these elements in these different years of sampling. Other complicating factors that could have had an effect on the accumulation patterns of the elements in the tissue of the antelope could have been the age, sex and the availability of the elements to the animals (Parker, 2003:28).

Both sets of PCA ordinations, for each of the sampling periods, revealed clear but different associations between the different organ tissue sampled and their associated elemental concentrations. The three different organ tissues were each ordinated within its own quadrant.

The only element with a positive correlation for the 2007 elemental data with the lungs was the K concentration. In the following year's PCA results, Fe and Al were added to this association. As for the elements correlating with the kidneys, Cd and Ni were positively associated with the kidneys in 2007, while Ba and As revealed a close association in the 2008 data.

A similar trend occurred in the liver tissue and the elements associated with it. In 2007, the liver tissue was positively associated with V, Mg and Mn and was grouped in the same group consisting of Cu, Ba, Ca, Rb and Co nearby. A negative association existed between the liver and Fe, Pb, Na and Br elemental concentrations. The elements positively associated with the liver tissue in 2008, the wet growth season, changed to only being the Cu and Mn elemental concentration, while having a negative association with the Na, Ni, Zn and Br elemental concentrations.

It became apparent that statistically significant differences exist between the Mn and Ni elemental concentrations with regard to the different organ tissues sampled in the different growth years. The Mn, Ni and As elemental concentrations were compared within the organ tissue as well as between the different years. It became clear that no significant differences regarding these elements were found, although differences existed in 2007. By examining the different years, statistically significant differences between the Ni elemental concentration in the liver tissue and lung tissue and the Mn elemental concentration in the liver tissue and lung tissue were noted in 2008, while no statistical differences were found in 2007's sampling season.

CHAPTER 4

Conclusion, further recommendations

4.1 Conclusions

To achieve the objectives set and to test the proposed hypothesis made for this study, the elemental concentrations within the soil, vegetation, watering holes, the catchment area of the watering holes and the kidney tissue, lung tissue and liver tissue of the antelope at RDM had to be identified and quantified. It quickly became apparent that the distribution of the different elements in the study area was subject to the natural gradient in the area, the activities present at or near the sampling site and the surface runoff during precipitation. Factors influencing the concentration of the elements quantified at the respective sites as well as their distribution could have been the time of exposure to environment, the bioavailability, mobility and other characteristics of the elements themselves. The environmental factors include the properties of the soil and vegetation to uptake or to ensure the availability to other parties of interest. Therefore, the uptake of elements into the environment would, hypothetically, decrease with the distance travelled due to the decrease in concentration and availability along the way. According to this statement, it is expected that the higher concentration of the elements associated with a certain activity will be closer to the point of impact, decreasing in relation with the distance from the area of impact. This was precisely the case with the elemental concentration in the soil. This occurrence can especially be seen in the concentrations of the areas under the actual grounds where testing and manufacturing took place.

It became apparent that the Na, Mg and K elemental concentrations had a similar pattern at RDM, increasing from the higher regions towards the lower regions in the watering holes and their catchments. This occurrence could have been subject to the natural slope in the area and the activities that took place along the route and introduced the elements into the area. According to the vegetation analysis, different groups with various impacts on the area could be identified according to the different activities taking place at RDM. These areas are the testing area (T), under the testing area (UT), factory area (F), under the factory area (UF) and the area above the factory area (AB). These would be addressed later on in more detail.

It was not only from the elemental concentration of an area that the possible areas of impact could be identified, but also from the species richness within the area. As mentioned earlier, the increase in environmental impact could cause a decrease in the species richness of such an area influenced

by similar activities (Bausinger, 2007:269). This may be due to the tolerance of specific species to certain concentration of elements in an area. In the RDM area, the most dominant species in each of the sampling sites were *Themeda triandra* and *Eragrostis curvula*. The low species richness could be ascribed to the impact of the activities taking place in that specific area and the effect it has on the vegetation surrounding those areas.

Higher Al and Fe concentrations that were associated with the testing area also indicated the influence that the testing area had on the rest of the region. This finding was confirmed by the PCA analysis that identified the elements that correlated with certain sites on the premises. The significant differences in the K, Mg, Al and Fe concentrations in the soil also helped to identify the different activities that took place at the area. Significant differences regarding these elements between the testing area, under the testing area and the under the factory area were found, and it became apparent that the differences were not only limited to the elements, but also the areas. Therefore, the assumption could be made that significant differences between the testing area, the area underneath the testing area and the area under the factory also existed. It was by this assumption that the difference in activities at RDM could also be identified.

It became apparent within the catchment areas of the watering holes at RDM that an elemental gradient existed that was associated with the natural gradient of the area. The B, Na, Mg, Al, K, Fe, Br and Sr elemental concentrations in the catchments of the watering holes increased from watering hole 1 (CM: WH1) to watering hole 3 ((CM: WH3). It can be assumed that the activities associated with the factory area could have contributed to the elemental increase towards the lower region at RDM. The increase in the Na, Mg and K elemental concentrations from watering hole 1 to watering hole 3 could also be seen in the results of the water analyses.

The elemental concentration in the water of the different waterholes at RDM was a direct result of the impact of the activities that took place at RDM. This became apparent when high Mg, Cu and Zn concentrations were found in waterhole 1, situated in the runoff route from the testing area. This resulted in the distribution of the explosives and ammunition residue of that area to be relocated to the lower regions, such as the waterholes. The antelope in the area were also free to roam in that area and were in these situations directly exposed to the residues of the testing area. Along with the associated elements in waterhole 1, a gradient of elemental concentration, starting at waterhole 1 and increasing in the concentrations of Na, K, Mg and Ca towards waterhole 3 in the lower region at RDM, became apparent. According to Martiny (2007:9), Ca and K are both elements associated with ammunition production and testing and can therefore explain the higher concentration

occurring closer to the actual testing site and the decrease according to the distance from that specific area. This decrease could be due to the uptake of elements from the area by the vegetation, soil etc., but it could also be due to the exposure to other environmental factors such as precipitation. According to the PCA analysis done on the waterholes and the respective elements, groupings according to associations were identified. The elements associated with watering hole 1 are Fe, Si, Co, Ni and Al. The significance of the associations of these elements with waterhole 1 was that these elements were also associated with ammunition and explosives (Martiny, 2007). It could therefore be assumed that the surface runoff in the area does carry elements to the lower areas, and in this case collected at lower areas to from waterholes. Min *et al.* (2007:85) also exclaimed the distribution of elements through various systems by means of water and food, ultimately also influencing humans. The concentration and availability of the elements to consumers, such as the antelope at RDM, play an important role in the distribution of the elements to other parts of the food chain and the distribution of those elements in the area will finally depend on the binding characteristics of the ground and vegetation (Min *et al.*, 2007:85).

From the PCA analyses of the vegetation, soil, waterholes and catchments, four areas of interest were identified that were influencing the surroundings. This grouping was done according to the elemental association and positioning of the mentioned areas at RDM. By looking at the natural gradient as identified in Figure 1, it became apparent that it was one of the key factors influencing the distribution of the elements. The activities that took place at these mentioned groups were as follows:

Under the factory (UF): S1, S2, S3 and S8

No specific activities took place in this area; it was merely subjected to the elements carried by the surface runoff to this area. It could therefore be stated that this region's elemental composition would have been a direct result of the activities that took place in the factory itself.

Under the test area (UT): S4, S6 and S7

This area was only subjected to the gradient and the elements that enter the area during the testing that took place at the testing soil.

Test area (T): S10, S11, S12 and S13

This was the group with the most significant input of elements into the physical area, as well as the regions underneath it due to the natural gradient. In this area, testing of the durability of the explosives and munitions was done and all residues remained in this area. Elements associated

with these activities were particularly Fe, Al, Si, Cu and Pb, to name but a few. The trial of these elements was found in the soil and vegetation of the “Under the test area” as well as in waterhole 1, which was associated with the mentioned area. These elements also had a positive correlation with the testing site, and resulted in the identification of the test area as one of the activities that had a major influence on the area at RDM.

Above the factory (AB): S9

This was the only area that was not influenced by the surface runoff and activities upward from the gradient, and was located above the factory ground.

Therefore, by identifying the potential influential activities at RDM it was easier to understand the occurrence of elements in this area. By identifying these four groups according to their relations with certain elements, it became apparent what the significant activities at RDM were.

Rainfall was identified as one of the potential factors that could have had a mitigating influence on the potential impact on the area's elemental concentration as well as that of the tissue's concentrations. This was confirmed by the distinct difference in elemental concentration in the organ tissue of the antelope sampled in the different years. It became apparent that a decrease in elemental concentrations in the organ tissue of the antelope took place with an increase in the rainfall in 2008. The opposite is in fact also true, that an increase in elemental concentration in the tissue took place with a decrease in rainfall in 2007. The availability and mobility of these elements in the surroundings at RDM influence the further distribution of it into the food chain of the antelope roaming there.

Similar patterns of elemental accumulation were present in the tissue of the antelope. Higher N, Fe and K concentrations in the lungs, lower concentrations of the mentioned elements in the kidneys and finally the lowest concentrations in the liver were measured. These similarities were unaffected by the overall decrease in concentrations due to the rainfall, even though differences in elemental concentration of up to 100 mg/l were measured.

Another interesting finding was that the elements associated with the separate organs also changed in accordance with the amount of rainfall. For example, the only element that had a positive association with the lung tissue in 2007 was K, but this association changed in 2008 to K, Fe and Al. A similar phenomenon was recorded for the elements associated with the liver tissue sampled during the different years and consequently different rainfall seasons. The elements found to show obvious differences between the organs and the years sampled were analysed to see

whether any significant differences existed. The elements that were used were Mn, Ni and As. There were no distinct differences between these elements concerning the tissue in 2007. Significant differences were, however, found in the comparison of the concentrations of Mn and Ni that was found between the liver tissue and the lung tissue of the tissue sampled in 2008. The difference between the kidneys and the lungs regarding As were not significant, although it was the only comparison that showed signs that differences ought to exist. Furthermore, distinct differences became apparent in the comparison of the Fe, Se and Cu concentrations of the different years, as well as for Se and Cu in the comparison of the different tissue samples.

During this study, it was confirmed that the natural gradient present at RDM played an important role in the distribution of the elements from the factory and testing areas at RDM to the lower regions. This was also confirmed during the quantification of the elemental concentrations in the soil, vegetation, catchment area and watering holes sampled, which similarly showed an elemental gradient correlated with that of the natural gradient. As for the elemental concentrations in the organ tissue of the antelope, valuable differences between the organ tissues were found during the quantification of the elemental concentrations. Differences within the elemental concentrations, compositions and distribution in the organ tissue were found to be associated with the amount of rainfall measured.

Although a lack of specific literature hampered the study, the results and data obtained during this study can provide valuable baseline data for future studies.

4.2 Suggestions for further studies

I would suggest that the following subjects be studied in further studies:

- Impact of the rainfall patterns on the concentration and distribution of elements in the tissue of antelope.
- Continued studies on the patterns of distribution of the elements associated with munitions manufacturing companies.
- Continued research to determine the processes in the environment that minimises the availability in a highly polluted area to antelope.
- Distribution and bioavailability of elements in the vegetation for antelope during seasons with different amounts of precipitation.

- A study on the tendency of specific elements to accumulate in specific organs and why these associations change when there is a change in the amount of precipitation.

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Appendix

Elemental abbreviations

Table 1: Abbreviations of the elements mentioned

Aluminium	Al	Lithium	Li
Uranium	U	Beryllium	Be
Boron	B	Bromine	Br
Sodium	Na	Rubidium	Rb
Magnesium	Mg	Strontium	Sr
Silicon	Si	Molybdenum	Mo
Calcium	Ca	Rubidium	Ru
Potassium	K	Lead	Pb
Scandium	Sc	Silver	Ag
Vanadium	V	Cadmium	Cd
Chromium	Cr	Tin	Sn
Manganese	Mn	Antimony	Sb
Iron	Fe	Tellurium	Te
Cobalt	Co	Iodine	I
Nickel	Ni	Caesium	Cs
Copper	Cu	Barium	Ba
Zinc	Zn	Selenium	Ce
Gallium	Ga	Tungsten	W

Germanium	Ge	Gold	Au
Selenium	Se	Thallium	Tl
Arsenic	As	Bismuth	Bi
Osmium	Os	Mercury	Hg
Lead	Pb		

2. Units

Table 2: Abbreviations of the units used to describe the necessary methods, etc.

g	gram
mg	milligram
ppm	Parts per million
µg	Microgram
L	Litre
µg/L	Microgram per litre
µmol	Micromole
ml	millilitre
mg/L	Milligram per litre
cm	centimetre

Environmental data

Table 3: Abbreviations used to describe the different samples and sites

GRS:S1	Grass: Site number
WH1	Watering hole
CM:WH1	Catchment: Watering hole number
GRND:S1	Ground: Site number
kdn	Kidney
liv	Liver
lung	Lung
UF	Under the factory
UT	Under the test area
T	Test area
AB	Above factory